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Providing evidence to assess the integration of household water filters into Rwanda's national environmental health promotion program

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Doctor of Philosophy

Environmental Health Sciences

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Abstract

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Enteric infections are the third leading cause of death in young children globally and are linked to ailments such as diarrheal disease, environmental enteropathy, growth faltering, and undernutrition. The disease burden is highest in low-income settings that have limited access to safe water, sanitation, and hygiene (WASH). Household water treatment and safe storage (HWTS) is shown to be effective in reducing exposure to fecal pathogens and preventing disease in these settings. However, HWTS is seldom delivered at scale and its effectiveness seldom assessed over more than one year. This dissertation seeks to provide evidence to assess the effectiveness of integrating an advanced household water filter within Rwanda's national environmental health program on increasing access to safe drinking water.

This research has three aims, all conducted within the context of Rwanda's Community-Based Environmental Health Promotion Programme (CBEHPP). The first aim was to evaluate the effectiveness of integrating a household-based water filter to improve drinking water quality. Using a cluster randomized-controlled trial design, we enrolled 1,199 CBEHPP beneficiary households with young children or a pregnant person across 60 randomly selected villages in Rwamagana district. A random half of villages received the filter-integrated program, while the other half received the program's original form. We conducted follow-up visits over 13-16 months and reported effects on drinking water quality (primary outcome) and 7-day diarrhea prevalence of children under 5. We found that the intervention reduced the proportions of households with detectable *E.coli* in water samples and children under 5 experiencing diarrhea.

The second aim was to assess the longer-term effectiveness of the CBEHPP-filter intervention by following intervention households for an additional 16 months. We assessed uptake, water quality, and child diarrhea outcomes at approximately 6, 12, 24, and 30 months among households enrolled in the intervention arm and estimated the effects of time on the outcomes, adjusting for household and seasonal factors. We found that uptake declined throughout the study duration but remained relatively high, with most households reporting to use the filter for treating drinking water after 2 years. Water quality and child health outcomes were unchanged through the study period.

The third aim was to assess various indicators of water access and water insecurity in the study population over 30 months. We estimated associations of rainfall, temperature, basic water access, and the filter intervention with household experiences of water insecurity. We found that water insecurity varied between and within households overtime and is affected by changing temperature, access to basic water sources, and access to the filter with safe storage. Effects of the filter intervention were additionally assessed with the context of the trial and found to be effective in lowering the prevalence of water insecurity.

This research suggests that a household filter with safe storage delivered as a part of the CBEHPP can improve microbial water quality and reduce child diarrhea in a population that largely lacked access to safe water. The uptake and water quality and child health effects of the intervention can be sustained for over 2 years. Household experiences of water insecurity are influenced by seasons and may decrease with interventions that improve access to safe drinking water.

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Acknowledgments

This dissertation is dedicated to my parents, who showed me the world and inspired me to pursue a career in public health. My mother first immigrated to this country to study chemistry and graduated with her Ph.D., 9-months pregnant with me. Therefore, I'd like to think of this as my second Ph.D. It was somehow a lot harder this time around…

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Chapter 1 – Introduction

1.1 Drinking water supply and health

Diarrheal diseases are the third leading cause of mortality in young children worldwide, accounting for an estimated 573,047 deaths among children under five in 2019.[1] Fecal pollution of drinking water supply is a well-documented and pervasive environmental determinant of diarrheal and other disease burdens, such as additional enteric illnesses, undernourishment, and impaired gastrointestinal functioning.[2-6] Repeated enteric infections in early childhood are further linked to chronic ailments of environmental enteric dysfunction (EED), growth faltering, and reduced cognitive development.[3,7-10] Inadequate quantities of household water also exacerbate these health risks and others by restricting water use for caregiving and improved hygiene behaviors.[11] Aside from the health consequences, limited access to safe drinking water emphasizes inequalities and conditions of global poverty by undermining human rights, racial and gender equity, educational attainment, livelihoods, and well-being.[12-14]

Global diarrheal burdens and unsafe access to water are most concentrated within parts of Africa, Asia, and Latin America and the Caribbean.[15,16] Single-pathogen vaccines and therapies have had a critical role in lessening diarrheal burdens in these areas over time.[17] However, the changing and wide variety of pathogens transmitted through human and animal feces suggest these interventions will have limited success in reliably lowering the incidence of diarrhea across settings.[17] Forces of population growth, urbanization, and climate change are more importantly projected to deteriorate the availability of safe water and increase the risk of epidemics and pandemics of infectious diseases in the future.[18,19]

The provision of water, sanitation, and hygiene (WASH) services that effectively reduce fecal loading in the environment and sustain the availability of safe water is a longstanding public health strategy for increasing resiliency to water-related health burdens.[20] Along with poor community-level sanitation and hygiene, unsafe water supply exacerbates environmental pathways of fecal exposure (e.g., contaminated fluid, food, fields/floors, hands, and flies).[21] Meta-analyses find interventions that improve safe water access reduce the risk of diarrhea between 34-79% in areas with limited water access at baseline.[22]

1.2 Limitations of water service delivery in low- and middle-income countries

Safe water services are not provided in many parts of the world, particularly in low- and middle-income countries (LMICs). Efforts to increase access to safe drinking water have depended mainly on providing "improved water sources[1]" that should be structurally protected from contact with human and animal excreta. Between 2000 and 2020, about 2 billion people gained access to improved water sources by international standards within 30 minutes of roundtrip access (i.e., basic water access as defined by WHO/UNICEF).[15] About 10% of the global population remains without basic water access. They are primarily among the poorest households, with the majority residing in rural Sub-Saharan Africa, either collecting drinking water from far away improved sources or directly from unprotected structures, rivers, and lakes that are often highly polluted with fecal bacteria.[15]

However, basic access to improved water still does not guarantee that drinking water is safe or adequate. A 2014 global assessment of drinking water estimated that 10% of all improved water sources contain very high levels of fecal contamination (>100 TTC or *E. coli*/100mL).[23] Poor water quality is especially difficult to address in areas lacking the financial and institutional capacity to provide and maintain high-quality water infrastructure.[24] With the exception of treated, continuous on-premise piped water, there is no strong evidence to suggest that improved sources reduce diarrheal burden in LMICs.[22,25] In many LMICs, gains in improved access are owed largely to the provision of low-cost infrastructure, such as protected springs, boreholes/wells, and public standpipes shared among communities. About a third of households in least developed countries have access to piped water sources, with most access exclusive to urban dwellers.[15] Rural and still many urban LMIC residents regularly travel some distance to collect water for their household needs.[26] Improved water sources and even piped water supply may also be unreliable or

[1] Improved sources include: piped water, boreholes or tubewells, protected dug wells, protected springs, rainwater, and packaged or delivered water (WHO/UNICEF, 2021)

intermittent in access, depending on the season and maintenance of infrastructure, increasing the chance of using multiple drinking water sources.[27] These factors have been shown to necessitate families to ration and store water, which ultimately compromises the safety and the health benefits of improved water sources.[28-30] For example, the likelihood of fecal contamination has generally been shown to increase from the point-of-collection (PoC) (e.g., contamination at the water source) to the household's point-of-use (PoU) in areas with limited access to water supply.[31-34]

The Sustainable Development Goals (SDG) respond to these shortcomings by redefining the global water target to meet universal access to "safely managed water services (SMWS)." The new goal builds upon predecessor global targets to increase access to improved water sources but requires that SMWS access additionally is verified to be on-premise, available when needed, and free of priority contaminants, including indicators of fecal bacteria. Current estimates indicate that at least 2 billion people access drinking water contaminated with fecal or priority chemical contaminants.[15] However, this is likely an underestimate of true exposure due the limited availability of household data.[15] An analysis of 27 nationally-representative surveys measuring water quality in LMICs suggests that *E.coli* contamination of water sources is widespread, ranging from 16 to 90%, and is the primary reason water sources do not meet SMWS criteria.[31] *E.coli* prevalence at the PoU was found to range between 19 and 99% across surveyed countries.[31]

Providing universal access to safe water sources should remain a development priority as it facilitates benefits related to health, livelihood, dignity, and racial and gender equality.[35] However, reaching this goal in LMICs demands substantial investment. A World Bank costing study estimates that the total capital costs alone of meeting SDG 6.1 on universal access to SMWS is \$37.6 billion per year from 2015 to 2030.[36] The latest projections from WHO/UNICEF indicate that the world is not on track to meet SDG 6.1 by 2030, with current rates of progress needing to be quadrupled for the target to be achieved.[15] In the meantime, complementary, intermediate interventions targeted at improving drinking water quality at the household-level need to be delivered for immediate public health benefits as the expansion of reliable water and sanitation infrastructure and service capacity development continues.

1.3 Household water treatment and safe storage interventions: Advantages and implementation challenges

Systematic reviews conclude that point-of-use water treatment is one of the few low-cost water interventions that reduce fecal exposure and diarrheal prevalence in areas with poor water quality.[22,37,38] Point-of-use water quality or household water treatment and safe storage (HWTS) interventions are characterized by their microbiological effectiveness in reducing contamination in household water.[39] Common HWTS interventions include filtration, boiling, chemical disinfectants, solar disinfection, and use of covered collection and storage containers. Although safe storage does not actively remove contaminants, it does effectively reduce the risk of additional microbial contamination. For instance, some PoU water treatment technologies have been shown to be ineffective in improving health without the added provision of safe storage.[22]

HWTS interventions have advantages to delivering health outcomes compared to water source improvements for two main reasons. First, they rely less on the technological sophistication of water infrastructure and developing institutional capacity to manage services. Second, they intervene at the PoU, reducing contamination from both the water source and handling and storage practices post-collection. Though there is a consensus that HWTS interventions effectively improve water quality,[40] there are limited examples of where HWTS interventions are successfully scaled and sustained at the PoU, except boiling in some parts of Asia.[41] Chlorine dispensers installed at shared water points have shown promising effects on improving access to safe water supply and have been increasingly scaled in LMICs in recent years. Although the innovation intervenes at the PoC, residuals are found to be present in stored household water.[42] In Sub-Saharan Africa, it has been estimated that 22% of households report treating water post-collection and 18% reported treatment practices considered to be microbiologically effective.[43] Examples of evidence-based interventions failing to reach their target populations are pervasive throughout public health. The field of implementation science labels this issue as the “know-do gap” – that is, what is learned in the laboratory or efficacy studies does not translate to what is implemented in practice.

Although systematic reviews show pooled effects of HWTS, individual studies are mixed with large heterogeneity in effect sizes on health. HWTS interventions have several implementation challenges that may help to explain their limited use and impact in some settings. First, not all HWTS technologies are efficacious in eliminating priority enteropathogens circulating in the local environment. A number of trials on the effectiveness of PoU chlorine have found null effects on improvements in health, despite relatively high adherence to the intervention.[44-46] These findings have raised concerns about the effectiveness of chlorine in some populations, which is generally accepted as among the most cost-effective water interventions for improving health.[47] However, there have been increasing evaluations on the burden of specific enteropathogens in recent years.[16,48] with some research suggesting that highly prevalent enteropathogens can demonstrate chlorine-resistance, which may explain limited health effects in certain settings.[49,50] In contrast, positive health effects from some HWTS evaluations have been substantiated by showing significant reductions in immune responses to common enteric infections endemic to the region.[51,52] The discussion of these results should not suggest general prioritization of specific HWTS technologies – chlorination is still an effective option in some populations. Rather, the examples cited suggests the importance of choosing efficacious HWTS hardware appropriate to the local population.

Second, understanding the need and relative benefit of HWTS interventions is essential for informing appropriate targeting strategies for their implementation. Related to the sufficiency of technology, the effectiveness of HWTS also depends on the overall WASH context. For example, their effectiveness may differ across emergency/disaster response settings versus non-emergency/stable settings.[53] HWTS only target household drinking water and disregard other significant environmental pathways of fecal exposure. In settings with severe water and sanitation insecurity, HWTS may have limited impact if waterborne transmission is not the dominant pathway or recontamination of drinking water is likely.[54] Similarly, HWTS has been demonstrated to have little benefit in populations that have reliable access to safe source water.[55] For this reason, researchers have strongly advocated for improved reporting on baseline WASH levels and other contextual factors to improve the external validity of findings.[22]

Third, high coverage and use are difficult to achieve in practice. Consistent and correct use of HWTS is a universal determinant of their impact.[56,57] However, HWTS interventions entail high transaction costs in reaching individual households, sustaining behavioral uptake, and additional time and resource burdens placed on families to practice safe HWTS. Evaluations on HWTS are commonly unblinded, which likely overestimates use and health effects. However, adherence to HWTS is documented to decline over time, especially if the technology is not acceptable in the local population or there is limited maintenance.[51,58-61] Several reviews acknowledge the contribution of behavior-change strategies in explaining the effectiveness of HWTS.[62-64] One review notes that positive health effects found from chlorine-based interventions are only among studies that report daily to fortnightly contact between implementors and individuals,[63] which is likely impractical for most programs. The finding also underscores the importance of evaluating HWTS in pragmatic programs that show promises of sustainability and replicability.

Finally, HWTS often lacks an institutional home and committed financing, perhaps due to the range of implementation challenges described. There are valid concerns on the resources needed to scale HWTS interventions, including the lack of products in local markets and intensity of behavior-change promotion required to sustain household use and interest in interventions over time.[54] Further, the delivery of HWTS interventions is not traditionally thought of as a public good or service, but rather a household responsibility. HWTS also does not help governments meet international standards of water point access, and policymakers are discouraged from diverting scarce resources from water supply development to scaling HWTS interventions intended to be temporary solutions to improving household water quality.[54] A survey to WASH practitioners finds that the “cost of products” is the most frequently cited barrier to scaling HWTS solutions[65]. To reduce implementation costs and increase cost-effectiveness of HWTS interventions, it is strongly encouraged to partner with health sectors to integrate delivery into existing health promotion programs rather than having disparate efforts.[66] Yet, health agendas that explicitly include HWTS-specific targets are underdeveloped.

1.4 Delivery of HWTS interventions in Rwanda

Rwanda has high fecal contamination rates of drinking water despite infrastructural improvements. Between 60 and 75% of the population consumes drinking water contaminated with indicators of fecal bacteria.[15,67] Water quality is worst in rural regions of Rwanda,[67] perhaps due to elementary water infrastructure (e.g., protected springs, wells, communal taps), intermittent access, and long travel times for collecting water. The WHO/UNICEF estimates that 60% of Rwandan households have basic access to improved water sources within 30 minutes roundtrip, 12% of the population have access to SMWS.[15] Unsafe storage collection and handling practices are common in Rwanda, and 90% of households report that they do not treat their water.[67]

Rwanda's main environmental strategy for reducing diarrheal disease is its Community-Based Environmental Health Promotion Program (CBEHPP). The program began in 2009 and has been scaled nationally. The CBEHPP organizes Community Health Clubs (CHC) in villages to promote safe treatment of water, improved hygiene behaviors, and zero open defecation.[68] However, a cluster randomized controlled trial in Rwanda's Ruzizi District showed that the CBEHPP is ineffective in reducing fecal exposure in drinking water or diarrhea and undernutrition.[69] Analysis of program monitoring data has suggested the null effects could be due to low protocol fidelity and may not be generalizable to the rest of the country.[70] Nevertheless, the Ministry of Health is seeking ways to revise the CBEHPP, which has traditionally relied on promoting boiling and other safe handling behaviors. One option for improvement is integrating HWTS hardware based on positive experiences of delivering water filters through the public-private partnership in Rwanda's Western Province.[51] However, there are questions on whether the filter could be integrated into a public program like the CBEHPP, effects are sustained over time, and if the filter is associated with water insecurity.

1.5 Dissertation Aims

Closing the HWTS implementation gap requires context-specific evidence that informs the design of replicable programming appropriate for the population. This dissertation seeks to provide evidence on key outcomes to assess the integration of household water filters into the CBEHPP. It builds upon previous research identifying various implementation challenges of scaling HWTS innovations in Rwanda.

The research aims of the dissertation are summarized below. Additional background of each aim is provided in their respective chapters.

1.5.1 Research Aim 1

The first aim was to evaluate the effectiveness of integrating water filter delivery and promotion into the implementation of CBEHPP in a predominantly rural district in eastern Rwanda. The research is described in Chapter 2 in the form of a manuscript currently under review: *Effects of adding household water filters to Rwanda's Community-Based Environmental Health Promotion Programme: A cluster-randomized controlled trial in Rwamagana district*. Although there is strong evidence that the household water filter under investigation is microbiologically effective, used, and achieves health benefits in some Rwandan populations, we cannot assume that the filter will be effective in all implementation contexts, such as in the CBEHPP.

The research assesses the primary effects on fecal contamination of household drinking over 13-16 months following program delivery. Our main hypothesis was that the intervention would improve drinking water quality as indicated by the proportion of samples with detectable *E. coli* and contamination levels at moderate or higher risk (≥10 CFU/100ml) and very high risk (≥100 CFU/100mL). We additionally examined secondary outcomes on coverage and uptake of the filter, caregiver-reported diarrhea among children under 5, and reported healthcare visits for diarrhea treatment among children under 5 over the study period.

1.5.2 Research Aim 2

The second aim was to better understand the longer-term sustainability of the intervention by conducting a follow-up study to the main trial presented in aim 1. The research is described in Chapter 3 in the form of a draft manuscript entitled, *Assessing the sustained effects of a water filter intervention in Rwamagana,* *Rwanda: a 30-month longitudinal study*. Most HWTS studies are limited to one year of follow-up; yet there is evidence of declining coverage and use of HWTS in even shorter-duration study periods. This is one of the few assessments of an HWTS intervention measuring sustained effects for nearly three years.

The research assesses outcomes on filter uptake, including coverage, use, and acceptability of the filter, and filter effects, including detection of fecal contamination in sampled drinking water and 7-day recall of diarrhea in children under 5 over 30 months of follow-up. While the filter is designed to provide safe drinking water for at least three years, we hypothesized that we would observe reductions in these measures over time. As a secondary analysis, we additionally measured outcomes in a group newly receiving the filter at the same time and hypothesized that uptake and water quality would be better in the group with 13-16-months of exposure compared to the group with 28-32-months of exposure to the filter.

1.5.3 Research Aim 3

The third aim was to advance the understanding of water insecurity across multiple seasons. The study is described in a draft manuscript in Chapter 5 entitled, *Household water insecurity in rural Rwanda: a 30-month study to assess effects of a water filter intervention and associations with water services, precipitation, and temperature*. The research follows the same study population from aims 1 and 2 and identifies trends and drivers of different indicators of household water insecurity. We hypothesized that water insecurity experiences vary over time and meteorological factors and are reduced through access to basic water services and the filter with safe storage during times of water stress. The study additionally attempts to describe water security of the study population in order to contextualize the results and improve the generalizability of the findings of the filter evaluation to populations with similar contexts.

1.5.4 Commentary – Implementation Science in WASH

A major challenge in successful WASH interventions is in the failure to translate an intervention shown effective in the laboratory or small, efficacy trials into effective interventions programmatically delivered at scale. We address this challenge in a commentary, *The applications of implementation science in water, sanitation, and hygiene (WASH) research and practice,*[71] which appears in the annex. The commentary emphasizes the need for improved research methods for studying the delivery of WASH programs in LMICs. The paper summarizes theories and methods from the field of implementation science that may help the sector improve the design, evaluation, and delivery of WASH interventions.

1.6 References

1 Vos, T. *et al.* Global burden of 369 diseases and injuries in 204 countries and territories, 1990–2019: a systematic analysis for the Global Burden of Disease Study 2019. *The Lancet* **396**, 1204-1222 (2020).

2 Brown, K. H. Diarrhea and malnutrition. *The Journal of nutrition* **133**, 328S-332S (2003).

3 Petri, W. A. *et al.* Enteric infections, diarrhea, and their impact on function and development. *The Journal of clinical investigation* **118**, 1277-1290 (2008).

4 Murray, C. J. *et al.* Global burden of 87 risk factors in 204 countries and territories, 1990–2019: a systematic analysis for the Global Burden of Disease Study 2019. *The Lancet* **396**, 1223-1249 (2020).

5 Goddard, F. *et al.* Faecal contamination of the environment and child health: a systematic review and individual participant data meta-analysis. *The Lancet Planetary Health* **4**, e405-e415 (2020).

6 Hodge, J. *et al.* Assessing the association between thermotolerant coliforms in drinking water and diarrhea: an analysis of individual–level data from multiple studies. *Environmental health perspectives* **124**, 1560-1567 (2016).

7 Kosek, M. N. *et al.* Causal pathways from enteropathogens to environmental enteropathy: findings from the MAL-ED birth cohort study. *EBioMedicine* **18**, 109-117 (2017).

8 Nasrin, D. *et al.* Pathogens associated with linear growth faltering in children with diarrhea and impact of antibiotic treatment: The Global Enteric Multicenter Study. *The Journal of infectious diseases* **224**, S848-S855 (2021).

9 Budge, S., Parker, A. H., Hutchings, P. T. & Garbutt, C. Environmental enteric dysfunction and child stunting. *Nutrition reviews* **77**, 240-253 (2019).

10 Khalil, I. A. *et al.* Morbidity, mortality, and long-term consequences associated with diarrhoea from Cryptosporidium infection in children younger than 5 years: a meta-analyses study. *The Lancet Global Health* **6**, e758-e768 (2018).

11 Stelmach, R. D. & Clasen, T. Household water quantity and health: a systematic review. *International journal of environmental research and public health* **12**, 5954-5974 (2015).

12 Guerrant, R. L., DeBoer, M. D., Moore, S. R., Scharf, R. J. & Lima, A. A. The impoverished gut—a triple burden of diarrhoea, stunting and chronic disease. *Nature reviews Gastroenterology & hepatology* **10**, 220-229 (2013).

13 Gimelli, F. M., Bos, J. J. & Rogers, B. C. Fostering equity and wellbeing through water: A reinterpretation of the goal of securing access. *World Development* **104**, 1-9 (2018).

14 Mehta, L. Water and human development. *World development* **59**, 59-69 (2014).

15 WHO/UNICEF. Progress on household drinking water, sanitation and hygiene 2000-2020: five years into the SDGs. Report No. 9240030840, (2021).

16 Liu, J. *et al.* Use of quantitative molecular diagnostic methods to identify causes of diarrhoea in children: a reanalysis of the GEMS case-control study. *The Lancet* **388**, 1291-1301 (2016).

17 Girard, M. P., Steele, D., Chaignat, C.-L. & Kieny, M. P. A review of vaccine research and development: human enteric infections. *Vaccine* **24**, 2732-2750 (2006).

18 Wu, X., Lu, Y., Zhou, S., Chen, L. & Xu, B. Impact of climate change on human infectious diseases: Empirical evidence and human adaptation. *Environment international* **86**, 14-23 (2016).

19 Hess, J. *et al.* Strengthening the global response to climate change and infectious disease threats. *bmj* **371** (2020).

20 Cutler, D. & Miller, G. The role of public health improvements in health advances: the twentieth-century United States. *Demography* **42**, 1-22 (2005).

21 Wagner, E. G., Lanoix, J. N. & Organization, W. H. *Excreta disposal for rural areas and small communities*. (World Health Organization, 1958).

22 Wolf, J. *et al.* Impact of drinking water, sanitation and handwashing with soap on childhood diarrhoeal disease: updated meta-analysis and meta-regression. *Tropical medicine & international health* **23**, 508-525 (2018).

23 Bain, R. *et al.* Fecal contamination of drinking-water in low-and middle-income countries: a systematic review and meta-analysis. *PLoS medicine* **11**, e1001644 (2014).

24 Cassivi, A. *et al.* Drinking water accessibility and quantity in low and middle-income countries: A systematic review. *International Journal of Hygiene and Environmental Health* **222**, 1011-1020 (2019).

25 Clasen, T. F. *et al.* Interventions to improve water quality for preventing diarrhoea. *Cochrane database of systematic reviews* (2015).

26 Pickering, A. J. & Davis, J. Freshwater availability and water fetching distance affect child health in sub-Saharan Africa. *Environmental science & technology* **46**, 2391-2397 (2012).

27 Elliott, M. *et al.* Addressing how multiple household water sources and uses build water resilience and support sustainable development. *NPJ Clean Water* **2**, 1-5 (2019).

28 Overbo, A., Williams, A. R., Evans, B., Hunter, P. R. & Bartram, J. On-plot drinking water supplies and health: a systematic review. *International Journal of Hygiene and Environmental Health* **219**, 317-330 (2016).

29 Shaheed, A., Orgill, J., Montgomery, M. A., Jeuland, M. A. & Brown, J. Why? improved? water sources are not always safe. *Bulletin of the World Health Organization* **92**, 283-289 (2014).

30 Jensen, P. K. *et al.* Domestic transmission routes of pathogens: The problem of in-house contamination of drinking water during storage in developing countries. *Tropical Medicine & International Health* **7**, 604-609 (2002).

31 Bain, R., Johnston, R., Khan, S., Hancioglu, A. & Slaymaker, T. Monitoring Drinking Water Quality in Nationally Representative Household Surveys in Low-and Middle-Income Countries: Cross-Sectional Analysis of 27 Multiple Indicator Cluster Surveys 2014–2020. *Environmental Health Perspectives* **129**, 097010 (2021).

32 Shields, K. F., Bain, R. E., Cronk, R., Wright, J. A. & Bartram, J. Association of supply type with fecal contamination of source water and household stored drinking water in developing countries: a bivariate meta-analysis. *Environmental health perspectives* **123**, 1222-1231 (2015).

33 Clasen, T. F. & Bastable, A. Faecal contamination of drinking water during collection and household storage: the need to extend protection to the point of use. *Journal of water and health* **1**, 109-115 (2003).

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

35 Fukuda, S., Murakami, M., Noda, K. & Oki, T. How achieving the Millennium Development Goals increases subjective well-being in developing nations. *Sustainability* **8**, 189 (2016).

36 Hutton, G. & Varughese, M. The costs of meeting the 2030 sustainable development goal targets on drinking water, sanitation, and hygiene. (2016).

37 Fewtrell, L. *et al.* Water, sanitation, and hygiene interventions to reduce diarrhoea in less developed countries: a systematic review and meta-analysis. *Lancet Infect Dis* **5**, 42-52, doi:10.1016/S1473-3099(04)01253-8 (2005).

38 Clasen, T. *et al.* Interventions to improve water quality for preventing diarrhoea. *Cochrane Database Syst Rev*, CD004794, doi:10.1002/14651858.CD004794.pub3 (2015).

39 WHO. Results of round II of the WHO international scheme to evaluate household water treatment technologies. (2019).

40 WHO. Combating waterborne disease at the household level. (2007).

41 Rosa, G. & Clasen, T. Estimating the scope of household water treatment in low-and medium-income countries. *The American journal of tropical medicine and hygiene* **82**, 289-300 (2010).

42 Pickering, A. J. *et al.* Effect of in-line drinking water chlorination at the point of collection on child diarrhoea in urban Bangladesh: a double-blind, cluster-randomised controlled trial. *The Lancet Global Health* **7**, e1247-e1256 (2019).

43 Geremew, A. & Damtew, Y. T. Household water treatment using adequate methods in sub-Saharan countries: evidence from 2013–2016 demographic and health surveys. *Journal of Water, Sanitation and Hygiene for Development* **10**, 66-75 (2020).

44 Boisson, S. *et al.* Effect of household-based drinking water chlorination on diarrhoea among children under five in Orissa, India: a double-blind randomised placebo-controlled trial. *PLoS medicine* **10**, e1001497 (2013).

45 Luby, S. P. *et al.* Effects of water quality, sanitation, handwashing, and nutritional interventions on diarrhoea and child growth in rural Bangladesh: a cluster randomised controlled trial. *The Lancet Global Health* **6**, e302-e315 (2018).

46 Jain, S. *et al.* Sodium dichloroisocyanurate tablets for routine treatment of household drinking water in periurban Ghana: a randomized controlled trial. *The american journal of tropical medicine and hygiene* **82**, 16 (2010).

47 WHO. Water quality interventions to prevent diarrhoea: cost and cost-effectiveness. (World Health Organization, 2008).

48 Kotloff, K. L. *et al.* Burden and aetiology of diarrhoeal disease in infants and young children in developing countries (the Global Enteric Multicenter Study, GEMS): a prospective, case-control study. *Lancet* **382**, 209-222, doi:10.1016/S0140-6736(13)60844-2 (2013).

49 Barreto, M. L. *et al.* Effect of city-wide sanitation programme on reduction in rate of childhood diarrhoea in northeast Brazil: assessment by two cohort studies. *The Lancet* **370**, 1622-1628, doi:https://doi.org/10.1016/S0140-6736(07)61638-9 (2007).

50 Lin, A. *et al.* Effects of water, sanitation, handwashing, and nutritional interventions on child enteric protozoan infections in rural Bangladesh: a cluster-randomized controlled trial. *Clinical Infectious Diseases* **67**, 1515-1522 (2018).

51 Kirby, M. A. *et al.* Effects of a large-scale distribution of water filters and natural draft rocket-style cookstoves on diarrhea and acute respiratory infection: A cluster-randomized controlled trial in Western Province, Rwanda. *PLoS medicine* **16**, e1002812 (2019).

52 Zambrano, L. D. *et al.* Use of serologic responses against enteropathogens to assess the impact of a point-of-use water filter: a randomized controlled trial in Western Province, Rwanda. *The American journal of tropical medicine and hygiene* **97**, 876 (2017).

53 Hunter, P. R. Household water treatment in developing countries: comparing different intervention types using meta-regression. *Environmental science & technology* **43**, 8991-8997 (2009).

54 Schmidt, W.-P. & Cairncross, S. Household water treatment in poor populations: is there enough evidence for scaling up now? *Environmental science & technology* **43**, 986-992 (2009).

55 Hellard, M. E., Sinclair, M. I., Forbes, A. B. & Fairley, C. K. A randomized, blinded, controlled trial investigating the gastrointestinal health effects of drinking water quality. *Environmental Health Perspectives* **109**, 773-778 (2001).

56 Brown, J. & Clasen, T. High adherence is necessary to realize health gains from water quality interventions. *PloS one* **7**, e36735 (2012).

57 Enger, K. S., Nelson, K. L., Rose, J. B. & Eisenberg, J. N. The joint effects of efficacy and compliance: a study of household water treatment effectiveness against childhood diarrhea. *Water research* **47**, 1181-1190 (2013).

58 Pickering, A. J., Arnold, B. F., Dentz, H. N., Colford Jr, J. M. & Null, C. Climate and health co-benefits in low-income countries: a case study of carbon financed water filters in Kenya and a call for independent monitoring. *Environmental health perspectives* **125**, 278-283 (2017).

59 Kirby, M. A., Nagel, C., Rosa, G. A., Thomas, E. A. & Clasen, T. F. in *American Journal of Tropical Medicine and Hygiene.* 582-582 (AMER SOC TROP MED & HYGIENE 8000 WESTPARK DR, STE 130, MCLEAN, VA 22101 USA).

60 Crider, Y. *et al.* Can you taste it? Taste detection and acceptability thresholds for chlorine residual in drinking water in Dhaka, Bangladesh. *Science of the Total Environment* **613**, 840-846 (2018).

61 Brown, J., Proum, S. & Sobsey, M. Sustained use of a household-scale water filtration device in rural Cambodia. *Journal of water and health* **7**, 404-412 (2009).

62 Arnold, B. F. & Colford, J. M. Treating water with chlorine at point-of-use to improve water quality and reduce child diarrhea in developing countries: a systematic review and meta-analysis. *The American journal of tropical medicine and hygiene* **76**, 354-364 (2007).

63 Pickering, A. J. *et al.* The WASH benefits and SHINE trials: interpretation of WASH intervention effects on linear growth and diarrhoea. *The Lancet Global Health* **7**, e1139-e1146 (2019).

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

65 Ojomo, E., Elliott, M., Goodyear, L., Forson, M. & Bartram, J. Sustainability and scale-up of household water treatment and safe storage practices: Enablers and barriers to effective implementation. *International Journal of Hygiene and Environmental Health* **218**, 704-713, doi:https://doi.org/10.1016/j.ijheh.2015.03.002 (2015).

66 Clasen, T. F. Household Water Treatment and the Millennium Development Goals: Keeping the Focus on Health. *Environmental Science & Technology* **44**, 7357-7360, doi:10.1021/es1018674 (2010).

67 Kirby, M. A. *et al.* Faecal contamination of household drinking water in Rwanda: A national cross-sectional study. *Science of the Total Environment* **571**, 426-434 (2016).

68 Ministry of Health. (Kigali, Rwanda, 2010).

69 Sinharoy, S. S. *et al.* Effect of community health clubs on child diarrhoea in western Rwanda: cluster-randomised controlled trial. *The Lancet Global Health* **5**, e699-e709 (2017).

70 Waterkeyn, J. *et al.* The value of monitoring data in a process evaluation of hygiene behaviour change in Community Health Clubs to explain findings from a cluster-randomised controlled trial in Rwanda. *BMC public health* **20**, 1-16 (2020).

71 Haque, S. S. & Freeman, M. C. The Applications of Implementation Science in Water, Sanitation, and Hygiene (WASH) Research and Practice. *Environmental Health Perspectives* **129**, 065002 (2021).

Chapter 2 – Research Aim 1: Effects of adding household water filters to Rwanda's Community-Based Environmental Health Promotion Programme: A cluster-randomized controlled trial in Rwamagana district [2]

2.1 Abstract

Background: Unsafe drinking water remains a major cause of mortality and morbidity. While Rwanda's Community-Based Environmental Health Promotion Programme (CBEHPP) promotes boiling and safe storage, previous research found these efforts to be ineffective in reducing fecal contamination of drinking water. We conducted a cluster randomized control trial to determine if adding a household-based water filter with safe storage to the CBEHPP would improve drinking water quality and reduce child diarrhea.

Methods: We enrolled 1,199 households with a pregnant person or child under 5 across 60 randomly selected villages in Rwanda's Rwamagana district. CBEHPP implementers distributed and promoted water purifiers to all eligible households in randomly selected half of villages between March and June 2019. We conducted unannounced follow-up visits at 6-8 (midline) and 13-16 (endline) months after the delivery of the filter to observe whether the filter was present and appeared to be in use, to sample and test drinking water for fecal contamination (primary outcome), and to determine caregiver reported diarrhea among children under 5.

Findings: The filter was observed to be present in 98% of intervention households, and appeared in good condition in 93%. About 95% of intervention households reported using the filter over the follow-up period. The intervention reduced the proportion of households with detectable *E.coli* in drinking water samples (primary outcome) by 20% (PR 0.80, 95% CI 0.74-0.87, p<0.0001); it reduced, the proportion of households with moderate and higher fecal contamination (≥10 CFU/100mL) by 35% (PR: 0.65; 95%CI:

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[2] This chapter is a manuscript under review at *NPJ Clean Water*. The formatting is consistent with the journal's requirements. Authors of the submitted manuscript include Sabrina Haque, Miles A. Kirby, Laurien Iyakaremye, Alemayehu Gebremariam, Getachew Tessema, Evan Thomas, Howard H. Chang, and Thomas Clasen

0.57 - 0.74; p<0.0001). The intervention reduced the proportion of children under 5 with caregiver-reported diarrhea in the previous 7 days by 49% (aPR: 0.51 95%CI: 0.35 – 0.73, p< 0.0001).

Interpretation: A household water filter delivered as part of the CBEHPP program was effective in improving drinking water quality and reducing diarrhea among young children.

Funding: The Bill & Melinda Gates Foundation

2.2 Background

Unsafe drinking water remains a leading risk factor for global mortality and morbidity, accounting for at least 1.23 million deaths and 65.1 million disability-adjusted life years (DALYs) from enteric infections in 2019[1]. While Rwanda achieved 82% coverage of access to improved water sources, a 22 percentage point increase since 2000,[2,3] three out of four Rwandan households rely on drinking water contaminated with fecal bacteria.[4] Enteric infections are currently the fifth leading cause of death of children under 5 in the country [5], with unsafe drinking water contributing to an estimated 83% of diarrheal disease deaths in 2019.[1]

As countries work to develop reliable water supply systems, household water treatment and safe storage (HWTS) interventions (e.g., filtration, boiling, chemical disinfectants, solar disinfectant, use of covered collection and storage containers) serve as interim options for obtaining safe drinking water in the home. Various HWTS interventions have been shown effective to reduce diarrheal disease in settings with unsafe drinking water.[6-8] Though the disease burden from unsafe drinking water falls disproportionately on the poorest households living in low- and middle-income countries (LMICs), HWTS interventions seldom reach these populations at scale.[9] This implementation gap could be explained in part by a shortage of replicable, evidence-based models that work to achieve sustained coverage and use in disparate contexts.[10-12] The effectiveness of HWTS interventions on improving health depends on the acceptability and use of technologies in the population, pathogen environment, and the delivery and promotion strategy of the intervention, warranting a need for evidence-based models tailored to the local context.[9,13]

Rwanda has undertaken major initiatives for scaling up HWTS. In 2009, the Ministry of Health began the Community-Based Environmental Health Promotion Programme (CBEHPP) as its primary strategy to combat childhood diarrheal disease. CBEHPP adapts a "Community Health/Hygiene Club" (CHC) approach to promote hygienic practices, intending to achieve zero open defecation, at least 80% hygienic latrine coverage, and improvements in water handling as well as handwashing. The program operates throughout Rwanda, with nearly all villages forming a CHC and implemented by the Ministry of Health working through local authorities and a consortium of NGOs and international donors.[14] While the CBEHPP primarily promotes boiling with safe storage, only 10-34% of Rwandan households report the practice.[4,15] Moreover, a 12-month trial of the CBEHPP in Rwanda's Ruzizi district finds that the program did not improve drinking water quality or reduce diarrhea or nutritional outcomes in young children, even with increases in reported boiling and other safe water handling and treatment practices and access to improved sanitation facilities.[16] The authors speculate that CBEHPP is likely ineffective in improving health because it overly relies on hygiene behavior promotion without the provision of effective WASH hardware to enable households to act on acquired knowledge.

The 2014 *Tubeho Neza* ("Live well" in Kinyarwanda) campaign is another significant effort to scale HWTS in Rwanda. The social enterprise DelAgua Health, in cooperation with the Ministry of Health, delivered tabletop *LifeStraw® Family 2.0* purifiers and improved cookstoves free of cost to over 100,000 households belonging to the lowest economic quartile in Rwanda's Western Province.[17] The campaign involved an intensive effort to promote full coverage and correct and exclusive use of the filter in the target population. Promotional activities included community education (e.g. meetings, skits, radio advertisements), behavior-change materials, and regular household visits by community health workers (CHWs) paid by the implementer to repair or replace failed units, address issues, and reinforce the need for consistent use of the filter by all household members.[17] Kirby and Nagel et al.[18] found that the intervention reduced the proportion of households with detectable fecal contamination in drinking water samples by 38% (PR 0.62, 95% CI 0.57-0.68) and caretaker-reported child diarrhea by 29% (PR 0.71, 95% CI 0.59-0.87) over 12 months. Lower seroprevalence of immunoglobulin G (IgG) antibody response to *Cryptosporidium* was also observed in intervention children under 2 (RR 0.62, 95% CI 0.44–0.89).[19] Although an effective intervention and one of the largest distribution of these filters to date, *Tubeho Neza* is no longer operating and has not been replicated in other regions of Rwanda due to inadequate financing to continue the intensive campaign and household-level support that characterized the *Tubeho Neza* initiative.

Western Province's filter campaign was an effective model for improving point-of-use water quality and child health outcomes in a large vulnerable population in Rwanda. Separately, the CBEHPP succeeds in mobilizing WASH actors and establishing sustained village institutions dedicated to promoting hygienic behaviors nationally; however, it does not effectively improve access to safe water nor reduce childhood diarrhea. The Government of Rwanda is considering ways to strengthen CBEHPP implementation. One option is integrating components of the evidence-based model of delivering household filters as similar to the *Tubeho Neza* campaign into CBEHPP. CBEHPP's existing institutional infrastructure could be leveraged as a platform to scale promotion and delivery of the filter. It is uncertain, however, whether the technology can achieve similar results when provided with the less resource-intensive approach that differentiates the CBEHPP's CHC model from the *Tubeho Neza* program.

This study was designed to address whether filters can be delivered as part of the CBEHPP in a manner that improves household drinking water quality. We hypothesized that the intervention would improve drinking water quality as measured by the proportion of samples with detectable *E. coli* and contamination levels at moderate or higher risk (≥10 CFU/100ml) and very high risk (≥100 CFU/100mL). We report effects on the primary outcome on *E. coli* presence in drinking water and secondary outcomes on coverage and uptake of the filter, caregiver-reported diarrhea among children under 5, and reported healthcare visits for diarrhea treatment among children under 5 over 13-16 months.

2.3 Results

2.3.1 Study participants

1,109 households across intervention villages and 907 households across control villages were identified as eligible according to the inclusion criteria. For the evaluation, 608 and 591 households were randomly selected in the intervention and control groups, respectively. All households selected to be enrolled into the study provided written consent to participate. At baseline, 752 and 719 children under 5 years of age were enrolled into the intervention and control groups, respectively **(Figure 2-1).** We enrolled an average of 20 households per village (SD: 5; range: 10-36 households). Enrollment in seven villages exceeded our cap of 25 households (26 households in five villages and 29 and 36 households in two villages) due to communication barriers in the field.

Baseline characteristics by study group are reported in **Table 2-1.** Access to a place for handwashing, access to improved sanitation, and government-defined socio-economic status had appreciable differences between study groups and were examined as potential confounders in separate sensitivity analyses of adjusted models of the effects. The adjusted model with government-defined socio-economic status made a 3-percentage-point difference on the effect on diarrhoea.

A total of 2,226 household observations and 2,455 child observations were analyzed at midline and endline visits, respectively. Attrition of observations was slightly higher in the intervention group **(Figure 2-1).** Reasons for lost to follow up include moving away, unavailable at time of visit (e.g., enumerators visited household at least twice in a day, with at least 2-hours between visits), or households no longer wished to participate. Five children died in the intervention arm. Deaths were reported to the Emory IRB and RNEC, but deemed unrelated to the intervention.

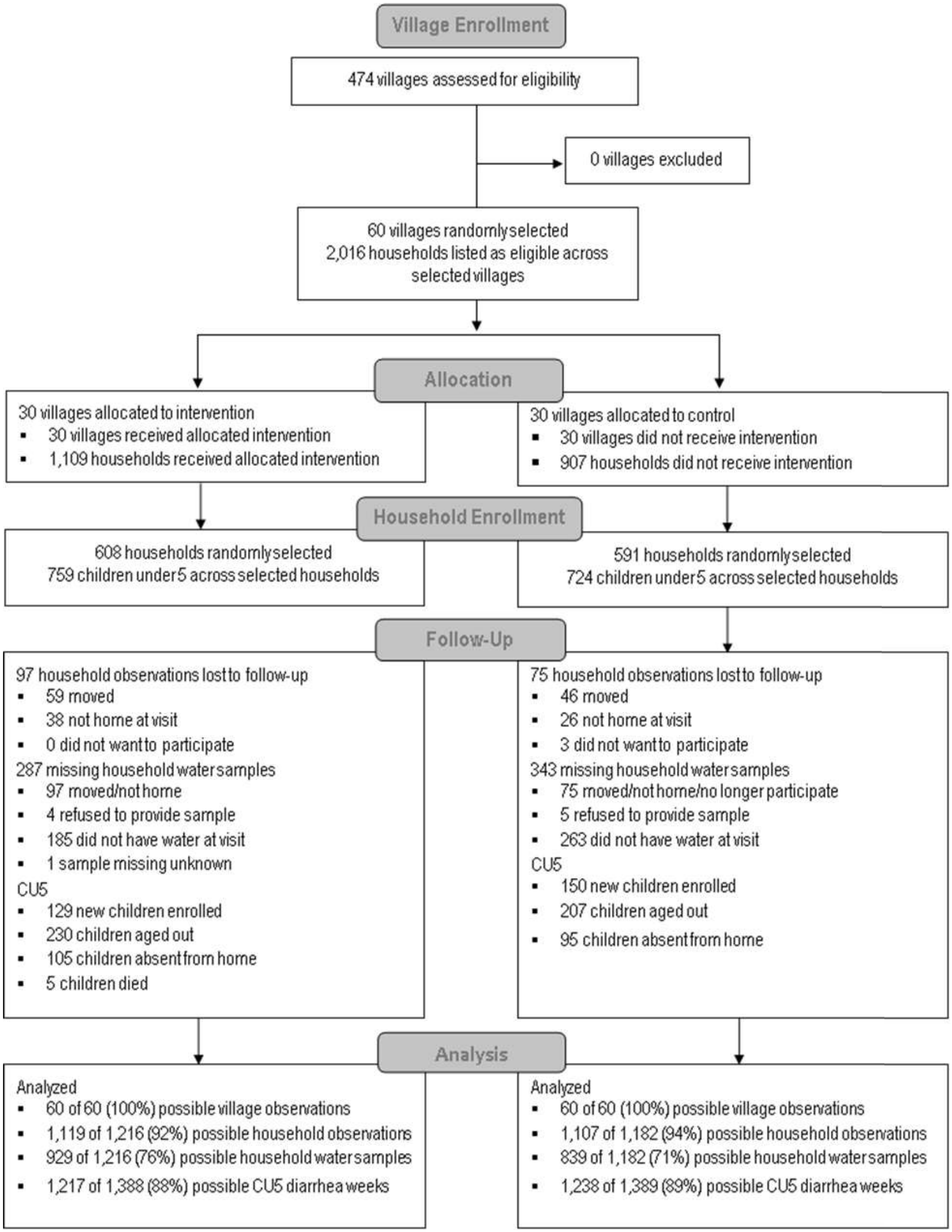

Figure 2-1. Trial flow diagram

Table 2-1. Household and child characteristics at baseline by study arm

	Overall		Intervention		Control	
Demographic and household information	**N**	**%**	**N**	**%**	**N**	**%**
Female respondent	1,197	6.9	608	7.2	589	6.6
Female household head	1,195	7.1	606	7.1	589	7.1
Respondent completed primary school or higher	1,193	50.4	605	50.9	588	49.8
Household head completed primary school or higher	1,138	47.5	575	51.5	563	43.3
Household belongs to *Ubudehe* I or II (lowest government-defined socio-economic classes)	1,189	41.7	603	48.8	586	34.5
Household owned house	1,193	89.2	603	89.4	590	89.0
Household had electricity	1,197	58.4	607	59.1	590	57.8
Household owned livestock	1,199	64.2	608	61.7	591	66.8
Household floor material made of earth/sand	1,199	71.1	608	70.9	591	71.4
Demographic and household information	**N**	**Mean (SD)**	**N**	**Mean (SD)**	**N**	**Mean (SD)**
Respondent age in years	1,199	34.4 (9.9)	608	34.6 (9.9)	591	34.3 (9.8)
Household head age in years	1,199	40.8 (12.1)	608	40.6 (12.1)	591	41.0 (12.1)
Number of residents in household	1,199	5.1 (1.7)	608	5.1 (1.7)	591	5.1 (1.7)
Number of rooms	1,199	5.2 (1.9)	608	5.1 (1.8)	591	5.2 (1.9)
Sanitation and hygiene	**N**	**%**	**N**	**%**	**N**	**%**
Access to JMP improved sanitation	1,198	76.0	607	72.0	591	80.0
Evidence of chickens or cows in compound or yard	1,199	6.4	608	5.6	591	7.3
Has a handwashing location	1,198	39.8	607	37.4	591	42.3
Drinking water source and practices	**N**	**%**	**N**	**%**	**N**	**%**
Main drinking water source: JMP Improved	1,199	87.9	608	89.1	591	86.6
Main drinking water source: JMP Basic Water (Improved <30 min. roundtrip)	1,199	26.1	608	25.5	591	26.7
Main water source type						
Piped water to dwelling or yard/plot	1,199	12.8	608	12.3	591	13.2
Piped water to neighbor	1,199	7.8	608	6.4	591	9.3
Public tap/stand pipe	1,199	30.0	608	32.7	591	27.2

Protected spring, dug well, borehole, tube well	1,199	36.8	608	37.0	591	36.6
Unprotected spring, dug well, borehole, tube well	1,199	2.9	608	2.6	591	3.2
Surface water	1,199	6.2	608	5.4	591	6.9
No reported drinking water treatment practice	1,196	50.5	606	48.3	590	52.7
Observed to store drinking water	853	95.0	414	95.4	439	94.5
Drinking water quality (point-of-use)	**N**	**%**	**N**	**%**	**N**	**%**
<2 CFU/100 mL (no detectable *E.coli*)	853	6.9	414	9.4	439	4.6
1-10 CFU/100 mL	853	15.8	414	16.4	439	15.3
Drinking water quality (point-of-use)	**N**	**Mean (SD)**	**N**	**Mean (SD)**	**N**	**Mean (SD)**
E.coli CFU/100 mL	853	211.5 (285.8)	414	207.4 (272.1)	439	215.4 (298.3)
Child Under 5 Years of Age Characteristics	**N**	**%**	**N**	**%**	**N**	**%**
Female	1,483	46.2	759	44.8	724	47.7
Caretaker-reported 7-day diarrhoea	1,471	6.9	752	6.5	712	7.3
Completed rotavirus vaccination (3-dose series observed on vaccination card	996	80.5	514	80.2	482	80.9
Child Under 5 Years of Age Characteristics	**N**	**Mean (SD)**	**N**	**Mean (SD)**	**N**	**Mean (SD)**
Age in months	1,483	30.2 (16.4)	759	30.4 (16.6)	724	30.0 (16.3)

N denotes the total number of household or child observations in baseline sample.

2.3.2 Filter Coverage, Use, and Acceptability

Table 2-2 provides data on filter coverage, use, and acceptability at midline and endline visits in the intervention group. In combined data from both follow-ups, the filter was observed to be in 99% and functioning in 93% of intervention households. About 95% of intervention households reported using the filter, with 97% at midline and 94% at endline. There was a decline in the percentage of households reporting filling the filter in the previous 7 days, from 97% in midline to 92% in endline. We also found a decline in filters that were observed to have water in the storage container from 81% in midline to 75% in endline. Overall, 81% of households with children under the age of 5 reported that at least one child drank filtered water the previous day. Fewer households reported to treat the provided water sample with the filter at endline, dropping from 95% to 81%. Overall, households generally accepted the filter in terms of water appearance, water smell, water taste, and time to filter water. The amount of time to treat water was the least acceptable feature of the filter.

Table 2-2. Coverage, use, and acceptability of filter at midline and endline in intervention group

	Midline		Endline		Overall	
Coverage	**N**	**% (95% CI)**	**N**	**% (95% CI)**	**N**	**% (95% CI)**
Filter observed in household	555	99.1 (97.9, 99.6)	563	97.9 (96.3, 98.8)	1,118	98.5 (97.6, 99.1)
Filter observed to be in good condition*	532	94.0 (91.6, 95.7)	507	91.9 (89.2, 94.0)	1,039	93.0 (91.2, 94.4)
Use						
Filter reported to be used currently	552	96.6 (94.7, 97.8)	551	93.6 (91.3, 95.4)	1,103	95.1 (93.7, 96.2)
Filter reported to be filled in last 7 days	543	96.9 (95.0, 98.0)	550	91.6 (89.0, 93.7)	1,093	94.2 (92.7, 95.5)
Storage container of filter observed to have water in it	544	81.4 (77.9, 84.5)	545	75.0 (71.2, 78.5)	1,089	78.2 (75.7, 80.6)
Drinking water sample provided reported to be treated by *LifeStraw®* filter	447	94.6 (92.1, 96.4)	482	80.7 (76.9, 84.0)	929	87.4 (85.1, 89.4)
Report at least one young child drank filtered water yesterday	535	83.7 (80.4, 86.6)	523	78.8 (75.1, 82.1)	1,058	81.3 (78.8, 83.5)
Acceptability#						
Appearance of filtered water	549	100	551	100	1,100	100
Smell of filtered water	550	99.1 (97.8, 99.6)	551	99.5 (98.3, 99.8)	1,101	99.3 (98.6, 99.6)
Taste of filtered water	548	99.5 (98.3, 99.8)	546	99.6 (98.5, 99.9)	1,094	99.5 (98.9, 99.8)
Time to filter water	549	91.4 (88.9, 93.5)	551	88.2 (85.2, 90.6)	1,100	89.8 (87.9, 91.5)

N denotes the number of household observations in survey round

* Good condition refers to being observed to have been assembled properly, working tap, no leaking, undamaged container, adequate flowrate, and ability to backwash

Respondent reported feature to be acceptable or very acceptable

2.3.3 Drinking water quality

A total of 929 and 839 water samples were collected during follow-ups in the intervention and control groups, respectively. The control group had more missing water samples compared to the intervention group. Reasons for missing water samples were either due to household lost to follow up, lost sample, or more commonly because households did not have available drinking water at the time of visit (**Figure 2-1)**.

Overall, the proportion of drinking water samples with no detectable *E.coli* was higher in the intervention group **(Figure 2-2)**. **Table 2-3** shows the effects of the intervention on the drinking water quality, analyzed by detectable *E.*coli and other WHO risk categories.[20] The intervention reduced the proportion of drinking water with detectable *E.coli* by 20% (PR: 0.80; 95%CI: 0.74 - 0.87) compared to the control. It reduced the proportion of drinking water samples with moderate and higher fecal contamination (≥10 CFU/100mL) by 35% (PR: 0.65; 95%CI: 0.57 - 0.74; p-value <0.0001) and the proportion of drinking water samples with very high fecal contamination (≥100 CFU/100mL) by 44% (PR: 0.56; 95%CI: 0.46 - 0.69; p-value <0.0001). The adjusted models did not differ with crude models of effects on water quality outcomes. The improvement in drinking water quality among intervention households is also evident in comparing mean levels of colony forming units (CFUs) of *E coli* **(Table 2-4)**. The intervention group had an arithmetic mean of 91.8 CFU/100 mL (95%CI: 80.6, 103.1) and Williams mean of 14.1 CFU/100 mL (95%CI: 12.3, 16.1), and the control group had an arithmetic mean of 175.3 CFU/100 mL (95%CI: 158.3, 192.2) and Williams mean of 44.4 CFU/100 mL (95%CI: 38.8, 50.8).

Table 2-3. Effects of intervention during follow-up on household-level drinking water quality outcomes

Model	Primary Outcome	Intervention		Control			
	Drinking water quality	**n**	**%**	**n**	**%**	**PR (95% CI)**	***p***
1[a]	≥2 CFU/100 mL (any detectable *E.coli contamination*)	929	69.9	839	87.0	0.80 (0.74, 0.87)	<0.001
2[a]	≥10 CFU/100 mL (Moderate and higher *E.coli* contamination)	929	49.3	839	74.7	0.66 (0.58, 0.75)	<0.001
3[a]	≥100 CFU /100 mL (Very high *E.coli contamination*)	929	22.4	835	39.8	0.56 (0.46, 0.68)	<0.001
4[b]	≥2 CFU/100 mL (any detectable *E.coli contamination*)	923	69.8	835	87.2	0.80 (0.74, 0.87)	<0.001
5[b]	≥10 CFU/100 mL (Moderate and higher *E.coli* contamination)	923	49.2	835	75.0	0.65 (0.57, 0.74)	<0.001
6[b]	≥100 CFU /100 mL (Very high *E.coli contamination*)	923	22.4	835	39.8	0.56 (0.46, 0.68)	<0.001
7[c]	≥2 CFU/100 mL (any detectable *E.coli contamination*)	929	69.9	839	87.0	0.80 (0.76, 0.85)	<0.001
8[c]	≥10 CFU/100 mL (Moderate and higher *E.coli* contamination)	929	49.3	839	74.7	0.66 (0.61, 0.72)	<0.001
9[c]	≥100 CFU /100 mL (Very high *E.coli contamination*)	929	22.4	839	39.8	0.56 (0.48, 0.66)	<0.001
10[d]	≥2 CFU/100 mL (any detectable *E.coli contamination*)	923	69.8	835	87.2	0.80 (0.76, 0.84)	<0.001
11[d]	≥10 CFU/100 mL (Moderate and higher *E.coli* contamination)	923	49.2	835	75.0	0.66 (0.61, 0.71)	<0.001
12[d]	≥100 CFU /100 mL (Very high *E.coli contamination*)	923	22.4	835	39.8	0.56 (0.48, 0.65)	<0.001

n denotes the total number of household water samples analyzed in follow-up rounds.

[a] Prevalence ratio (PR), 95% Confidence Interval (95% CI) and p-value derived from log-binomial generalized estimating equations with robust standard errors to account for clustering within village. Model only conditions group assignment and drinking water quality outcome.

[b] PR, 95% CI and p-value derived from log-binomial generalized estimating equations with robust standard errors to account for clustering within village. Model further adjusts for government-defined socio-economic status.

[c] PR, 95% CI and p-value derived from log-binomial generalized estimating equations with robust standard errors to account for clustering within household from repeated measurements. Model only conditions group assignment and drinking water quality outcome.

[d] PR, 95% CI and p-value derived from log-binomial generalized estimating equations with robust standard errors to account for clustering within household from repeated measurements. Model only conditions group assignment and drinking water quality outcome.

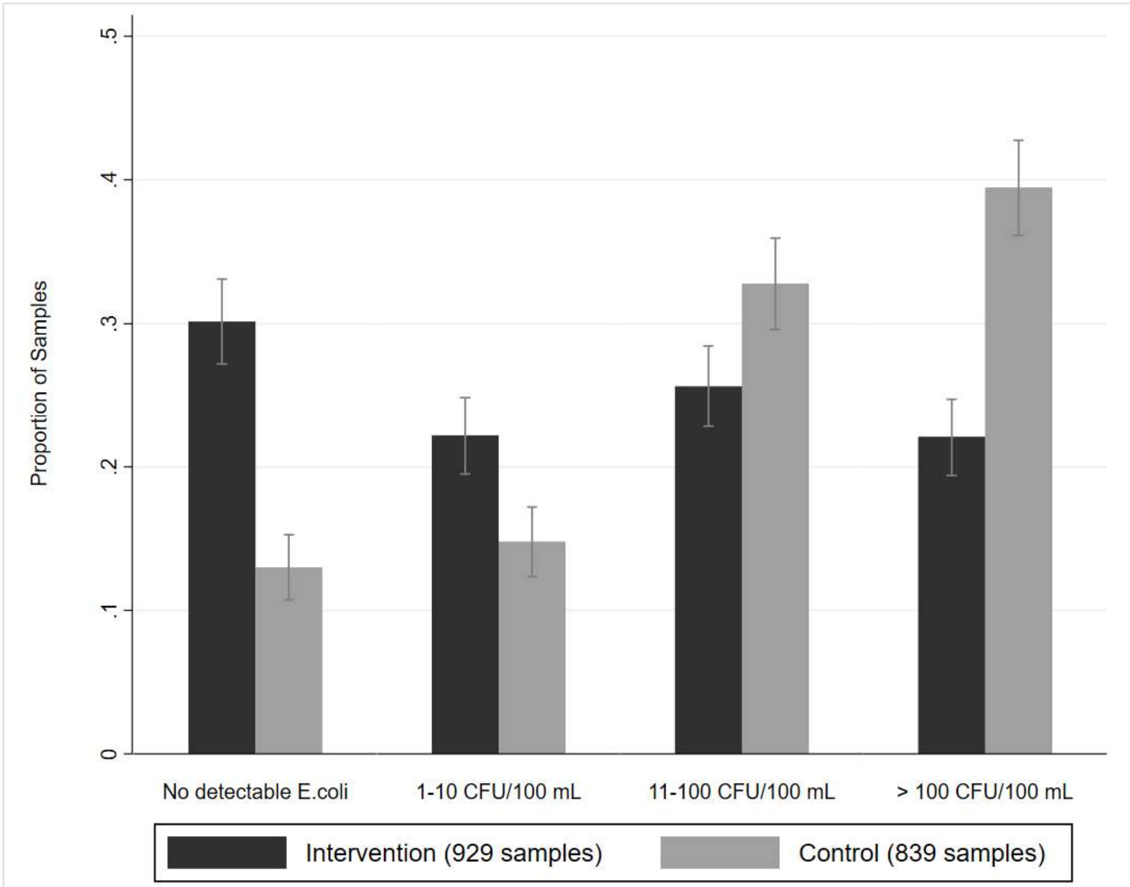

Figure 2-2. Distribution of water quality result by WHO risk level (midline and endline combined)

Table 2-4. Means of CFU count per 100 mL of drinking water samples by study group and round

	Intervention			**Control**		
Visit	**N**	**AM (95% CI)**	**WM (95% CI)**	**N**	**AM (95% CI)**	**WM (95% CI)**
Midline	448	88.6 (73.0, 104.2)	14.9 (12.3, 18.0)	366	174.5 (148.1, 200.8)	43.6 (35.6, 53.3)
Endline	481	94.5 (78.7, 111.0)	13.4 (11.0, 16.2)	473	175.9 (153.8, 198.0)	45.0 (37.5, 54.0)
Overall	929	91.8 (80.6, 103.1)	14.1 (12.3, 16.1)	839	175.3 (158.3, 192.2)	44.4 (38.8, 50.8)

AM: Arithmetic mean; WM: Williams Mean. To calculate WM, 1 was added to the variable before taking the geometric mean to account for values less than 1 and then the result was subtracted by 1.

2.3.4 Child Diarrhea

The intervention reduced the prevalence of child diarrhea **(Table 2-5).** Among children under 5, diarrheal prevalence in the previous 7-days was reduced by 49% (PR: 0.51 95%CI: 0.35 – 0.73, p-value < 0.0001) after adjusting for government defined socio-economic status. Similar effects were seen in children under two (PR: 0.55 95%CI: 0.37 –0.83 p-value=0.005). Caregivers reported fewer visits to CHWs or clinics for diarrhea treatment for children under 5 (PR: 0.46 95%CI: 0.22 – 0.96; p-value=0.039) after adjusting for government-defined socio-economic status. Although the proportion of reported visits to CHC or clinics was lower in the intervention group among children under two, there were no overall effects from the intervention on CHW or clinic visits for this age group. The effects on child diarrheal outcomes observed from the models unadjusted for socio-economic status are slightly lower compared to adjusted models.

Table 2-5. Effects of intervention during follow-up on diarrhea outcomes for children under 5 and 2

Model	Secondary Outcome	Intervention		Control			
	Diarrhea- Children Under 5	**n***	**%**	**n***	**%**	**PR (95% CI)**	***p***
1[a]	In the last 7 days, child reported to have 3 or more loose stools in 24 hours	1,217	4.9	1,238	9.3	0.54 (0.38, 0.78)	0.001
2[a]	In the last 7 days, child reported to be taken to CHW or clinic for diarrhoea treatment	1,222	1.5	1,243	3.0	0.53 (0.28, 0.98)	0.045
3[a]	In the last 7 days, child reported to be taken to CHW for diarrhoea treatment	1,223	0.6	1,243	1.2	0.48 (0.18, 1.26)	0.138
4[a]	In the last 7 days, child reported to be taken to clinic for diarrhoea treatment	1,222	1.0	1,243	2.1	0.48 (0.23, 0.98)	0.043
	Diarrhea- Children Under 2						
5[a]	In the last 7 days, child reported to have 3 or more loose stools in 24 hours	379	8.7	371	15.6	0.55 (0.37, 0.83)	0.005
6[a]	In the last 7 days, child reported to be taken to CHW or clinic for diarrhoea treatment	379	3.2	370	5.7	0.52 (0.26, 1.02)	0.059
7[a]	In the last 7 days, child reported to be taken to CHW for diarrhoea treatment	379	0.8	370	1.9	0.45 (0.11, 1.85)	0.268
8[a]	In the last 7 days, child reported to be taken to clinic for diarrhoea treatment	379	2.6	370	3.8	0.63 (0.29, 1.39)	0.255
	Diarrhea- Children Under 5						
9[b]	In the last 7 days, child reported to have 3 or more loose stools in 24 hours	1,205	4.9	1,233	9.3	0.51 (0.35, 0.73)	<0.001
10[b]	In the last 7 days, child reported to be taken to CHW or clinic for diarrhoea treatment	1,210	1.5	1,238	3.0	0.52 (0.27, 0.98)	0.044
11[b]	In the last 7 days, child reported to be taken to CHW for diarrhoea treatment	1,211	0.6	1,238	1.2	0.47 (0.18, 1.27)	0.138
12[b]	In the last 7 days, child reported to be taken to clinic for diarrhoea treatment	1,210	1.0	1,243	2.1	0.46 (0.22, 0.96)	0.039
	Diarrhea- Children Under 2						
13[b]	In the last 7 days, child reported to have 3 or more loose stools in 24 hours	377	8.8	371	15.6	0.55 (0.37, 0.83)	0.005
14[b]	In the last 7 days, child reported to be taken to CHW or clinic for diarrhoea treatment	377	3.2	370	5.7	0.51 (0.25, 1.02)	0.057
15[b]	In the last 7 days, child reported to be taken to CHW for diarrhoea treatment	377	0.8	370	1.9	0.49 (0.12, 2.08)	0.334
16[b]	In the last 7 days, child reported to be taken to clinic for diarrhoea treatment	377	2.7	370	3.8	0.61 (0.27, 1.37)	0.229

n denotes the total number of child observations analyzed in follow-up rounds*

.[a] Prevalence ratio (PR), 95% Confidence Interval (95% CI) and p-value derived from log-binomial generalized estimating equations with robust standard errors to account for clustering within village. Model conditions group assignment, age in months, sex, and diarrhoea outcome.

[b] PR, 95% CI and p-value derived from log-binomial generalized estimating equations with robust standard errors to account for clustering within village. Model further adjusts for government-defined socio-economic status.

2.4 Discussion

Our results show that adding filter delivery to the CBEHPP in Rwamagana district improved drinking water quality and reduced diarrheal prevalence and reported CHW visits for diarrhea in the previous 7-days among children under 5. Thirteen to 16 months after delivery, we observed nearly universal coverage of filters in households and found that the intervention increased household-reported treatment of drinking water. While delivery and support of the filter was less intensive than the *Tubeho Neza* program in Western Province, the results show the intervention to be similarly protective in the CBEHPP.[18] These findings are in contrast to previous evidence showing no improvement in water quality or diarrhea under current approaches to the CBEHPP that depend only on behavior-change communication.[16]

Nevertheless, we saw evidence of decreasing trends in filter condition, use, and acceptability between rounds. For example, the proportion of households providing drinking water samples reportedly treated by the filter dropped by 14 percentage points from the first follow-up visit. Households also reported less acceptability of the duration it took filter water by the end of the follow-up. The declining trends in the intermediate outcomes could be the result of seasonality effects on water handling practices in follow-up visits, unsustainable behavior-change, or filter breakage over time.[21,22] In our study population, we observed that the proportion of households using unimproved water sources for their primary drinking water source nearly doubled in the dry season (i.e., endline) in both the intervention and control groups. The use of highly turbid water may influence filter condition, such as risk of clogging and requiring more time for water to pass through the purification system.[23] In parallel to scaling HWTS interventions, governments should invest in long-term improvements to water supply to fully realize health goals.

Program slippage overall is also common in WASH programs, where households gradually resort back to original practices pre-intervention. Notably, most protective effects from HTWS interventions on drinking water quality and health are among studies with short follow-up periods (e.g., < 12 months).[6] Studies that have done follow-up work on HWTS evaluations have been mixed in showing sustained impact, but overall, most show that there is significant decline in use.[18,22,24-26] The positive health effects observed in shorter duration trials could also reflect attenuation in implementation intensity, where the effectiveness of HWTS interventions on health is likely dependent on the frequency of contact between behavior-change promoters and households.[27] In our context, we note that there was more implementation activity, including one planned filter promotional and maintenance visit to households, in the first 6 months of follow-up in the intervention group. Additionally, COVID-19 restrictions and sporadic lockdowns beginning in March 2020 may have constrained the ability to regularly hold and attend CHC meetings in the latter portion of the study period among both groups. The observed decline in use in the intervention group supports a need for more deliberate implementation efforts to upkeep use and functionality of HWTS innovations.

Although our study is limited to 13-16 months of follow-up, it is one of the few long-term evaluations showing positive effects on drinking water and health using an HWTS implementation model. In a matched cohort study, Kirby and colleagues [26] showed that water quality effects from similar filters in Rwanda can be sustained for over 2 years if replace and repair mechanisms are in place. Regardless of declining trends in intermediate outcomes, we found that drinking water quality and child diarrheal prevalence was consistently better compared to the control group at both midline and endline visits. Additional follow-up rounds are planned over the next 12 months to evaluate trends in implementation activities, coverage, use, acceptability, condition, drinking water quality, and diarrhea.

Our study has limitations including the non-blinded nature of the intervention and reliance on reported outcomes, presenting the risk of courtesy/social desirability and recall bias on reported use and health outcomes. Observed water in the filter may not indicate consistent use,[28] and unannounced visits are still vulnerable to household reactivity bias on observational outcomes.[29] Nevertheless, the positive effects on use and diarrheal disease prevalence are reinforced through reductions in *E. coli* contamination in drinking water samples and null effects on health outcomes unrelated to intervention such as 7-day prevalence of toothaches. Although cross-sectional measurement of household drinking water quality is an imperfect proxy for exposure to fecal-contaminated water and disease risk in the preceding week of the survey,[30-32] it is demonstrated to significantly increase the risk of waterborne illnesses.[33,34] The dependence on reported diarrhea also does not capture other health consequences such as chronic environmental enteropathy or asymptomatic and sub-clinical infections related to contaminated drinking water.[35]

Our evaluation supports the intervention's underlying theory of change that the delivery and promotion of locally-acceptable HTWS hardware improves drinking water quality and, subsequently, child health. Our findings suggest that Rwanda's CBEHPP and other similar programs using CHC models can be used to deliver acceptable HWTS technologies to vulnerable communities. The integration of microbiologically proven filters into the CBEHPP is one evidence-based option that may help the program meet its objectives of reducing the diarrheal burden in Rwanda. Future studies should document the long-term sustainability and use of HWTS hardware, given the trends in declining use and functionality observed over 13-16 months. Research should also examine strategies for ongoing monitoring (e.g., use and drinking water quality) and compare and optimize implementation strategies that will help policymakers and development partners feasibly scale safe drinking water solutions in their local contexts.

2.5 Methods

We conducted a cluster randomized control trial in Rwamagana district to determine whether adding a household-based water filter with safe storage to the CBEHPP could be effective in improving drinking water quality.

2.5.1 Intervention

The intervention under evaluation is the delivery and promotion of the *LifeStraw*® Family 2.0 filters in the CBEHPP program. The filter is a tabletop point-of-use water treatment system that includes an 80 μm pre-filter to remove coarse material, 20 nm hollow-fiber ultrafiltration membrane, backwash lever, and covered storage container with 5.5L capacity. The system meets the WHO's "comprehensive protection" guideline for household water treatment technologies,[36] it can filter up to 18,000 liters of water, which should be able to supply a family of five with clean drinking water for three to five years, without any replacement of parts.[37]

Delivery and promotion of the filter is through the CBEHPP, which organizes village-level CHCs with a maximum membership of one hundred households. Clubs aim to meet weekly and are led by volunteer CHC facilitators that are trained to deliver a 20-module curriculum designed by the Ministry of Health. The filter-integrated intervention tasks CHC facilitators to additionally serve as the primary service providers of the filter. The CBEHPP filter integration was intended to have "lighter touch" engagement compared to the delivery of filters in the *Tubeho Neza* campaign. Major differences between the approaches include *Tubeho Neza's* additional delivery of improved cookstoves, exclusive targeting of households belonging to the lowest economic quartile, mass media campaigns, and supplementary promotional activities such as regular CHW cooperative and community meetings and frequent household visits.[17]

Bradshaw et al.[38] publish further details on the intervention and delivery in their process evaluation. CHC facilitators were trained to promote the filter and to repair or replace non-functional units. Eligible households were invited to receive the filter at a mass-distribution event held at the main health center serving the geographical sector. Following the distribution, CHC facilitators conducted individual household visits to teach households how to use the filter and provide a promotional poster. Households were instructed not to use the filter until the initial visit was completed. A second promotional household visit by CHC facilitators was completed ~6-months later to monitor upkeep/functionality, use, and satisfaction with the filter. CHC facilitators additionally reinforced messaging in CHC meetings. Households that are eligible to receive the filter include CHC members and have at least one child under the age of 5 or have at least one pregnant woman living in the household. All eligible households were able to receive the filter regardless of being selected to participate in the study.

Catholic Relief Services (CRS) and SNV, two of the government's primary implementing NGO partners of CBEHPP, delivered the intervention with their local partner African Evangelist Enterprise (AEE). The NGOs implement CBEHPP and its CHC model through *Gikuriro*, a USAID WASH and nutrition program. SNV, CRS, and AEE were supported in this initial distribution and promotion by Amazi Yego, the social enterprise that collaborated in the *Tubeho Neza* filter promotion in Western Province.[17] Amazi Yego trained

CRS, SNV, and AEE and shared experiences in filter delivery. Amazi Yego was also significantly involved in designing the implementation protocol, providing promotional material to be provided to householders and implementing the intervention alongside CRS/SNV/AEE.

2.5.2 Study design

We employed a cluster-randomized controlled trial design to assess the effects of the intervention on point-of-use (PoU) drinking water quality as the primary outcome; we also assess intervention coverage and use and effects on reported diarrhea as secondary outcomes. The trial was conducted over 13-16 months in two follow-up visits. Rwamagana is a primarily rural district in Rwanda's Eastern Province and has a population of 313,461.[39] Rwamagana was selected because it is located in Eastern Province which has one of the highest rates of fecal contamination of drinking water in the country[4] and because it was one of the districts the implementers worked in. SNV and CRS are active in all 474 villages across Rwamagana.

Sixty villages (clusters) were randomly selected, with 30 receiving the intervention (CBEHPP+filter) and 30 serving as controls (CBEHPP alone). Villages were randomly selected from a list of the 474 eligible villages using probability proportional-to-size sampling (PPS) without replacement using *samplepps* in Stata 16 software.[40] PPS was done based on the implementer's reported size of the CHC in each village.

Households in selected villages were eligible to participate in the study if they were verified eligible to receive the intervention (CHC member households who have at least one child under 5 or pregnant person living in the household at time of baseline) and had a household member that was over 18 years of age available to consent to enrollment. A list of eligible households was made for each of the 60 villages by consulting the district registers, CHC registers, and with the CHC facilitators. Eligible households per village ranged from 10-72 households. Twenty-five households were randomly selected to be enrolled in the study from each village list using simple random sampling using the sample function to randomly order households in R statistical software[41]. Other eligible households were deemed as replacement study households. Enumerators were instructed to attempt each of the randomly selected 25 households twice at least 2 hours apart during the day. If households could not be reached or were otherwise found to be ineligible, enumerators enrolled one of the replacement households based on a random order. To complete a village, at least half of the eligible households in the village needed to have been enrolled, but a cap of 25 households per village was enforced due to logistical constraints.

2.5.3 Randomization and blinding

Random allocation of the intervention and control groups was done at the village level. To help ensure geographical balance between arms, random allocation of the intervention was stratified by the 13 sectors within the district. An individual unaffiliated with the project conducted the allocation. The data collection team, village-level implementers/leaders (e.g., CHC facilitators, village leaders, CHWs, AEE staff) and participating households were blinded to the allocation during baseline data collection. Enumerators and households could not be blinded after implementation due to the nature of the intervention. The primary data analyst additionally oversaw and managed the data collection, and therefore, could not be blinded. The principal investigator remained blinded throughout the study duration.

2.5.4 Baseline and follow-ups

A baseline survey was conducted from December 2018 to March 2019 prior to intervention delivery. The intervention was delivered from March to June 2019. A midline survey was conducted 5-7 months (median 6 months) following intervention delivery from October to December 2019. The endline survey was originally planned to be conducted 6 months later. However, due to government lockdowns and restrictions from COVID-19, the endline survey was delayed by approximately 2 months and was completed 13-16 months (median 14 months) after intervention delivery from July-September 2020. We aimed to have equal number of intervention and control villages visited in a day. We collected drinking water samples and information on household and demographic characteristics, reported and observed WASH access based on the WHO/UNICEF Joint Monitoring Programme (JMP) core household survey questions[42], reported and observed water treatment and handling practices, and caretaker-reported health of children under 5. Questions were directed to the primary cooks aged 18 and over. If the primary cook was unavailable or under 18, questions were directed to another household member aged 18 and over. Respondents were asked to confirm questions on individual children with their respective primary caregivers if they were available. Survey data were collected and managed using *REDCap* electronic data capture tools hosted at Emory University.[43]

2.5.5 Primary and secondary outcomes

The primary outcome is detectable fecal contamination of drinking water. Following the WHO/UNICEF JMP core household survey questions, each respondent was asked to serve drinking water. A 100 mL sample was collected in a sterile *Whirl-Pak®* bag containing sodium thiosulfate (Nasco, Madison, WI, USA) and kept on ice until tested within 8 hours with *CompactDry™* (Nissui Pharmaceutical, Tokyo, Japan) media plates using membrane filtration procedures prescribed by UNICEF[44]. Samples were initially diluted to 50 mL in order to reduce the likelihood of plates that were too numerous to count (TNTC). If drinking water samples were visibly turbid, then they were subsequently diluted to 20 mL, 10 mL, and 5mL based on the severity of turbidity. Plates were incubated at 30 degrees Celsius for 24 hours using an *IncuBox Thermocult* (Boehringer, Mannheim, Germany). One technician then counted and recorded individual *E. coli* CFU on each plate. Random spot checks were performed by managers to validate counts. Water quality results were double entered by two different staff. Plates that were TNTC were assigned a level of 300 CFUs. At least one duplicate and blank of distilled water were tested with samples daily. For duplicate samples, the results of both counts were summed and divided by the total volume processed. In order to obtain standardized totals per 100 mL, we normalized the CFU count by the total volume processed and multiplied the result by 100.

Secondary health outcomes include caregiver-reported diarrhea and healthcare visits for diarrhea within the previous 7-days in children under 5 years of age and under 2 years of age at follow-up visits. For reporting diarrhea in the previous 7-days, we followed the World Health Organization (WHO) standard definition, which defines diarrhea as three or more loose stools in a 24-hour period that can take the shape of a container.[45] For reporting healthcare visits, we asked caregivers if they sought medical care from a health clinic or CHW for any reported diarrhea cases within previous 7-days following the WHO definition of diarrhea or caregiver's interpretation of diarrhea. We also collected data on whether children had a toothache in the previous 7-days to serve as negative control to account for courtesy bias.[46]

We collected data on filter coverage, use, and acceptability at midline and endline visits. To measure filter coverage, we observed whether the household had the filter and if the filter was in good condition at the time of visit (e.g. assembled properly, working tap, no leaking, undamaged container, adequate flowrate, and ability to backwash). To measure filter use, we collected data on whether the filter was observed to have water in it at the time of visit and whether the household reported using the filter, filling the filter in the previous 7-days, treating drinking water, and if a child under 5 drank filtered water the previous day. To measure filter acceptability, we asked households to rate their acceptability of the appearance of filtered water, smell, taste of filtered water, and time to filter water on a scale from 1 to 4, with 3 and 4 being acceptable and very acceptable, respectively.

2.5.6 Statistical approach

The study was powered to detect a 25% reduction in prevalence of detectable *E. coli* bacteria in point-of-use water samples, measured at each household visit. The number of households required in each group was derived by first using Diggle, Heagerty, Liang, and Zeger's[47] formula for estimating sample-size requirements for differences in proportions across multiple time points. The result of this equation was then adjusted to account for both village-level clustering and the assumed 15% rate of attrition. We assumed 50% prevalence of *E. coli* presence in drinking water samples in the control group based on national water quality surveys. We assumed an intra-village correlation of 0.14 and intra-household ICC of 0.21 based on previous studies,[18] 2 visits post baseline, and 25 households per village would meet eligibility requirements. This gave us a sample size requirement of 51 villages to have 80% power for a 25% reduction. To accommodate the uncertainties of CHC enrollment rates and village size, we aimed to enroll up to 1,300 households across 60 villages.

We defined the primary outcome as the presence of *E. coli* bacteria in 100 mL samples of drinking water. As the samples were diluted for purposes of this analysis, presence of *E. coli* CFU follows the limit of detection (LOD) according to the volume processed. The laboratory results showed that the total volume of water processed for household samples that did not display any CFUs (e.g. non-detect plates) ranged from 50mL to 100 mL Therefore, results were categorized into a binary variable, where non-detectable *E.coli* contamination is overall reported as <2 CFU/100mL water (e.g. LOD for a 50mL sample). We additionally categorized *E. coli* presence into two other binary outcomes according to WHO risk category cutoffs for moderate-to-high (≥10 CFU/100mL) and very high (≥100 CFU/100mL) contamination.[20] We examined the latter outcomes based on findings from meta-analysis on water quality and diarrhea, which found a marked increase in disease risk for households when fecal contamination exceeded 10 TTC/100 mL.[33] We calculated arithmetic and Williams means of CFU counts to account for the skewed distribution. The Williams mean is calculated by adding 1 to all values, taking the geometric mean, and then subtracting the mean by 1.[48] Williams mean were used to account for values less than 1. Non-detect plates were included in the mean calculation as half of their specific LOD.

The effect of the intervention was assessed based on group assignment, regardless of uptake of the intervention (i.e. intention-to-treat). For the household-level primary outcomes on *E. coli* presence in drinking water and the individual-level secondary outcomes on child health, we used binomial regression with a log link and generalized estimating equations (GEE) with robust standard errors to account for village-level clustering.[49,50] For the child health models, we adjusted for sex and age in months. We estimated prevalence ratios (PR) by calculating the exponential of the model coefficients for the group assignment. We provide sample proportions and 95% confidence intervals for outcomes on filter coverage, acceptability, and use in the intervention group.

Covariate adjustment for imbalance: We reviewed the baseline data to see if there were large differences (>10% difference) between arms in socio-economic and household variables that are established determinants of drinking water quality or childhood diarrhoea (**Table 2-1**). Covariates that had little variation in the study population (e.g. over 95% prevalence or less than 5% prevalence) were excluded from adjustment. We then examined the relationship between primary and secondary outcomes and imbalanced covariates of concern (e.g., socio-economic status, access to handwashing location, and access to improved sanitation) in individual bivariate analyses. Socio-economic status was related diarrhoeal prevalence in children under 5 and 2 ($p<0.05$). Access to a handwashing location was related ($p<0.05$) to only very high levels of *E.coli* bacteria (≥100 CFU/100mL) and to diarrheal prevalence in children under 5 ($p<0.05$). Access to sanitation did not have an effect on any outcome. We adjusted for socio-economic status and access to handwashing station in separate sensitivity analyses and compared results to unadjusted models to see if there were considerable differences in effects of the intervention. Water quality effects observed in unadjusted models were comparable to adjusted models with access to handwashing. Effects on under-5 child diarrhoea prevalence from the intervention had a 5 percent difference between the unadjusted model and adjusted model with socio-economic status. Effects on under-5 child diarrhoea prevalence from the intervention had less than one percent difference between the unadjusted model and adjusted model with access to handwashing location. Therefore, we chose to only adjust for socio-economic status in all final models. Unadjusted and adjusted models are presented together in **Table 2-3** and **Table 2-5**.

Clustering considerations: Current GEE statistical packages are limited in that they only allow for adjusting for one level of clustering. We adjusted at the village-level because it is the highest level of clustering that is of concern and the unit of randomization,[51] which should intrinsically adjust for lower levels of clustering[49]. In sensitivity analyses, we adjusted for household-level clustering to account for longitudinal sampling, but did not see major differences in the water quality or diarrhea effects compared to the models adjusted for village-level clustering. The comparison in presented in the water quality results in **Table 2-3.**

All analyses were done using Stata 16 (Stata Corporation, College station, TX, USA).[52]

2.5.7 Ethics and registration

The trial is registered under the Pan African Clinical Trial Registry, Trial ID= PACTR201812547047839. The protocol received ethical approval and was annually renewed by the Emory University Institutional

Review Board (CR001-IRB00106424) and Rwanda National Ethics Committee (IRB 0001497). We obtained signed informed consent from the main survey respondent during enrollment.

2.5.8 Data availability

Study protocol and underlying de-identified data can be found at Emory/UNC Dataverse. https://doi.org/10.15139/S3/H3UJMQ

2.5.9 Role of the funding source

The Bill & Melinda Gates Foundation funded this research, and had input on the study design and progress of the study, but did not have any role in data collection, data analysis, data interpretation, or writing of these results. Vestergaard International donated the filters for the study, but had no role at any stage in the study design, data collection, data analysis, data interpretation, or writing of these results. The authors had full access to all of the data and had the final responsibility for the decision to submit for publication.

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Author contributions

TC and MK conceptualized the study. SH, MK, TC, AG, GT, and ET authored the study protocol. HC informed the statistical approach. AG, GT, and ET led the design and implementation of the intervention. SH, MK, and LI managed data collection. SH analyzed the data and wrote the first draft of the manuscript. All authors reviewed and provided edits to the writing of the manuscript.

Competing interests

The Authors declare no Competing Financial or Non-Financial Interests.

2.7 References

1 Murray, C. J. *et al.* Global burden of 87 risk factors in 204 countries and territories, 1990–2019: a systematic analysis for the Global Burden of Disease Study 2019. *The Lancet* **396**, 1223-1249 (2020).

2 Bain, R., Johnston, R., Khan, S., Hancioglu, A. & Slaymaker, T. Monitoring Drinking Water Quality in Nationally Representative Household Surveys in Low-and Middle-Income Countries: Cross-Sectional Analysis of 27 Multiple Indicator Cluster Surveys 2014–2020. *Environmental Health Perspectives* **129**, 097010 (2021).

3 WHO/UNICEF. Progress on household drinking water, sanitation and hygiene 2000-2020: five years into the SDGs. Report No. 9240030840, (2021).

4 Brown, K. H. Diarrhea and malnutrition. *The Journal of nutrition* **133**, 328S-332S (2003).

5 Petri, W. A. *et al.* Enteric infections, diarrhea, and their impact on function and development. *The Journal of clinical investigation* **118**, 1277-1290 (2008).

6 Vos, T. *et al.* Global burden of 369 diseases and injuries in 204 countries and territories, 1990–2019: a systematic analysis for the Global Burden of Disease Study 2019. *The Lancet* **396**, 1204-1222 (2020).

7 Kosek, M. N. *et al.* Causal pathways from enteropathogens to environmental enteropathy: findings from the MAL-ED birth cohort study. *EBioMedicine* **18**, 109-117 (2017).

8 Nasrin, D. *et al.* Pathogens associated with linear growth faltering in children with diarrhea and impact of antibiotic treatment: The Global Enteric Multicenter Study. *The Journal of infectious diseases* **224**, S848-S855 (2021).

9 Budge, S., Parker, A. H., Hutchings, P. T. & Garbutt, C. Environmental enteric dysfunction and child stunting. *Nutrition reviews* **77**, 240-253 (2019).

10 Khalil, I. A. *et al.* Morbidity, mortality, and long-term consequences associated with diarrhoea from Cryptosporidium infection in children younger than 5 years: a meta-analyses study. *The Lancet Global Health* **6**, e758-e768 (2018).

11 Guerrant, R. L., DeBoer, M. D., Moore, S. R., Scharf, R. J. & Lima, A. A. The impoverished gut—a triple burden of diarrhoea, stunting and chronic disease. *Nature reviews Gastroenterology & hepatology* **10**, 220-229 (2013).

12 Gimelli, F. M., Bos, J. J. & Rogers, B. C. Fostering equity and wellbeing through water: A reinterpretation of the goal of securing access. *World Development* **104**, 1-9 (2018).

13 Mehta, L. Water and human development. *World development* **59**, 59-69 (2014).

14 Liu, J. *et al.* Use of quantitative molecular diagnostic methods to identify causes of diarrhoea in children: a reanalysis of the GEMS case-control study. *The Lancet* **388**, 1291-1301 (2016).

15 Girard, M. P., Steele, D., Chaignat, C.-L. & Kieny, M. P. A review of vaccine research and development: human enteric infections. *Vaccine* **24**, 2732-2750 (2006).

16 Platts-Mills, J. A. *et al.* Pathogen-specific burdens of community diarrhoea in developing countries: a multisite birth cohort study (MAL-ED). *The Lancet Global Health* **3**, e564-e575 (2015).

17 Cutler, D. & Miller, G. The role of public health improvements in health advances: the twentieth-century United States. *Demography* **42**, 1-22 (2005).

18 Wagner, E. G., Lanoix, J. N. & Organization, W. H. *Excreta disposal for rural areas and small communities*. (World Health Organization, 1958).

19 Goddard, F. *et al.* Faecal contamination of the environment and child health: a systematic review and individual participant data meta-analysis. *The Lancet Planetary Health* **4**, e405-e415 (2020).

20 Hodge, J. *et al.* Assessing the association between thermotolerant coliforms in drinking water and diarrhea: an analysis of individual–level data from multiple studies. *Environmental health perspectives* **124**, 1560-1567 (2016).

21 Wolf, J. *et al.* Impact of drinking water, sanitation and handwashing with soap on childhood diarrhoeal disease: updated meta-analysis and meta-regression. *Tropical medicine & international health* **23**, 508-525 (2018).

22 Clasen, T. F. *et al.* Interventions to improve water quality for preventing diarrhoea. *Cochrane database of systematic reviews* (2015).

23 Pickering, A. J. & Davis, J. Freshwater availability and water fetching distance affect child health in sub-Saharan Africa. *Environmental science & technology* **46**, 2391-2397 (2012).

24 Elliott, M. *et al.* Addressing how multiple household water sources and uses build water resilience and support sustainable development. *NPJ Clean Water* **2**, 1-5 (2019).

25 Overbo, A., Williams, A. R., Evans, B., Hunter, P. R. & Bartram, J. On-plot drinking water supplies and health: a systematic review. *International Journal of Hygiene and Environmental Health* **219**, 317-330 (2016).

26 Shaheed, A., Orgill, J., Montgomery, M. A., Jeuland, M. A. & Brown, J. Why? improved? water sources are not always safe. *Bulletin of the World Health Organization* **92**, 283-289 (2014).

27 Jensen, P. K. *et al.* Domestic transmission routes of pathogens: The problem of in-house contamination of drinking water during storage in developing countries. *Tropical Medicine & International Health* **7**, 604-609 (2002).

28 Shields, K. F., Bain, R. E., Cronk, R., Wright, J. A. & Bartram, J. Association of supply type with fecal contamination of source water and household stored drinking water in developing countries: a bivariate meta-analysis. *Environmental health perspectives* **123**, 1222-1231 (2015).

29 Clasen, T. F. & Bastable, A. Faecal contamination of drinking water during collection and household storage: the need to extend protection to the point of use. *Journal of water and health* **1**, 109-115 (2003).

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

31 Fukuda, S., Murakami, M., Noda, K. & Oki, T. How achieving the Millennium Development Goals increases subjective well-being in developing nations. *Sustainability* **8**, 189 (2016).

32 Hutton, G. & Varughese, M. The costs of meeting the 2030 sustainable development goal targets on drinking water, sanitation, and hygiene. (2016).

33 WHO. Combating waterborne disease at the household level. (2007).

34 Luby, S. P. *et al.* Effects of water quality, sanitation, handwashing, and nutritional interventions on diarrhoea and child growth in rural Bangladesh: a cluster randomised controlled trial. *The Lancet Global Health* **6**, e302-e315 (2018).

35 Barreto, M. L. *et al.* Effect of city-wide sanitation programme on reduction in rate of childhood diarrhoea in northeast Brazil: assessment by two cohort studies. *The Lancet* **370**, 1622-1628, doi:https://doi.org/10.1016/S0140-6736(07)61638-9 (2007).

36 Lin, A. *et al.* Effects of water, sanitation, handwashing, and nutritional interventions on child enteric protozoan infections in rural Bangladesh: a cluster-randomized controlled trial. *Clinical Infectious Diseases* **67**, 1515-1522 (2018).

37 Kirby, M. A. *et al.* Effects of a large-scale distribution of water filters and natural draft rocket-style cookstoves on diarrhea and acute respiratory infection: A cluster-randomized controlled trial in Western Province, Rwanda. *PLoS medicine* **16**, e1002812 (2019).

38 Zambrano, L. D. *et al.* Use of serologic responses against enteropathogens to assess the impact of a point-of-use water filter: a randomized controlled trial in Western Province, Rwanda. *The American journal of tropical medicine and hygiene* **97**, 876 (2017).

39 Schmidt, W.-P. & Cairncross, S. Household water treatment in poor populations: is there enough evidence for scaling up now? *Environmental science & technology* **43**, 986-992 (2009).

40 Hellard, M. E., Sinclair, M. I., Forbes, A. B. & Fairley, C. K. A randomized, blinded, controlled trial investigating the gastrointestinal health effects of drinking water quality. *Environmental Health Perspectives* **109**, 773-778 (2001).

41 Brown, J. & Clasen, T. High adherence is necessary to realize health gains from water quality interventions. *PloS one* **7**, e36735 (2012).

42 Enger, K. S., Nelson, K. L., Rose, J. B. & Eisenberg, J. N. The joint effects of efficacy and compliance: a study of household water treatment effectiveness against childhood diarrhea. *Water research* **47**, 1181-1190 (2013).

43 Pickering, A. J., Arnold, B. F., Dentz, H. N., Colford Jr, J. M. & Null, C. Climate and health co-benefits in low-income countries: a case study of carbon financed water filters in Kenya and a call for independent monitoring. *Environmental health perspectives* **125**, 278-283 (2017).

44 Kirby, M. A., Nagel, C., Rosa, G. A., Thomas, E. A. & Clasen, T. F. in *American Journal of Tropical Medicine and Hygiene.* 582-582 (AMER SOC TROP MED & HYGIENE 8000 WESTPARK DR, STE 130, MCLEAN, VA 22101 USA).

45 Crider, Y. *et al.* Can you taste it? Taste detection and acceptability thresholds for chlorine residual in drinking water in Dhaka, Bangladesh. *Science of the Total Environment* **613**, 840-846 (2018).

46 Arnold, B. F. & Colford, J. M. Treating water with chlorine at point-of-use to improve water quality and reduce child diarrhea in developing countries: a systematic review and meta-analysis. *The American journal of tropical medicine and hygiene* **76**, 354-364 (2007).

47 Pickering, A. J. *et al.* The WASH benefits and SHINE trials: interpretation of WASH intervention effects on linear growth and diarrhoea. *The Lancet Global Health* **7**, e1139-e1146 (2019).

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

49 Kirby, M. A. *et al.* Faecal contamination of household drinking water in Rwanda: A national cross-sectional study. *Science of the Total Environment* **571**, 426-434 (2016).

50 Sinharoy, S. S. *et al.* Effect of community health clubs on child diarrhoea in western Rwanda: cluster-randomised controlled trial. *The Lancet Global Health* **5**, e699-e709 (2017).

51 WHO/UNICEF. (World Health Organization and UNICEF, 2019).

52 Clasen, T. *et al.* Interventions to improve water quality for preventing diarrhoea. *Cochrane Database Syst Rev*, CD004794, doi:10.1002/14651858.CD004794.pub3 (2015).

53 Wolf, J. *et al.* Impact of drinking water, sanitation and handwashing with soap on childhood diarrhoeal disease: updated meta-analysis and meta-regression. *Trop Med Int Health* **23**, 508-525, doi:10.1111/tmi.13051 (2018).

54 Fewtrell, L. *et al.* Water, sanitation, and hygiene interventions to reduce diarrhoea in less developed countries: a systematic review and meta-analysis. *Lancet Infect Dis* **5**, 42-52, doi:10.1016/S1473-3099(04)01253-8 (2005).

55 Ojomo, E., Elliott, M., Goodyear, L., Forson, M. & Bartram, J. Sustainability and scale-up of household water treatment and safe storage practices: Enablers and barriers to effective implementation. *International Journal of Hygiene and Environmental Health* **218**, 704-713, doi:https://doi.org/10.1016/j.ijheh.2015.03.002 (2015).

56 WHO. Scaling up household water treatment among low-income populations. (World Health Organization, 2009).

57 Fiebelkorn, A. P. *et al.* Systematic review of behavior change research on point-of-use water treatment interventions in countries categorized as low-to medium-development on the human development index. *Social Science & Medicine* **75**, 622-633 (2012).

58 Albert, J., Luoto, J. & Levine, D. (ACS Publications, 2010).

59 Ministry of Health. (Kigali, Rwanda, 2010).

60 NISR, M. Rwanda Demographic and Health Survey 2014–15. *Key indicators*, 1045-1049 (2015).

61 Sinharoy, S. S. *et al.* Effect of community health clubs on child diarrhoea in western Rwanda: cluster-randomised controlled trial. *Lancet Glob Health* **5**, e699-e709, doi:10.1016/S2214-109X(17)30217-6 (2017).

62 Barstow, C. K., Nagel, C. L., Clasen, T. F. & Thomas, E. A. Process evaluation and assessment of use of a large scale water filter and cookstove program in Rwanda. *BMC Public Health* **16**, 1-19 (2016).

63 Zambrano, L. D. *et al.* Use of serologic responses against enteropathogens to assess the impact of a point-of-use water filter: a randomized controlled trial in Western Province, Rwanda. *The American journal of tropical medicine and hygiene* **97**, 876-887 (2017).

64 WHO. Guidelines for drinking-water quality. *World Health Organization* **216**, 303-304 (2011).

65 Cassivi, A., Tilley, E., Waygood, E. O. D. & Dorea, C. Household practices in accessing drinking water and post collection contamination: a seasonal cohort study in Malawi. *Water Research* **189**, 116607 (2021).

66 Walters, A. *A performance evaluation of the lifestraw: a personal point of use water purifier for the developing world*, The University of North Carolina at Chapel Hill, (2008).

67 Luby, S. P., Mendoza, C., Keswick, B. H., Chiller, T. M. & Hoekstra, R. M. Difficulties in bringing point-of-use water treatment to scale in rural Guatemala. *The American journal of tropical medicine and hygiene* **78**, 382-387 (2008).

68 Harshfield, E., Lantagne, D., Turbes, A. & Null, C. Evaluating the sustained health impact of household chlorination of drinking water in rural Haiti. *The American journal of tropical medicine and hygiene* **87**, 786-795 (2012).

69 Kirby, M. A. *et al.* Use, microbiological effectiveness and health impact of a household water filter intervention in rural Rwanda—A matched cohort study. *International journal of hygiene and environmental health* **220**, 1020-1029 (2017).

70 Pickering, A. J. *et al.* The WASH Benefits and SHINE trials: interpretation of WASH intervention effects on linear growth and diarrhoea. *Lancet Glob Health* **7**, e1139-e1146, doi:10.1016/S2214-109X(19)30268-2 (2019).

71 Thomas, E. A., Barstow, C. K., Rosa, G., Majorin, F. & Clasen, T. Use of remotely reporting electronic sensors for assessing use of water filters and cookstoves in Rwanda. *Environmental science & technology* **47**, 13602-13610 (2013).

72 Arnold, B. F. *et al.* Reactivity in rapidly collected hygiene and toilet spot check measurements: a cautionary note for longitudinal studies. *The American journal of tropical medicine and hygiene* **92**, 159 (2015).

73 Goddard, F. G., Chang, H. H., Clasen, T. F. & Sarnat, J. A. Exposure measurement error and the characterization of child exposure to fecal contamination in drinking water. *npj Clean Water* **3**, 1-9 (2020).

74 Ercumen, A. *et al.* Potential sources of bias in the use of Escherichia coli to measure waterborne diarrhoea risk in low-income settings. *Tropical Medicine & International Health* **22**, 2-11 (2017).

75 Luby, S. P. *et al.* Microbiological contamination of drinking water associated with subsequent child diarrhea. *The American journal of tropical medicine and hygiene* **93**, 904 (2015).

76 Goddard, F. G. *et al.* Faecal contamination of the environment and child health: a systematic review and individual participant data meta-analysis. *The Lancet Planetary Health* **4**, e405-e415 (2020).

77 WHO. Results of round II of the WHO international scheme to evaluate household water treatment technologies. (2019).

78 Clasen, T., Naranjo, J., Frauchiger, D. & Gerba, C. Laboratory assessment of a gravity-fed ultrafiltration water treatment device designed for household use in low-income settings. *The American journal of tropical medicine and hygiene* **80**, 819-823 (2009).

79 Bradshaw, A., Mugabo, L., Gebremariam, A., Thomas, E. & MacDonald, L. Integration of Household Water Filters with Community-Based Sanitation and Hygiene Promotion—A Process Evaluation and Assessment of Use among Households in Rwanda. *Sustainability* **13**, 1615 (2021).

80 National Institute of Statistics of Rwanda. (NISR Kigali, 2012).

81 Jenkins, S. SAMPLEPPS: Stata module to draw a random sample with probabilities proportional to size. (2014).

82 R Core Team. A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL (2019).

83 WHO/UNICEF. Core questions on drinking water, sanitation and hygiene for household surveys: 2018 update. *United Nations Children's Fund (UNICEF) and World Helath Organisation, New York* (2018).

84 Harris, P. A. *et al.* Research electronic data capture (REDCap)—a metadata-driven methodology and workflow process for providing translational research informatics support. *Journal of biomedical informatics* **42**, 377-381 (2009).

85 WHO/UNICEF. *Handbook IMCI: integrated management of childhood illness*. (World Health Organization, 2005).

86 Arnold, B. F., Ercumen, A., Benjamin-Chung, J. & Colford Jr, J. M. Brief report: negative controls to detect selection bias and measurement bias in epidemiologic studies. *Epidemiology (Cambridge, Mass.)* **27**, 637 (2016).

87 Diggle, P., Diggle, P. J., Heagerty, P., Liang, K.-Y. & Zeger, S. *Analysis of longitudinal data*. (Oxford university press, 2002).

88 Bottomley, C., Kirby, M. J., Lindsay, S. W. & Alexander, N. Can the buck always be passed to the highest level of clustering? *BMC medical research methodology* **16**, 1-7 (2016).

89 Zeger, S. L. & Liang, K.-Y. Longitudinal data analysis for discrete and continuous outcomes. *Biometrics*, 121-130 (1986).

90 Stata Statistical Software: Release 16 (College Station, TX: StataCorp LLC., 2019).

Chapter 3 – Research Aim 2: Assessing the sustained effects of a water filter intervention in Rwamagana, Rwanda: a 30-month longitudinal study

3.1 Abstract

Background: Household water treatment and safe storage interventions effectively improve microbial water quality and reduce diarrheal disease in areas lacking access to safe water, at least in the short term. However, little is known about their sustainability, with few studies evaluating effectiveness of interventions delivered at scale and for over a year post-implementation. We aimed to assess the longer-term uptake and effects of a household-based filter with safe storage delivered through Community Health Clubs in Rwanda's national environmental health program.

Methods: We undertook a 30-month longitudinal study in Ramagana district, following 608 households across 30 villages receiving the filter intervention. We conducted four unannounced follow-up visits and measured filter coverage, condition, and use, drinking water quality, and child diarrhea prevalence at ~6, 15, 24, and 30 months since the delivery of the intervention.

Findings: Coverage of the water filter remained high throughout the follow-up period, with 94% of households observed to have the filter by the 30-month visit. Compared to the 6-month visit, the households with filters in good condition declined by 12% at the 30 month-visit. Rates of use were comparable between the 6- and 15-month visits but fell by the 24- and 30-month visits. About 84% of households reported using the filter, and 59% had filters with observed water in the storage container at the follow-up. Water quality did not deteriorate, and child diarrhea prevalence did not increase between the 6-month visit.

Interpretation: Coverage, condition, and use of a household water filter delivered using Community Health Clubs in Rwanda declined modestly over time. However, the effects on drinking water quality and child diarrhea were sustained even 30 months post-implementation.

Funding: The Bill & Melinda Gates Foundation

3.2 Background

An estimated 2 billion people use drinking water contaminated with indicators of fecal bacteria, with the majority residing in Sub-Saharan Africa, Central America, and South Asia.[1,2] This exposure is an immediate threat to public health, raising the incidence of enteric infections, anemia, growth faltering, and other health hazards, mostly among young children. For the first time, the United Nations has incorporated targets on water quality into the global development agenda. By 2030, Sustainable Development Goal (SDG) 6.1 aims to achieve universal access to "safely managed water services," which requires drinking water to be free from fecal contamination.[1] In many high-income settings, the microbial safety of drinking water is achieved using treated and well-maintained piped water systems. However, ensuring microbial safety in low-resource areas is a significant challenge due to a shortage of adaptable service models that provide comprehensive and lasting improvements to water supply.

Household water treatment and safe storage (HWTS) is an interim solution to address the health risks of contaminated drinking water. HWTS generally refers to various evidence-based methods that improve water quality at the point of consumption or use. Common methods include point-of-use (PoU) chlorination, filtration, boiling, and solar disinfection. Although the use of covered and hygienic storage containers does not actively remove contaminants, safe storage is shown to effectively protect water from further contamination.[3] HWTS is not designed to improve water quantity or access – two critical aspects of safely managed water services. However, most evidence suggests that HWTS can protect populations from fecal exposure and diarrheal diseases in areas with unsafe water and could more reliably do so than elementary water infrastructure improvements (e.g., provision of protected wells and springs).[2,4-11]

The long-term use, and thus, the effectiveness of HWTS, is not well-understood. Protective health effects are mostly limited to studies evaluating unblinded interventions or studies with short durations (e.g., <12 months).[7,10] The diminished effect of longer-term follow-up periods was first identified in a review evaluating the impact of PoU chlorination.[8] Nearly all studies that met the inclusion criteria were short, with a median follow-up period of 30 weeks. Nevertheless, longer trials overall showed an attenuation of the intervention's effects on child diarrhea. A second review found that duration of follow-up, blinding, and study setting (e.g., emergency or non-emergency context) were significant predictors of the effectiveness of different types of HWTS interventions, predicting that ceramic filters were the only HWTS intervention with protective effects over 12 months.[12]

The long-term impact from HWTS interventions is contingent on an array of contextual factors but importantly is determined by the consistent and correct use of the technology in the population.[13-16] Programs are shown to need considerable behavior-change promotion to continue the uptake of HWTS, raising questions on whether scaling HWTS interventions is a worthwhile investment for sustainably improving drinking water quality[8,17,18]. Even slight declines in adherence to efficacious water treatment practices have been predicted to avert nearly all realized health gains in some settings.[14,15] The number of HWTS studies with extended follow-up periods (e.g., ≥12 months) has increased over the years.[19-24] However, most indicate a decline in use and compliance over time.

3.3 Research aims

The main aim of this study was to assess the longer-term uptake and effects of a PoU water filter over 30 months. The filter was delivered using Community Health Clubs (CHCs) in Rwanda's national environmental health program. Data were collected within the intervention arm of a randomized control trial (RCT), which focused on the technology's uptake, microbiological performance, and health effects during the first 13-16 months of follow-up.[25] While the filter is engineered to be microbiologically effective for at least three years, there have limited assessments of their programmatic sustainability past one year. A secondary aim was to compare microbiological performance and child diarrheal prevalence between treatment arms – the initial intervention arm communities to the control communities that had received the filter at the conclusion of the trial. The purpose was to contemporaneously compare the duration of intervention exposure (i.e., 13-16 months versus 28-32 months).

3.3 Methods

We undertook a 30-month longitudinal study of 608 households eligible to receive a PoU household water filter with safe storage through CHCs in Rwamagana, Rwanda. We measured filter coverage and use, drinking water quality, and child diarrhea prevalence at four visits over 28-32 months and assessed changes over time.

For the secondary aim, we followed 591 households that had received the filter shortly after the 15-month visit. We assessed drinking water quality and child diarrhea prevalence over 13-15 months and contemporaneously compared these outcomes to the households exposed to the filter for 28-32 months.

3.3.1 Study context and post-intervention follow-up visits

This work utilized data from two follow-up visits for a 15-month cluster RCT evaluating the effects of the intervention (i.e., PoU filter delivered through CHCs) on drinking water quality and child diarrhea, and then two subsequent monitoring visits conducted over an additional 13-15 months to assess the intervention's longer-term sustainability.

In the main trial, we found that the filter had high uptake and the overall intervention reduced the proportion of households with detectable *E.coli* in drinking water samples by 20% (PR 0.80, 95% CI 0.74-0.87) and the proportion of children under 5 with caregiver-reported diarrhea in the previous 7 days by 49% (aPR: 0.51 95% CI: 0.35 – 0.73) over 13-16 months. Further details on the trial design and results are presented elsewhere.[25] Briefly, we enrolled 1,199 households across 60 randomly selected villages in Rwamagana district and measured baseline characteristics. The intervention was then implemented to all eligible households in 30 randomly assigned villages, with the other half of the villages serving as the control arm. The intervention, program eligibility, and study inclusion criteria are described in latter sections.

The trial ended at 13-16 months post-implementation. Monitoring of all study households continued for another 13-16 months in both the original intervention group and control group who had received the filter at the conclusion of the trial. In summary, data used for this present study were collected across four visits over 28-32 months after the delivery of the filter in the original intervention group (i.e., from October 2019 to January 2022). A detailed timeline of the study activities is provided in **Figure 3-1**.

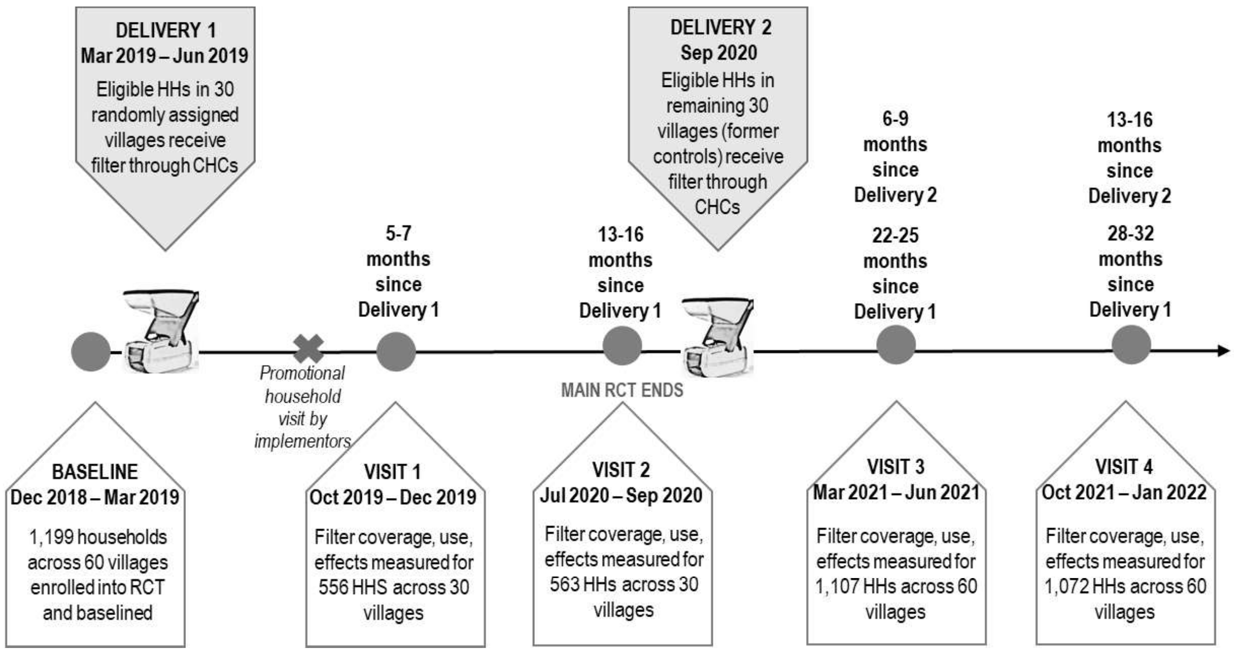


Figure 3-1. Study timeline

3.3.2 Intervention

The intervention was the delivery and promotion of the *LifeStraw® Family 2.0* filters as a part of Rwanda's Community-Based Environmental Health Promotion Programme (CBEHPP). The CBEHPP is a nationally scaled program that organizes village CHCs to encourage safe WASH behaviors. CHCs are open to all village members and aim to meet weekly to bi-weekly. Volunteer CHC facilitators are trained to deliver a 20-module curriculum designed by the Ministry of Health. As a part of the intervention, CHC facilitators were additionally tasked to deliver fully-subsidized *LifeStraw® Family 2.0* filters to households meeting intervention eligibility requirements (i.e., CHC member with a child under five or pregnant person living the household). The *LifeStraw® Family 2.0* is a PoU water filter with an 80 µm pre-filter to remove coarse material, 20 nm hollow-fiber ultrafiltration membrane, backwash lever, and covered storage container with

5.5 L capacity and meets the WHO's "comprehensive protection" guideline for HWTS technologies.[2] It is estimated to be functional for three to five years without replacing parts.[26]

Catholic Relief Services (CRS) and SNV-Rwanda, with their local partner African Evangelist Enterprise (AEE), were the leading implementors of the intervention and trained and supported CHC facilitators to provide household-level support. Promotional activities on the filter included a mass-distribution event with demonstrations and skits, initial household visits to teach members to use the filter, poster distribution, community meetings, a maintenance household visit ~6-months after filter distribution, and a repair and replacement process for non-functioning filters. In the first year, the implementors were additionally supported by Amazi Yego, a social enterprise with extensive experience designing and delivering programs using *LifeStraw*®[27]. In the second year, the implementors trained CHC facilitators and delivered the filters to the control group at the end of the trial through smaller village-level distribution events in order to adapt to COVID-19 restrictions. After this delivery, the implementors did not provide additional support to CHC facilitators on visiting households, monitoring or promoting filter use, repairing or replacing broken filters, or otherwise providing any continued management for the program to either study groups. Further details on the intervention and first-year implementation are described elsewhere.[25,27]

3.3.3 Eligibility and inclusion criteria

For the primary study aim, households enrolled in the main trial and assigned to the intervention arm (i.e., 608 households) were eligible to be included in the 30-month study. To be enrolled in the main trial, households had to live in the study villages, be verified eligible to receive the intervention (CHC member households who have at least one child under 5 or pregnant person living in the household at time of baseline), and have a household member that was over 18 years of age available to complete informed consent. Eligible households were randomly selected for study enrollment. Details on the village and household selection are described elsewere.[25] For the second study aim, all enrolled study households from the intervention and former control arms attempted in the last two follow-up visits were eligible to be included in the analyses (i.e., 1,199 households). Children also had to be under the age of 5 at the time of visit to be included in assessments on health.

3.3.4 Outcomes

For our primary aim of following the original intervention group over 30 months, we measured outcomes related to filter uptake, including the coverage and use, and filter effects, including detection of fecal contamination in sampled drinking water and 7-day recall of diarrhea in children under 5. Outcomes were measured through self-report survey questions and observations by enumerators. For our secondary aim of contemptuously comparing exposure periods, we examined fecal contamination in sampled drinking water and 7-day recall of diarrhea in children under 5. **Supplementary Table 1** summarizes the outcomes.

Filter uptake. On **coverage**, enumerators observed the physical presence of the filter in the household. On **condition**, they observed whether the filter appeared to be in good condition (i.e., proper assembly/missing parts, visible cracks, adequate flowrate, and ability to backwash/reverse flow of water). If households were observed to not have the filter, we asked additional follow-up questions on why the filter was not present. For our primary parameters on **use**, respondents reported if they used the filter as a water treatment practice, and enumerators observed whether there was visible water in the storage container of the filter at the time of visit. We collected secondary parameters on reported use, including if the filter had been to be filled in the past 7 days from the time of visit, if at least one young child drank water treated with the filter in the last day, and if drinking water samples provided were treated with the filter.

Filter effects. To measure **microbial water quality**, we asked respondents to serve drinking water as they would to a young child. We sampled 100mL of the drinking water using sterile *Whirl-Pak®* bags containing sodium thiosulfate (Nasco, Madison, WI, USA) and kept on ice until testing for detectable *E.coli* within 8 hours using *CompactDry*™ (Nissui Pharmaceutical, Tokyo, Japan) media plates and membrane filtration procedures prescribed by UNICEF.[28] We counted and recorded the number of colony-forming units (CFU) on plates. Sample processing and additional information on procedures are described in Haque et al. in review.[25] Water quality results were categorized into a binary variable for detectable vs. non-detectable

E.coli contamination, which served as our primary outcome on drinking water quality. We also categorized *E. coli* presence into two other binary outcomes according to WHO risk category cutoffs for moderate-to-high (≥10 CFU/100mL) and very high (≥100 CFU/100mL) contamination.[29] We estimated arithmetic and Williams means of CFU counts. The Williams mean is a geometric mean that accounts for values less than 1 by adding 1 to all values and then subtracting the geometric mean by 1.[30] Non-detect plates were included in the mean calculation as half of their specific limit of detection.

Diarrhea. We asked respondents to report whether each under-five child in the household had diarrhea in the previous 7-days. We defined diarrhea as three or more loose stools in a 24-hour period that can take the shape of a container.[31]

Household surveys were directed to the primary cooks aged 18 and over. If the primary cook was unavailable or under 18, questions were directed to another household member aged 18 and over. Survey data were collected on tablets and managed using *REDCap* electronic data capture tools hosted at Emory University.[32]

3.3.5 Statistical Approach

For our primary aim, we estimated adjusted prevalence rate ratios (PR) and their 95% confidence intervals (CI) that compared binary outcomes on filter coverage, filter use, contaminated drinking water, and child diarrhea between the first follow-up and later follow-up visits. PRs were estimated by exponentiating coefficients derived from log Poisson regression with generalized estimating equations (GEE) using robust standard errors. Poisson regression was used due to issues of convergence commonly observed in binomial models and models with a large number of covariates.[33] We assumed an exchangeable working correlation structure, adjusting for household-level characteristics and clustering at the village level.[34,35] Statistically significant effects were determined by using a two-sided Type I error rate of 0.05.

The main exposure variable of interest is an ordered categorical time variable corresponding to each of the four follow-up rounds, marking the range of months exposed in the original intervention arm. We adjusted for other covariates based on the literature on their potential relation to water quality or season, including socio-economic status, household size, basic drinking water access, water treatment at baseline, average monthly rainfall, and average monthly land surface temperature. The contamination status of the source water could determine water quality outcomes as well as uptake, the condition of the filter, and child health. Households that perceive their primary water source as contaminated could be more likely to use the filter[16] and could be more likely to use one type of water source for drinking during dry seasons and another type during rainy season. Metrological conditions and household demographics could influence drinking water availability/quality.[36] Covariates considered are defined in **Supplementary Table 2.** Diarrhea models were additionally adjusted for the child's sex and age in months. The exponentiated regression coefficient of the time variable provides the PRs of the outcome between exposure to 5-7-months of the intervention and proceeding follow-up periods (e.g., 5-7-months compared to 13-16, 22-25, and 28-32 months of exposure).

To address our secondary aim, we estimated the PRs for contaminated drinking water and child diarrhea in the last two follow-up visits, comparing both the longer-exposed intervention group (i.e., original intervention group from the trial with 28-32 months of filter exposure) to the shorter-exposed intervention group (i.e., original control group from the trial with 13-16 months of filter exposure). In the main trial, it was previously found that both groups were comparable on most household characteristics before receiving the filter intervention. Baseline data and issues of imbalance are discussed in detail in Haque et al., in review. We estimated the PRs and 95% CIs using similar methods as described for earlier models, but used log-binomial regression. The diarrhea model additionally adjusted for sex, age in months, and socio-economic status due to imbalance found at baseline.[25]

All statistical analyses were done using Stata 16 (Stata Corporation, College Station, TX, USA).

3.3.6 Ethics

The protocol received ethical approval and was annually renewed by the Emory University Institutional Review Board (CR001-IRB00106424) and Rwanda National Ethics Committee (IRB 0001497). We obtained signed informed consent from the main survey respondent during study enrollment. The associated trial is registered under the Pan African Clinical Trial Registry, Trial ID=PACTR201812547047839

3.4 Results

3.4.1 Filter uptake, microbial water quality, and child diarrhea over 30-months in the intervention group

Participant summary: 608 households from the original intervention arm were eligible to be followed for over 30 months at four visits. Across all visits, a total of 2,235 out of a possible 2,432 household observations (91.5%) were analyzed for uptake of the filter; 1,836 of 2,432 possible water samples analyzed (75%) to estimate fecal contamination; and 2,343 of 3,036 possible child observations (77%) were analyzed for under 5 diarrhea prevalence. Missing household observations mainly were due to lost-to-follow-up (moved away/not home at the time of visit/did not want to participate). Missing water samples were either due to household lost-to-follow-up or the household not having available drinking water at the time of visit. Missing child observations were either due to household lost-to-follow-up or if children aged out of the study eligibility or were no longer in the household (**Figure 3-2**).

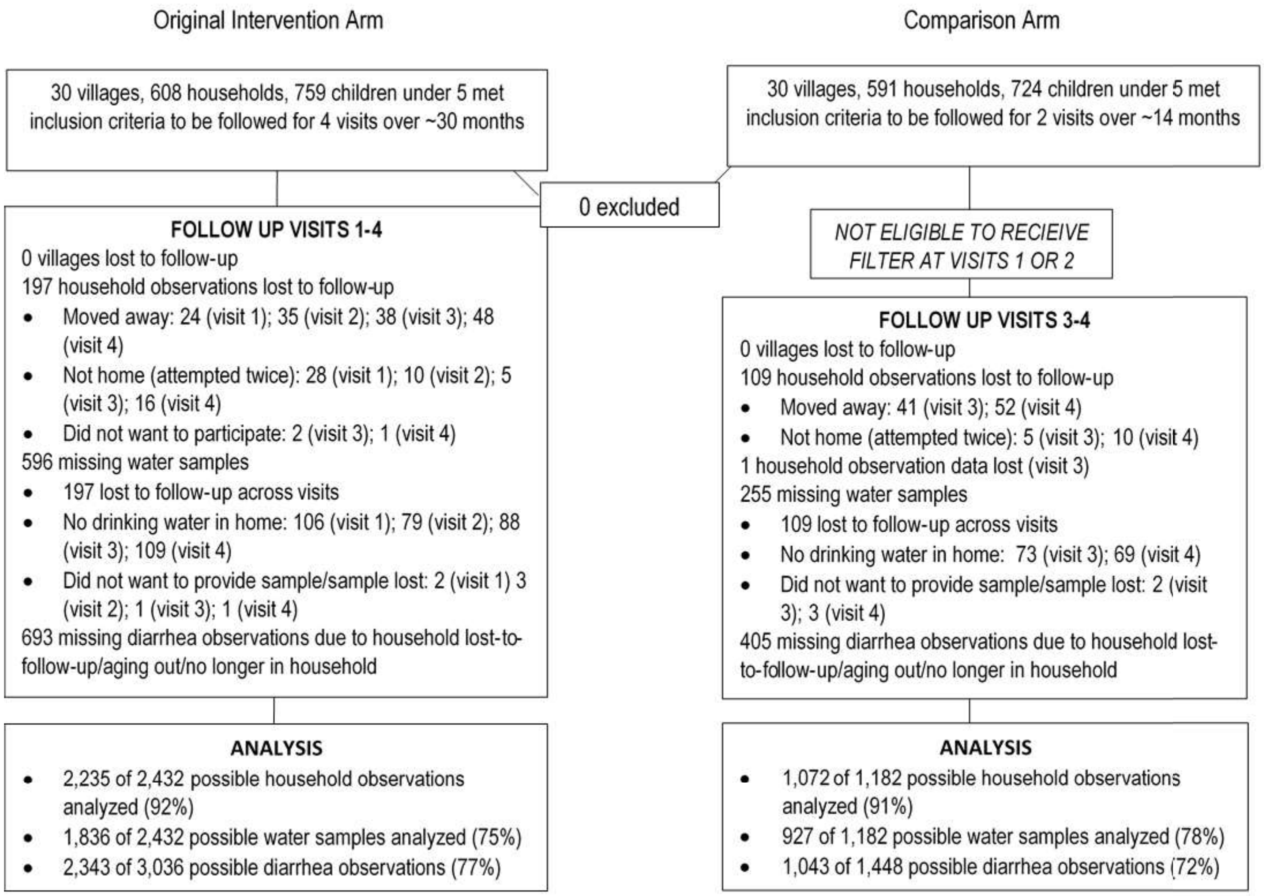


Figure 3-2. Participant Flow

Filter uptake: coverage, condition, and use over 30 months. Filter coverage was relatively high across all four follow-up visits in the intervention group (**Table 3-1** and **Figure 4-3**). At the first follow-up visit (~6 months post-implementation), 99% of households were observed to have the filter, and 94% had filters that were observed to be in good condition, i.e., no apparent issues in the assembly, leaking, storage container, tap, ability to backwash, and flow-rate.

Table 3-1. Coverage, condition, use, microbial performance, and child diarrhea prevalence in the intervention group over 30 months

	Visit 1 5-7 months since delivery		Visit 2 13-16 months since delivery		Visit 3 22-25 months since delivery		Visit 4 28-32 months since delivery	
Coverage and Condition	**N**	**% (95% CI)**	**N**	**% (95% CI)**	**N**	**% (95% CI)**	**N**	**% (95% CI)**
Filter observed present in household	555	99.1 (97.9, 99.6)	563	97.9 (96.3, 98.8)	564	95.6 (93.5, 97.0)	543	94.3 (92.0, 96.0)
Filter observed in good condition*	532	94.0 (91.6, 95.7)	507	91.9 (89.2, 94.0)	504	86.3 (83.0, 89.5)	446	84.5 (80.9, 87.6)
Use								
Reported to use filter for water treatment	556	96.9 (95,1, 98.1)	563	94.0 (91.7, 95.7)	563	87.7 (84.8,.90.2)	543	84.3 (81.0, 87.2)
Storage container of filter observed to have water in it	544	81.4 (77.9, 84.5)	545	75.0 (71.2, 78.5)	536	67.0 (62.9, 70.9)	512	59.4 (55.1, 63.6)
Microbial risk level of drinking water								
≥2 CFU/100 mL (Any detectable *E.coli* contamination)	448	73.2 (68.9, 77.1)	481	66.7 (62.4, 70.8)	474	73.2 (69.0, 77.0)	433	73.7 (69.3, 77.6)
≥10 CFU /100 mL (Moderate and higher *E.coli* contamination)	448	49.3 (44.7, 54.0)	481	46.2 (41.7, 50.6)	474	53.6 (49.1, 58.0)	433	47.8 (43.1, 52.5)
≥100 CFU /100 mL (Very high *E.coli* contamination)	448	22.8 (19.1, 26.9)	481	21.4 (18.0, 25.3)	474	24.1 (20.4, 28.2)	433	21.7 (18.1, 25.9)
CFU count per 100 mL#	**N**	**Mean (95% CI)**	**N**	**Mean (95% CI)**	**N**	**Mean (95% CI)**	**N**	**Mean (95% CI)**
Arithmetic Mean	448	88.9 (73.3, 104.4)	481	95.2 (79.0, 111.3)	474	100.4 (84.7, 116.2)	433	87.5 (71.3, 103.8)
Geometric Mean	448	14.7 (12.2, 17.6)	481	13.2 (10.9, 15.9)	474	18.1 (15.1, 21.8)	433	13.7 (11.4, 16.6)
Diarrhea- Children Under 5	**n**	**% (95% CI)**	**n**	**% (95% CI)**	**n**	**% (95% CI)**	**n**	**% (95% CI)**
In the last 7 days, child reported to have 3 or more loose stools in 24 hours	648	5.7 (4.2, 7.8)	569	3.9 (2.6, 5.8)	659	2.9 (1.8, 4.5)	467	5.9 (4.2, 8.6)

N denotes the number of household observations in the survey round

* Good condition refers to being observed to have been assembled properly, working tap, no leaking, undamaged container, adequate flowrate, and ability to backwash

Coverage of the filter fluctuated slightly since the first follow-up visit but remained over 94% across the study duration (**Table 3-1** and **Figure 3-3)**. Compared to the first visit, the proportion of households with the filter declined by 6% at the second and fourth visits (aPR 0.94, 95% CI 0.88-0.99; aPR 0.94, 95% CI 0.91-0.96, **Table 3-2**), but was found similar at the third visit (aPR 0.98, 95% CI 0.96-1.00). Common reasons for not having the filter in the household were because the filter was reported to be broken, stolen, on loan, out for repair, taken by another family member, or because the household members no longer liked it (data not shown).

Condition of filters declined modestly since the first visit. Condition was similar over 13-16 months (aPR 0.91, 95% CI 0.78-1.06, **Table 3-2**). However, compared to the first 6-months, condition declined by 7% at the third visit (~24 months post-implementation - aPR 0.93, 95% CI 0.89-0.98) and by 12% by the fourth visit (~30 months post-implementation aPR 0.88, 95% CI 0.80-0.97, **Table 3-2**). The most frequent reasons that filters were not considered to be in good condition were due to leaks, improper assembly, damaged taps, and difficulty backwashing and slow filtration (data not shown).

Indicators of filter use declined over 30-months, particularly in the last two visits (**Table 3-2 and Figure 3-3)**. In the first visit, 97% of households reported to use the filter for water treatment, and 81% of filters were observed to have water in the filter's storage container.

Estimates on indicators of use were similar over 13-16 months (reported filter as water treatment: aPR 0.95, 95% CI 0.90-0.99; observed water in filter's storage container: aPR 0.95, 95% CI 0.90-0.99, **Table 3-2**). The proportion of reported use of the filter for water treatment decreased by 5% (aPR 0.95, 95% CI 0.90-0.99) and by 14% in the fourth visit (aPR 0.86, 95% CI 0.80-0.93, **Table 3-2**).). Observed water in the filter's storage container decreased sharply afterwards. The proportion fell 14% by the third visit (aPR 0.86, 95% CI 0.76-0.98) and 31% by the fourth visit (aPR 0.69, 95% CI 0.59-0.82, **Table 3-2**).

Secondary parameters measuring filter use (i.e., frequency of filling filters, child use, and water treatment of provided drinking water sample) showed similar patterns of decline over the 30 months, with the most dramatic reductions in the last half of the follow-up period (**Supplementary Figure 1**).

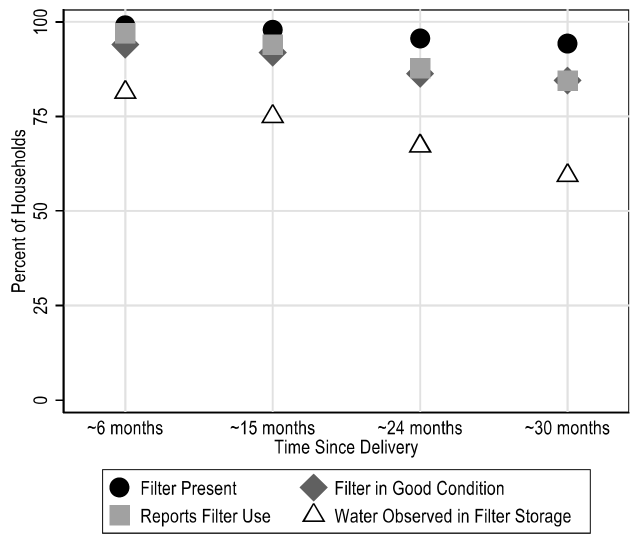


Figure 3-3. Uptake of filter over 30 months

Table 3-2. Coverage, condition, and use overtime compared to 5-7 months post-implementation

Model	*(1[a])* *Filter Present* *N*= 2,200*		*(2[a])* *Filter Observed in Good Condition* *N= 1,967*		*(3[a])* *Filter reported to be used for water treatment* *n= 2,200*		*(4[a])* *Storage container of filter observed to have water* *n= 2,115*	
Variable	**PR (95% CI)**	***p***	**PR (95% CI)**	***P***	**PR (95% CI)**	***p***	**PR (95% CI)**	***p***
Visit 2 (13-16 months post-implementation)	0.94 (0.88, 0.99)	0.03	0.91 (0.78, 1.06)	0.17	0.89 (0.80, 1.04)	0.31	0.79 (0.60, 1.12)	0.21
Visit 3 (22-25 months post-implementation)	0.98 (0.96, 1.00)	0.12	0.93 (0.89, 0.98)	<0.01	0.91 (0.87, 0.96)	<0.01	0.86 (0.76, 0.98)	0.02
Visit 4 (28-32 months post-implementation)	0.94 (0.91, 0.96)	<0.01	0.87 (0.79, 0.96)	<0.01	0.86 (0.81, 0.91)	<0.01	0.69 (0.59, 0.81)	<0.01

N denotes the total number of observations analyzed in follow-up rounds*

.[a] Prevalence ratio (PR), 95% Confidence Interval (95% CI) and p-value derived from log-Poisson generalized estimating equations with robust standard errors to account for clustering within villages. Model conditions follow-up visit, socio-economic status, household size, average monthly rainfall in previous 30 days, average monthly land surface temperature, basic water access, and binary water quality outcome.

Microbial water quality over 30 months: Drinking water samples did not show a clear pattern of decreasing or increasing fecal contamination (**Table 3-3**) over the follow-up period, but fecal contamination rates stayed lower compared to baseline levels (**Figure 3-4**). Visit 2 had the lowest contamination rates among all rounds. In the second visit, the proportion of households with any detectable fecal contamination was lower compared to the 6-month visit (aPR 0.71, 95% CI 0.57-0.90, **Table 3-3**) compared to the 6-month visit. All other estimates in proceeding follow-up visits were comparable to the first 6-month visit.

Under-5 child diarrhea over 30 months: The proportion of children under five experiencing diarrhea in the last 7 days did not change throughout the follow-up period in the intervention group (**Figure 3-4**), but remained lower than baseline levels. Visit 3 had the lowest prevalence of diarrhea (2.9%), while Visit 4 had the highest (5.9%). **Table 3-3** reports the effects of time on diarrhea outcomes. Estimates in proceeding rounds were comparable to the first follow-up visit.

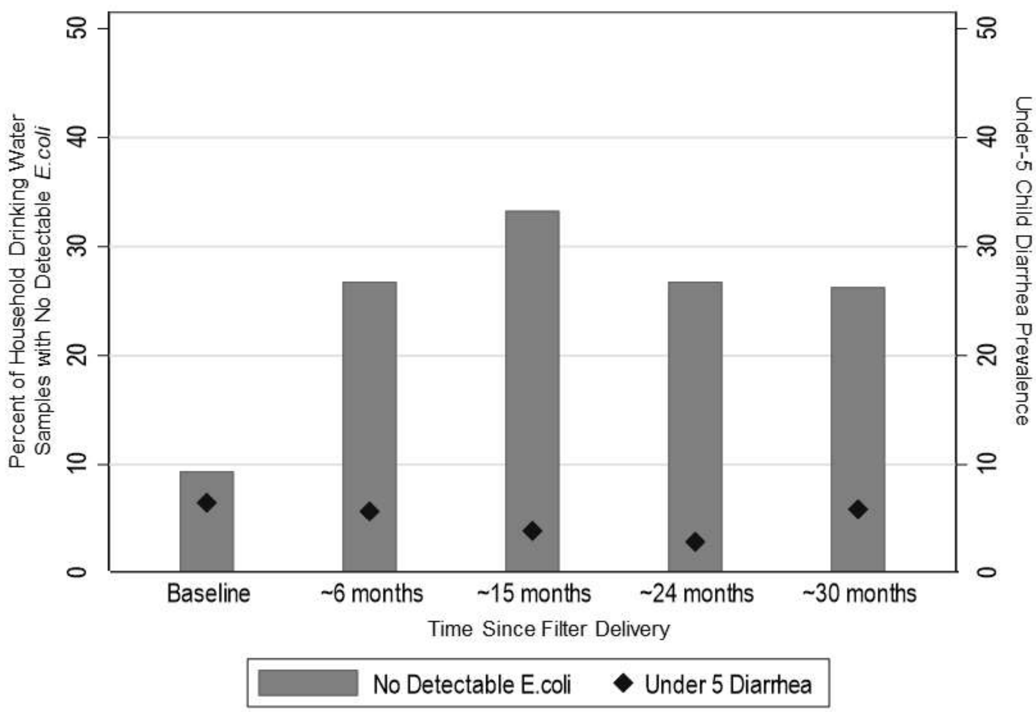


Figure 3-4. Effects of filter on water quality and diarrhea over 30 months among 608 intervention households

Table 3-3. Presence of *E.coli* in drinking water and child diarrhea compared to 5-7 months post-implementation

Model	*(5[a])* ≥2 CFU/100 mL (any detectable *E.coli* contamination) *N= 1,816*		*(6[a])* ≥10 CFU/100 mL (Moderate and higher *E.coli* contamination) *N= 1,816*		*(7[a])* ≥100 CFU /100 mL (Very high *E.coli* contamination) *N= 1,816*		*(8[b])* In the last 7 days, child reported to have 3 or more loose stools in 24 hours *N= 2,315*	
Variable	**PR (95% CI)**	***p***	**PR (95% CI)**	***P***	**PR (95% CI)**	***p***	**PR (95% CI)**	***p***
Visit 2 (13-16 months post-implementation)	0.71 (0.57, 0.90)	<0.01	0.64 (0.44, 0.94)	0.02	0.60 (0.36, 1.0)	<0.05	0.33 (0.08, 1.27)	0.12
Visit 3 (22-25 months post-implementation)	1.05 (0.95, 1.17)	0.35	1.16 (0.97, 1.40)	0.11	1.08 (0.80, 1.52)	0.63	0.57 (0.24,1.37)	0.21
Visit 4 (28-32 months post-implementation)	0.93 (0.83, 1.04)	0.19	0.86 (0.71,1.04)	0.12	0.84 (0.61, 1.15)	0.28	0.68 (0.29, 1.56)	0.36

N denotes the total number of observations analyzed in follow-up rounds*

.[a] Prevalence ratio (PR), 95% Confidence Interval (95% CI) and p-value derived from log-Poisson generalized estimating equations with robust standard errors to account for clustering within villages. Model conditions follow-up visit, socio-economic status, household size, average monthly rainfall in previous 30 days, average monthly land surface temperature, basic water access, and binary water quality outcome.

[b] PR, 95% CI and p-value derived from log-Poisson generalized estimating equations with robust standard errors to account for clustering within village. Model conditions follow-up visit, socio-economic status, household size, average monthly rainfall in previous 30 days, average monthly land surface temperature in previous 30 days, basic water access, age in months, sex, and binary diarrhea outcome.

3.4.2 Microbial drinking water quality and child diarrhea prevalence between shorter- and longer-filter exposed groups in the same period

Participant summary: 591 households were newly eligible to receive the filter and be followed for over ~14 months at 2 visits. Participant flow was previously described for the original intervention group in the primary aim of the study. In the group most recently eligible to receive the filter, 1,072 of 1,182 possible household observations analyzed (91%) were analyzed for coverage and use of the filter; a total of 600 out of a 927 of 1,182 possible water samples were analyzed for fecal contamination; and a total of 1,043 of

1,448 possible child observations were analyzed for diarrhea prevalence. Missing observations were due to lost to-follow-up, no drinking water, or children ageing out or no longer in the household **(Figure 3-2).**

Microbial water quality and under-5 child diarrhea differences- Fecal contamination levels were similar between the shorter- and longer-exposed groups (*any detectable contamination*: PR 1.02, 95% CI 0.95-1.11 p=0.54; *moderate and higher contamination:* PR 1.06, 95% CI 0.92-1.21 p=0.44; *very high contamination*: PR 1.13, 95% CI 0.90-1.42 – **Table 3-4)**. Similarly, exposure group did not have an effect on diarrheal prevalence (aPR 0.66, 95% CI 0.41-1.07 – **Table 3-4)**. Coverage and use rates were slightly higher in the shorter-exposed group (**Supplementary Table 3**).

Table 3-4. Effects of exposure group assignment on the presence of *E.coli* in drinking water and child diarrhea

Model	Outcome	Group 1 (28-32 months exposure) %	Group 2 (13-16 months exposure) %		
	Drinking water quality N=1,834	**N=907**	**N=927**	**PR (95% CI)**	***p***
12[a]	≥2 CFU/100 mL (any detectable *E.coli contamination*)	73.4	71.4	1.02 (0.95, 1.11)	0.54
13[a]	≥10 CFU/100 mL (Moderate and higher *E.coli* contamination)	50.8	47.8	1.06 (0.92, 1.21)	0.44
14[a]	≥100 CFU /100 mL (Very high *E.coli contamination*)	22.9	20.4	1.13 (0.90, 1.42)	0.29
	Diarrhea- Children Under 5 N= 2,156	**N=1,091**	**N=1,065**		
14[b]	In the last 7 days, child reported to have 3 or more loose stools in 24 hours	4.2	6.4	0.66 (0.41, 1.07)	0.09

N denotes the total number of observations analyzed in follow-up rounds*

.[a] Prevalence ratio (PR), 95% Confidence Interval (95% CI) and p-value derived from log-binomial generalized estimating equations with robust standard errors to account for clustering within villages. Model conditions group assignment and binary water quality outcome.

[b] PR, 95% CI and p-value derived from log-binomial generalized estimating equations with robust standard errors to account for clustering within villages. Model conditions group assignment, age in months, sex, household socio-economic status, and binary diarrhea outcome.

3.5 Discussion

We conducted a study in Rwamagana District, Rwanda that aimed to assess longer-term sustainability of an advanced household water filter delivered through CHCs. Our results show evidence of declining household coverage, condition, and use of the filter over the roughly 30-month follow-up period. While filters were still largely present in the home at the end of follow-up, filters in good condition dropped steadily to 84.5%. The decline was greater in the second half of the follow-up period when implementer support was discontinued. Use also declined, particularly in the second year, with 85% of households reporting to use the filter for water treatment and 59.4% having water in the filter's storage container at the time of the visit. These declining trends over the 30-moth follow-up are apparent even after adjusting for meteorological and household characteristics that may influence uptake of the filter at specific times. Our study is one of the few assessments of HWTS interventions over two years.

Among those households from which we could procure a water sample for testing, or a report of child diarrhea, we found no evidence of deteriorating drinking water quality or a change in diarrhea prevalence over the follow-up period. Th 30-month analysis within the intervention group was limited in that we did not have an ideal contemporaneous comparison group that did not have the filter. Our additional analysis on comparing the two groups with varying exposure times to the filter similarly did not show differences in microbial water quality nor diarrheal prevalence. The purpose of the analysis was to reduce the influence of seasonality and secular trends[37] by studying the two exposure groups in the same time period. The groups were randomly assigned at the beginning of the trial and well-balanced in most household characteristics.[25] However, there were no differences in effects between the group that was exposed to the filter for 13-16 months and the group that was exposed over 28-32 months. This could be due to differences in implementation between the groups. Although both groups received the same filter, the intervention was implemented differently between the groups. For example, the second group to receive the intervention were not given the filter using the same type of distribution model (i.e., filters were delivered through smaller distribution events) nor did they have dedicated maintenance or promotion visits from the implementors. The study design could have been improved by comparison of households without the filter using a case-control analysis.

The study period coincided with the start of the SARS-CoV-2 pandemic, beginning at Visit 2 (July 2020-September 2020) and onwards. Filter promotional activities planned during CHC sessions were interrupted beginning in March 2020. Although we were not able to directly measure the number of CHC sessions held in the study period, qualitative surveys carried out with 20 CHC facilitators from the study population revealed that all CHC facilitators had to cancel several sessions due to pandemic restrictions. Pandemic interventions, such as social distancing and improved hygiene may have also influenced water quality and diarrheal outcomes, particularly during the last three follow-up visits.

Our study is limited in its reliance on self-reported outcomes that are subject to reporting and courtesy bias. We aimed to reduce this risk of bias by surveying multiple indicators on coverage and use and including some observational measures. Our observational indicators, such as on filter condition and the presence of water in the filter's storage container, are still limited. For example, enumerators could only note issues with the filter that were visible at the time of the visit. Although survey visits were unannounced, observational indicators are still vulnerable to reactivity bias.[38] Sampling the household's main water source and estimating the differences in fecal contamination between the point-of-source and point-of-use could have helped us understand the sustained microbiological performance of the filter over time.

Our indicators, such as on water quality and diarrhea, measure limited cross-sectional measurements within the study period. Missing data for water samples and diarrhea observations is also a study limitation. We obtained water samples or diarrhea reports at about three-quarters of the possible study visits. The missing data represents a possible source of bias that would increase as the number of samples obtained decreased over time. It also is a limitation on the generalizability of these results over the entire study population.

Our results are in line with other longer-term studies assessing the sustainability of filter interventions, which have all have noted a decline in uptake. However, the intervention seemed to yield better coverage and use compared to other studies. A study in Cambodia followed up with a random sample of households after 5-48 months of receiving a subsidized filter through an NGO program.[39] The authors found that 31% of the surveyed households reported using the filter and identified the time since receipt of the as an important determinant of use, estimating an average declining rate of 2% per month. An independent monitoring study in Kenya of an 800,000-filter distribution campaign aimed at reaching 90% of the population found that about 50% of households reported ever receiving the filter from the campaign and less than 20% of households reported using the filter 2-3 years since the program began. The authors did observe that water quality was markedly better in water treated by the filter compared to untreated water, demonstrating that the technology did demonstrate microbiological effusiveness over the 3 years.[40] A 12-month trial in rural Rwanda evaluating a nearly identical filter to ours found that after delivery of 100,000 filters, coverage sustained in about 92% of households and reported use observed to 53% provided drinking water samples treated by the filter by the end of the 12-month follow-up.[23] In comparison, our study observed better coverage and a higher proportion of samples treated with filter at both the 15-month and 30-month visits. Finally, a small pilot study of about 100 households preceding the large filter-campaign in Rwanda found that the filter was observed to be working in 85% of households and the odds of fecal bacteria detection were nearly 80% lower compared to matched control households 12–24 months after filter delivery.[41] However, comparisons to other studies should be interpreted with caution due to the differences in scale of implementation. Our program delivered roughly 1,000 filters in first year and another 1,000 in the second year to the control group.

None of the findings on the filter technology itself should be interpreted without the consideration of the implementation strategy/service model used in the intervention.[42] The other studies discussed here were all campaign-style implementations. Although most had promotional visits by implementors, they could have had difficulty in promoting effective-behavior change. The use of CHCs was a hallmark to our intervention and may have unique characteristics as a community institution that enables sustained support of the intervention, even with limited support from central implementors.

Our findings on declined coverage and use of the filter overtime suggests the intervention is vulnerable to "program slippage," where the target population gradually falls back to their original baseline indicators pre-intervention. Nevertheless, nearly all households at least still had the filter throughout the study period and 85% of observed filters seemed to be in good condition. Households reporting to use the filter was estimated to be 85% by the end of the follow-up. Water quality seemed to be maintained throughout the study period and were comparable to a group that had a shorter exposure period to the intervention. These findings support that the intervention has the potential to have high uptake and sustained effects at least over 28-32 months. However, continued program support to maintain the filters and promote consistent use is still recommended.

3.6 References

1 WHO/UNICEF. Progress on household drinking water, sanitation and hygiene 2000-2020: five years into the SDGs. Report No. 9240030840, (2021).

2 WHO. Results of round II of the WHO international scheme to evaluate household water treatment technologies. (2019).

3 Packiyam, R., Kananan, S., Pachaiyappan, S. & Narayanan, U. Effect of storage containers on coliforms in household drinking water. *International Journal of Current Microbiology and Applied Sciences* **5**, 461-477 (2016).

4 WHO. Combating waterborne disease at the household level. (2007).

5 Fewtrell, L. *et al.* Water, sanitation, and hygiene interventions to reduce diarrhoea in less developed countries: a systematic review and meta-analysis. *The Lancet infectious diseases* **5**, 42-52 (2005).

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

7 Clasen, T. F. *et al.* Interventions to improve water quality for preventing diarrhoea. *Cochrane database of systematic reviews* (2015).

8 Arnold, B. F. & Colford, J. M. Treating water with chlorine at point-of-use to improve water quality and reduce child diarrhea in developing countries: a systematic review and meta-analysis. *The American journal of tropical medicine and hygiene* **76**, 354-364 (2007).

9 Wolf, J. *et al.* Systematic review: assessing the impact of drinking water and sanitation on diarrhoeal disease in low-and middle-income settings: systematic review and meta-regression. *Tropical medicine & international health* **19**, 928-942 (2014).

10 Wolf, J. *et al.* Impact of drinking water, sanitation and handwashing with soap on childhood diarrhoeal disease: updated meta-analysis and meta-regression. *Tropical medicine & international health* **23**, 508-525 (2018).

11 Waddington, H., Snilstveit, B., White, H. & Fewtrell, L. Water, sanitation and hygiene interventions to combat childhood diarrhoea in developing countries. *Delhi: International Initiative for Impact Evaluation* (2009).

12 Hunter, P. R. Household water treatment in developing countries: comparing different intervention types using meta-regression. *Environmental science & technology* **43**, 8991-8997 (2009).

13 Fiebelkorn, A. P. *et al.* Systematic review of behavior change research on point-of-use water treatment interventions in countries categorized as low-to medium-development on the human development index. *Social Science & Medicine* **75**, 622-633 (2012).

14 Enger, K. S., Nelson, K. L., Rose, J. B. & Eisenberg, J. N. The joint effects of efficacy and compliance: a study of household water treatment effectiveness against childhood diarrhea. *Water research* **47**, 1181-1190 (2013).

15 Brown, J. & Clasen, T. High adherence is necessary to realize health gains from water quality interventions. *PloS one* **7**, e36735 (2012).

16 Daniel, D., Pande, S. & Rietveld, L. Endogeneity in water use behaviour across case studies of household water treatment adoption in developing countries. *World Development Perspectives* **25**, 100385 (2022).

17 Ginja, S., Gallagher, S. & Keenan, M. Water, sanitation and hygiene (WASH) behaviour change research: why an analysis of contingencies of reinforcement is needed. *International journal of environmental health research* **31**, 715-728 (2021).

18 Pickering, A. J. *et al.* The WASH benefits and SHINE trials: interpretation of WASH intervention effects on linear growth and diarrhoea. *The Lancet Global Health* **7**, e1139-e1146 (2019).

19 Ercumen, A. *et al.* Effects of source-versus household contamination of tubewell water on child diarrhea in rural Bangladesh: a randomized controlled trial. *PloS one* **10**, e0121907 (2015).

20 Humphrey, J. H. *et al.* Independent and combined effects of improved water, sanitation, and hygiene, and improved complementary feeding, on child stunting and anaemia in rural Zimbabwe: a cluster-randomised trial. *The Lancet Global Health* **7**, e132-e147 (2019).

21 Luby, S. P. *et al.* Effects of water quality, sanitation, handwashing, and nutritional interventions on diarrhoea and child growth in rural Bangladesh: a cluster randomised controlled trial. *The Lancet Global Health* **6**, e302-e315 (2018).

22 Null, C. *et al.* Effects of water quality, sanitation, handwashing, and nutritional interventions on diarrhoea and child growth in rural Kenya: a cluster-randomised controlled trial. *The Lancet Global Health* **6**, e316-e329 (2018).

23 Kirby, M. A. *et al.* Effects of a large-scale distribution of water filters and natural draft rocket-style cookstoves on diarrhea and acute respiratory infection: A cluster-randomized controlled trial in Western Province, Rwanda. *PLoS medicine* **16**, e1002812 (2019).

24 Hartinger, S. *et al.* Improving household air, drinking water and hygiene in rural Peru: a community-randomized–controlled trial of an integrated environmental home-based intervention package to improve child health. *International journal of epidemiology* **45**, 2089-2099 (2016).

25 Haque, S. *et al.* Effects of adding household water filters to Rwanda's Community-Based Environmental Health Promotion Programme: A cluster-randomized controlled trial in Rwamagana district. *NPJ Clean Water* (in review).

26 Clasen, T., Naranjo, J., Frauchiger, D. & Gerba, C. Laboratory assessment of a gravity-fed ultrafiltration water treatment device designed for household use in low-income settings. *The American journal of tropical medicine and hygiene* **80**, 819-823 (2009).

27 Bradshaw, A., Mugabo, L., Gebremariam, A., Thomas, E. & MacDonald, L. Integration of Household Water Filters with Community-Based Sanitation and Hygiene Promotion—A Process Evaluation and Assessment of Use among Households in Rwanda. *Sustainability* **13**, 1615 (2021).

28 Bain, R., Johnston, R., Khan, S., Hancioglu, A. & Slaymaker, T. Monitoring Drinking Water Quality in Nationally Representative Household Surveys in Low-and Middle-Income Countries: Cross-Sectional Analysis of 27 Multiple Indicator Cluster Surveys 2014–2020. *Environmental Health Perspectives* **129**, 097010 (2021).

29 WHO. Guidelines for drinking-water quality. *World Health Organization* **216**, 303-304 (2011).

30 Rosa, G., Miller, L. & Clasen, T. Microbiological effectiveness of disinfecting water by boiling in rural Guatemala. *The American journal of tropical medicine and hygiene* **82**, 473-477 (2010).

31 WHO/UNICEF. *Handbook IMCI: integrated management of childhood illness*. (World Health Organization, 2005).

32 Harris, P. A. *et al.* Research electronic data capture (REDCap)—a metadata-driven methodology and workflow process for providing translational research informatics support. *Journal of biomedical informatics* **42**, 377-381 (2009).

33 Zou, G. A modified poisson regression approach to prospective studies with binary data. *American journal of epidemiology* **159**, 702-706 (2004).

34 MacKinnon, J. G. & Webb, M. When and how to deal with clustered errors in regression models. (Queen's Economics Department Working Paper, 2019).

35 Bottomley, C., Kirby, M. J., Lindsay, S. W. & Alexander, N. Can the buck always be passed to the highest level of clustering? *BMC medical research methodology* **16**, 1-7 (2016).

36 Pearson, A. L., Mayer, J. D. & Bradley, D. J. Coping with household water scarcity in the savannah today: implications for health and climate change into the future. *Earth Interactions* **19**, 1-14 (2015).

37 Kostyla, C., Bain, R., Cronk, R. & Bartram, J. Seasonal variation of fecal contamination in drinking water sources in developing countries: a systematic review. *Science of the Total Environment* **514**, 333-343 (2015).

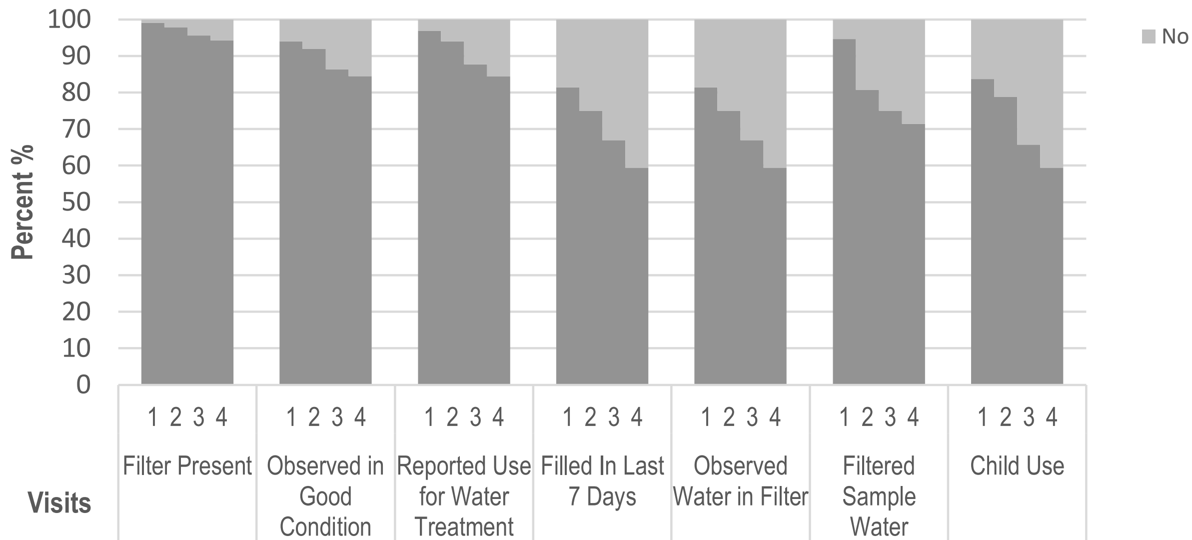
38 Arnold, B. F. *et al.* Reactivity in rapidly collected hygiene and toilet spot check measurements: a cautionary note for longitudinal studies. *The American journal of tropical medicine and hygiene* **92**, 159 (2015).

39 Brown, J., Proum, S. & Sobsey, M. Sustained use of a household-scale water filtration device in rural Cambodia. *Journal of water and health* **7**, 404-412 (2009).

40 Pickering, A. J., Arnold, B. F., Dentz, H. N., Colford Jr, J. M. & Null, C. Climate and health co-benefits in low-income countries: a case study of carbon financed water filters in Kenya and a call for independent monitoring. *Environmental health perspectives* **125**, 278-283 (2017).

41 Kirby, M. A., Nagel, C., Rosa, G. A., Thomas, E. A. & Clasen, T. F. in *American Journal of Tropical Medicine and Hygiene*. 582-582 (AMER SOC TROP MED & HYGIENE 8000 WESTPARK DR, STE 130, MCLEAN, VA 22101 USA).

42 Haque, S. S. & Freeman, M. C. The Applications of Implementation Science in Water, Sanitation, and Hygiene (WASH) Research and Practice. *Environmental Health Perspectives* **129**, 065002 (2021).



Supplementary Figure 1. Primary and secondary indicators of coverage and use of filter over 30 months

Supplementary Table 1. Outcomes of interest

Outcomes	Code	Description
Coverage		
Observed filter	0. No 1. Yes	Filter was present at time of visit
Appeared to be in good condition	0. No 1. Yes	Filter appeared to be in good condition (i.e., proper assembly/missing parts, visible cracks, adequate flowrate, and ability to backwash).
Use		
Reported use	0. No 1. Yes	Filter reported to be used in the past seven days from time of visit
Reported child use	0. No 1. Yes	Child reported drinking filtered water yesterday from time of visit
Observed water in filter storage container	0. No 1. Yes	Filter has observed water in storage container of filter at visit
Reported treatment of sample water	0. No 1. Yes	Household reported to treat sample water with filter at time of visit
Microbial water quality		
Detectable fecal contamination	0. No 1. Yes	Detectable *E. coli* in 100 mL sample of drinking water
Moderate and higher fecal contamination	0. No 1. Yes	Moderate or higher *E.coli* contamination (≥ 10 CFU/100mL CFU) in 100 mL sample drinking water
Very fecal high contamination	0. No 1. Yes	Very high *E.coli* contamination (≥ 100 CFU/100mL CFU) in 100 mL sample drinking water
Child health		
Child diarrhea 7-day recall	0. No 1. Yes	Self-report of diarrhea in past 7 days of children under 5 based on WHO definition

Supplementary Table 2. Independent variables and covariates of interest

Variable	Type/Coding	Description
Time	Categorical 1. Visit 1 (ref) 2. Visit 2 3. Visit 3 4. Visit 4	Time corresponds to the data collection round and the amount of time since the delivery of the intervention. Visit 1 = 5-7 months exposure to filter Visit 2= 13-16 months exposure to filter Visit 3= 22-25 months exposure to filter Visit 4 = 28-32 months exposure to filter
Basic water access	Binary 0. No access 1. Access	Household reports using an improved water source w (i.e., piped water, boreholes or tubewells, protected dug wells, protected springs, rainwater, and packaged or delivered water) that is within 30 minutes of access at the time of follow up. This variable could be related to the outcomes because some sources of water are more likely to be contaminated than others. Further, household drinking water is more likely to be contaminated when the water was collected from sources that are far away.
Water treatment at baseline	Binary 0. Did not treat water 1. Treated water	Reported household treatment practice at baseline (e.g. before exposure to the intervention). This may predict whether the household is more or less likely to uptake treating drinking water with the filter. For example, they could be less willing to switch to new water treatment practice or more likely to sustain a water treatment practice because they had taken up a similar behavior beforehand.
Socio-economic status	Binary 0. Not Ubudehe 1 or 2 1. Ubudehe 1 or 2	Indicates whether the household received benefits from government welfare/social protection programs. This is a proxy for socio-economic status, which is related to water insecurity and health behaviors.
Household size	Continuous	Number of people reported to sleep in the household during weekdays at the time of follow-up. The number of people using the filter is likely related to use and condition of the filter. For example, tabletop *LifeStraw®* filter 2.0 is designed to provide clean drinking water for a family of five for at least five years.
Precipitation	Continuous	Average precipitation levels experienced by household within 5km area in past 30 days from visit in millimeters. Estimated by overlaying household GPS coordinates onto the monthly gridded estimates of precipitation provided by Climate Hazards Group InfraRed Precipitation with Station (CHIRPS) dataset. Monthly averages weighted based on 30 days prior to the survey date.
Temperature	Continuous	Average land surface temperature within 5km area of household in past 30 days from visit in Celsius. Estimated by overlaying household GPS coordinates onto the monthly gridded estimates of land surface temperature provided by Terra/Moderate Resolution Imaging Spectradradiom (MODIS) satellite data available on the NASA earth database. Monthly averages weighted based on 30 days prior to the survey date.

Supplementary Table 3. Coverage and use of filter in first and second deliveries across visits

	Visit 3 6-9 months since delivery		Visit 4 13-16 months since delivery	
Coverage	**N**	**%**	**%**	**N**
Filter observed present in household	544	96.0	529	94.3
Filter observed in good condition*	497	92.2	452	88.7
Use				
Reported to use filter for water treatment	544	91.7	529	86.0
Storage container of filter observed to have water in it	522	71.3	499	66.9

N denotes the number of household observations in the survey round

* Good condition refers to being observed to have been assembled properly, working tap, no leaking, undamaged container, adequate flowrate, and ability to backwash

Chapter 4 – Research Aim 3: Household water insecurity in rural Rwanda: a 30-month study to assess effects of a water filter intervention and associations with water services, precipitation, and temperature

4.1 Abstract

Background: Household water insecurity is globally widespread, yet there are few longitudinal studies that examine its multidimensionality, drivers, and variability in populations over time. This gap limits the ability to identify interventions that can build population resilience to water insecurity, which is projected to become more severe due to climate change and increasing water demand.

Methods: We assessed water insecurity over 30-months in 1,169 households in Rwanda's Rwamagana District. We utilized a longitudinal dataset with indicators on water insecurity, demographics, drinking water access and collection practices, and meteorology at four time points, spaced approximately 6-9 months apart. Water insecurity was defined as a binary outcome using the Household Water InSecurity Experiences (HWISE) scale. Data were collected in the context of a ~15-month randomized-controlled trial and a subsequent ~15-month follow-up study evaluating the effects of a water filter with safe storage intervention on water quality and child health. Using mixed-effects models, we examined water insecurity associations with access to the filter-storage intervention, water services, total monthly rainfall, and average monthly land surface temperature over 30 months. We also estimated the impact of the filter-storage intervention on water insecurity over 15 months using the original trial design.

Findings: Household water insecurity prevalence ranged between 10.7-25.4% in the 30-month period. Prevalence was highest during the hottest and driest period of data collection. The odds of being water insecure were closely associated with monthly average temperature (aOR: 1.14; 95%CI: 1.03, 1.26), access to basic water services, (aOR: 0.58; 95%CI: 0.44, 0.76), and access to the water filter-storage intervention (aOR:0.65; 95%CI: 0.45, 0.93). Monthly rainfall levels were not associated with the odds of being water insecure (aOR: 1.01; 95% CI: 1.00–1.01). The effect of the water filter-storage intervention on water insecurity was also confirmed using data from the main trial, where intervention households had lower odds of being water insecure compared to control households (aOR:0.59; 95% CI: 0.35, 0.99).

Interpretation: Household water insecurity is variable in populations across seasons. Provision of safe drinking water through the delivery of accessible water services and household water treatment and safe storage interventions is protective against household water insecurity.

Funding: The Bill & Melinda Gates Foundation

4.2 Background

Billions of people worldwide likely experience household water insecurity, defined as "the inability to access and benefit from adequate, reliable, and safe water for wellbeing and a healthy life.[1]" As many as four billion people live in areas facing freshwater scarcity for at least part of the year.[2] Eight hundred million people use unimproved water sources or travel over 30 minutes to collect household water, and at least two billion lack access to drinking water free from priority contaminants.[3] These challenges are a public health concern because of their varied effects on infectious disease transmission, mental health, nutrition, food security, educational attainment, and other aspects of wellbeing.[4-8] Moreover, water-related hazards are projected to become more frequent and severe due to increasing water demand and climate change, with the adverse effects concentrated within populations living in global poverty.[9,10]

The prevalence of household water insecurity is estimated mainly using cross-sectional data or indicators limited to household access to drinking water services. However, experiences of water insecurity are multifaceted and time-varying due to various political, social, and environmental factors. Temperature and precipitation, for example, are well documented to impact water demand, groundwater recharge, and pathogen environments.[11-14] Seasonal behaviors and labor opportunities can influence water resource allocation and consumption rates.[15-17] Extreme-weather events and conflict are also known to cause distress and disrupt the availability of water services.[18,19]

The dependence on cross-sectional data and traditional metrics on water access ultimately narrows our understanding of the drivers and variability of household water insecurity in populations over time.[1,20] Longitudinal monitoring of multiple water burdens is better suited and may importantly improve our ability to design and target interventions that effectively build population resilience to water-related risks.[21] For instance, the devastating impact of extreme shocks such as droughts and flooding is well-studied.[22] However, little is known on the water-related burdens of smaller variations of rainfall and temperature patterns over time, which may especially have enduring implications on communities dependent on rain-fed water sources.[23]

The aim of this research is to assess household water insecurity over 30 months in a predominantly rural population in Rwamagana District, Rwanda. It also seeks to identify associations of precipitation, temperature, water service levels and the effects of a water filter intervention on experiences of water insecurity. We measured the prevalence of household water insecurity using the recently developed Household Water InSecurity Experiences (HWISE) scale,[24] which aims to capture multifaceted experiences of water stress. We utilized longitudinal data that repeatedly measured water insecurity at four time-points in 1,199 households participating in Rwanda's Community-Based Environmental Health Promotion Program (CBEHPP), a national program promoting village-level "Community Health Clubs," with the aim of reducing the disease burden related to inadequate water, sanitation, and hygiene (WASH).[25] Study households were initially enrolled in a randomized control trial (RCT) evaluating an advanced household water filter with safe storage on drinking water quality and child diarrhea.[26] The assessment on household water insecurity was initiated after baseline data revealed that water scarcity might be highly prevalent in the study population and could impact the effects of the filter intervention. The trial found that the filter intervention improved microbial water quality and reduced the prevalence of child diarrhea.[26]

We hypothesize that meteorological-related seasonality changes such as fluctuations in temperature and rainfall and basic access to improved water sources are inputs to household water insecurity by influencing the availability of drinking water and consumption patterns. We hypothesize that the filter and safe storage intervention reduces household water insecurity due to expanding the extent of potentially acceptable drinking water supplies during times of water stress. For instance, with access to appropriate household water treatment and safe storage (HWTS) interventions, households may have more usable water they otherwise might have avoided and allocate more water for drinking with dedicated safe storage.

4.3 Methods

We used longitudinal data to assess household water insecurity in Rwamagana, Rwanda. We estimated the prevalence of household water insecurity at four-time points over 30-months in a cohort of households that participated in an RCT evaluating the effects of a water filter-storage intervention. We recorded overall household water insecurity scores and categorized households as being "water insecure" if they scored 12 or higher on the HWISE scale. We additionally measured water access and water fetching practices as secondary parameters of household water insecurity, defining water access using WHO/UNICEF definitions of improved and basic access and additionally asking household members about their water collection practices in the previous 7-days. Indicators are disaggregated by gender and age when appropriate.

Second, we examined the associations of monthly rainfall and land surface temperature, access to basic water services, and access to a water filter with safe storage with household water insecurity using mixed-effects models. Models were adjusted for household demographics, time of survey visit, and random intercepts arising from repeated measurements of households and village clustering. We additionally utilized the RCT design to rigorously evaluate the effects of the intervention on household water insecurity by comparing household water insecurity prevalence between control and intervention groups.

4.3.1 Study setting and population

The study was conducted in Rwamagana District in Rwanda's Eastern Province. In the district, 92% of residents live in rural areas and 75% of households work in agriculture.[27] Because of its proximity to Kigali city, the district has high rates of internal migration. About a quarter of households are considered to live below the national poverty line.[28] The area has some of the highest rates of fecal contamination of drinking water in the country.[29] The region experiences two rainy and two dry seasons, referred to as long and short. The long rainy season typically occurs from March to May, and the short rainy season from September to November. The short dry season lasts from December to February, while the long dry runs from June-September.[30] Rainfall is on average observed to be lower and temperatures observed to be higher in eastern parts of Rwanda.[31]

The study population is limited to participants who were enrolled in a cluster RCT evaluating the delivery of *LifeStraw® Family 2.0* water purifiers through the CBEHPP, a national program that aims to reduce diarrheal disease prevalence and improve sanitation and hygiene behaviors, including reducing rates of open defecation, promoting handwashing practices, and improved safe water treatment and handling practices. The CBEHPP delivers its programming through Community Health/Hygiene Clubs established in villages. The trial randomly selected 60 villages using probability proportional-to-size sampling and selected eligible households using simple random sampling. Further details on the intervention and design of the trial are reported elsewhere.[26,32] To be eligible for the RCT and intervention, households had to be a member of the village Community Hygiene Club and had a member that was either pregnant or was under the age 5. An adult aged 18 and over had to be present in the household to consent to enrollment in the study. According to the baseline survey from the original trial, most households in this setting report protected springs or wells as their primary source of drinking water, followed by public taps/stand pipes. About 6% of study households reported surface water as their main drinking water source.[26]

4.3.2. Study Design and Data Collection

The study followed a 30-month longitudinal study design, which included data collection efforts from the 15-month RCT with two survey visits and a subsequent 15-month follow-up with an additional two survey visits. After enrollment, a random half of the villages received the intervention in accordance with the trial design.[26]

Data were collected using household questionnaires implemented at four follow-up visits, spaced ~6-9 months apart. Follow-up visits overlapped with varying rainy and dry seasons. The first two survey visits occurred between October 2019 and September 2020. The trial then concluded after the second follow-up visit, and households living in control villages were eligible to receive the filter-storage intervention. Over the next 15 months, two additional follow-ups were done across all villages to monitor the use and effects of the intervention. These last visits occurred between March 2021 and January 2022. A detailed timeline of the study activities and estimated rainy/dry seasons are provided in **Figure 4-1**.

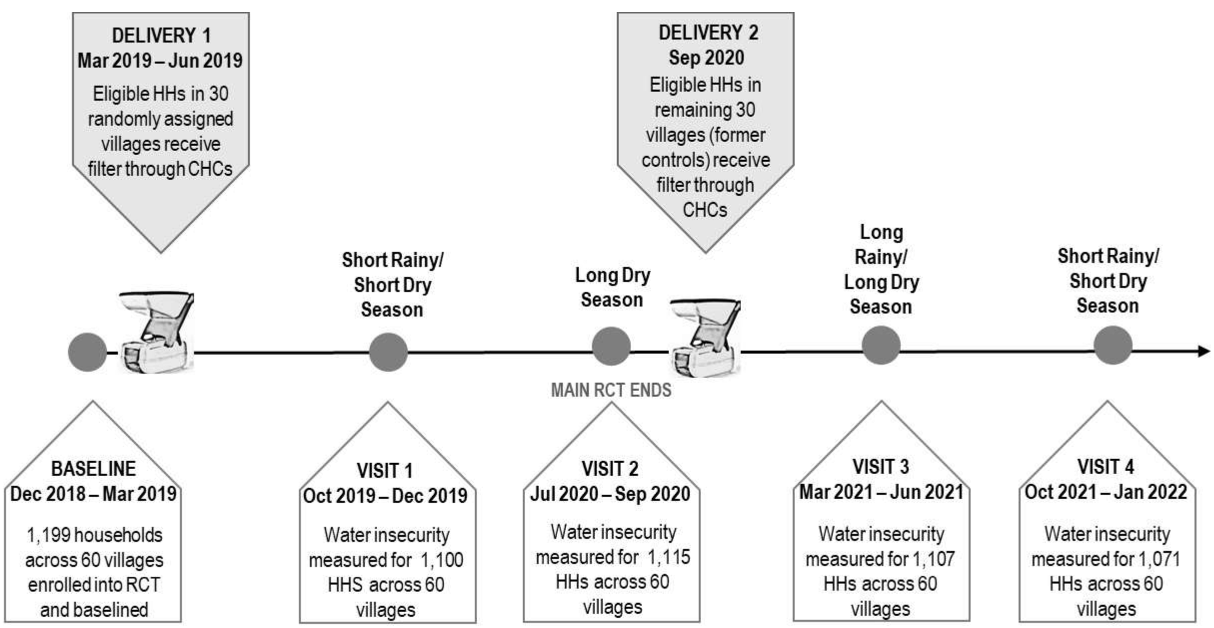


Figure 4-1. Study timeline

Data were collected trained field teams involved in the filter trial but not in the delivery or promotion of the intervention. Household surveys were directed to the primary cooks aged 18 and over. If the primary cook was unavailable or under 18, questions were directed to another household member aged 18 and over. Data were managed using *REDCap* electronic data capture tools hosted at Emory University.[33] The study protocol received ethical approval and was annually renewed by the Emory University Institutional Review Board (CR001-IRB00106424) and Rwanda National Ethics Committee (IRB 0001497). The trial is registered under the Pan African Clinical Trial Registry, Trial ID= PACTR201812547047839.

4.3.2 Data

Water indicators

We measured water indicators during four follow-up visits using the HWISE-12 survey tool on water insecurity, the JMP core questions on main water source access, and original survey questions on household water fetching in the previous 7-days.

*HWISE score***.** Water insecurity scores were estimated on the HWISE scale, a globally validated tool that consists of 12 questions that quantify household experiences with water.[24] The original survey questions were informed through literature review and field testing of relevant components of water insecurity and validated using data from 23 low- and middle-income countries (LMICs). Households were asked to estimate the number of times they have experienced water problems in the last four weeks. Experiences include feelings of worry, thirst, shame, and anger, service interruptions, lack of available water for activities, and disruptions in life events due to water problems. The original HWISE questions were piloted and translated into Kinyarwanda and back-translated into English. The HWISE user manual questions recommend ordering questions in increasing severity and sensitivity of topics in the local setting [24]. This was decided through consultation with local enumerators and during piloting. The HWISE questions and their ordering are provided in the appendix.

We followed the HWISE protocol to analyze responses.[24] Responses were coded and scored as "never" (0 times – score 0), "rarely" (1-2 times – score 1), "sometimes" (3-10 times – score 2), "often" (11-20 times –

score 3), and "always" (more than 20 times – score 3). The scores are summed across all 12 questions to give a final HWISE score. The score is then made into a binary indicator of water insecurity. Households scoring 12 or more were considered to be water insecure as outlined by the HWISE protocol.

WHO/UNICEF core questions on water access. We collected data on households reported main water source technology, on-premise location of water source, and roundtrip collection time to the main water source. Using this data, we then coded water access by WHO/UNICEF water service ladders corresponding to improved and basic access. Improved water access is defined as whether households report their main water source for drinking is either piped water, boreholes or tubewells, protected dug wells, protected springs, rainwater, and packaged or delivered water. Basic access included improved water sources that are accessible within 30 minutes roundtrip. Questions were based on the JMP core survey questions on WASH[34]

Water fetching practices. A survey module was separately designed for the study to measure the frequency and amount of time that each household member collected water in the previous 7-days from the time of visit. Respondents were asked to list all members that regularly slept in the household on a given weekday. Age and sex are recorded for each household member. Respondents were asked to estimate the number of times each household member fetched water and the average roundtrip time it takes for the individual to retrieve water. Using this data, we estimated 3 household-level variables: total members per household collecting water in the last 7 days, total water collection trips per household in the last 7 days, and total time collecting water per household in the last 7 days. For individual-level statistics, we report whether the household member collected water, the number of times they collected water in the last 7 days, and the total time they spent collecting water in the last 7 days (e.g., frequency of trips X average roundtrip collection time).

Temporal and spatial meteorological data

Total monthly rainfall. We obtained high-resolution spatial data on precipitation from the Climate Hazards Group InfraRed Precipitation with Station (CHIRPS) dataset. CHIRPS provides monthly time-series precipitation estimates available from 1981 to the present day at 4 km resolution by blending station observations with satellite observations from the Tropical Applications of Meteorology using SATellite data and ground-based observations (TAMSAT) project.[35]

We overlaid households coordinates onto the gridded estimates of rainfall using the World Geodetic System[36] and extracted total rainfall values in millimeters for all households and months during the study period. Because the HWISE survey tool is based on a 30-day recall period, we estimated the total rainfall each household experienced in the previous 30 days since the survey date. We did this by calculating the daily average rainfall for each month. Next, we multiplied the averages by the number of days in a specific month within each 30-day block and then summed the total. For example, if a household was surveyed on November 15th, we calculated the average daily rainfall values in October and November. We then multiplied the October daily average by 16 and the November daily average by 14 and summed these values to approximate the total monthly rainfall in the previous 30 days for the household.

Average monthly land surface temperature. We obtained ~6-km spatial data on average land surface temperature (LST) from the Terra/Moderate Resolution Imaging Spectradradiom (MODIS) satellite data available on the NASA earth database.[37] We overlaid household GPS locations onto the gridded data using the World Geodetic System and extracted LST values for all households and months during the study period. We estimated the average LST in the previous 30 days by weighting monthly averages based on the survey date. For example, if a household was surveyed on November 15th, we obtained the average LST values in October and November. We then multiplied the October average by 16 and the November average by 14, summed these values, and then divided by 30 to approximate the household's average LST in the previous 30 days.

Household characteristics and access to filter

Household size. Household size was measured at each visit by asking respondents to estimate the number of people that regularly slept in the household on a given weekday.

Socio-economic status. We used the government's official classification of vulnerable households as a proxy for socio-economic status.[38] At baseline, households were asked to report whether they belonged to one of the two official socially vulnerable categories: Ubudehe 1 or 2.

Access to filter with safe storage. This indicated whether the households were eligible to receive the *LifeStraw® Family 2.0* filter at the time of visit.

4.3.3 Statistical approach

Water insecurity, access, and fetching descriptive statistics

We reported descriptive statistics across the four follow-up rounds. On the HWISE scale, we reported the proportion of households considered as "water insecure" and additional report raw HWISE scores. We disaggregated household water insecurity prevalence by intervention group (e.g., eligible to receive the filter-storage intervention). For the JMP standard indicators, we estimated the proportion of households with access to improved water sources and access to basic water sources. Medians and interquartile ranges (IQR) were provided for HWISE score, water fetching, and climate indicators. Although, it was not a main aim of the study, we also reported individual-level statistics on water fetching practices throughout the follow-up period, including the proportion of individuals in the study population collecting water in the past 7 days and their median number of trips and total time collecting water in the previous 7 days. We stratified these estimations by age group and sex.

Associations of rainfall, temperature, water access, and filter-storage access with household water insecurity over 30 months

We built separate multilevel generalized mixed-effects models for two outcomes of household water insecurity: our primary outcome of whether households are considered water insecure (i.e., HWISE score $\geq$12) (Model 1) and a secondary outcome on continuous raw HWISE scores (Model 2). Although the HWISE scale is globally validated, there is some debate on the threshold to indicate water insecurity across contexts.[24] This is why we chose to additionally analyze water insecurity as a continuous score. We examined the effects of access to the water filter with safe storage, basic water access, rainfall, and temperature, controlling for socio-economic status, household size, time of survey visit, and two-level nested random intercepts from repeated household measurements and village-level clustering. Associations of the filter-storage intervention were analyzed using intention-to-treat, meaning that all households eligible to receive the intervention were considered to have access, regardless of coverage or use of the technology. Statistically significant effects were determined by using a two-sided Type I error rate of 0.05. Coefficients for Model 1 were exponentiated to obtain odds ratios. We modeled each outcome using the following models:

(1)

$$logit\left(\Pr\left(Insecure_{ijt} = 1\right)\right) = \mu_j + \mu_{ji} + \beta_0 + \beta_1 Filter_{ijt} + \beta_2 Water_{ijt} + \beta_3 Rain_{ijt} + \beta_4 LST_{ijt} + \beta_5 Ubu_{ijt} + \beta_6 HHsize_{ijt} + \beta_7 Visit_{ij} + \beta_8\, Resid_{ij}$$

(2)

$$HWISE_{ijt} = \mu_j + \mu_{ji} + \beta_0 + \beta_1 Filter_{ijt} + \beta_2 Water_{ijt} + \beta_3 Rain_{ijt} + \beta_4 LST_{ijt} + \beta_5 Ubu_{ijt} + \beta_6 HHsize_{ijt} + \beta_7 Visit_{ij} + \beta_8\, Resid_{ij}$$

where *i* is the measurement taken at the individual household *(i=1… 1,169)*, *j* represents the household's village *(j=1…60),* and *t* represents the time of visit *(t=1…4). Insecure* is the insecurity status (0/1) as indicated by the HWISE and *HWISE* is the total HWISE score. For predictors, *Filter* is access to the filter with safe storage (0/1), *Rain* is total rainfall in the last 30 days, *LST* is the average land surface temperature in the last 30 days, *water* is access to basic improved water (0/1), *Ubu* is whether the household belongs to the poorest two government-defined socio-economic groups (0/1), *HHsize* is the number of members that regularly sleep in the household on a given weekday, *Visit* is the data collection round (1-4), and *u* includes random intercepts from household and village clustering.

Impact of the filter-storage intervention on household water insecurity over 15-months: RCT analysis

We utilized the trial design to rigorously test the effectiveness of the filter with safe storage intervention on reducing household water insecurity. We restricted the analyses to the first two follow-up visits (e.g., over 13-16 months), when there were randomly allocated intervention and control groups. This analysis is considered secondary analysis of trial data, since water insecurity was not prespecified as a primary or secondary outcome in the original analysis plan of the trial [26]. We estimated the impact of the intervention using intention-to-treat. We used generalized mixed effects models defining HWISE-insecurity status (Model 3) and HWISE scores (Model 4) as outcomes and study arm as the independent variable. We additionally adjusted for village and household clustering and socio-economic status to account for imbalance found at baseline.[26] Coefficients in Model 3 were exponentiated to obtain odds ratios. The models are as follows:

(3)

$$logit\left(\Pr\left(Insecure_{ijt} = 1\right)\right) = \mu_j + \mu_{ji} + \beta_0 + \beta_1 Arm_{ijt} + \beta_2 Resid_{ij}$$

(4)

$$HWISE_{ijt} = \mu_j + \mu_{ji} + \beta_0 + \beta_1 Arm_{ijt} + \beta_2 Resid_{ij}$$

4.4 Results

4.4.1 Study population

Of the 1,199 households that were originally enrolled at baseline, 1,169 households were surveyed in at least one of the follow-up visits measuring water indicators. A total of 4,405 out of a possible 4,795 household observations (91.9%) were analyzed over the approximate 30-month follow-up period. For the RCT analysis, a total of 1,119 out of a possible 1,216 household observations in the intervention arm (92.0%) and a total of 1,107 out of a possible 1,182 household observations in the control arm (93.7%) were analyzed over the approximate 15-month follow-up period. Reasons for lost-to-follow up included households moving away, not home at time of visit after two attempts, or the household did not wish to participate (**Figure 4-2**).

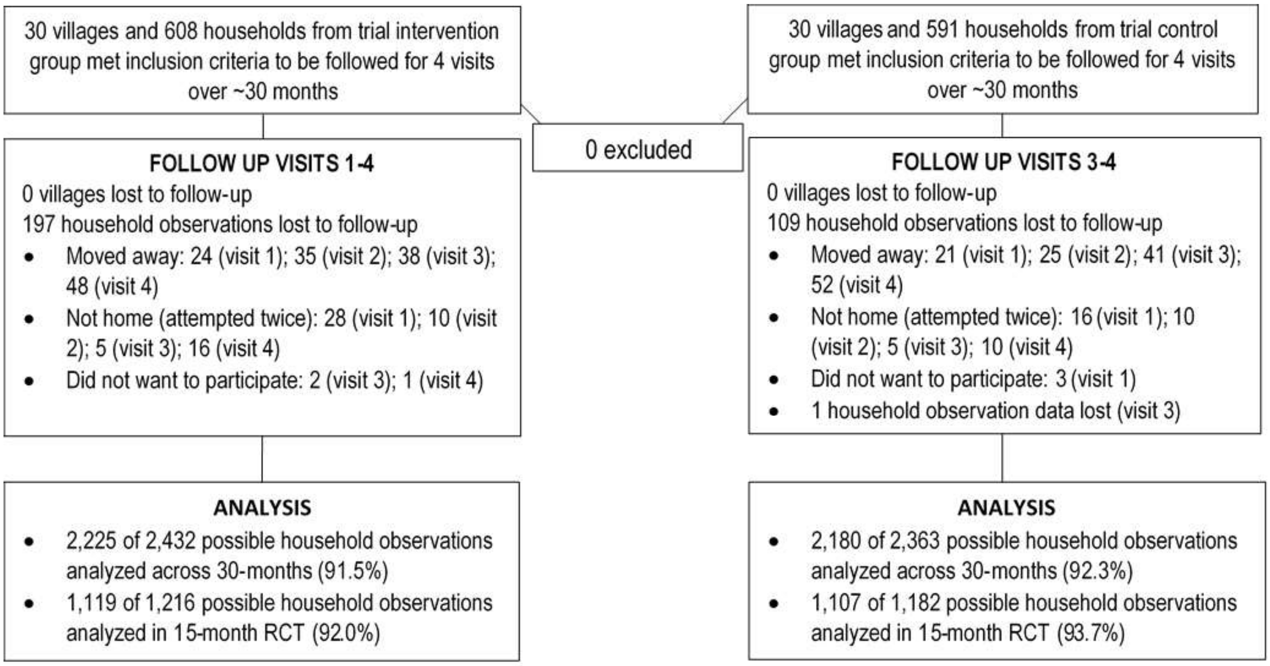


Figure 4-2. Participant flow

Baseline characteristics of the enrolled households in the original RCT are reported elsewhere.[26] While the HWISE scale was not implemented at baseline, underlying demographics and water access were measured to assess balance between study arms. Socio-economic status, which could be related to water insecurity, appeared to be imbalanced between arms (>10% difference) and was considered as a covariate to be adjusted in the analysis. A higher proportion of households in the intervention arm were considered to be of lower socio-economic status.[26]

4.4.2 Water insecurity, water access, and water fetching trends over 30 months

We reported the study population's water insecurity, water access, and water fetching practices, stratified by each survey round, to examine trends overtime (**Table 4-1**). Prevalence of household water insecurity ranged from 10.7-25.4%, and median HWISE scores ranged from 0-5 in the 30-month period. Visit 2, which overlapped with the long dry season, was observed to have the highest temperatures and lowest rainfall levels, followed by Visit 4 (short rainy/short dry combination), Visit 1 (short rainy/long dry combination), and Visit 3 (long rainy/long dry combination). Household water insecurity prevalence was highest during hotter and drier seasons observed in Visit 2, followed by Visit 4.

Table 4-1. Household-level water and meteorology indicators across visits

	1st visit Short Rainy/Short Dry	**2nd visit** Long Dry	**3rd visit** Long Rainy/Long Dry	**4th visit** Short Rainy/Short Dry	**Overall**
	% (95% CI) or median (IQR)	**% (95% CI) or median (IQR)**	**% (95% CI) or median (IQR)**	**% (95% CI) or median (IQR)**	**% (95% CI) or median (IQR)**
Household Water Insecurity Experiences (HWISE)	**N= 1,100**	**N= 1,115**	**N= 1,107**	**N= 1,071**	**N= 4,393**
Water Insecure (HWISE ≥12)	11.0 (9.6, 13.0)	25.4 (22.9, 28.0)	10.7 (9.1, 12.7)	16.4 (14.3, 18.8)	15.9 (14.9, 17.0)
Total HWISE score	2 (0-6)	5 (0-12)	0 (0-5)	1 (0-8)	2 (0-8)
Water source access	**N= 1,106**	**N= 1,119**	**N= 1,108**	**N= 1,072**	**N= 4,405**
Improved water access	90.7 (88.8, 92.3)	85.8 (83.6, 87.7)	91.2 (89.3, 92.7)	89.6 (87.7, 91.3)	89.3 (88.4, 90.2)
Basic water access	44.4 (41.5, 47.3)	30.3 (27.7, 33.1)	40.4 (37.6, 43.4)	42.9 (40.0, 45.9)	39.5 (38.1, 40.9)
Water fetching*	**N= 929**	**N= 963**	**N= 932**	**N= 882**	**N= 3,706**
Total members per household fetching water in last 7 days	1 (1-2)	2 (1-3)	1 (1-2)	2 (1-2)	2 (1-2)
Total water collection trips per household in the last 7 days	4 (2-7)	14 (7-22)	7 (3-14)	11 (4-21)	7 (3-16)
Total time per household collecting water in the last 7 days	82 (30-280)	420 (175-1055)	190 (60-500)	280 (94-720)	227.5 (70-600)
Meteorology	**N= 1,107**	**N= 1,119**	**N= 1,107**	**N= 1,072**	**N= 4,405**
Total rainfall (mm) in previous 30 days	116.5 (107.9-120.9)	4.7 (3.7-7.3)	140.5 (125.8-168.2)	75.6 (53.0-93.2)	101.9 (17.6-122.3)
Average Land Surface Temperature (°C)	26.5 (25.9-27.4)	29.8 (28.6-30.8)	24.0 (22.8-25.1)	28.2 (27.4-28.9)	27.3 (22.8-25.1)

*water fetching data only available among households who travel off-premises to collect water

Water service levels also varied over the 30 months. Reported access to improved water sources fluctuated between 85.8-91.2%. Access to basic water services (i.e., improved water sources accessible within 30 minutes roundtrip) was overall lower and ranged from 30.3-42.9%. Water fetching practices similarly varied overtime. The median number of members per household collecting water in the last 7 days ranged from 1-2, median trips per household in the last 7 days ranged from 4-14, and the median household time spent collecting water in last days ranged from 82-420 minutes. Similarly, water service levels and water fetching practices were worst in the hotter and drier seasons observed in Visit 2, followed by Visit 4. Water fetching practices stratified by age and sex revealed minimal sex-differences. However, there were apparent age-differences, with water fetching tasks were most concentrated within individuals in the 12-17 years age group (**Supplementary Table 4**).

Household water insecurity was additionally stratified by study arm across survey rounds (**Figure 4-3).** The prevalence of household water insecurity was overall lower among intervention households compared to control households during the trial follow-up period. The difference in water insecurity prevalence between the two arms decreased after the completion of the trial, when control households were eligible to receive the filter-storage intervention. An alluvial plot in **Figure 4-4** shows the longitudinal patterns of water insecurity in households, stratified by study arm. In both arms, water insecurity and water security were concentrated in the same cohorts of households throughout the 30-month follow-up. However, there were also cohorts in both arms that fell in and out of water insecurity, demonstrating variability across time. For instance, 37.6% of households were considered to water insecure during at least one visit through the follow-up (data not shown).

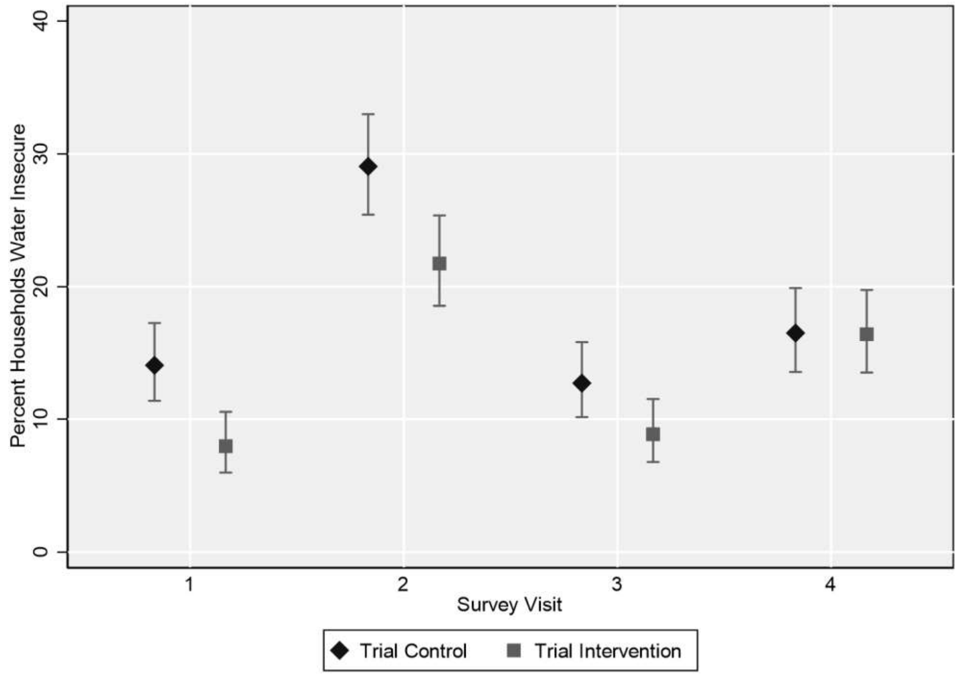


Figure 4-3. Percentage of households considered water insecure (HWISE ≥12) by study arms and visits. Note: Trial control group had access to the filter during visits 3 and 4 after the conclusion of the trial. Intervention group had access to the filter throughout follow-up period.

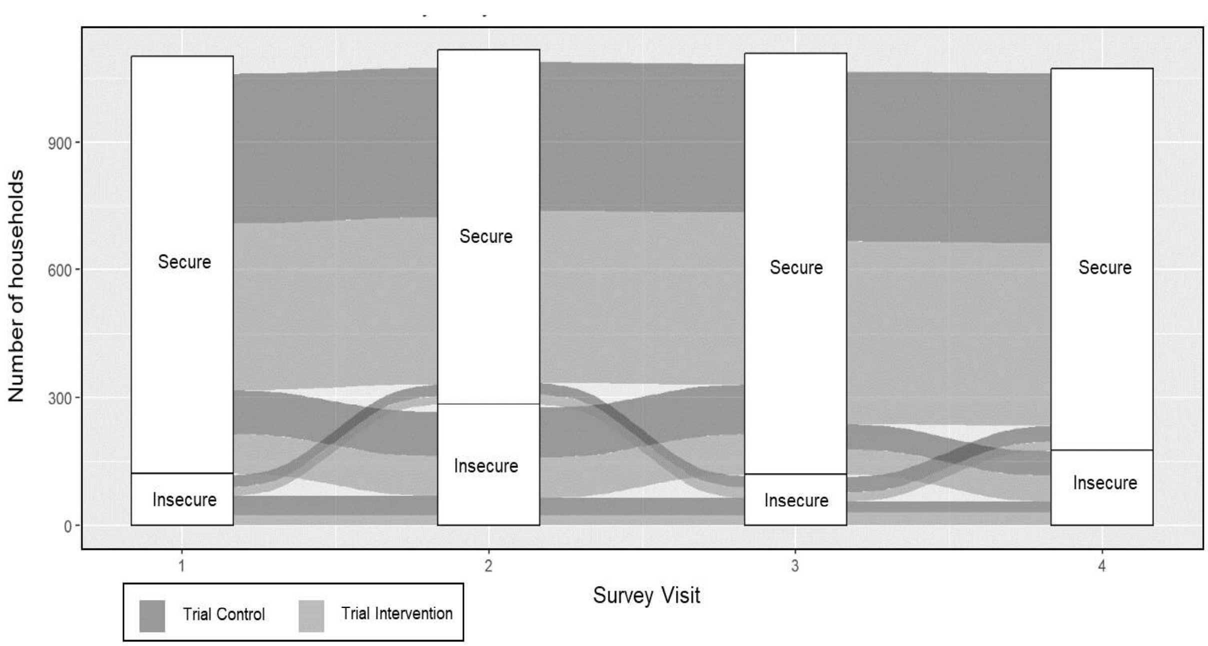


Figure 4-4. Alluvial plot of the number of households considered water insecure or secure by study group across visits. Note: Trial control group had access to the filter during visits 3 and 4 after the conclusion of the trial. Intervention group had access to the filter throughout follow-up period.

4.4.3 Associations with household water insecurity

We examined associations of water insecurity and total HWISE scores with filter with safe storage access, basic water access, total rainfall in previous 30 days, and average land surface temperature in the previous 30 days, adjusting for socio-economic status, household size, time of visit, random intercepts at the village- and household-levels In model 1, households with eligible to receive the filter-storage intervention had 0.65 (95% CI: 0.45–0.93) times the odds of being water insecure compared to those not eligible **(Figure 4-5 and Table 4-2).** Access to basic water had 0.58 times the odds (95% CI: 0.44–0.76) compared to those without access. Higher average monthly temperature increased the odds, (aOR, 1.14; 95% CI: 1.03–1.26), while total rainfall in previous 30 days was not associated with water insecurity status (aOR, 1.01; 95% CI: 1.00–1.01). When analyzing HWISE score as a continuous measure (model 2- **Table 4-2**), the filter with safe storage was also associated with lower household water insecurity scores (e.g., fewer experiences of water insecurity) (-0.96; 95% CI -1.51– -0.36). Basic water access also lowered total scores (1.08; 95% CI: -1.49–-0.67). Higher rainfall (0.02; CI: 0.01– 0.03) and temperature (0.30; 95% CI: 0.15– 0.45) were associated with higher overall scores (e.g., more experiences of water insecurity).

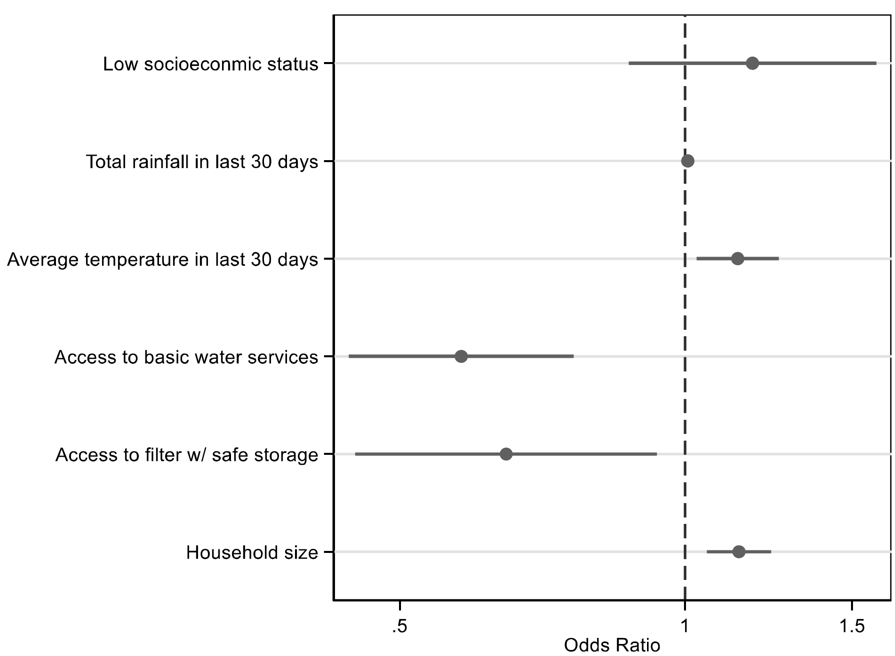


Figure 4-5. Odds ratio (OR) point estimates and 95% confidence intervals for factors associated with household water insecurity over 30 months. N=4,359 household observations. Adjusted for time of survey and random intercepts for repeated measures of households and villages. X axis displayed in logarithmic scale.

Table 4-2. Associations of household experiences of water insecurity with filter and safe storage access, basic water access, rainfall, and temperature

Model 1[a] – Household is water insecure n= 4,359	**Odds Ratio**	**(95% CI)**	**p-value**
Filter with safe storage	0.65	(0.45, 0.93)	0.02
Basic water access	0.58	(0.44, 0.76)	< 0.01
Total rainfall in previous 30 days	1.01	(1.00, 1.01)	0.12
Average LST in previous 30 days	1.14	(1.03, 1.26)	0.01
Model 2[a] – HWISE score n= 4,359	**β**	**(95% CI)**	**p-value**
Filter with safe storage	-0.96	(-1.51, -0.40)	<0.01
Basic water access	-1.08	(-1.49, -0.67)	< 0.01
Total rainfall in previous 30 days	0.02	(0.01, 0.03)	<0.01
Average LST in previous 30 days	0.30	(0.15, 0.45)	< 0.01

[a] The model is additionally adjusted for socio-economic status, household size, and time of survey visit with random intercepts to account for clustering from repeated measurements of households and from the village.

4.4.4 Impact of the filter-storage intervention with household water insecurity

Table 4-3 provides the estimates on the impact of the water filter with safe storage using the original RCT design during the first two visits. Estimates of the intervention from crude model (data not shown) and model adjusted for socio-economic status was appreciably different. In the intention-to-treat analysis, or those randomly allocated to the intervention group, the odds of water insecurity decreased by 41% (aOR, 0.59; 95% CI: 0.35-0.99). The intervention did not have a statistical effect on overall HWISE scores (-1.01; 95% CI: -2.19-0.16). The differences in effects between models 1 and 2 could reflect left-skewed continuous data, with a high-frequency of zeros.

Table 4-3. Impact of filter and safe storage on household experiences of water insecurity

Model 3[a] – Water Insecure (0/1) n= 2,198	Odds Ratio	(95% CI)	p-value
Intervention arm	0.59	(0.35, 0.99)	<0.05
Model 4[a] – HWISE score n= 2,198	**β**	**(95% CI)**	**p-value**
Intervention arm	-1.01	(-2.19, 0.16)	0.09

[a] The model is additionally adjusted for socio-economic status with random intercepts to account for clustering from repeated measurements of households and from the village. Socio-economic status was adjusted for due to imbalance between study groups found at baseline.

4.5 Discussion

We aimed to assess water insecurity across time, and identify possible associations with safe drinking water access and meteorological factors. Although limited to 30-months, this is one of the few studies to longitudinally examine water insecurity and access in the same population.[21] The findings support the importance of seasonal variation and highlights the disadvantages of measuring water indictors cross-sectionally. It also identifies possible interventions that can increase resilience to seasonal variation and demonstrates the utility of using the HWISE in evaluation frameworks of WASH programs.

Overall, water insecurity varied in the population over time and seemed to have been driven by meteorological factors. Although, there were households that chronically experienced water insecurity throughout the study period, there were households that fell in and out water insecurity over the 30-months. These household experiences may not have been captured in cross-sectional measurements during other times of the year. In our study population, water insecurity, as well as other indicators on drinking water access, were worst during Rwanda's long dry season. A cross-county comparison of HWISE scores similarly revealed that scores from cross-sectional surveys conducted during the dry seasons were higher (i.e. increased water insecurity) compared to those conducted during rainy season.[39] Although longitudinal monitoring would be preferred, it is costly to implement and may not always be feasible. In our study setting, our findings would suggest that household water insecurity is best measured during the dry seasons, when perceived experiences are the worst. However, seasonal differences are likely context-specific and not generalizable to all geographies, populations, or other water-related parameters, such as microbial water quality, heavy metal pollutants, and various enteric diseases that exhibit diverse seasonal patterns [30,40,41]. The data collection effort that had had the highest prevalence of water insecurity coincided with the early months of the COVID-19 pandemic (i.e., July-September 2020). New restrictions and distress on households could have influenced perceived water insecurity at the time. For instance, a national phone survey deployed by WHO/UNICEF revealed that between 25-40% of Rwandan households reported water service interruptions due to the pandemic.[3] Nevertheless, our analyses still found a relationship between increasing temperatures and water insecurity, even after adjusting for survey visits. A dedicated COVID-19 survey module we implemented during the study also did not reveal apparent service interruptions due to the pandemic (data unpublished).

Another important aim of our study was to identify protective factors against household water insecurity. We found that the filter with safe storage had an overall effect on reducing water insecurity prevalence, shown both observationally and experimentally. Policymakers traditionally do not view HWTS interventions as solutions for increasing water availability or facilitating progress towards meeting international and national water access targets.[42] Delivering low-cost household-level products may not be sustainable for long-term use and adoption.[43] Like others, we assert that HWTS interventions should never replace efforts to strengthen public utilities that reliably provide safe drinking water.[44] Our study supports the need for the continued investment in high-quality and accessible water services, finding a strong relationship between access to basic water services and water insecurity.

However, HWTS interventions may complement public service provision to build household resilience. For example, improved water infrastructure is not guaranteed microbiologically safe and services are often intermittent.[45,46] Access to safe HWTS interventions could improve household resiliency by empowering households to have more control over their water security during service interruptions or times of stress. . This could be especially important during climate shocks such as extreme flooding and drought when health risks are the highest and HWTS is in higher demand.[19] HWTS is already well used in the humanitarian sector during times of crisis or natural disasters, but they have not been traditionally used in the context of climate adaption in terms of increasing everyday resiliency to chronic experiences of water insecurity. The safe storage container integrated into the filter's design may also importantly helped households retain and allocate safe water for drinking.

Although we found positive effects of the filter-storage technology, we are restricted in our ability to understand the exact mechanisms of how the intervention reduced water insecurity. Our analysis on the impact of the intervention was a secondary analysis to the man trial, and measurement of process outcomes specifically relating to improved water insecurity was limited. In the main trial, we reported that the intervention had high uptake and use, signaling that there was a demand for the intervention in the population.[26] It should be noted that our findings are exclusive to this particular filter-storage technology and implementation strategy, and therefore, may not be applicable to other HWTS interventions. Future research should investigate the role of various HWTS interventions in improving dimensions of water insecurity beyond water quality, such as investigating effects on climate resiliency, water quantity, water accessibility, and water resource allocation.

A final strength of our study is the integration of a multidimensional indicator of household water insecurity into the evaluation framework. Few rigorous evaluations of WASH interventions have examined the effects on overall household experiences of water insecurity. An evaluation on a community water supply improvement project in Ethiopia found reductions in perceptions of water problems on a similar measurement scale to the HWISE.[47] A trial on a demand-based sanitation intervention aimed to improve hygiene behaviors measured impact on water insecurity as defined by the HWISE scale, but did not observe reductions in household water insecurity prevalence.[48] To our knowledge, there have been no investigation on the effects of an HWTS intervention on water insecurity as measured by HWISE or comparable metrics that capture multiple domains of water insecurity.

Future HWTS and WASH evaluations should consider measuring household water insecurity using HWISE along with other objective measures. The value of the HWISE-scale is its focus on user experiences and frustrations with multiple types of water-related burdens, which are not necessarily captured in single measurements of infrastructural access. The HWISE is particularly relevant to the evaluation of HWTS interventions because the tool includes specific measurements on household experiences with drinking water, such as measuring the frequency of having no useable or drinkable water whatsoever in the household, going to sleep thirsty because of no drinking water in the house, being angry about the quality of their water, feeling shame for not being able to serve water to visitors, and having enough water for drinking in the household.[24] However, due to the HWIE scale's dependence on self-reporting, evaluations should also define parameters that objectively demonstrate effectiveness of WASH interventions in improving use, safety, and health.

Our study has other limitations. Eligibility was limited to CBEHPP participants in a single district in Rwanda who were members of their village CHC, a source of selection bias and a limitation on external validity. Outcomes of water access, water insecurity, and water fetching were dependent on self-reported indicators and are therefore vulnerable to recall and reporting biases. The effects of the water filter and safe storage are vulnerable to bias as the main trial was unblinded, and HWISE scores were not measured at baseline to assess balance between study arms. Water access and some of the other household-level covariates were also measured cross-sectionally and may not represent the household's exposure to those variables during the 30-day recall period on measuring experiences of water insecurity.

Overall, our findings support that household water insecurity is variable across time in populations and sensitive to seasonality driven by meteorological factors. Interventions that improve access to safe drinking water in the home, such as access to appropriate HWTS and basic water services, should be prioritized in climate-resilient frameworks. Future research should also compare different ways to comprehensively assess water insecurity and account for seasonality in monitoring and evaluation frameworks.

4.6 References

1 Jepson, W. E., Wutich, A., Colllins, S. M., Boateng, G. O. & Young, S. L. Progress in household water insecurity metrics: a cross-disciplinary approach. *Wiley Interdisciplinary Reviews: Water* **4**, e1214 (2017).

2 Mekonnen, M. M. & Hoekstra, A. Y. Four billion people facing severe water scarcity. *Science advances* **2**, e1500323 (2016).

3 WHO/UNICEF. Progress on household drinking water, sanitation and hygiene 2000-2020: five years into the SDGs. Report No. 9240030840, (2021).

4 Murray, C. J. *et al.* Global burden of 87 risk factors in 204 countries and territories, 1990–2019: a systematic analysis for the Global Burden of Disease Study 2019. *The Lancet* **396**, 1223-1249 (2020).

5 Geere, J.-A. L., Cortobius, M., Geere, J. H., Hammer, C. C. & Hunter, P. R. Is water carriage associated with the water carrier's health? A systematic review of quantitative and qualitative evidence. *BMJ Global Health* **3**, e000764 (2018).

6 Prüss-Ustün, A., Vickers, C., Haefliger, P. & Bertollini, R. Knowns and unknowns on burden of disease due to chemicals: a systematic review. *Environmental health* **10**, 1-15 (2011).

7 Venkataramanan, V. *et al.* In pursuit of 'safe'water: the burden of personal injury from water fetching in 21 low-income and middle-income countries. *BMJ global health* **5**, e003328 (2020).

8 Bhutta, Z. A. & Das, J. K. Interventions to address maternal and childhood undernutrition: current evidence. *International Nutrition: Achieving Millennium Goals and Beyond* **78**, 59-69 (2014).

9 Damania, R. *et al. Uncharted waters: The new economics of water scarcity and variability*. (World Bank Publications, 2017).

10 Stoler, J. *et al.* Connecting the dots between climate change, household water insecurity, and migration. *Current Opinion in Environmental Sustainability* **51**, 36-41 (2021).

11 Levy, K., Woster, A. P., Goldstein, R. S. & Carlton, E. J. Untangling the impacts of climate change on waterborne diseases: a systematic review of relationships between diarrheal diseases

and temperature, rainfall, flooding, and drought. *Environmental science & technology* **50**, 4905-4922 (2016).

12 Kraay, A. N. *et al.* Understanding the impact of rainfall on diarrhea: testing the concentration-dilution hypothesis using a systematic review and meta-analysis. *Environmental health perspectives* **128**, 126001 (2020).

13 Gato, S., Jayasuriya, N. & Roberts, P. Temperature and rainfall thresholds for base use urban water demand modelling. *Journal of hydrology* **337**, 364-376 (2007).

14 Mileham, L., Taylor, R. G., Todd, M., Tindimugaya, C. & Thompson, J. The impact of climate change on groundwater recharge and runoff in a humid, equatorial catchment: sensitivity of projections to rainfall intensity. *Hydrological sciences journal* **54**, 727-738 (2009).

15 Rathnayaka, K. *et al.* Seasonal demand dynamics of residential water end-uses. *Water* **7**, 202-216 (2015).

16 Foster, T. Predictors of sustainability for community-managed handpumps in sub-Saharan Africa: evidence from Liberia, Sierra Leone, and Uganda. *Environmental science & technology* **47**, 12037-12046 (2013).

17 Stelmach, R. D. & Clasen, T. Household water quantity and health: a systematic review. *International journal of environmental research and public health* **12**, 5954-5974 (2015).

18 Wolf, A. T., Kramer, A., Carius, A. & Dabelko, G. D. *Managing water conflict and cooperation*. (Routledge, 2017).

19 Khan, S. J. *et al.* Extreme weather events: Should drinking water quality management systems adapt to changing risk profiles? *Water research* **85**, 124-136 (2015).

20 Bartram, J. *et al.* Global monitoring of water supply and sanitation: history, methods and future challenges. *International journal of environmental research and public health* **11**, 8137-8165 (2014).

21 Rosinger, A. Y. & Young, S. L. The toll of household water insecurity on health and human biology: current understandings and future directions. *Wiley Interdisciplinary Reviews: Water* **7**, e1468 (2020).

22 Lee, J., Perera, D., Glickman, T. & Taing, L. Water-related disasters and their health impacts: A global review. *Progress in Disaster Science* **8**, 100123 (2020).

23 Grasham, C. F. *et al.* Engaging with the politics of climate resilience towards clean water and sanitation for all. *npj Clean Water* **4**, 1-4 (2021).

24 Young, S. L. *et al.* The Household Water InSecurity Experiences (HWISE) Scale: development and validation of a household water insecurity measure for low-income and middle-income countries. *BMJ Global Health* **4**, e001750 (2019).

25 Ministry of Health. (Kigali, Rwanda, 2010).

26 Haque, S. *et al.* Effects of adding household water filters to Rwanda's Community-Based Environmental Health Promotion Programme: A cluster-randomized controlled trial in Rwamagana district. *NPJ Clean Water* (in review).

27 National Institute of Statistics of Rwanda. (NISR Kigali, 2012).

28 NISR, M. Rwanda Demographic and Health Survey 2014–15. *Key indicators*, 1045-1049 (2015).

29 Kirby, M. A. *et al.* Faecal contamination of household drinking water in Rwanda: A national cross-sectional study. *Science of the Total Environment* **571**, 426-434 (2016).

30 Mukanyandwi, V. *et al.* Seasonal assessment of drinking water sources in Rwanda using GIS, contamination degree (Cd), and metal index (MI). *Environmental monitoring and assessment* **191**, 1-13 (2019).

31 Asumadu-Sarkodie, S., Rufangura, P., Jayaweera, M. & Owusu, P. A. Situational analysis of flood and drought in Rwanda. (2017).

32 Bradshaw, A., Mugabo, L., Gebremariam, A., Thomas, E. & MacDonald, L. Integration of Household Water Filters with Community-Based Sanitation and Hygiene Promotion—A Process Evaluation and Assessment of Use among Households in Rwanda. *Sustainability* **13**, 1615 (2021).

33 Harris, P. A. *et al.* Research electronic data capture (REDCap)—a metadata-driven methodology and workflow process for providing translational research informatics support. *Journal of biomedical informatics* **42**, 377-381 (2009).

34 WHO/UNICEF. Core questions on drinking water, sanitation and hygiene for household surveys: 2018 update. *United Nations Children's Fund (UNICEF) and World Helath Organisation, New York* (2018).

35 Funk, C. *et al.* The climate hazards infrared precipitation with stations—a new environmental record for monitoring extremes. *Scientific data* **2**, 1-21 (2015).

36 National Geospatial-Intelligence Agency (NGA). (2014).

37 Wan, Z., Hook, S. & Hulley, G. (ed NASA EOSDIS Land Processes DAAC) (2015).

38 Ezeanya, C. Home-grown and grassroots-based strategies for determining inequality towards policy action: Rwanda's Ubudehe approach in perspective. Report No. 9292308939, (WIDER Working Paper, 2015).

39 Stoler, J. *et al.* The Household Water Insecurity Experiences (HWISE) Scale: comparison scores from 27 sites in 22 countries. *Journal of Water, Sanitation and Hygiene for Development* **11**, 1102-1110 (2021).

40 Kulinkina, A. V. *et al.* Seasonality of water quality and diarrheal disease counts in urban and rural settings in south India. *Scientific reports* **6**, 1-12 (2016).

41 Levy, K., Hubbard, A. E. & Eisenberg, J. N. Seasonality of rotavirus disease in the tropics: a systematic review and meta-analysis. *International journal of epidemiology* **38**, 1487-1496 (2009).

42 Clasen, T. F. Household Water Treatment and the Millennium Development Goals: Keeping the Focus on Health. *Environmental Science & Technology* **44**, 7357-7360, doi:10.1021/es1018674 (2010).

43 Wolf, J. *et al.* Impact of drinking water, sanitation and handwashing with soap on childhood diarrhoeal disease: updated meta-analysis and meta-regression. *Tropical medicine & international health* **23**, 508-525 (2018).

44 Ray, I. & Smith, K. R. Towards safe drinking water and clean cooking for all. *The Lancet Global Health* **9**, e361-e365 (2021).

45 Shields, K. F., Bain, R. E., Cronk, R., Wright, J. A. & Bartram, J. Association of supply type with fecal contamination of source water and household stored drinking water in developing countries: a bivariate meta-analysis. *Environmental health perspectives* **123**, 1222-1231 (2015).

46 Bain, R. *et al.* Fecal contamination of drinking-water in low-and middle-income countries: a systematic review and meta-analysis. *PLoS medicine* **11**, e1001644 (2014).

47 Stevenson, E., Ambelu, A., Caruso, B., Tesfaye, Y. & Freeman, M. Community water improvement, household water insecurity, and women's psychological distress: an intervention and control study in Ethiopia. *PloS one* **11**, e0153432 (2016).

48 Freeman, M. C. *et al.* The impact of a demand-side sanitation and hygiene promotion intervention on sustained behavior change and health in Amhara, Ethiopia: a cluster-randomized trial. *PLOS Global Public Health* **2**, e0000056 (2022).

Supplementary Table 4. Individual-level water fetching practices throughout follow-up, disaggregated by age and sex

	n	% reporting to collect water in the past 7 days (95% CI)	Water collection trips in past 7 days among fetchers Median (IQR)	Time in minutes collecting water in past 7 days among fetchers Median (IQR)
Total	**17,226**	**38.3 (37.6, 39.1)**	**4 (2-8)**	**30 (15-60)**
2-4 years old	1,837	3.2 (2.5, 4.1)	3 (2-6)	40 (5-60)
5-11 years old	4,578	38.1 (36.7, 39.6)	4 (2-9)	40 (10-60)
12-17 years old	2,535	72.5 (70.7, 74.2)	6 (3-14)	40 (20-60)
18-40 years old	5,745	44.9 (43.6, 46.1)	4 (2-8)	30 (20-60)
40+ years old	5,745	15.1 (13.7,16.5)	3 (2-7)	30 (20-60)
Female	**9,047**	**39.6 (38.6, 40.6)**	**4 (2-10)**	**30 (15-60)**
2-4 years old	882	4.3 (3.1, 5.9)	3 (2-7)	60 (10-90)
5-11 years old	2,152	38.8 (36.8, 40.9)	4 (2-7)	40 (10-60)
12-17 years old	1,307	69.9 (67.4, 72.4)	6 (3-14)	35 (20-60)
18-40 years old	3,404	46.8 (45.2, 48.5)	3 (2-7)	30 (20-60)
40+ years old	1,302	15.2 (13.4, 17.3)	3 (2-7)	30 (15-60)
Male	**8,130**	**36.9 (35.9, 38.0)**	**4 (2-8)**	**40 (20-60)**
2-4 years old	952	2.2 (1.4, 3.4)	3 (2-6)	30 (5-60)
5-11 years old	2,414	37.5 (35.6, 39.4)	4 (2-10)	40 (10-60)
12-17 years old	1,214	75.2 (72.7, 77.6)	6 (3-14)	40 (20-60)
18-40 years old	2,327	42.1 (40.1, 44.1)	4 (2-10)	30 (20-60)
40+ years old	1,223	15.0 (13.1, 17.2)	3 (2-7)	30 (20-60)
Other	**38**	**39.5 (25.0, 56.1)**	**7 (3-14)**	**30 (20-60)**

*water fetching data only available among households who travel off-premises to collect water

Chapter 5 – Summary, implications, and future directions

5.1.1 Summary of findings

In order to inform Rwanda strategy for improving environmental health, we evaluated the water quality and child health effects of integrating an advanced household-based water filter with safe storage free-of-cost to households into the delivery of the Community-Based Environmental Health Promotion Programme (CBEHPP). While previous research showed the filter to be effective if delivered as part of an intensive, focused and well-funded campaign, it was not clear if it could be equally effective if rolled into the government's existing programs.[1] We enrolled 1,199 CBEHPP beneficiaries in a cluster randomized controlled trial (RCT), delivering the newly designed program to a random half of villages. In the first aim, we found strong evidence that over 13-16 months, this intervention reduced the proportions of households with fecally contaminated drinking water and under-5 children experiencing diarrhea in the last week. These results are supported by high coverage and use of the filter and complementary reductions in child healthcare visits for diarrhea treatment over the study period.

In the second aim, we studied the sustainability of the CBEHPP-filter intervention over 28-32 months. Although the hardware is designed to last over 3-5 years, little is known about the filter's real-world sustainability after a year. Our research is one of the few studies to have monitoring of a household water treatment intervention for over two years. Using longitudinal surveys at four-time points, we followed the intervention group, collecting data on reported and observed coverage, condition, and use of the filter and microbial water quality and caregiver-reported diarrhea among children under five. After adjusting for seasonality factors, we found that outcomes on filter coverage, condition, and use declined over time, particularly after the first 13-16 months of exposure to the filter. Continued use remained generally high with 85% of households reporting to still use the filter 28-32 months post-implementation. While households with water in the filter's storage container declined by the last follow-up, we did not observe differences in the prevalence of fecal-contaminated drinking water nor under 5 child diarrhea prevalence between survey rounds, even after adjusting for seasonality factors. Similarly, a secondary analysis contemporaneously comparing duration of exposure to the filter did not find statistical differences in microbial water quality or diarrhea prevalence. These findings suggest that the effects of the household filter delivered as a part of the CBEHPP can be programmatically sustained for 30 months.

In the third aim, we explored water insecurity in the study population over seasons, and assessed meteorological and water access risk factors to overall water insecurity as measured by the Household Water InSecurity Scale (HWISE). We found that water insecurity changes across time and is closely associated with temperature and accessible water sources. Data revealed that water insecurity can be improved with access to the filter with safe storage, which was also experimentally tested in the main trial. The findings underscore the variation of water insecurity within and between populations and illustrate the limitations of measuring water indicators cross-sectionally. Further, they highlight the potential role of household water treatment in reducing experiences of water insecurity.

5.1.2 Limitations

While our first research question was rigorously assessed through an RCT, there are limitations to the interpretations of the results. First, our study population was restricted to participating CBEHPP households with young children or pregnant persons within Rwamagana district, which limits the generalizability of our findings. Although the CBEHPP is centrally designed by the Ministry of Health, it is implemented through a variety of contracted NGOs and non-state actors. In our study region, CBEHPP activities were delivered by CRS and SNV, two international NGOs working under a larger WASH and nutrition program funded by USAID. The filter intervention was integrated within the same curriculum and Community Health Club (CHC) service model that are universal hallmarks of the CBEHPP.[2] Further, this region is observed to have high rates of fecal contamination in drinking water supply and overall low access to basic water sources compared to the rest of the country. These limitations on generalizability are also relevant to the interpretation of the findings from the second and third research aims. A random sampling of villages throughout Rwanda would have provided a more representative assessment of the expected benefits of integrating the filter nationally, sustained effects, and longitudinal trends in household water insecurity.

Second, many of the evaluation outcomes, particularly on child health and experiences of household water security, depended on self-reported data, which are subject to recall and reporting bias. Due to the nature of the intervention, households could not be blinded to their group assignment. Non-blinding has been a well-documented source of bias for overestimating effects in WASH evaluations.[3] We attempted to reduce this bias by using objective measures of effects, such as defining our primary outcome as the presence of *E.coli* in point-of-use drinking water and collecting additional measures on observed coverage and use of the filter. Although all household visits were unannounced, there is still a chance that observed household behaviors are influenced by the presence of research teams.[4] Related, our water quality outcome may be prone to measurement error in estimating exposure to fecal-contaminated drinking water outside the household.[5] The measurement of *E.coli* concentrations in drinking water is an imperfect proxy for estimating the burden of enteropathogens.[6] The study design could have been improved by collecting more objective exposure or health outcomes, such as quantitative assays using serology[7,8] or stool samples[9,10] to measure immune responses to common enteropathogens transmitted through drinking water.

Although the first aim used experimental methods, the second and third aims relied mostly on observational study designs. Our estimates on the long-term effects and the risk factors of household water insecurity were adjusted for household characteristics but could be subject to unobserved confounding. The second aim could have benefited from comparing water quality from the point-of-source and point-of-use to better characterize the microbiological performance of the filter over time. The longitudinal design is a strength of both research aims but is restricted to four measurements over 30-months. We could have strived to measure continuous data on the compliance to intervention in the study period. For example, the installation of electronic sensors on similar filters and WASH hardware have been used to provide time-series data on household use and functionality of interventions and additionally reduce the reliance on self-reported indicators on use.[11,12] Although a process evaluation of the intervention was conducted in the first year of the program,[13] documentation of CHC attendance, implementor activities, all-related program costs and inputs would have improved our understanding of the intervention delivery through the entire study period. Collection of qualitative data, such as key informant interviews and focus groups with government stakeholders, program implementors, community leaders, and households would have also been valuable to identify facilitators and barriers of effective implementation.

Finally, the evaluation of the intervention's effects on household water insecurity was largely exploratory and did not measure theory-driven process outcomes that show how the intervention reduced experiences of household water insecurity. We found evidence of high coverage, use, and acceptability of the intervention that indicate demand of the filter-storage intervention as well as positive effects on improving the microbial safety of water, and thus the availability of potable drinking water. Our dataset does include measurements of primary water sources and secondary water sources, so in the future we could be able to assess if the filter had an effect on the choice of water sources by comparing water sources between study groups. We could also disaggregate the HWISE scale, and assess which specific questions were influenced the most by the intervention. However, the authors of the tool caution against extrapolating on individual questions as the scale was designed and validated to holistically measure water insecurity.[14] Additional information on the role of filter's safe storage container would also improve our understanding the effects on water insecurity.

5.2 Implications

We summarize five key implications of this work:

1. **The integration of fully-subsidized advanced household water filters is one evidence-based option for improving the implementation of CHC models and a nationally-scaled environmental health program that previous research showed to be ineffective in improving child health.**

CHCs in the WASH sector were originally intended to be a low-cost innovation for generating demand for improved hygiene behaviors in both urban and rural communities in LMICs.[15] Their focus on health knowledge, social norms, collective action, social cohesion, and consensus-building leverages tenants from several established behavior-change theories including the health belief model, the theory of reasoned action and planned behavior, and social learning theory.[15,16] Evaluations have at least found that CHCs do increase WASH and health knowledge and the uptake of hygienic behaviors, such as handwashing, water treatment, latrine construction, and limiting open defecation.[15,17] However, there is limited evidence demonstrating their effectiveness on health outcomes. We are aware of only one rigorous evaluation of a CHC model, which also found improvements in self-reported hygienic behaviors, but null effects on fecal-contaminated drinking water, diarrhea, and undernutrition.[18] The evaluation was similarly in the context of the CBEHPP in Rwanda and was a key motivation for conducting the study presented in the first aim. Nevertheless, the findings are consistent with other common community demand-based interventions in the WASH sector that have shown limited effects on improving health.[19-21] Our research suggests that the integration of acceptable and fully-subsidized HWTS hardware can improve access to safe drinking water and health likely by helping households to act on knowledge acquired through CHCs and likely other demand-based interventions.[22]

2. **The use of CHC models is an effective and replicable implementation strategy for increasing the uptake of HWTS innovations.**

The uptake of HWTS technologies is known to reduce diarrheal disease burden in LMICs.[23-25] However, there are few real-world examples of where HWTS practices have been successfully scaled in areas with poor access to safe water sources.[26] A key barrier to this delivery is a dearth of replicable and sustainable service models capable of reaching vulnerable populations.[27] For example, the *Tubeho Neza* campaign in Western Province, Rwanda delivered over 100,000 filters to vulnerable populations and effectively improved child health, but the campaign's intensive design has not been able to scale to other parts of the country.[28] CHCs, however, operate throughout Rwanda and serve as long-standing village institutions that efficiently organize community members and promote behavior-change. CHC models have also been implemented in at least 14 LMICs in parts of Asia, Africa, and the Caribbean.[15] Although the generalizability of our findings are limited to the Rwandan context and to the HWTS technology, the intervention (i.e., filters with safe storage delivered and promoted through CHCs) could likely be replicated to other similar settings.

3. **The effects of an HWTS intervention can be sustained for over 30 months.**

The sustainability of low-cost WASH interventions, beyond HWTS innovations, is a concern among policymakers.[29] These concerns are supported by a paucity of studies that monitor the uptake and effects of HWTS innovations past 6-12 months.[30] Our study provides evidence that these particular household water filters (*LifeStraw*® Family water filters 2.0) in the context of CHCs in Rwanda can at least provide safe drinking water for over 2.5 years. We note that in our study context, program support was minimal in the last year of the study duration, suggesting that effects are not highly sensitive to declining implementor involvement as other studies on HWTS have suggested.[31] However, it is critical that we do not undermine the role of CHCs in the intervention. For example, other longer-term evaluations using campaigns to deliver filters have found sustainability outcomes noticeably lower compared to ours.[1,32,33] In our study context, membership in CHCs could have helped build collective efficacy[34] to use of the filter and sustain the effects through ongoing contact with the CHC facilitators.

4. **The provision of HWTS technologies meets multiple development objectives, including improving access to safe drinking water, reducing diarrheal disease burden, and reducing experiences of household water insecurity.**

HWTS interventions are effective in improving point-of-use drinking water quality and reducing diarrhea prevalence. Nevertheless, limited institutional support is a documented barrier of scaling HWTS technologies. Limited support could be due to hesitation of allocating scarce funds in the water sector to an intervention that is largely considered temporary and perhaps unsustainable.[35,36] Recent high-profile trials[37-40] in the water sector have prompted policy debates on the efficiency of low-cost, fragmented WASH products and the need for more transformative interventions able to meet population needs and improve health in LMICs.[41] However, our findings suggest that benefits could go beyond short-term improvements in drinking water quality and child health. HWTS interventions could also reduce overall experiences of household water insecurity and could have a role in building household resiliency to water-related burdens, as water service capacity continues to develop. HWTS should viewed as a complementary rather than a competing water intervention to high quality water services.

5. **Monitoring efforts on household water should recognize the limitations of cross-sectional measurements and consider collecting multiple indicators of water insecurity.**

Our research shows the variability of water access and water insecurity over time. Global and national monitoring that relies cross-sectional measurements of water indicators during low-stress seasons could underestimate outcomes. The dependence on singular water indicators on infrastructure, accessibility, and quality could miss important water-related risks to well-being. Although longitudinal monitoring could be impractical for many settings, monitoring efforts should consider the contribution of seasonality and strive to collect multiple indicators of water-stress and insecurity.

5.3 Future directions

This dissertation responded to several implementation challenges of improving access to safe drinking water using HWTS interventions and Rwandan-driven research priorities. We identified a potential institutional home for an effective HWTS product, studied the sustainability of the intervention, and discussed the various roles that HWTS can play in meeting sector objectives. While there were limitations to our methods and areas that could have been improved, we feel that the research largely met its objectives. Future research should focus on closing other knowledge gaps in implementation that would support the efficient delivery and scaling of HWTS in throughout Rwanda and similar contexts. We describe some of these gaps below.

Financing. Our research found that filters delivered-free-of-cost in the context of the CBEHPP is effective in improving access to safe water and child health. However, we are unable to comment on whether this intervention would have been effective without the use of subsidies. The filter's market price is estimated around 30 USD,[13] which is likely inaccessible for communities in these settings. Willingness-to-pay studies have a number of limitations, but could be used to inform an appropriate subsidy structure.[42] Donors, governments, and other large aid organizations could be able to integrate the costs into existing programs, knowing that the effects of the intervention can at least be sustained for 2-3 years. In the past, carbon-credit based financing has also been used as a financing strategy since the intervention should offset carbon-emissions from boiling.[28,32] However, carbon savings from boiling could be limited since the practice is not always widespread in some settings,[43] Our larger project is also exploring the use of results-based financing or pay-for-performance models,[44,45] which have shown promise in other development sectors in Rwanda, as options for alleviating some financial risk on donors/governments. However, identifying reliable performance indicators on use and effects and independent monitoring required by both carbon-credit and results-based financing can be challenging,[32]

Optimizing delivery and identifying other service models. Randomized-controlled trial (RCT) designs, by design, inhibit our understanding of the varied contextual details that contribute to intervention effectiveness.[46] RCTs are critical for establishing causal inference, but they can be improved by integrating pragmatic design elements (i.e., hybrid trial designs) that aid policy-decision making.[47] For example, the integration of rigorous process evaluations that can document implementation and validate the theory of change are helpful for identifying the barriers and facilitators of effective delivery. Other trials have used "head-to-head" designs, randomizing and comparing the effectiveness of competing implementation strategies/service models of the same intervention. Although we found positive effects of the intervention in improving drinking water quality, there is still room for improvement, especially given that we observed that a high proportion of drinking water samples were still found to be contaminated. Per-protocol analysis using process evaluation data could improve our understanding of the gaps and improve upon the intervention. This may also be helpful in identifying appropriate process and performance outcomes for program monitoring. Future research could test the filter product using other implementation strategies or contexts such as within early childhood development and nutrition programs.

Testing other HWTS hardware in the CBEHPP/CHC service models. Previous research suggested that the CBEHPP was ineffective in improving health and that a key gap in its delivery is perhaps the integration of WASH hardware.[48] Our findings identified one evidence-based option for improvement, but are limited in providing recommendations on the use of other HWTS products in CHC models. We recommend evaluating other types of HWTS and WASH hardware and comparing cost-effectiveness for the CBEHPP's improvements.

5.4 References

1 Kirby, M. A. *et al.* Effects of a large-scale distribution of water filters and natural draft rocket-style cookstoves on diarrhea and acute respiratory infection: A cluster-randomized controlled trial in Western Province, Rwanda. *PLoS medicine* **16**, e1002812 (2019).

2 Ministry of Health. (Kigali, Rwanda, 2010).

3 Wolf, J. *et al.* Impact of drinking water, sanitation and handwashing with soap on childhood diarrhoeal disease: updated meta-analysis and meta-regression. *Tropical medicine & international health* **23**, 508-525 (2018).

4 Arnold, B. F. *et al.* Reactivity in rapidly collected hygiene and toilet spot check measurements: a cautionary note for longitudinal studies. *The American journal of tropical medicine and hygiene* **92**, 159 (2015).

5 Goddard, F. G., Chang, H. H., Clasen, T. F. & Sarnat, J. A. Exposure measurement error and the characterization of child exposure to fecal contamination in drinking water. *npj Clean Water* **3**, 1-9 (2020).

6 Wu, J., Long, S., Das, D. & Dorner, S. Are microbial indicators and pathogens correlated? A statistical analysis of 40 years of research. *Journal of water and health* **9**, 265-278 (2011).

7 Zambrano, L. D. *et al.* Use of serologic responses against enteropathogens to assess the impact of a point-of-use water filter: a randomized controlled trial in Western Province, Rwanda. *The American journal of tropical medicine and hygiene* **97**, 876-887 (2017).

8 Bhuiyan, M. S. *et al.* Assessment of disease specific immune responses in enteric diseases using dried blood spot (DBS). *PloS one* **14**, e0218353 (2019).

9 Platts-Mills, J. A. *et al.* Pathogen-specific burdens of community diarrhoea in developing countries: a multisite birth cohort study (MAL-ED). *The Lancet Global Health* **3**, e564-e575 (2015).

10 Liu, J. *et al.* Use of quantitative molecular diagnostic methods to identify causes of diarrhoea in children: a reanalysis of the GEMS case-control study. *The Lancet* **388**, 1291-1301 (2016).

11 Thomas, E. A., Barstow, C. K., Rosa, G., Majorin, F. & Clasen, T. Use of remotely reporting electronic sensors for assessing use of water filters and cookstoves in Rwanda. *Environmental science & technology* **47**, 13602-13610 (2013).

12 Meyer, D. D. *et al.* Embedding Usage Sensors in Point-of-Use Water Treatment Devices: Sensor Design and Application in Limpopo, South Africa. *Environmental Science & Technology* **55**, 8955-8964 (2021).

13 Bradshaw, A., Mugabo, L., Gebremariam, A., Thomas, E. & MacDonald, L. Integration of Household Water Filters with Community-Based Sanitation and Hygiene Promotion—A Process Evaluation and Assessment of Use among Households in Rwanda. *Sustainability* **13**, 1615 (2021).

14 Young, S. L. *et al.* The Household Water InSecurity Experiences (HWISE) Scale: development and validation of a household water insecurity measure for low-income and middle-income countries. *BMJ Global Health* **4**, e001750 (2019).

15 Rosenfeld, J., Berggren, R. & Frerichs, L. A review of the community health club literature describing water, sanitation, and hygiene outcomes. *International Journal of Environmental Research and Public Health* **18**, 1880 (2021).

16 Waterkeyn, J. & Cairncross, S. Creating demand for sanitation and hygiene through Community Health Clubs: A cost-effective intervention in two districts in Zimbabwe. *Social science & medicine* **61**, 1958-1970 (2005).

17 Ntakarutimana, A. & Ekane, N. Performance of community health clubs in transforming sanitation and hygiene conditions. (2017).

18 Sinharoy, S. S. *et al.* Effect of community health clubs on child diarrhoea in western Rwanda: cluster-randomised controlled trial. *Lancet Glob Health* **5**, e699-e709, doi:10.1016/S2214-109X(17)30217-6 (2017).

19 Freeman, M. C. *et al.* The impact of a demand-side sanitation and hygiene promotion intervention on sustained behavior change and health in Amhara, Ethiopia: a cluster-randomized trial. *PLOS Global Public Health* **2**, e0000056 (2022).

20 Patil, S. R. *et al.* The effect of India's total sanitation campaign on defecation behaviors and child health in rural Madhya Pradesh: a cluster randomized controlled trial. *PLoS Med* **11**, e1001709, doi:10.1371/journal.pmed.1001709 (2014).

21 Whittington, D., Radin, M. & Jeuland, M. Evidence-based policy analysis? The strange case of the randomized controlled trials of community-led total sanitation. *Oxford Review of Economic Policy* **36**, 191-221, doi:10.1093/oxrep/grz029 (2020).

22 Pattanayak, S. K. *et al.* Shame or subsidy revisited: social mobilization for sanitation in Orissa, India. *Bull World Health Organ* **87**, 580-587, doi:10.2471/blt.08.057422 (2009).

23 Clasen, T., Schmidt, W. P., Rabie, T., Roberts, I. & Cairncross, S. Interventions to improve water quality for preventing diarrhoea: systematic review and meta-analysis. *BMJ* **334**, 782, doi:10.1136/bmj.39118.489931.BE (2007).

24 Clasen, T. *et al.* Interventions to improve water quality for preventing diarrhoea. *Cochrane Database Syst Rev*, CD004794, doi:10.1002/14651858.CD004794.pub3 (2015).

25 Wolf, J. *et al.* Impact of drinking water, sanitation and handwashing with soap on childhood diarrhoeal disease: updated meta-analysis and meta-regression. *Trop Med Int Health* **23**, 508-525, doi:10.1111/tmi.13051 (2018).

26 Rosa, G. & Clasen, T. Estimating the scope of household water treatment in low-and medium-income countries. *The American journal of tropical medicine and hygiene* **82**, 289-300 (2010).

27 Haque, S. S. & Freeman, M. C. The Applications of Implementation Science in Water, Sanitation, and Hygiene (WASH) Research and Practice. *Environmental Health Perspectives* **129**, 065002 (2021).

28 Barstow, C., Clasen, T., Kirby, M. & Thomas, E. Health, livelihood, and environmental impacts of the distribution of a carbon-credit-financed, large-scale water filter and improved cookstove programme in Rwanda. *The Lancet Planetary Health* **2**, S31-S32 (2018).

29 Ray, I. & Smith, K. R. Towards safe drinking water and clean cooking for all. *The Lancet Global Health* **9**, e361-e365 (2021).

30 Clasen, T. F. *et al.* Interventions to improve water quality for preventing diarrhoea. *Cochrane database of systematic reviews* (2015).

31 Pickering, A. J. *et al.* The WASH benefits and SHINE trials: interpretation of WASH intervention effects on linear growth and diarrhoea. *The Lancet Global Health* **7**, e1139-e1146 (2019).

32 Pickering, A. J., Arnold, B. F., Dentz, H. N., Colford Jr, J. M. & Null, C. Climate and health co-benefits in low-income countries: a case study of carbon financed water filters in Kenya and a call for independent monitoring. *Environmental health perspectives* **125**, 278-283 (2017).

33 Brown, J., Proum, S. & Sobsey, M. Sustained use of a household-scale water filtration device in rural Cambodia. *Journal of water and health* **7**, 404-412 (2009).

34 Delea, M. G. *et al.* Collective efficacy: development and validation of a measurement scale for use in public health and development programmes. *International journal of environmental research and public health* **15**, 2139 (2018).

35 Schmidt, W.-P. & Cairncross, S. Household water treatment in poor populations: is there enough evidence for scaling up now? *Environmental science & technology* **43**, 986-992 (2009).

36 Ojomo, E., Elliott, M., Goodyear, L., Forson, M. & Bartram, J. Sustainability and scale-up of household water treatment and safe storage practices: Enablers and barriers to effective implementation. *International Journal of Hygiene and Environmental Health* **218**, 704-713, doi:https://doi.org/10.1016/j.ijheh.2015.03.002 (2015).

37 Luby, S. P. *et al.* Effects of water quality, sanitation, handwashing, and nutritional interventions on diarrhoea and child growth in rural Bangladesh: a cluster randomised controlled trial. *Lancet Glob Health* **6**, e302-e315, doi:10.1016/S2214-109X(17)30490-4 (2018).

38 Null, C. *et al.* Effects of water quality, sanitation, handwashing, and nutritional interventions on diarrhoea and child growth in rural Kenya: a cluster-randomised controlled trial. *The Lancet Global Health* **6**, e316-e329 (2018).

39 Humphrey, J. H. *et al.* Independent and combined effects of improved water, sanitation, and hygiene, and improved complementary feeding, on child stunting and anaemia in rural Zimbabwe: a cluster-randomised trial. *Lancet Glob Health* **7**, e132-e147, doi:10.1016/S2214-109X(18)30374-7 (2019).

40 Knee, J. *et al.* Effects of an urban sanitation intervention on childhood enteric infection and diarrhea in Maputo, Mozambique: a controlled before-and-after trial. *Elife* **10**, e62278 (2021).

41 Pickering, A. J. *et al.* The WASH Benefits and SHINE trials: interpretation of WASH intervention effects on linear growth and diarrhoea. *Lancet Glob Health* **7**, e1139-e1146, doi:10.1016/S2214-109X(19)30268-2 (2019).

42 Blum, A. G., Null, C. & Hoffmann, V. Marketing household water treatment: willingness to pay results from an experiment in rural Kenya. *Water* **6**, 1873-1886 (2014).

43 Geremew, A. & Damtew, Y. T. Household water treatment using adequate methods in sub-Saharan countries: evidence from 2013–2016 demographic and health surveys. *Journal of Water, Sanitation and Hygiene for Development* **10**, 66-75 (2020).

44 Anderson, D. M., Thomas, E. A. & Clasen, T. F. Quantifying Averted Disability-Adjusted Life Years as a Performance Indicator for Water Quality Interventions: A Review of Current Methodologies and Challenges. *Water* **10**, 744 (2018).

45 Thomas, E. A. *Broken pumps and promises: incentivizing impact in environmental health*. (Springer, 2016).

46 Berwick, D. M. The science of improvement. *JAMA* **299**, 1182-1184, doi:10.1001/jama.299.10.1182 (2008).

47 Brown, C. H. *et al.* An Overview of Research and Evaluation Designs for Dissemination and Implementation. *Annu Rev Public Health* **38**, 1-22, doi:10.1146/annurev-publhealth-031816-044215 (2017).

48 Sinharoy, S. S. *et al.* Effect of community health clubs on child diarrhoea in western Rwanda: cluster-randomised controlled trial. *The Lancet Global Health* **5**, e699-e709 (2017).

Appendix: Household Questionnaire

A10 Demographics

Sector ID	
Village ID Number and Village name (example: XX - Villagename)	______________________________
Household ID	______________________________
Today's Date and Current Time:	______________________________
Survey completed by: (Ibuka:Amazina y'ukusanya amakuru/ hint: enumerator	
Specify other	______________________________
Ni inde uteka kenshi muri uru rugo? (ibuka: Amazina yose, direct questions to only primary cook if possible)	______________________________
Who is the primary cook in this household? (hint: full name, direct questions to only primary cook if possible)	

Primary cook age (hint: check ID card if respondent doesn't know)	______________________
Ni iyihe sano mufitanye n'umukuru w'urugo? (hint: RELATIONSHIP OF RESPONDENT TO HEAD OF HOUSEHOLD) How is the primary cook related to the household head? (hint: RELATIONSHIP OF RESPONDENT TO HEAD OF HOUSEHOLD)	◯ Household head ◯ Wife ◯ Mother ◯ Daughter ◯ Son ◯ Grandchild ◯ Grandmother ◯ Mother-in-law ◯ Other, specify
Specify Other	______________________
Nshobora kuvungano [a10_cookname]? (Ibuka: Baza niba utamaze kuvugana n'umutetsi w'ibanze. Erekanisha 'yego' niba uri kuvugana n'umutetsi w'ibanze) Can I speak to [a10_cookname]? (hint: ask if not already talking to primary cook. Indicate 'yes' if you are already speaking to primary cook.)	◯ Yes ◯ No
Ni wowe uteka kenshi muri uru rugo? (Ibuka: Baza niba utamaze kuvugana n'umutetsi w'ibanze. Erekanisha 'yego' niba uri kuvugana n'umutetsi w'ibanze) Are you the primary cook of the household? (hint: ask if not already talking to primary cook. Indicate 'yes' if you are already speaking to primary cook.)	◯ Yes ◯ No
Navugana nundi muntu muri uru rugo ufite imyaka 18 cyangwa ayirengeje? Can I speak to someone else in the household that is aged 18 years or older?	◯ Yes ◯ No
Ni ayahe mazina yawe yose? What is your full name?	______________________
Ufite imyaka ingahe? What is your age?	______________________
How is [a10_respothername] related to the household head? (hint: RELATIONSHIP OF RESPONDENT TO HEAD OF HOUSEHOLD)	◯ Household head ◯ Wife ◯ Mother ◯ Daughter ◯ Son ◯ Grandchild ◯ Grandmother ◯ Mother-in-law ◯ Other, specify

SOMA CYANE: Turabashimiye gusubiza ibi bibazo. Ariko dusanze utujuje ibisabwa byose by ubushakashatsi tukaba turekeyeho kubaza ibibazo by ikusanya amakuru. Turabashimiye igihe mumaze muganira natwe. (ibuka:Nta gisubizo gikenewe)

SAY: Thank you for answering these questions. Unfortunately, you are not eligible to participate in the study and we will not proceed with the survey. We thank you for your time. (hint: no response needed)

Survey time end

____

Ubu ufite filitiri ikora (Lifestraw filter)?

Do you currently have a working LifeStraw filter?

- ◯ Yes
- ◯ No
- ◯ Don't know

Haba hari ikiganiro wowe cyangwa undi muntu wo muri uru rugo yitabiriye cyateguwe na kelebe y'ubuzima (cg isuku) muri uyu mudugudu? (hint: Kelebe y'isuku ni itsinda ry'abaturage rihura buri gihe, rigizwe n'abagabo n'abagore bihuje ku bushake bafite intego yo guteza imbere ubuzima n'isuku by'abaturage biciye mu guhuza ibitekerezo no gushyira mu bikorwa imyitwarire myiza y'isuku mu ngo zabo).

Have you or any other household member attended any session organized by the community health club IN THIS VILLAGE? (hint: A CHC is a community based organization that meets regulary, made up of voluntary men and women dedicated to improving the health and welfare of the community through common understanding and the practice of safe hygiene in the home)

- ◯ Yes
- ◯ No

Ni ikihe kiciro cy'ubudehe umuryango wawe ubarizwamo?

To which Ubudehe category does your household belong?

- ◯ Ubudehe I (poorest)
- ◯ Ubudehe II
- ◯ Ubudehe III
- ◯ Ubudehe IV
- ◯ Don't know

Ni abana bangahe bari munsi yimyaka 5 baba muri uru rugo, igihe kinini mu mwaka? (Ibuka: Ntushyiremo abantu baba bari mu rugo mu biruhuko gusa. - VERIFY AGE OF CHILDREN BY LOOKING AT ID OR VACCINE CARD)

How many young children under 5 years of age live in this household the majority of the year? (hint: Do not include people who are only home during holidays)

____

Haba hari umuntu utwite muri uru rugo?

Is anyone in the household currently pregnant?

- ◯ Yes
- ◯ No
- ◯ Don't know

SOMA CYANE: Turabashimiye gusubiza ibi bibazo. Dusanze wujuje ibisabwa byose by ubushakashatsi! Ubu ngiye gukomeza ikusanya amakuru. (ibuka:Nta gisubizo gikenewe)

SAY: Thank you for answering these questions. You are eligible to participate in the study! I will now begin the rest of the survey. (hint: no response needed)

SOMA CYANE: Turabashimiye gusubiza ibi bibazo. Ariko dusanze utujuje ibisabwa byose by ubushakashatsi tukaba turekeyeho kubaza ibibazo by ikusanya amakuru. Turabashimiye igihe mumaze muganira natwe. (ibuka:Nta gisubizo gikenewe)

SAY: Thank you for answering these questions. Unfortunately, you are not eligible to participate in the study and we will not proceed with the survey. We thank you for your time. (hint: no response needed)

Survey time end	________________________
Did participant give consent?	◯ Yes ◯ No
Survey time end	________________________
OBSERVE: GENDER OF RESPONDENT	◯ Female ◯ Male ◯ Don't know ([hint: OBSERVE])
Waba warigeze ugera mu ishuri? (hint: INCLUDES PRESCHOOL AND VOCATIONAL SCHOOL) Have you ever attended school?	◯ Yes ◯ No
Ni ikihe kiciro cyo hejuru cy' amashuli warangije? (hint: check multiple responses if attended vocational) What is the highest level of schooling you have had? (hint: check multiple responses if attended vocational)	☐ Ikiburamwaka /Preschool ☐ Sinarangije amashuli abanza/Primary school incomplete ☐ Narangije amashuli abanza/ Primary school complete ☐ Sinarangije amashuli yisumbuye/ Secondary school incomplete (e.g. high school) ☐ Narangije amashuli yisumbuye / Secondary school complete (e.g. high school ☐ Imyuga/ Vocational ☐ Amashuri makuru/ kaminuza / Some college or university ☐ Don't know
Inzu mutuyemo ni (hint: read options) The house where you live is (hint: read options)	◯ Iyanyu / Owned ◯ Inkodeshanyo / Rented or Leased ◯ Intizanyo/ Borrowed ◯ Other (specify) ◯ Don't know
Specity other	________________________
Wibariyemo, ni abantu bangahe barara muri iyi nzu mucyumweru gisanzwe? (hint: Ntushyiremo abantu baba bari mu rugo mu biruhuko gusa.) In total including you, how many people sleep in this house on a typically weeknight? (hint: Do not include people who are only home during holidays)	________________________

Houshold Census (DO NOT relist primary cook, but DO relist non-primary cook respondent - start with youngest after the household head)

Ni irihe zina ry'umuntu wambere? Amazina y'umukuru w'umuryango (full name) What is the name of the first person? Start with the head of household (full name)	________________________
Uyu [a10_hheadname] igitsina ni ikihe? What is the gender of [a10_hheadname]?	◯ Male ◯ Female ◯ Other
[a10_hheadname] afite imyaka ingahe? (round down to nearest integer) How old is [a10_hheadname]? (round down to nearest integer)	________________________
Ni irihe zina ry'umuntu wambere? (hint: full name, start with youngest in household) What is the name of the first person? (hint: full name, start with youngest in household)	________________________
What is the gender of [a10_member1]?	◯ Male ◯ Female ◯ Other
How old is [a10_member1]? (hint: round down to nearest integer)	________________________
What is [a10_member1]'s date of birth? NOTE SURVEY CENSUS FOR EACH HH MEMBER	________________________
Umukuru w'umuryango yaba yarigeze agera mu ishuri? / Has [a10_hheadname] ever attended school? (hint: INCLUDES PRESCHOOL AND VOCATIONAL SCOOL)	Yes No Don't know

Ni ikihe cyiciro umukuru wumuryango yagarukiyemo yiga? (hint: check multiple responses if attended vocational) / What was the highest level of schooling [a10_hheadname] has had? (hint: check multiple responses if attended vocational)	☐ Ikiburamwaka /Preschool ☐ Sinarangije amashuli abanza/Primary school incomplete ☐ Narangije amashuli abanza/ Primary school complete ☐ Sinarangije amashuli yisumbuye/ Secondary school incomplete (e.g. high school) ☐ Narangije amashuli yisumbuye / Secondary school complete (e.g. high school ☐ Imyuga/ Vocational ☐ Amashuri makuru/ kaminuza / Some college or university ☐ Don't know
Urugo rwawe rwaba rufite amashanyarazi? / Does your household have electricity? (hint: includes solar energy)	◯ Yes ◯ No
Ubu ngubu, ni ubuhe bwoko bwibicanwa mukoresha bwibanze mu guteka? / Currently, what type of fuel do you use primarily for cooking?	◯ Inkwi / Wood ◯ Udushami duto tw'ibiti, inyayu, ibyatsi / Straw/shrubs/grass ◯ Bisigazwa by ibihingwa / Agricultural crop ◯ Amakara / Charcoal ◯ Gazi yo mu icupa, gazi ku muyoboro rusange, biyogazi / LPG/Natural Gas/Biogas ◯ Amashanyarzi / Electricity ◯ Peterori / Kerosene ◯ Other, specify ◯ Don't know
Specify fuel other	________________________
Ni ubuhe bwoko bw'ibanze bw'amashyiga mukoresha? What is the main type of stove that you use for cooking?	◯ Ku mabuye 3 / 3-stone ◯ Irondereza / Rondereza ◯ Imbabura / Imbabura ◯ Ishyiga rya gaze/Biyogaze/ Icupa / Gasifier stove/Biogas stove ◯ LPG ◯ Ecozoom ◯ Ubundi bwoko bw'ishyiga / Other ◯ SIMBIZI / DON'T KNOW
Ni ubuhe bwoko bwa kabiri bw'amashyiga mukoresha? What is the second most common stove that you use for cooking?	◯ Ku mabuye 3 / 3-stone ◯ Irondereza / Rondereza ◯ Imbabura / Imbabura ◯ Ishyiga rya gaze/Biyogaze/ Icupa / Gasifier stove/Biogas stove ◯ LPG ◯ Ecozoom ◯ No secondary stove ◯ Ubundi bwoko bw'ishyiga / Other ◯ SIMBIZI / DON'T KNOW

Assets	
Ese mu rugo iwawe mwaba mufite televiziyo?/Does your household have a color television? (hint: observe if possible)	◯ Yes ◯ No
Ese mu rugo iwawe mwaba mufite televiziyo y'umugozi cyangwa igisahane?/Does your household have cable/dish TV? (hint: observe if possible)	◯ Yes ◯ No
Ese mu rugo iwawe mwaba mufite iradiyo?/Does your household have a radio? (hint: observe if possible)	◯ Yes ◯ No
Ese mu rugo iwawe mwaba mufite mudasobwa?/Does your household have a computer? (hint: observe if possible)	◯ Yes ◯ No
Ese mu rugo iwawe mwaba mufite umuyoboro w'itumanaho rya murandasi?/Does your household have an internet connection? (hint: includes internet from smartphone)	◯ Yes ◯ No
Ese hari umuntu uwo ari we wese mu rugo iwawe waba ufite telephone igendanwa?/Does any member of your household have a mobile phone? (hint: observe if possible)	◯ Yes ◯ No
Ese urugo rwanyu rufite akabati k'ibitabo?/Does your household have a bookshelf? (hint: observe if possible)	◯ Yes ◯ No
Ese urugo rwanyu rufite amadirishya afite amarido?/ Does your household have windows with cloth curtains or blinds? (hint: observe if possible)	◯ Yes ◯ No
Ese urugo rwanyu rufite intebe z'imisego?/Does your household have a sofa? (hint: observe if possible)	◯ Yes ◯ No
Ese urugo rwanyu rufite ameza yo kuriraho? (hint: observe if possible - do not include small "coffee tables") /Does your household have a dining room table? (hint: observe if possible - do not include small "coffee tables")	◯ Yes ◯ No
Ese urugo rwanyu rufite matora?/Does your household have a mattress?	◯ Yes ◯ No

Ese urugo rwanyu rufite icyuma gishyushya ibyo kurya gikoresheje amashanyarazi?/Does your household have a microwave? (hint: observe if possible)	◯ Yes ◯ No
Ese urugo rwanyu rufite icyuma gikonjesha (Firigo)?/Does your household have a refrigerator? (hint: observe if possible)	◯ Yes ◯ No
Ese hari umuntu uwo ari wese mu rugo iwawe ufite konti muri banki? (hint: do not include SACCO)/Does any member of your household have a bank account? (hint: do not include SACCO)	◯ Yes ◯ No
Ese urugo rwanyu rufite igare?/ Does your house have a bicycle? (hint: observe if possible)	◯ Yes ◯ No
Ese urugo rwanyu rufite moto/akamoto gato?/Does your household have a motorcycle/scooter (hint: observe if possible)	◯ Yes ◯ No
Ese hari umuntu uwo ari wese mu rugo iwawe ufite imodoka?/Does any member of your household have a car or truck? (hint: observe if possible)	◯ Yes ◯ No
Urugo rwanyu rwaba rufite ubutaka/ikibanza? / Does your household own land/plot?	◯ Yes ◯ No
Urugo rwawe rwaba rufite imirima yoguhingamo yanyu? / Does your household own agricultural land?	◯ Yes ◯ No
Urugo rwawe rwaba rufite amatungo? (hint: include domestic and owned)/ Does your household own animals? (hint: include domestic and owned)	◯ Yes ◯ No
Ese urugo rwanyu rufite inkoko zingahe?/How many chickens does your household have?	______________________
Ese urugo rwanyu rufite imbata/dendo zingahe?/How many ducks/turkeys does your household have?	______________________
Ese urugo rwanyu rufite ihene zingahe?/How many goats does your household have?	______________________
Ese urugo rwanyu rufite intama zingahe?/How many sheep does your household have?	______________________

Ese urugo rwanyu rufite ingurube zingahe?/How many pigs does your household have?	______________________
Ese urugo rwanyu rufite inka zingahe?/How many cows does your household have?	______________________
Ese urugo rwanyu rufite imbwa zingahe?/How many dogs does your household have?	______________________
Specify number of other small animals	______________________
Specify number of other large animals	______________________
REBA: Hasi mu nzu y'ibanze hubakishijwe iki? (hint: Kwibutsa: Hitamo kugeza ku mahitamo 4) OBSERVE: What is the floor made of in the main house? (hint: select up to 4 options.)	☐ Ibyatsi/Thatch ☐ Ibisika/Woven reed ☐ Imbariro zisobetse/Wattle (woven sticks) ☐ Icyondo/ibumba, ibitaka, amase/ Mud/clay/dirt/dung ☐ Amatafari ya rukarakara/ Mud bricks ☐ Kidatwitse/Earthen/Unfired Tile ☐ Amabuye/ Stone ☐ Amatafari ahiye/Fired bricks ☐ Amabati/ Corrugated metal ☐ Amabati abonerana/Corrugated Fiberglass ☐ Isima/ Concrete/cement ☐ Ibiti/Wood ☐ Imbaho zisashe hasi/Vinyl/laminate ☐ Amakaro/Ceramic/Fired Tile ☐ Other (specify)
Specify other floor material	______________________
Inzu yanyu ifite ibyumba bingahe? (hint: include kitchen and storage rooms) How many rooms are there in your household? (hint: include kitchen and storage rooms)	______________________
Ni ibyumba bingahe mu rugo rwawe bikoreshwa mu kuryama igihe kinini mu mwaka? How many rooms in your household are used for sleeping the majority of the year?	______________________
GENERAL INFORMATION AND HOUSEHOLD CHARACTERISTICS COMMENTS	____________________________

B20 Sanitation

Ni ubuhe bwoko bw'umusarani abantu bo mu rugo rwawe bakunze gukoresha? Ushobora kunyereka? What kind of toilet facility do members of your household usually use? Can you show me?	◯ Flush/pour flush to piped sewer system ◯ Flush/pour flush to septic tank ◯ Flush/pour flush to pit latrine ◯ Flush/pour flush to open drain ◯ Flush/pour flush to DON'T KNOW where ◯ Ventilated Improved Pit (VIP) latrine ◯ Pit latrine with slab ◯ Pit latrine without slab/open pit ◯ Composting toilet ◯ Twin pit with slab ◯ Twin pit without slab ◯ Bucket ◯ Hanging toilet / Hanging latrine ◯ No facility / Bush / Field ◯ Other (specify) ◯ CANNOT OBSERVE (Slab bivuga hasi hakozwe (sima, ubutaka n' icyondo,etc) ku buryo udashobora kureba mo hasi kereka urebeye mu mwobo HINT: SLAB MEANS FLOOR (CEMENT, WOOD WITH MUD, ETC) SO THAT YOU CANNOT SEE INTO PIT EXCEPT THROUGH HOLE.)
Niba waba wageze k' umusarani, uherereye he? If you have access to a toilet facility, where is it located?	◯ Mu nzu/In own dwelling ◯ Hanze /In own yard/plot ◯ Ahandi/Elsewhere
Ni ubuhe bwoko bw'umusarani abantu bo mu rugo rwawe bakunze gukoresha? Mwambwira uko umeze? (hint: Slab bivuga hasi hakozwe (sima, ubutaka n' icyondo,etc) ku buryo udashobora kureba mo hasi kereka urebeye mu mwobo) What kind of toilet facility do members of your household usually use? Can you describe it? HINT: SLAB MEANS FLOOR (CEMENT, WOOD WITH MUD, ETC) SO THAT YOU CANNOT SEE INTO PIT EXCEPT THROUGH HOLE.	◯ Flush/pour flush to piped sewer system ◯ Flush/pour flush to septic tank ◯ Flush/pour flush to pit latrine ◯ Flush/pour flush to open drain ◯ Flush/pour flush to DON'T KNOW where ◯ Ventilated Improved Pit (VIP) latrine ◯ Pit latrine with slab ◯ Pit latrine without slab/open pit ◯ Composting toilet ◯ Twin pit with slab ◯ Twin pit without slab ◯ Bucket ◯ Hanging toilet / Hanging latrine ◯ No facility / Bush / Field ◯ Other (specify) (Slab bivuga hasi hakozwe (sima, ubutaka n' icyondo,etc) ku buryo udashobora kureba mo hasi kereka urebeye mu mwobo HINT: SLAB MEANS FLOOR (CEMENT, WOOD WITH MUD, ETC) SO THAT YOU CANNOT SEE INTO PIT EXCEPT THROUGH HOLE.)

Mu byumweru bibiri bishize umusarani waba warigeze ugira ikibazo ntubashe gukoreshwa mu gihe cy'umunsi wose? In the past two weeks, was the this toilet facility ever unsuable for one day?	◯ Yes ◯ No ◯ Don't know
Waba ufatanya umusarane n'izindi ngo? / Do you share a toilet facility with other households?	◯ Yes ◯ No
SPECIFY NUMBER OF OTHER HOUSEHOLDS SHARES A TOILET WITH	____________________
Ubwo umwana wawe muto aherutse kwituma, wakoze iki ngo ukureho uwo mwanda? The last time youngest child passed stools, what was done to dispose of the stools?	◯ Umwana yakoresheje umusarani//Child used toilet/latrine ◯ Twawushyize/twawogereje mu musarani/ Put/rinsed into toilet or latrine ◯ Twawushyize /twawogereje mu muyoboro cyangwa umuringoti//Put/rinsed into drain or ditch ◯ Twawujugunye mu myanda/ Thrown into the garbage ◯ Narawutabye/Buried ◯ Twawurekeye hanze/ Left in the open ◯ Twawukoresheje nk'ifumbire/ Used as manure ◯ Ibindi (bivuge)/ Other (specify) ◯ Ntabwo mbizi/ Don't know ([hint: Only for child < 3 years of age living in household.])
SECTION COMMENTS	____________________

C30 Handwashing

Ushobora kunyereka aho abagize urugo bakunda gukarabira intoki bavuye mu musarani? Can you please show me where members of your household most often wash their hands after using the toilet?	◯ Nabirebye: kandagira ukarabe hanze/ Observed: tippy tap station observed in yard/plot ◯ Nabirebye: ahantu hubakiye(nka robine) hanze/ Observed: fixed facility (sink/tap) in yard/plot ◯ Nabirebye: ahantu hubakiye (nka robine) mu nzu/ Observed: fixed facility (sink/tap) in dwelling ◯ Nabirebye: igikoresho kigendanwa (indobo/ijagi)/ Observed: mobile object observed(bucket/jug/kettle) ◯ Sinabirebye: nta hantu ho gukarabira intoki hahari yaba mu nzu cyangwa hanze / Not Observed: no hand washing place in dwelling or yard/plot ◯ Sinabirebye: sinemerewe kureba / Not Observed: no permission to see
REBA: Niba hari amazi aho bakarabira intoki. (kwibutsa : genzura ureba ko amazi ahari muri robine, ibase, indobo, cyangwa ikindi gikoresho kibikwamo amazi) OBSERVE: Presence of water at the place for handwashing. (hint: verify by checking the tap/pump, or basin, bucket, water container or similar objects for presence of water)	◯ Amazi arahari/Water is available ◯ Nta mazi ahari/Water is not available ◯
REBA: Hari isabuni, umuti, ivu, cyangwa ikindi gikoreshwa mugusukura aho bakarabira intoki? OBSERVE: Is there any soap, detergent, ash or other cleansing agent for handwashing?	◯ Isabune y'agati cyangwa y'amazi / Bar or liquid soap ◯ Detergent (powder/liquid/paste) ◯ Ash ◯ Other, specify ◯ Oya, ntayihari No , not present
Niba hari undi, wuvuge./If other, specify.	____________________
Nihe wowe cyangwa abandi bagize urugo mukunda gukarabira intoki? Where do you or other members of your household most often wash your hands?	◯ Kandagira ukarabe hanze/ tippy tap station in yard/plot ◯ Ahantu hubakiye(nka robine) hanze/Fixed facility (sink/tap) in yard/plot ◯ Ahantu hubakiye (nka robine) mu nzu/ Fixed facility (sink/tap) in dwelling ◯ Igikoresho kigendanwa (indobo/ijagi)/Mobile object ◯ Nta hantu ho gukarabira intoki hahari yaba mu nzu cyangwa hanze / No hand washing place in dwelling or yard/plot
Ese mu nzu mwaba mufite isabune yo gukaraba mu intoki?/Do you have any soap or detergent in your house for washing hands?	◯ Yes ◯ No

Ese ushobora kuyinyereka? Can you please show it to me?	◯ Yes ◯ No
REBA: Hari amazi muri metero 5 cyangwa intambwe 10 uvuye aho isabune iri /Kwibutsa : genzura ureba ko amazi ahari muri robine, ibase, indobo, cyangwa ikindi gikoresho kibikwamo amazi. REBA: Hari amazi muri metero 5 cyangwa intambwe 10 uvuye aho isabune iri /Kwibutsa : genzura ureba ko amazi ahari muri robine, ibase, indobo, cyangwa ikindi gikoresho kibikwamo amazi. OBSERVE: presence of water within 5 meters/10 steps of soap or detergent. Hint: verify by checking the tap/pump, or basin, bucket, water container or similar objects for presence of water.	◯ Amazi arahari /Water is available ◯ Nta mazi ahari/ Water is not available
OBSERVE: Type of soap	☐ Isabune y'agati cyangwa y'amazi / Bar or liquid soap ☐ Detergent (powder/liquid/paste)
OBSERVE EVIDENCE OF CHICKENS IN COMPOUND (example: feces, animal pen, chickens in yard)	◯ Yes ◯ No
OBSERVE EVIDENCE OF COWS IN COMPOUND (example: feces, animal pen, cows in yard)	◯ Yes ◯ No
SECTION COMMENTS	____________________________

D40 Water

Ni iyihe soko y'ibanze abagize urugo bavomaho amazi yo kunywa? Ni hehe muvoma? Kwibutsa: Niba bitumvikana, komeza ubaze kugira ngo umenye aho abagize umuryango bakunda kuvoma amazi yo kunywa. What is the main source of DRINKING water for members of your household? Where do you fetch water? hint: if unclear, probe to identify the place from which members of this household most often collect drinking water (collection point).	Robine yo mu nzu / Piped water into dwelling Itiyo y'amazi ijya mu kibanza/mu ruzitiro / Piped water into yard/plot ◯ Robine yo ku muturanyi/Piped water to neighbour ◯ Robine rusange / Public tap/standpipe ◯ Kw' ipompo / Tube well / borehole ◯ Icyobo gicukuye cyubakiwe / Protected dug well /cover well ◯ Icyobo gicukuye kitubakiye/ Unprotected dug well ◯ Isoko yubakiye / Protected spring ◯ Isoko itubakiye / Unprotected spring ◯ Amazi y'imvura / Rainwater ◯ Siterine y'ikamyo/Imodoka ifite ikigunguru / Tanker truck ◯ Cart with drum ◯ Water kiosk ◯ Amazi aboneka hejuru y'ubutaka / Surface water, specify type (seasonal stream, river, pond, lake, etc) ◯ Amazi yo mu icupa rifunze / Packaged water: Bottled water ◯ Packaged water: Sachet water ◯ Other, specify
Niba hari undi, wuvuge./If other, specify.	______________________
Specify surface water type	◯ Seasonal stream ◯ River ◯ Pond/Lake ◯ Other, specify
Niba hari undi, wuvuge./If other, specify.	______________________
Ese iyo soko y'amazi iherereye he? Where is that water source located?	◯ Mu nzu yanjye/ In own dwelling ◯ Mu rugo rwanjye/ In own yard/plot ◯ Ahandi hantu /Elsewhere
Ukoresha igihe kingana iki kugenda,kubona amazi no kugaruka uva ku isoko y'aho ukura amazi yo kunywa? (hint: write in minutes WRITE 9999 IF DON'T KNOW.) / How long does it take for members of your household to go there, get water, and come back? (hint: write in minutes WRITE 9999 IF DON'T KNOW.)	______________________
Ubusanzwe, ni kangahe mu rugo muvoma amazi yo kunywa? / How often does your household usually fetch drinking water?	◯ Buri munsi/Daily, specify number of times ◯ Incuro 2-4 mu cyumweru/ 2-4 times per week ◯ Rimwe mu cyumweru/ Once per week ◯ Other, specify ◯

Specify number of times each day water fetched	______________________
Niba hari undi, wuvuge./If other, specify.	______________________
Mu gihe cy'ibyumweru bibiri bishize, amazi y'iyi soko yaba atarabonetse byibura mu gihe cy'umunsi umwe wuzuye? In the past two weeks, was the water from this source not available for at least one full day?	◯ Yes ◯ No ◯ Don't know
Wowe cyangwa undi muntu wo muri uru rugo mujya mugira icyo mukora ngo amazi yo kunywa abe meza? Do you or any other member of this household do anything to the water to make it safer to drink?	◯ Yes ◯ No ◯ Don't know
Niba ari yego, ni iki mukora burigihe ngo amazi yo kunywa abe meza? Ubusanzwe uyasukura ute? Hitamo ibijyanye byose/ hint: Hint: probe, "Anything else?" and check all that apply] If so, what do you usually do to make the water safer to drink?	☐ Guteka /Boiling ☐ Gushyiramo umuti wica udukoko (bleach)/ Add bleach / chlorine ☐ Kuyayunguruza umwenda /Strain it through a cloth ☐ Strain it through a tea strainer ☐ Gukoresha filitiri (ibumba, umucanga, ibindi.)/Use water filter (ceramic, sand, composite, etc.) ☐ Gukoresha imirasire y'izuba /Solar disinfection ☐ Kuyareka agacayuka /Let it stand and settle ☐ Ubundi, buvuge/Other, specify ☐ Simbizi /Don't know
Specify type of water filter	◯ LIFESTRAW Filter ◯ Other, specify
Niba hari undi, wuvuge./If other, specify.	______________________
Specify other usual treatment method	______________________
Umwana ashatse kunywa amazi nonaha wayakurahe? Wanyereka? Niba umwana wawe ataratangira kunywa amazi, wowe wayakurahe uyashatse? (hint: FOLLOW RESPONDENT) If a child under 5 wants a drink of water right now, where would you take it from? Can you show me? If your child is not yet drinking water, where would you take it from if you want a drink of water? (hint: FOLLOW RESPONDENT)	◯ Yes, child drinking water ◯ Yes, adult drinking water only ◯ No/refused ◯ No drinking water in home
OBSERVE: Does household store water in the home? (hint: Do not ask, just observe and note.)	◯ Yes ◯ No, Uses directly from piped tap ◯ No, obtains water from neighbor ◯ Don't know ◯

OBSERVE: What type of container do they use for storing THIS drinking water?	◯ Jerrycan (1L) ◯ Jerrycan (3ml) ◯ Jerrycan (5L) ◯ Jerrycan (10L) ◯ Jerrycan (20L) ◯ Bucket ◯ Kettle ◯ LIFESTRAW Filter ◯ Bottle ◯ Jug/Pitcher ◯ Other narrow-neck container ◯ Other wide-mouth container ◯ Other, specify
Niba hari undi, wuvuge./If other, specify.	________________________
REBA: Igikoresho bayabikamo kirapfundikiye? OBSERVE: Is the storage container covered?	◯ Yes ◯ No ◯ Don't know
ASK: iki gikoresho mujya mugikoresha muvoma amazi? / Is this container also used to fetch water?	◯ Yes ◯ No ◯ Don't know
Ni gute mutanga amazi yo kunywa? Wanyereka? How is the drinking water served? / Can you show me?	◯ Pour water into cup/glass ◯ Dip cup/container into the water ◯ Poured directly from Lifestraw filter ◯ Piped tap into cup/glass ◯ Drink directly from storage container ◯ Drink directly from filter ◯ Drink directly from piped tap ◯ Other, specify
Other serving method	________________________
Nafataho amazi yo gupima? / May I take a water sample? CONFIRM WATER SAMPLE TAKEN	◯ Yes ◯ No ([hint: LABEL BAG: "D" drinking from other container;; "D(LSF)" drinking from LSF])
Ni ubuhe bwoko bw'isoko mwavomyeho aya mazi? / What type of source was this water collected from?	◯ SAME AS MAIN SOURCE ◯ Different source (specify in next question)

Ni ubuhe bwoko bw'isoko mwavomyeho aya mazi? / What type of source was this water collected from?	◯ Robine yo mu nzu / Piped water into dwelling ◯ Itiyo y'amazi ijya mu kibanza/mu ruzitiro / Piped water into yard/plot ◯ Robine yo ku muturanyi/Piped water to neighbour ◯ Robine rusange / Public tap/standpipe ◯ Kw' ipompo / Tube well / borehole ◯ Icyobo gicukuye cyubakiwe / Protected dug well /cover well ◯ Icyobo gicukuye kitubakiye/ Unprotected dug well ◯ Isoko yubakiye / Protected spring ◯ Isoko itubakiye / Unprotected spring ◯ Amazi y'imvura / Rainwater ◯ Siterine y'ikamyo/Imodoka ifite ikigunguru / Tanker truck ◯ Cart with drum ◯ Water kiosk ◯ Amazi aboneka hejuru y'ubutaka / Surface water, specify type (seasonal stream, river, pond, lake, etc) ◯ Amazi yo mu icupa rifunze / Packaged water: Bottled water ◯ Packaged water: Sachet water ◯ Other, specify
Niba hari undi, wuvuge./If other, specify.	________________________
Specify surface water type	◯ Seasonal stream ◯ River ◯ Pond/Lake ◯ Other, specify ◯
Specify surface water type	________________________
Ukoresha igihe kingana iki kugenda,kubona amazi no kugaruka uva ku isoko y'aho ukura AMAZI YO KUNYWA? (hint: Write in minutes. WRITE 9999 IF DON'T KNOW) How long does it take to go there, get DRINKING water and come back from the water source you use? (hint: Write in minutes. WRITE 9999 IF DON'T KNOW)	________________________
Ubusanzwe mujya mwishyura kugira ngo mukoreshe iyi soko y'amazi? / Do you usually have to pay to use this water source?	◯ Yes ◯ No ◯ Don't know
Waba warasukuye aya mazi ngo abe meza yo kunyobwa? Did you treat this water to make it safer to drink?	◯ Yes ◯ No ◯ Don't know

Aya mazi wayasukuye ute? (hint: probe: anything else?)

How did you treat this water? (hint: probe: anything else?)

- ☐ Guteka /Boiling
- ☐ Gushyiramo umuti wica udukoko (bleach)/ Add bleach / chlorine
- ☐ Kuyayunguruza umwenda /Strain it through a cloth
- ☐ Strain it through a tea strainer
- ☐ Gukoresha filitiri (ibumba, umucanga, ibindi.)/Use water filter (ceramic, sand, composite, etc.)
- ☐ Gukoresha imirasire y'izuba /Solar disinfection
- ☐ Kuyareka agacayuka /Let it stand and settle
- ☐ Ubundi, buvuge/Other, specify
- ☐ Simbizi /Don't know

Niba hari undi, wuvuge./If other, specify.

- ☐ [a10_cookname]
- ☐ [a10_hheadname]
- ☐ [a10_member2]
- ☐ Non-household member

WATER FETCHING FOR ALL PURPOSES INCLUDING DRINKING

Mu minsi irindwi ishize, ni nde wajyaga kuvoma amazi? (hint: water for all purposes including drinking)

In the past seven days, who went to collect the water from the household? (hint: water for all purposes including drinking)

Mu minsi irindwi ishize, ni nde wajyaga kuvoma amazi? (hint: water for all purposes including drinking)

In the past seven days, who went to collect the water from the household? (hint: water for all purposes including drinking)

RESPONSE OPTIONS ADJUSTS TO HOUSEHOLD SIZE

- ☐ [a10_cookname]
- ☐ [a10_hheadname]
- ☐ [a10_member2]
- ☐ Non-household member

Ni inshuro zingahe [a10_cookname] yavomye muri iki cyumweru/ How many times did [a10_cookname] collect water this week? ____________________

Bitwara igihe kingana iki [a10_cookname] kujya kuvomayo amazi ukanagaruka?/How long does it take [a10_cookname] to go there, get water, and come back? ____________________

Ni litilo zingahe [a10_cookname] yavomye inshuro imwe?/How many liters of water does [a10_cookname] collect in one trip? ____________________

Total Collect ____________________

Ni inshuro zingahe [a10_hheadname] yavomye muri iki cyumweru/ How many times did [a10_hheadname] collect water this week? ____________________

Bitwara igihe kingana iki [a10_hheadname] kujya kuvomayo amazi ukanagaruka?/ How long does it take [a10_hheadname] to go there, get water, and come back? ____________________

Ni litilo zingahe [a10_hheadname] yavomye inshuro imwe?/How many liters of water does [a10_hheadname] collect in one trip? ____________________

Total Collect	______________________
Ni inshuro zingahe [a10_member2] yavomye muri iki cyumweru/ How many times did [a10_member2] collect water this week?	______________________
Bitwara igihe kingana iki [a10_member2] kujya kuvomayo amazi ukanagaruka?/How long does it take [a10_member2] to go there, get water, and come back?	______________________
Ni litilo zingahe [a10_member2] yavomye inshuro imwe?/How many liters of water does [a10_member2] collect in one trip?	______________________
Total Collect	______________________
Ni inshuro zingahe [a10_respothername] yavomye muri iki cyumweru/ How many times did [a10_respothername] collect water this week?	______________________
Bitwara igihe kingana iki [a10_respothername] kujya kuvomayo amazi ukanagaruka?/How long does it take [a10_respothername] to go there, get water, and come back?	______________________
Ni litilo zingahe [a10_respothername] yavomye inshuro imwe?/How many liters of water does [a10_respothername] collect in one trip?	______________________
Total Collect	______________________
Mu minsi irindwi ishize, ni amazi angana iki yavuye cyangwa mwavomye y'imvura cyangwa ku yandi masoko?/In the past seven days, how much water was delivered or collected from rainwater or on-premise sources?	______________________
Total Water	______________________
Urugo rwanyu rwavomye [d40_whocollectsa3total] litiro z'amazi mu minsi irindwi ishize. Ni amazi angana iki yakoreshejwe mu kunywa?/ Your household collected [d40_whocollectsa3total] liters of water in the past seven days. How much of that water was used for drinking	______________________

E50 Child health

[a10_member1]	
OBSERVE: Able to talk to primary caregiver?	Yes No
Ejo hashize, n'ibihe binyobwa [a10_member1] umwana wawe yanyoye? Hari ibindi? (hint: check all that apply) What liquids did [a10_member1] drink YESTERDAY? Anything else? (hint: check all that apply)	☐ Amazi y'umugezi adasukuye / plain untreated water ☐ Amazi yasukuwe na filitire / water treated by lifestraw ☐ Amazi yasukuwe ku buundi buryo / water treated by other method ☐ Amashereka / breastmilk ☐ Amata y'inka/amata y'ihene/ animal milk ☐ Igikatsi / banana water ☐ Umutobe / banana juice ☐ Urwagwa /banana beer ☐ Ubushera / non-alcoholic millet/sorghum drink ☐ Ikigage / millet/sorghum beer ☐ Igikoma /Porridge ☐ Other, specify ☐ Don't know
Niba hari ibindiundi, wuvugebivuge. If other, specify.	______________________
[a10_member1] yaba yarigeze yonswa? Has [a10_member1] ever been breastfed?	◯ Yes ◯ No ◯ Don't know
[a10_member1] aracyonka? Is [a10_member1] still being breastfed?	◯ Yes ◯ No ◯ Don't know
Mu minsi irindwi ishize, (uhereye umunsi nk'uyu mu cyumweru gishize), [a10_member1] yigeze agira (UMURIRO)? In the last 7 days, since this day last week, has the [a10_member1] had fever?	◯ Yes ◯ No ◯ Don't know
Ese umwana yaba yaripimishije bikagaragara ko arwaye maraliya (aha turashaka kuvuga niba yaratanze ikizamini cy'amaraso/Was the child tested and confirmed to have malaria? (hint: by blood test)	◯ Yes ◯ No

[a10_member1] yagiye KU MUJYANAMA W'UBUZIMA ku mpamvu y'umuriro? In the last seven days, since this day last week, was [a10_member1] seen by a CHW for fever? in the last seven days (since this day last week)?	◯ No ◯ Don't know
Name of CHW	________________________
Mu minsi 7 ishize (kuva uyu munsi icyumweru gishize) [a10_member1] yagiye ku kigo nderabuzimkwa muganga ku mpamvu y'umuriro? Did [a10_member1] visit any health facility for fever in the last seven days since this day last week?	◯ Yes ◯ No ◯ Don't know
Name of health facility	________________________
Ese [a10_member1] yaba yarigezi agira ikibazo cyo GUHITWA mu minsi 7 ishize (uhereye umunsi nk'uyu mu cyumweru gishize)? In the last 7 days, since this day last week, has [a10_member1] had diarrhea?	◯ Yes ◯ No ◯ Don't know
Ese [a10_member1] yaba yarigezi agira ikibazo cy' Impiswi (diyare/gucibwamoguhitwa) mu minsi 7 ishize (uhereye umunsi nk'uyu w'imu cyumweru gishize)? Impiswi dukururikije ibisobanuro bitangwa n'umuryango w'abibumbye wita ku buzima: ivuga kwituma umusarani w'amazi inshuro 3 cyangwa zirenga mu masaha 24? In the last 7 days, since this day last week, has [a10_member1] had diarrhea? Diarrhea defined as passage of 3 or more loose stools (that can take the shape of a container) within a 24 h period	◯ Yes ◯ No ◯ Don't know
Mu minsi irindwi ishize Uhereye umunsi nk'uyu mu cyumweru gishize [a10_member1] yigeze YITUMA IBIVANZEMO NAMARASO? In the last 7 days, since this day last week, has [a10_member1] had blood in the stool?	◯ Yes ◯ No ◯ Don't know
Mu minsi 7 ishize (kuva uyu umunsi nk'uyu w' icyumweru gishize) [a10_member1] yagiye KU MUJYANAMA W'UBUZIMA ku mpamvu y'IMPISWI? Was [a10_member1] seen by a CHW for diarrhea in the last seven days (since this day last week)?	◯ Yes ◯ No ◯ Don't know
Name of CHW	________________________

Mu minsi 7 ishize (kuva umunsi nk'uyu w'icyumweru gishizekuva uyu munsi icyumweru gishize) [a10_member1] yagiye ku kigo nderabuzima ku mpamvu y'MPISWI? Did [a10_member1] visit any health facility for diarrhea in the last seven days since this day last week?	Yes ◯ No ◯ Don't know
Name of health facility	________________________
[a10_member1] yamaze iminsi ingahe ahitwa? Impiswi dukururikije ibisobanuro bitangwa n'umuryango w'abibumbye wita ku buzima: ivuga kwituma umusarani w'amazi inshuro 3 cyangwa zirenga mu masaha 24. [a10_member1] yamaze iminsi ingahe ahitwa? For how many days did [a10_member1] have diarrhea? Diarrhea defined as passage of 3 or more loose stools (that can take the shape of a container) within a 24 h period.	________________________ ([hint: write in days])
Explain Bristol Stool Chart	
Mu minsi 7 ishize [a10_member1] yaba yaritumye ibimeze ubwoko bwa 1? In the past 7 days, has [a10_member1] passed type 1 stool?	◯ Yes ◯ No ◯ Don't know
Mu minsi 7 ishize [a10_member1] yaba yaritumye ibimeze ubwoko bwa 2? In the past 7 days, has [a10_member1] passed type 2 stool?	◯ Yes ◯ No ◯ Don't know
Mu minsi 7 ishize [a10_member1] yaba yaritumye ibimeze ubwoko bwa 3? In the past 7 days, has [a10_member1] passed type 3 stool?	◯ Yes ◯ No ◯ Don't know
Mu minsi 7 ishize [a10_member1] yaba yaritumye ibimeze ubwoko bwa 4? In the past 7 days, has [a10_member1] passed type 4 stool?	◯ Yes ◯ No ◯ Don't know
Mu minsi 7 ishize [a10_member1] yaba yaritumye ibimeze ubwoko bwa 5? In the past 7 days, has [a10_member1] passed type 5 stool?	◯ Yes ◯ No ◯ Don't know

Muminsi 7 ishize , ni ryari [a10_member1] yitumye ubwoko bwa 4 cyangwa ubwa 5 inshuro nyinshi mumasha 24 kandi izo nshyuro zari zingahe ? In the past 7 days, when did [a10_member1] pass the most type 4 or type 5 stool in a 24 hour period and how many times?	________________________
Mu minsi irindwi ishize uhereye umunsi nk'uyu mu cyumweru gishize [a10_member1] yigeze agira KUBABARA AMENYO? In the last 7 days, since this day last week, has [a10_member1] had toothache?	◯ Yes ◯ No ◯ Don't know
Mu minsi 7 ishize (kuva uyu munsi icyumweru gishize) [a10_member1] yagiye KU MUJYANAMA W'UBUZIMA ku mpamvu y'KUBABARA AMENYO? Was [a10_member1] seen by a CHW for toothache in the last seven days (since this day last week)?	◯ Yes ◯ No ◯ Don't know
Name of CHW	________________________
Mu minsi 7 ishize (kuva uyu munsi icyumweru gishize) [a10_member1] yagiye ku kigo nderabuzima ku mpamvu y'KUBABARA AMENYO? Did [a10_member1] visit any health facility for toothache in the last seven days since this day last week	◯ Yes ◯ No ◯ Don't know
Name of health facility	________________________
Mu minsi 7 ishize (uheriye umunsi nk'uyu w'icyumweru gishize), [a10_member1] yigeze agira uburwayi bufite inkorora? (hint: ushyizemo uburwayi bw'inkorora gusa) In the last 7 days, since this day last week, has [a10_member1] had an illness with cough? (hint: includes illness of cough only)/Mu minsi 7 ishize, kuva uyu munsi mu cyumweru gishize, hari[a10-umuntu] wigeze agira uburwayi bufite inkorora?	◯ Yes ◯ No ◯ Don't know
Igihe [a10_member1] yagiraga uburwayi bufite inkorora, yigeze ahumeka yihuta kurenza ubusanzwe cyangwa bimugora guhumeka? When [a10_member1] had an illness with a cough, did he/she breathe faster than usual with short, rapid breaths or have difficulty breathing?	◯ Yes ◯ No ◯ Don't know

Guhumeka byihuse cyangwa bigoranye byaba byaratewe n'ikibazo cyo mu gatuza cyangwa byaratewe n'amazuru afunze cyangwa apfuna cyane? Was the fast or difficult breathing due to a problem in the chest or to a blocked or runny nose?	○ Agatuza konyine/chest only ○ mazuru yonyine/nose only ○ Byose agatuza n' amazuru/both ○ Simbizi/Don't know
Mu minsi 7 ishize (kuva uyu munsi icyumweru gishize) [a10_member1] yagiye KU MUJYANAMA W'UBUZIMA ku mpamvu y' uburwayi bufite inkorora? Was [a10_member1] seen by a CHW for ILLNESS WITH COUGH in the last seven days (since this day last week)?	○ Yes ○ No ○ Don't know
Name of CHW	______________________
Mu minsi 7 ishize (kuva uyu munsi icyumweru gishize) [a10_member1] yagiye ku kigo nderabuzima ku mpamvu y' uburwayi bufite inkorora? Did [a10_member1] visit any health facility for ILLNESS WITH COUGH in the last seven days since this day last week?	○ Yes ○ No ○ Don't know
Name of health facility.	______________________
OBSERVE VACCINE CARD: Did child have rotavirus vaccine?	○ No Doses ○ First Dose ○ First and Second Dose ○ All Three Doses ○ Not able to observe vaccine card

CHILD QUESTIONS LOOP FOR EACH CHILD UNDER 5

F60 Health access

N'irihe zina ry'ikigo cy'ubuzima abantu bo mu muryango wawe bivurizaho indwara zoroheje n'izikomeye cg bafatiraho izindi servisi z'ubuzima? / What is the name of the health facility that members of your household would visit for regular health care, or for an illness of mild/moderate severity? (hint: Write '9999' if 'Don't know')	______________________________
Mugereranyije bibatwara igihe kingana iki kugirango muhagere (Iminota, kugenda guse uvuye aha turi)? / Approximately how long does it take to travel there (in minutes, one-way, from where we are now)? (hint: write in minutes. WRITE 9999 IF DON'T KNOW)	______________________________
SECTION COMMENTS	____________________________________

G70 Program Exposure

SOMA CYANE: Ubu ngiye kukubaza ibibazo bijyanye n'ubwitabire bwawe muri gahunda y'amakelebe y' ubuzima (cg isuku). (hint: no response needed) SAY: I am going to ask you questions about your participation in CHCs program. (hint: no response needed)	______________________
Haba hari ikiganiro witabiriye cyateguwe na kelebe y'ubuzima (cg isuku) muri uyu muduggudu? Have you attended any session organized by the community health club IN THIS VILLAGE?	◯ Yes ◯ No
Haba hari undi muri uru rugo witabiriye ikiganiro cyateguwe na kelebe muri uyu mudugudu? Has anyone else in this household attended any session organized by the community health club in this village?	◯ Yes ◯ No ◯ Don't know
Muri aya masomo akurikira, ni irihe by'umwihariho witabiriye? Among the following topics which did you specifically attend for the club in this village?	☐ Indwara z'uruhu/Skin Diseases ☐ Isuku y'umubiri/ Personal Hygiene ☐ Gukaraba intoki/Hand Washing ☐ Impiswi/Diarrohea ☐ Inzoka zo munda/Intestinal Parasites/ Worms ☐ Amasoko y'Amazi/Water Sources ☐ Isuku n'isukura/Sanitation ☐ Simbizi/Don't know
SECTION COMMENTS	______________________

J90 Filter

section start time	______________________
Waba ufite filitiri? Wayinyereka?/Do you have Lifestraw water filter? Can you show me? CONFIRM HOUSEHOLD HAS FILTER	◯ Yes ◯ No
Ese haba hari umuntu wabigishije uko ukoresha filitire?/Did anyone teach you how to use the filter?	◯ Yes ◯ No ◯ Don't know
Ni nde wabahaye isomo ry'imkoreshereze ya filitire?/ Who taught you how to use the filter?	☐ Umufamyumvire wa kelebu y'ubuzima/Community Healt Club Facilitator ☐ Ugize urugo rwanyu/Household member ☐ Umukozi wa AEE/AEE staff ☐ Umukuru w'abajyanama wo kigo nderabuzima/CEHO fro health center ☐ Undi mubayobozi ba kelebu/Other CHC committee member ☐ Undi mubanyamuryango ba Kelebu/ Other CHC member ☐ Undi muntu wo murugo/Other household member ☐ Other specify
Specify other	______________________
Uzi gukoresha neza filitire? HINT: READ OPTIONS/ Do you feel like you mastered the use of the filter HINT: READ OPTIONS	◯ Yego ndabizi byose mugukoresha filitire/Yes-Everything in using the filter ◯ Bimwe nabimwe mugukoresha filitire/Somewhat in using the fiter ◯ Bike mugukoresha filitire/Little in using the filter ◯ Nta na kimwe/Not at all ◯ Don't know
Hari umuntu wegeze abasura murugo azankwe no kubaganiriza kubijyanye na Filitiri?/ Has any one come to your home to talk about your filter?	◯ Yes ◯ No
Uhereye igihe mwafatiye filitili ni inshuro zingahe babasuye babaganiriza kubya filitili/ Since you received the filter how many times has someone come in your home to talk about your filter?	______________________ (WRITE 999 if DON'T KNOW)
Ubwanyuma muheruka gusurwa ni ryari?/ When was the last time?	◯ Today ◯ Days ago (specify in next question)) ◯ Weeks ago (specify in next question)) ◯ Months ago (specify in next question) ◯ Don't know
Days ago	______________________

Weeks ago	___________________
Months ago	___________________
Mugereranije ni nkakangahe babasura mugihe runaka, SOMA IBISUBIZO Ikitabwaho:hitamo kimwe, unagaragaze umubare ku kibazo gikurikiraho/On average what is the frequency of these visits? READ RESPONSES HINT: SELECT ONE AND SPECIFY NUMBER IN NEXT QUESTION	◯ Nikangahe kumunsi/Number of times per day (specify) ◯ Nikangahe mu cyumweru/ Numer of times per week (specify) ◯ Nikangahe m kwezi/Number of times per month (specify) ◯ Once every 3 months ◯ Every other month ◯ Other (specify)
Per Day	___________________
Per Week	___________________
Per Month	___________________
Specify other	___________________
Filitire irakora neza? / Is LIFESTRAW working properly DIRECT TO RESPONDENT	◯ Yes ◯ No ◯ Don't know
SPECIFY PROBLEMS	☐ Firitire ntiyari ifunze neza/Filter not assembled properly ☐ Filitiri irava /Filter leaking ☐ Robine yaramenetse/Tap damaged ☐ Akagega k'amazi asukuye karamenetse/Bottom container damaged ☐ Birakomeye gukanda agapombo/Difficult to backwash ☐ iyungurura gake gake/ filters water slowly ☐ Amazi aza gake muri robine/Slow flow rate from tap ☐ Ibindi/ Other (specify)
Specify other	___________________
OBSERVE: Filitire irakora neza/ Lifestraw working properly?	◯ Yes ◯ No ◯ Don't know

SPECIFY PROBLEMS	☐ Firitire ntiyari ifunze neza/Filter not assembled properly ☐ Filitiri irava /Filter leaking ☐ Robine yaramenetse/Tap damaged ☐ Akagega k'amazi asukuye karamenetse/Bottom container damaged ☐ Birakomeye gukanda agapombo/Difficult to backwash ☐ iyungurura gake gake/ filters water slowly ☐ Amazi aza gake muri robine/Slow flow rate from tap ☐ Ibindi/ Other (specify)
Specify other	____________________________
Ese urugo rwanyu rwaba rukoresha iyi filitire? / Is your household using this water filter?	◯ Yes ◯ No ◯ Don't know
Ni ryari muheruka gukoresha iyi filitire? / When did you last use the Lifestraw filter	◯ Today ◯ Yesterday ◯ Day before yesterday ◯ Days ago (specify in next question)) ◯ Weeks ago (specify in next question)) ◯ Months ago (specify in next question) ◯ Don't know
Days ago	____________________________
Weeks ago	____________________________
Months ago	____________________________
Ni ryari umntu aheruka kuzuza amazi muri filitire? / When did SOMEONE last FILL the Lifestraw filter?	◯ Today ◯ Yesterday ◯ Day before yesterday ◯ Days ago (specify in next question)) ◯ Weeks ago (specify in next question)) ◯ Months ago (specify in next question) ◯ Don't know
Days ago	____________________________
Weeks ago	____________________________
Months ago	____________________________
Hari ubwo filitire yaba itarakoreshwaga bitewe nuko yangiritse cyangwa itegereje gusanwa? / Has your water filter ever been unusable due to breakage or needing repair?	◯ Yes ◯ No ◯ Don't know

Ni iminsi ingahe mutashoboye gukoresha filitiri? / How many days could you not use the filter? SPECIFY COVERSION IN DAYS	____________________ (HINT: WRITE 999 IF DON'T KNOW)
OBSERVE: DOES FILTER LOOK IN USE?	◯ Yes ◯ No
REBA: Kubera iki filitili igaragara ko idakoreshwa?/OBSERVE: WHY DOES FILTER NOT LOOK IN USE	☐ Biragoye kugera kuri filitili / HARD TO ACCESS FILTER ☐ Filitili igaragara nk'ifite umwanda / FILTER LOOKS DUSTY/DIRTY ☐ Ntamazi arimo mu igice cyo hejuru / NO WATER IN TOP 4, Ntamazi arimo mugice cyo hasi /NO WATER IN BOTTOM ☐ Filitili cyangwa amazi bihumura nabi /FILTER/WATER IS SMELLY ☐ FILTER LOOKS BROKEN/PARTS MISSING ☐ Ibindi,bivuge / OTHER, SPECIFY (HINT: SELECT ALL THAT APPLY.)
Specify other	____________________
OBSERVE: IS THERE WATER IN THE FILTER?	☐ BOTTOM (HALF OR MORE THAN HALF REMAINING) ☐ BOTTOM (LESS THAN HALF REMAINING) ☐ TOP (HALF OR MORE THAN HALF FULL) ☐ TOP (LESS THAN HALF FULL) ☐ TOP (LESS THAN 1/4 FULL) ☐ NO WATER IN FILTER (BOTTOM) ☐ NO WATER IN FILTER (TOP)
Hari ibindi ukoresha amazi ya filitire bitari ukuyanywa?/ Do you use filtered water for purposes OTHER THAN drinking?	◯ Yes ◯ No
Ni ibihe bindi bitari ukuyanywa?/ For what purposes other than drinking?	☐ Guteka/Cooking ☐ Koza ibyombo/Cleaning dishes ☐ Gufura imyenda/ Washing clothes ☐ Kwiyuhagira/ Bathing ☐ gukaraba intoki/handwashing ☐ Koza amenyo/ teeth brushing ☐ Other, specify (HINT: SELECT ALL THAT APPLY.)
SPECIFY OTHER	____________________
Ese abana bo munsi y'imyaka 5 bashobora kwiha ubwabo amazi yo muri filitire?/ Are children under 5 able to obtain water from the filter ON THEIR OWN?	◯ Yes ◯ No ◯ No under 5 children living in household ◯ Don't know
Hari ubwo izindi ngo zikoresha filitiri yanyu cyangwa zikoresha amazi yasukuwe na filitiri? HITAMO IBIJYANYE BYOSE. CHECK ALL THAT APPLY Do other households EVER use your filter or use water treated from the filter? CHECK ALL THAT APPLY	☐ Yego-basukura amazi yabo yo kunkwa bakoresheje filitiri/Yes - they treat their own drinking water using the filter ☐ Yego-Urugo rwacu rubaha amazi yo kunkwa asukuye./Yes - our household provides them with treated drinking water ☐ Oya/No

NIBA ARI YEGO, Baba barigeze basukura amazi yabo yo kunkwa bakoresheje filitiri muminsi 7 ishize? IF YES, Did they treat their own drinking water using the filter in the last 7 days?	◯ Yego/Yes ◯ Oya/No
NIBA ARI YEGO,Urugo rwanyu rwigeze rubaha amazi yo kunkwa asukuye mu minsi 7 ishize? IF YES, Did your household provide them with treated drinking water in the last 7 days?	◯ Yego/Yes ◯ Oya/No
NIBA ARI YEGO MURI Q3-Ni izindi ngo zingahe mwahaye amazi yo kunkwa mu minsi 7 ishize? IF YES, how many other households did you provide drinking water for in the last 7 days?	______________________________
NIBA ARI YEGO- Ni izindi ngo zingahe zasukuye amazi yabo yo kunkwa mu minsi 7 ishize? IF YES, How many other households treated their drinking water in the last 7 days?	______________________________
SECTION COMMENTS	____________________________________

Section end ______________________________

K100 Filter

section start time	____________________
READ ALOUD RESPONSES	
Ni gute wagereranya uko amazi yasukuwe na filitire aza asa? How would you describe the visual appearance/look of the treated water from the filter?	◯ Turayemera cyane/ Very acceptable ◯ Turayemera/Acceptable ◯ Ntituyemera/Unacceptable ◯ Nyituyemera na gato/Very unacceptable
Ni gute wagereranya impumuro y'amazi yasukuwe na filitire? How would you describe the smell/odour of the treated water from the filter?	◯ Turayemera cyane/ Very acceptable ◯ Turayemera/Acceptable ◯ Ntituyemera/Unacceptable ◯ Nyituyemera na gato/Very unacceptable
Ni gute wagereranya uburyohe bw' amazi yasukuwe na filitire? How would you describe the taste of the treated water from the filter?	◯ Turayemera cyane/ Very acceptable ◯ Turayemera/Acceptable ◯ Ntituyemera/Unacceptable ◯ Nyituyemera na gato/Very unacceptable
Ni gute wagereranya igihe filitire imara isukura amazi How would you describe the amount of time the filter takes to clean the water?	◯ Turayemera cyane/ Very acceptable ◯ Turayemera/Acceptable ◯ Ntituyemera/Unacceptable ◯ Nyituyemera na gato/Very unacceptable
Ese ingano ya filitire irahagije ugereranyije n'ibyifuzo by'umuryango wawe ku mazi yo kunywa? Is the storage container large enough for your family's drinking water needs?	◯ Yes ◯ No ◯ Don't know (HINT: The 6 liters of storage.)
Ni iki udakunda cyane kuri filitire? HINT: READ RESPONSES What do you like least about the filter?	◯ Nta na kimwe byose ni byiza/ Nothing, everything ok ◯ Amazi agenda buhoro/Flow rate is too slow ◯ Impumuro/The smell ◯ Uburyohe/ The taste ◯ Ingano y'ahabika amazi/The size of the storage ◯ Isukura rya filitire ku gace gatukura/Need to backwash ◯ Isukura ry'akayunguruzo ko ku mufuniko/Cleaning pre-filter ◯ Igihe isukura amazi ni kirerkire cyane/Time to clean water is too long ◯ Other, specify
Specify other	____________________ (HINT: Chose 1 that is the worst thing.)

Ujya unywa amazi atasukuye na filitire igihe uri cyangwa utari mu rugo? Do you ever drink unfiltered water while in or away from household?	◯ Yego(amazi adasukuye)/ Yes (untreated) ◯ Yego (Mazi asukuye mubundi buryo/ Yes (other treated water) ◯ Oya/ No
Uri mu rugo, ni kangahe unywa amazi atasukuwe na filitire? When you are in the household, how often do you drink water that has not been filtered?	◯ Nta na rimwe/Never ◯ Gake cyane/Rarely ◯ Rimwe na rimwe/Sometimes ◯ Incuro nyinshi/Most of the time ◯ Buri gihe/Always (HINT: READ RESPONSES ALOUD)
Utari mu rugo, ni kangahe unywa amazi atasukuwe na filitire? When you are away from the household, how often do you drink water that has not been filtered?	◯ Nta na rimwe/Never ◯ Gake cyane/Rarely ◯ Rimwe na rimwe/Sometimes ◯ Incuro nyinshi/Most of the time ◯ Buri gihe/Always (HINT: READ RESPONSES ALOUD)
Abana banyu bo munsi y'imyaka 5 bajya banywa amazi atasukuwe na filitire igihe bari cyangwa batari mu rugo? Do your children under 5 ever drink unfiltered water while in or away from household?	◯ Yego(amazi adasukuye)/ Yes (untreated) ◯ Yego (Mazi asukuye mubundi buryo/ Yes (other treated water) ◯ Oya/ No ◯ Child not yet drinking water ◯ Don't know ◯ No child in house
Ni kangahe mu rugo abana bawe bari munsi y'imyaka 5 banywa amazi atasusukuwe na filitire)? READ RESPONSES When your children under 5 are in the household, how often do they drink water that has not been filtered treated?	◯ Nta na rimwe/Never ◯ Gake cyane/Rarely ◯ Rimwe na rimwe/ Sometimes ◯ Incuro nyinshi/ Most of the time ◯ Buri gihe/Always ◯ Simbizi/Don't know
Ni kangahe abana bawe bari munsi y'imyaka 5 banywa amazi (atasukuwe na filitire), iyo batari mu rugo? READ RESPONSES When your children under 5 are away from the household, how often do they drink water that has not been filtered?	◯ Nta na rimwe/Never ◯ Gake cyane/Rarely ◯ Rimwe na rimwe/ Sometimes ◯ Incuro nyinshi/ Most of the time ◯ Buri gihe/Always ◯ Simbizi/Don't know
Ujya ubika amazi yasukuwe na filitire mukindi gikoresho nyuma yo kuyayungurura? / After you filter water, do you usually store the filtered water in a separate container?	◯ Yes ◯ No ◯ Don't know
Ni inshuro zingahe ubika amazi ayunguruwe nafilitire mu kindi gikoresho? READ RESPONSES How often do you store filtered water in a separate container?	◯ Gake cyane/Rarely ◯ Rimwe na rimwe/Sometimes ◯ Incuro nyinshi/ Most of the time ◯ Buri gihe/Always

Uyu munsi, wigeze unywa amazi atasukuwe na filitire?/ Did you drink any water that was not filtered today?	◯ Yes (untreated) ◯ Yes (other treated water) ◯ No
Kubera iki udafite filitire? Why don't you have the filter?	☐ Nta mpamvu yihariye /No particular reason ☐ Umuturanyi afite filitire/ Neighbor has filter ☐ Filitire yarapfuye / Filter broke ☐ Filitire yagiye gusanwa/Filter out for repair ☐ Filitire yagurishijwe/Filter sold ☐ Amazi yayo ntabwo aryoshe /Don't like the taste ☐ Sinkunda impumuro ya filitire/y'amazi / Don't like the smell of filter/water ☐ Imara igihe kinini iyungurura/Takes too long to filter ☐ Biragoye kuyikoresha / Difficult to use ☐ Filitire ntikoresha amazi yanduye/Filter can't use dirty water ☐ Filitire yaribwe/Filter stolen ☐ Filitire yarabuze/Filter lost/missing ☐ Umwe mu babaga mu rugo yarayimukanye /Household member moved away with filter ☐ Sinigeze mpabwa filitire /Never recieved filter ☐ Other, specify ☐ Don't know
Specify other	__________________________
Waba warigeze gukoresha mbere filitire ariko ubu ukaba utakiyikoresha Did you previously use the Lifestraw filter but now no longer?	◯ Yes - Nayikoreshaga mu bihe byashize/ Used in the past ◯ No - Sinigeze ndikoresha/ Never used
Ni ukubera iki mutigeze mukoresha/mwaretse gukoresha filitire?/Why did YOU NEVER USE OR STOP USING the Lifestraw filter?	☐ Nta mpamvu yihariye /No particular reason ☐ Umuturanyi afite filitire/ Neighbor has filter ☐ Filitire yarapfuye / Filter broke ☐ Filitire yagiye gusanwa/Filter out for repair ☐ Filitire yagurishijwe/Filter sold ☐ Amazi yayo ntabwo aryoshe /Don't like the taste ☐ Sinkunda impumuro ya filitire/y'amazi / Don't like the smell of filter/water ☐ Imara igihe kinini iyungurura/Takes too long to filter ☐ Biragoye kuyikoresha / Difficult to use ☐ Filitire ntikoresha amazi yanduye/Filter can't use dirty water ☐ Filitire yaribwe/Filter stolen ☐ Filitire yarabuze/Filter lost/missing ☐ Umwe mu babaga mu rugo yarayimukanye /Household member moved away with filter ☐ Sinigeze mpabwa filitire /Never recieved filter ☐ Other, specify ☐ Don't know
Specify other	__________________________

SECTION COMMENTS

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M110 Hwise

1) section start time

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SOMA CYANE: Ubu ngiye kukubaza ibibazo bimwe na bimwe k'ubunararibonye bwawe kubijyanye n'amazi, ndaba nkubaza inshuro wahuye n'ibibazo bimwe na bimwe by'amazi mubyumweru 4 bishize. Ndajya nkusobanurira ikibazo neza.

SAY: I am now going to ask you some questions on your experience with water by asking how frequently you experience certain water problems in the past 4 weeks. I can clarify any of the questions for you.

IF HOUSEHOLD MEMBERS DO NOT KNOW FOR ANY QUESTION, WRITE 999, BUT USE PROBING QUESTIONS FIRST

2) Mu byumweru 4 bishize ni kangahe wowe cyangwa undi muntu wo muri uru rugo yagize impungenge z'uko hataza kuboneka amazi ahagije yo gukoresha kubyo mukeneye byose mu rugo?

Ikitabwaho: Kubyo mukenera murugo harimo gufura imyenda, kwiyuhagira wowe cyangwa n'abana bawe, amazi yo guha amatungo, ayo koza ibyombo n'ibikoresho, gusukura inzu, cyangwa n'ibindi bisaba amazi. Muri iki kibazo, turashaka kuvuga impungenge zo kutagira amazi ahagije

In the last 4 weeks, how frequently did you or anyone in your household worry you would not have enough water for all of your household needs?

____

(HINT: Your household needs could include washing clothes, bathing yourself and/or your children, watering animals, washing dishes and utensils, cleaning your home, or other activities that require water. In this question, we are wondering about the worry of not having enough water.)

3) Mu byumweru 4 bishize ni kangahe isoko y'ibanze y'amazi yanyu yagize ikibazo/ yahagaze gukora (urugero: umuvuduko mucye w'amazi, amazi make ugereranyije nuko yakagombye kungana, umugezi warakamye?)

Ikitabwaho: (Urugero: umuvuduko w'amazi, amazi make ugereranyije nuko yakagombye, gukama k'umugezi)/ hariho ubwoko bwinshi bwa Kirogoya. Kuri Kirogoya, turavuga igihe amazi yawe ashobora kuba yarafunzwe n'ubuyobozi bwa leta cyangwa n'ikigo gitanga amazi.Ashobora kuba yarahagaritswe betewe n'umuyoboro cyangwa uyatanga, ikigega kibika amazi ntayarimo, cyangwa uwari usanzwe ubagurisha amazi ntawuhari. Cyangwa izuba ryaracanye cyane, cyangwa isoko mwari musanzwe mukoresha yarakamye kuburyo musabwa gukoresha indi soko kugirango mubone amazi. Ibi ntibishatse kuvuga gusa amazi yo mu matiyo.

In the last 4 weeks, how frequently has your main water source been interrupted or limited (e.g. water pressure, less water than expected, river dried up)?

____

(HINT: There are many types of interruptions. By interrupted, we mean that your water could have been turned off by the government or company that provides it. It could have stopped flowing due to issues with the supply or supplier, a storage tank no longer containing water, or the vendor you regularly use to purchase water from not being available. Or perhaps there is a drought and the spring you normally use is dry such that you have to use another source to get water. This item does not exclusively refer to piped water sources.)

4) Mu byumweru 4 bishize, nikangahe hatabonetse amazi yo kunywa ahagije kuri wowe cyangwa undi muntu wo muri uru rugo?

Ikitabwaho: iki kibazo kijyanye n'amazi yo kunkwa murugo rwawe. Mubice bimwe na bimwe ntamazi ahagije yo kunkwa kuburyo buhoraho kuri buri wese nkuko babishaka. Hakaba hashobora kuba hari amazi yo kunkwa ahagije kuri bamwe ariko kubandi ntayo.

In the last 4 weeks, how frequently has there not been as much water to drink as you would like for you or anyone in your household?

____

(HINT: This question refers to drinking water in your household. In some places, there is not always enough water for everyone to drink as much as they would like. Or, there may be drinking water for some people, but not others.)

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5) Mu byumweru 4 bishize, ni kangahe wowe cyangwa undi muntu wo muri uru rugo Yahinduye ibyari byateganyirijwe kuribwa kubera ikibazo cy'amazi (uregero: Kuronga ibiribwa, Guteka, n'ibindi.)?

Ikitabwaho: iki kibazo kijyanye n'amazi akoreshwa mu guteka cyangwa mugutegura ibiribwa gusa.iki kibazo gisobanuye ko mushobora kuba mwarahinduye ibyo mwari musanzwe murya bitewe nuko ntamazi ahagije yo kuronga,gutegura, cyangwa guteka ibiryo mwahisemo. Urugero, ushobora kuba wari buronge imboga, cyangwa utari ufite amazi ahagije yo guteka ibishyimbo.

In the last 4 weeks, how frequently have you or anyone in your household had to change what was being eaten because there were problems with water (e.g., for washing foods, cooking, etc.)?

____

(HINT: This question refers to water only used for cooking or preparing foods. This question means that your household may have changed what was eaten because there was not enough water to wash, prepare, or cook a preferred food. For example, you couldn't wash vegetables, or didn't have enough water to boil beans.)

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6) Mu byumweru 4 bishize, ni kangahe wowe cyangwa undi muntu wo muri uru rugo yarakajwe n'ikibazo cy'amazi?

Ikitabwaho: Iki kibazo kijyanye n'umujinya cyangwa andi marangamutima Atari meza wiyumvamo bitewe no gushaka amazi cyangwa gukoresha amazi. Kumiterere y'amazi yawe, bisobanuye uko ubona amazi, kutaba ufite amazi ahagije, kutaba ufite amazi wifuza kubana bawe, ufite impungenge z'ubwiza bw'amazi yawe, ibibazo by'amazi bigira ingaruka k'ubuzima n'imiteganyirize yawe, n'ikindi kintu cyose kerekeranye no kubona amazi ndetse no kuyakoresha gishobora kugutera uburakari

In the last 4 weeks, how frequently did you or anyone in your household feel angry about your water situation?

____

(HINT: This question refers to anger or other negative emotions you feel because of getting and using water. By your water situation, we mean how you get water, not having enough water, not having enough of the kinds of water you prefer, being worried about the quality of your water, water issues affecting your life and schedule, and anything else related to getting and using water that may cause you to feel angry.)

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7) Mu byumweru 4 bishize , ni kangahe mwagize ikibazo cy'amazi kuburyo mutashoboraga gufura imyenda?

Ikitabwaho: iki kibazo kijyanye n'amazi yo gufura imyenda gusa. Amazi yo gufura ashobora guturuka mu rugo cyangwa hanze y'urugo. (urugero: ku ma robine cyangwa no ku mugezi)

In the last 4 weeks ago, how often did you have problem of water for washing clothes?

____

(Hint: This question refers only to water for washing clothes. Water used for laundry can come from within the household or outside the household (e.g. at a taps and or river).)

8) Mu byumweru 4 bishize, Ni kangahe wowe cyangwa undi muntu wo muri uru rugo, yabuze uko yiyuhagira kubera ikibazo cy'amazi (urugero: Mazi adahagije, yanduye, adatekanye)?

Ikitabwaho: Iki kibazo kijyanye nuko hari umuntu uwo ariwe wese utarabashije koga umubiri we bitewe nuko hatari amazi ahagije yo koga. Rimwe narimwe umuntu wo murugo ashaka ariko hatari amazi ahagije yo kubikora. Cyangwa hari amazi ahagije yo koga kuri bamwe bo mumuryango ariko adahari kubandi.

In the last 4 weeks, how frequently have you or anyone in your household had to go without washing their body because of problems with water (e.g., not enough water, dirty, unsafe)

____

(HINT: This question refers to anyone in the household not being able to wash their body because there isn't enough water for bathing. Sometimes household members need to bathe, but there isn't enough clean water to do so. Or, there may be enough water for some members of the family to bathe but not others.)

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9) Mu byumweru 4 bishize, ni kangahe wowe cyangwa undi muntu wo muri uru rugo yagiye kuryama afite inyota kubera kubura amazi yo kunywa?

Ikitabwaho: iki kibazo kijyanye no kutagira amazi ahagije yo kunkwa murugo rwawe no kumva ufite inyota igihe ugiye kuryama.urugero, abantu bashobora kumara amasaha menshi batankwye amazi kuko badafite amazi ahagije, bakayabikira abandi mubagize umuryango, cyangwa amazi ahari simeza kuyankwa.

In the last 4 weeks ago, how often you or one of your household member went to bed thirsty due to the water problem?

____

(HINT: This question refers to not having enough water to drink in your household and feeling thirsty when you are going to sleep. For example, people can go many hours without drinking water because they do not have enough, they are saving it for other household members, or the water available isn't suitable for drinking.)

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10) Mu byumweru 4 bishize, ni kangahe wowe cyangwa undi muntu wo muri uru rugo byamusabye guhindura gahunda isanzwe cyangwa ibyateganyijwe bitewe n'imiterere y'ikibazo cy'amazi? (Imirimo yarogowe harimo kwita ku bandi, gukora imirimo yo murugo,imirimo y'ubuhinzi, imirimo yinjiza amafaranga, gusinzira, n'ibindi)

Ikitabwaho: iki kibazo kijyanye n'iby'umunsi wawe warogowe bitewe n'ikibazo cy'amazi. Ahantu hamwe, abantu bakora urugendo kugirango babone amazi, bikabafata igihe bikaba byakica gahunda. Muri Kirogoya harimo, niba ushaka gusura inshuti ariko ntubishobore kuko ugomba kujya gushaka amazi, Ukabuka mu ijoro hagati kugirango ubone amazi, cyangwa hakagira ibindi bibazo bigutera. (imirimo yarogowe harimo kwita ku bandi, gukora imirimo yo murugo,imirimo y'ubuhinzi, imirimo yinjiza amafaranga, gusinzira, n'ibindi).

In the last 4 weeks ago, how often you or one of your household member was required to change their plan due to the problem of water? (Activities that may have been interrupted include caring for others, doing household chores, agricultural work, income-generating activities, sleeping, etc.)

____

(Hint: This question refers to your day being interrupted by problems with water. In some places, people have to travel to get water, which takes time and can interrupt plans. Interruptions include if you want to go visit a friend but cannot because you have to go get water, waking in the middle of the night to get water, or because there are problems caused by flooding that you have to deal with instead. (Activities that may have been interrupted include caring for others, doing household chores, agricultural work, income-generating activities, sleeping, etc.))

11) Mu byumweru 4 bishize, ni kangahe mu rugo rwanyu hatari amazi namba haba ayo gukoresha cyangwa ayo

-

kunywa? (HINT: This question refers to not having any waterin your household that can be used for household

Ikitabwaho:iki kibazo kijyanye no kutagira amazi mu activities or for drinking. For example, in some rugo ashobora gukoreshwa igikorwa gukoresha igikorwa places, people do not have enough storage to keep icyo aricyo cyosebcyangwa ayo kunkwa.Urugero, mubice water or are unable to get enough water to have forbimwe na bimwe, abantu ntibagira hantu hahagije ho immediate needs as well as to store for later kubika amazi cyangwa bad Aashoboye kubona amazi needs. In other places, water may be flooding a ahagije yo kuba bakaresha igihe bayakeneye byihutirwa home, but none of the water that has gone into thecyangwa bayabika bakayakoresha igihe bazayakenerera. house is useful for drinking, washing, cooking, or Ahandi, amazi akaba yaba murugo ariko ntamazi yaba other activities)

yaje murugo ashobora gukoreshwa mukunkwa, kumesacyangwa ibindi bikorwa.

In the last 4 weeks, how frequently has there been nouseable or drinkable water whatsoever in your household?

12) Mu byumweru 4 bishize, ni kangahe wowe cyangwa undi muntu wo muri uru rugo, yabuze uko akaraba intoki

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amaze gukora imirimo yanduza kubera ikibazo cy'amazi (Hint: This question refers to water for washing (urugero: imirimo idafite isuku no guhindura ibyahi, hands. Sometimes you may need to do dirty/uncleangukoresha umusarani,gukukira amatungo? activities like changing diapers, using a toilet,

smearing mud or dung on walls or floors to insulate Ikitabwaho: iki kibazo kijyanye n'amazi yo gukoraba your home, cleaning, or taking care of animals, and intoki. Rimwe narimwe ushobora kukenera gukora imirimo you may not have enough water to wash your handsyanduza. urugero: imirimo idafite isuku no guhindura after. If you choose not to wash your hands, this ibyahi, gukoresha umusarani, ukaba ushobora kuba is different than not having enough water to wash ntamazi ufite yo gukaraba intoki nyuma.iyo uhisemo them.)

kudakaraba intoki, ibi bitandukanye no kuba ntamaziahagije ufite yo gukaraba intoki.

In the last 4 weeks, how frequently have you or anyonein your household had to go without washing hands after dirty activities (e.g., defecating or changing diapers, cleaning animal dung) because of problems with water?)

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13) Mu byumweru 4 bishize, ni kangahe wowe cyangwa undi muntu wo muri uru rugo yatewe ipfunwe/kumva usuzuguritse, kumva uhejwe, kwigunga n'ikibazo cy'amazi ?

(HINT: There are many reasons why people might feel ashamed, excluded, or stigmatized because of problems with water. This could include not being able to provide visitors with water if they stop by your home or feeling unclean due to lack of water.)

Ikitabwaho:hari impamvu nyinshi zituma abantu bagira ipfunwe, kwinuba, cyangwa kwigunga bitewe n'ibibazo by'amazi. Aha ushobora gushyiramo kutagira ubushobozi bwo guha abashyitsi amazi igihe bageze iwabo

In the last 4 weeks, how frequently have problems withwater caused you or anyone in your household to feel ashamed/excluded/stigmatized?/

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14) SECTION COMMENTS

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15) Section end

MG70 Programexposure

section start time

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SOMA CYANE: Ubu ngiye kukubaza ibibazo bijyanye n'ubwitabire bwawe muri gahunda y'amakelebe y' ubuzima (cg isuku). (hint: no response needed)

SAY: I am going to ask you questions about your participation in CHCs program. (hint: no response needed)

Mubyumweru 4 bishize ,wigeze witabira ibiganiro byateguwe na Kelebe y'isuku muri uyu mudugudu?

In the last four weeks, have you attended any session organized by the community health club IN THIS VILLAGE?

- ◯ Yes
- ◯ No

Mubyumweru 4 bishize, haba hari undi muntu wo muri uru rugo witabiriye ikiganiro cyateguwe na kelebe y'ubuzima muri uyu mudugudu?

In the past four weeks, has anyone else in this household attended any session organized by the community health club in this village?

- ◯ Yes
- ◯ No
- ◯ Don't know

Ni ukubera iki urugo rwawe rutitabiriye ibiganiro mu byumweru 4 bishize? HITAMO BYOSE BIJYANYE.

CHECK ALL THAT APPLY

Why did your household not attend a session in the past 4 weeks?

1, Community health club did not have a session/1,Kelebe y'ubuzima ntabiganiro yagize.
2, Household members were busy/2,Abagize urugo bari bahuze.
3, Household members do not have interest/3,Abagize urugo ntibabyitayeho.
4, Household members have finished all modules/4,Abagize urugo barangije amasomo yose 5, Other (specify)/5,Ibindi(bivuge)

Annex - The Applications of Implementation Science in Water, Sanitation, and Hygiene (WASH) Research and Practice

The following manuscript was published in the peer-reviewed journal, *Environmental Health Perspectives*. The published citation is Haque, S. S., & Freeman, M. C. (2021). The Applications of Implementation Science in Water, Sanitation, and Hygiene (WASH) Research and Practice. *Environmental Health Perspectives*, 129(6), 065002

The Applications of Implementation Science in Water, Sanitation, and Hygiene (WASH) Research and Practice

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Background: Delivery of high quality, at-scale, and sustained services is a major challenge in the water, sanitation, and hygiene (WASH) sector, made more challenging by a dearth of evidence-based models for adaption across contexts in low- and middle-income countries.

Objective: We aim to describe the value of implementation science (IS) for the WASH sector and provide recommendations for its application.

Methods: We review concepts from the growing field of IS—defined as the "scientific study of methods to promote the systematic uptake of research findings and other evidence-based practices into routine practice, and hence, to improve the quality and effectiveness of health services"—and we translate their relevance to WASH research, learning, and delivery.

Discussion: IS provides a suite of methods and theories to systematically develop, evaluate, and scale evidence-based interventions. Though IS thinking has been applied most notably in health services delivery in high-income countries, there have been applications in low-income settings in fields such as HIV/AIDS and nutrition. Expanding the application of IS to environmental health, specifically WASH interventions, would respond to the complexity of sustainable service delivery. WASH researchers may want to consider applying IS guidelines to their work, including adapting pragmatic research models, using established IS frameworks, and cocreating knowledge with local stakeholders. https://doi.org/10.1289/EHP7762

Introduction

The water, sanitation, and hygiene (WASH) sector has struggled to achieve at-scale and sustained improvements to its services, particularly for the world's most vulnerable populations (WHO/UNICEF 2019). Inconsistent and nonfunctional water supply and underused and deteriorating toilets undermine significant progress toward achieving universal access to safe water and sanitation. The United Nations (UN) estimates that at least 29% of the global population relies on some level of fecal or chemically contaminated or unimproved water source for drinking (WHO/UNICEF 2019). Two billion people do not use sanitation facilities coupled with safe excreta disposal and treatment services, and 3 billion people lack handwashing facilities with available soap and water (WHO/UNICEF 2019). Despite the strong biological plausibility that improving WASH conditions is a basic strategy for yielding gains in health, several rigorous, high-profile field trials reveal minimal or no reductions in childhood diarrheal disease or undernutrition from WASH interventions typically delivered to rural populations in low- and middle-income countries (LMICs) (Clasen et al. 2014; Humphrey et al. 2019; Luby et al. 2018; Null et al. 2018; Patil et al. 2014; Pickering et al. 2015). The evidence for health impact from WASH service delivery in urban areas in LMICs is also limited (Barreto et al. 2007).

The failure to sustain services and reliably quantify health gains in the sector is perhaps rooted in the complexity of innovation and implementation strategy requirements, limited external validity, diverse objectives, and the multiple service providers and multilevel nature of WASH interventions. Simply stated, there is limited rigorous research on what works to achieve sustained coverage and use at scale across myriad contexts. Organizational and behavioral theories are rarely applied to designing and adapting interventions, and context and delivery are seldom described thoroughly to inform scale-up and replication. In some cases, promising WASH innovations have been rapidly scaled with little rigorous assessment of how barriers and facilitators of favorable implementation outcomes vary across local settings (Hueso and Bell 2013; Sinharoy et al. 2017).

The challenges of sustaining WASH provision at scale, and for these gains to translate to health gains, warrant a new paradigm for how the sector operates and learns, especially as the sector aims to meet sustainable development goal six (SDG-6) to provide universal access to "safely managed" water and sanitation and "basic" hygiene by 2030 (WHO/UNICEF 2019). The SDG-6 targets aspire for higher quality WASH services that are more closely aligned with improved health and well-being outcomes than predecessor global goals. Achieving these targets will require complex and transformative interventions that reach consistently neglected populations and create institutional capacity able to monitor and maintain standards of quality and use of services (Pickering et al. 2019).

We believe that the field of implementation science (IS) offers theory, process, and rigor for the WASH sector to better deliver and evaluate its investments and disseminate its findings. IS focuses on the translation gap between what is learned in the laboratory or within efficacy studies and what is delivered under real-world conditions (Theobald et al. 2018). Community and stakeholder engagement are key to IS to ensure relevant questions and direct application. IS objectives have been applied to improve the delivery of global health programs (Madon et al. 2007; Van Belle et al. 2017), including in the HIV/AIDS (Hickey et al. 2017), nutrition (Tumilowicz et al. 2019), and health systems sectors (Remme et al. 2010; Sanders and Haines 2006). However, there have been limited attempts to apply IS to the WASH context (Setty et al. 2019) or to environmental health interventions in general (Rosenthal et al. 2017; 2020). Here, we describe the broader objectives of IS, defining fundamental terminology and concepts. Next, we identify the key challenges of operationalizing and delivering WASH interventions. We then discuss common IS guidelines that WASH researchers may want to consider applying to their work, including adapting pragmatic research models, using established IS frameworks, and cocreating knowledge with local stakeholders.

General Implementation Science Objectives and Concepts

In its earliest applications, IS was focused on improving health care practice in high-income countries. The most traditional

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definition of the field is the "scientific study of methods to promote the systematic uptake of research findings and other evidence-based practices into routine practice, and hence, to improve the quality and effectiveness of health services" (Eccles and Mittman 2006). However, as the field has grown outside clinical settings, sectors have made adaptations and additions to its scope. A common criticism is that the literature has competing nomenclature and frameworks (Nilsen 2015). For simplicity, we consistently use the term "implementation science" throughout this commentary. We recognize that some of the ideas we cite come from several alias or ally fields, including implementation research, translational science research, dissemination research, comparative effectiveness research, and others (Glasgow et al. 2012; Peters et al. 2013; Woolf 2008).

IS aims to apply evidence-based health interventions in high-risk populations with "greater speed, efficiency, appropriate fidelity, and relevant coverage" (Kemp et al. 2018). The defining qualities of IS in global health are its flexibility, real-world focus, emphasis on processes and outcomes for intervention delivery, application across stakeholders, and fit-to-purpose methods. These qualities are critical for global health research to reduce health disparities, inform policy design and implementation, improve management, enhance service delivery, and empower communities (Theobald et al. 2018). Those researchers focusing on improving WASH evidence and evidence-based practice may already incorporate these qualities into their work and examine implementation challenges. The past several years have also seen a greater focus on implementation research from some key donors (USAID 2020). However, a traditional gap persists between sector research focused on technology development and health impact assessment and programmatically relevant operational learning focused on coverage and delivery. Implementation research in WASH has often focused on institutional knowledge within organizations and has been ad hoc, without applying systematic methods. The purpose of this commentary is to highlight IS concepts and practices that the WASH sector as a whole can adapt.

A key framework by Proctor et al. (2009; Figure 1) depicts the basic concepts and domains of study within IS. A significant feature of the framework is that it disaggregates the intervention by its innovation or technology and implementation strategy. We note that the WASH innovations frequently employed—toilets, taps, soap, behavior change communication, etc.—are conventionally thought of as interventions, when in fact they are technologies that must be coupled with evidence-based implementation strategies. Examples of WASH innovations fall somewhere under categories of programs [ongoing service models or campaigns—e.g., community hygiene clubs, village water and sanitation committees, Community-Led Total Sanitation (CLTS)], products (WASH hardware and infrastructure), practices (WASH behaviors), principles (established and emerging theories—e.g., sanitation coverage thresholds, economies of scale), and policies (e.g., subsidies, standards, targeting) (Brown et al. 2017). Their counterpart, implementation strategies, are the intentional methods used to improve the adoption, delivery, and sustainability of the innovation (Proctor et al. 2013). Strategies are broadly grouped by six processes: planning (identifying actors, actions, targets, temporality, and dose), educating (promoting innovation and gaining buy-in), financing (funding, incentive structures), restructuring (reforming roles, systems adaptation), quality management (monitoring, maintenance, feedback), and attending to policy context (laws, enforcement, and institutions) (Powell et al. 2012; Proctor et al. 2013). For example, a sanitation program targeting slums as an intervention alone will likely be unsustainable without processes that restructure the roles of utilities and small and informal service providers and the policy context that enables enforcement of standards in those communities (Haque et al. 2020; Trémolet and Halpern 2006). Powell et al. (2015) compile

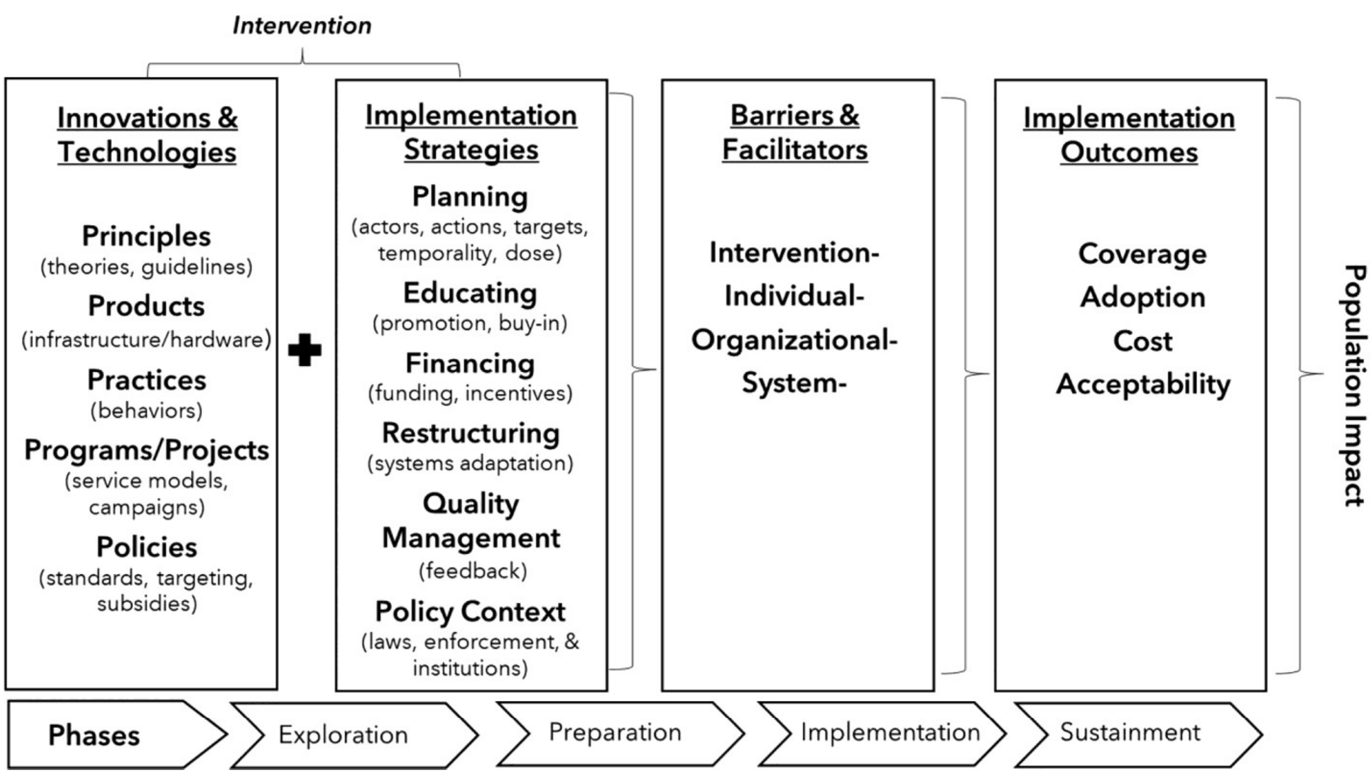

Figure 1. Conceptual framework for Implementation Science research (figure adapted from Proctor et al. 2009 and builds on concepts from Brown et al. 2017; Powell et al. 2012; Powell et al. 2020).

and define more than 70 discrete implementation strategies that illustrate the range of activities used to build a multifaceted approach. The intervention additionally faces contextual barriers and facilitators embedded at multiple levels (e.g., intervention-, individual-, organizational-, and system- levels) during real-world implementation. These factors will influence implementation outcomes, which measure the degree to which the intervention was delivered as intended (Fixsen et al. 2005; Proctor et al. 2013). An intervention will fail to deliver impacts due to implementation failure, theory failure, or both (Suchman 1968). Implementation failure results from poor implementation outcomes. Theory failure occurs when the intervention was implemented correctly but failed to achieve desired impact due to a problem in the underlying theory of change, an understanding of how the intervention should catalyze change.

Research on WASH provision has largely stayed in the exploration phase of this framework, studying questions on innovations' ability to deliver health gains without sufficient attention to the necessary pathway for health impact in a given context. The biological plausibility that safe or improved WASH is a foundation of public health is well established in history (Wagner and Lanoix 1958; Cutler and Miller 2005; Tulchinsky 2018). Yet, recent field trials have raised concerns that common WASH interventions implemented in LMICs are not delivering anticipated health gains, even under relatively controlled conditions (Clasen et al. 2014; Humphrey et al. 2019; Luby et al. 2018; Null et al. 2018; Patil et al. 2014; Pickering et al. 2015). To conclude from these trials that WASH, in principle, does not improve health, fails to consider the contextual and implementation nuances surrounding the tested interventions in each setting (Cumming et al. 2019; Whittington et al. 2020). Possible explanations for limited health impact have largely focused on the inability to effect implementation outcomes related to coverage and adoption, including the failure to break relevant pathways of fecal exposure, inadequate behavior change, and insufficient coverage to surpass sanitation thresholds that would improve health (Cumming et al. 2019; Pickering et al. 2019).

Challenges of WASH Provision

The interpretation of recent trials and faltering global progress in WASH delivery illustrate the complexity of providing sustainable WASH interventions at scale. We summarize this complexity by outlining four key challenges of WASH provision: *a*) complex innovation and implementation requirements; *b*) limited external validity of interventions; *c*) inconsistent development sector objectives; and *d*) diverse service providers working at multiple levels. Taken together, these four challenges demonstrate the demand for rigorous IS research on the development and delivery of evidence-based interventions, how interventions respond to different contexts, and the implementation outcomes that lead to population health and social impact.

Complex innovation and implementation requirements. We assert that WASH innovations and their implementation strategies are multifaceted, expensive, and not well-defined in the sector. Disrupting multiple exposure pathways to diverse enteric pathogens (Platts-Mills et al. 2015) entails a well-managed system of WASH interventions, with no single technology or behavior likely being sufficient to accrue significant health or social benefit and no single implementation strategy being able to achieve sufficient coverage and uptake of WASH innovations. The findings of recent trials have sparked debate on the utility of simple and fragmented WASH interventions in LMICs and the need for "transformative WASH" that requires investment in large-scale water and sanitation systems that enable behavior change (Cumming et al. 2019; Pickering et al. 2015). However, we lack an understanding of the technology and processes needed for this transformation. Although the sector has limited evidence on effective methods that lead to improved coverage and use of innovations over time, there have been successes in equitable improvements to sanitation, provision of continuous water supply, and programs to increase handwashing and hygiene behaviors (Biran et al. 2014; Kirby et al. 2019). In many of these cases, documentation of that delivery process has been limited. Process questions about the required intensity of behavior-change promotion, appropriate financing mechanisms, structuring service-provider roles and incentives, and improving monitoring and information systems are often left unanswered.

Limited external validity of interventions. A WASH intervention proven to be effective in one setting is not guaranteed to be effective in another. Dominant pathways of fecal exposure and pathogens are dynamic and differ by temporal and spatial scales (Kotloff et al. 2013; Robb et al. 2017; Sclar et al. 2016) due to a multitude of factors, such as community-level sanitation, climate, animal management, hydrogeology, vaccine coverage, social norms, etc. (Ercumen et al. 2017; Penakalapati et al. 2017). Broken water taps and pumps are also attributable to contextual factors, such as managing and incentive structures, hydrogeology, and access to energy (Alexander et al. 2015; van den Broek and Brown 2015; Whaley and Cleaver 2017; Yerian et al. 2014). So, too, a behavioral approach targeting specific drivers or norms in one context cannot readily be transferred to another context.

Generalizability concerns are evident in sanitation behavior-change programs that are shown to lose their effectiveness when replicated in new contexts. The initial deployment of CLTS, for example, was deemed promising in Bangladesh for eradicating open defecation behavior (Kar and Chambers 2008); however, CLTS exhibits varying success as an export to other countries. Ethiopia, for instance, had initial achievements with CLTS, with significant reduction of open-defecation rates between 2000 and 2015, decreasing from 80% to 27% (WHO/UNICEF 2017). However, Ethiopia faces problems of "slippage," where household members revert to open-defecation behavior or the community returns to having a high prevalence of sanitation-related diseases post program (Abebe and Tucho 2020). Slippage problems after CLTS deployment are being commonly reported in monitoring surveys throughout countries (Crocker et al. 2017; Harter and Mosler 2018; Jerneck et al. 2016). Different forms of CLTS have now spread to nearly 60 countries, but little of its diffusion is guided by robust scientific evidence (Zuin et al. 2019). Increasing implementation research finds that the innovation's effectiveness in sustaining villages that cease open defecation depends on a variety of household, community, policy environment, and program implementation factors, such as financial resources, access to construction materials, social cohesion, and strong local leadership (Venkataramanan et al. 2018; Zuin et al. 2019). A WASH intervention needs to be carefully tailored to its environmental, social, and political contexts, yet there is scant research on contextual factors that enable effective implementation (Dreibelbis et al. 2013; Whittington et al. 2020).

Inconsistent development sector objectives. The sector has a diverse constituency of interests, which we find results in a tension to determine whether the end goal of WASH investments should be, for example, health impact or the sustainable provision of services itself. WASH was declared a human right in 2010 as part of UN Resolution 64/292 (2010), but health, food security and nutrition, and gender equity are also major drivers of sector investment (HLPW 2016). Efforts to provide safe, reliable, and sufficient quantities of water and to provide for the effective separation of feces are largely implemented outside of the health system (Trémolet and Rama 2012), despite clear health end points.

WASH services delivered by state actors (e.g., the Ministry of Water, utilities), informal actors, or nongovernmental organizations (NGOs) may lack explicit health objectives, either operating within a financial model of service delivery or using a rights-based lens (Satterthwaite 2014; Sweetman and Medland 2017). WASH is typically seen as an input for meeting objectives of multiple sectors, scattering opportunities for improving WASH across development investments (Trémolet and Rama 2012; Seppälä 2002). Simple provision of SDG-6-defined technologies alone cannot guarantee knock-on effects toward achieving multiple development goals (Wolf et al. 2018). We note that a lack of consistent objectives makes it difficult to define systematic measures of success and thus develop theory-driven interventions and monitoring and accountability structures.

Diverse service providers working at multiple levels. A final challenge is that the sector operates as a complex system, with multiple levels of diverse service providers such as governments and nonstate actors, including NGOs, the private sector, and communities. Though there are a number of guidelines and standards for service provision available at national levels, the variety of vertical and horizontal actors involved in service delivery makes it difficult to assign and enforce liability (Seppälä 2002). Services become decentralized in practice, with a number of nonstate actors ultimately having discretion over how a WASH program is defined and delivered on the ground (Trémolet and Rama 2012). Implementation variability is high in places where WASH improvements rely on a consortium of NGOs and community-based management or in areas that lack formal mandates of service delivery (Sharma et al. 2010). Households and communities regularly take on management responsibilities and finance two-thirds of all WASH services, with many of these investments coming through self-supply solutions such as private wells, water tanks, pit latrines, or septic tanks (WHO/UN Water 2017). The diversity of service providers creates more opportunities for implementation failure where interventions are not delivered as intended and for decision-making that is not driven by theory and evidence. As is the case with much of the health and development sectors, there has also been limited attention to whether the implementing organizations themselves are sufficiently capacitated to innovate and adapt, and whether the funding mechanisms have even encouraged local adaptation.

IS Principles That Respond to the Complexity of WASH Provision

We recommend that the sector adapt three guiding IS principles to help address the complexity of WASH provision. The first is to conduct "pragmatic" research that reports on the "how" and "why" of intervention impact. This work requires researchers to fit methods to research questions and not vice versa, thus necessitating an appreciation for the full suite of available study designs. The application of hybrid effectiveness-implementation trial designs, economic evaluation, modeling, and process evaluations based on established theories of change would support questions on the means and rationales of intervention impact, adherence, and fidelity (Bauer et al. 2015). Second, we recommend routine use of established IS theories, frameworks, and models to understand context, design theory-based interventions, and document and evaluate interventions. This IS principle aids in understanding the generalizability of interventions and communicating implementation research using a shared language. Finally, we recommend co-creating knowledge with local policymakers, practitioners, and constituents to better align research questions with the needs of service providers at multiple levels and design theory-based interventions around the relevant interests of stakeholders (e.g., beyond health end points). This practice of co-creation may also improve the uptake of findings by conducting research under more real-world conditions and build IS capacity among stakeholders to sustain implementation research. All three recommendations will require the application of new tools and training but also will require new funding opportunities that prioritize this modality of learning and collaboration. We expand on these principles and describe their relevance and application to the sector below.

Adapt "pragmatic" research models. Studies that show causal inference of an intervention (e.g., experimental and quasi-experimental designs) are stressed as a precondition for interventions to be eligible for investment and replication (Woolcock 2013). However, research with this sole purpose often underreport the contextual and operational factors surrounding interventions, which are arguably the most important for guiding policy and practice at scale (Luoto et al. 2014). Experimental trials by design remove "local details" that inform how a program worked (Berwick 2008). Operational monitoring of individual projects may provide more detail on understanding if an intervention is working but often center around a specific context, without regard to how successes and challenges are related to the generalizability of the approach or for sectorwide learning. In many ways this is analogous to the debate between studies that prioritize internal validity over external validity (Victora et al. 2004). We believe that both approaches are necessary but insufficient for building the evidence base for guiding WASH policy.

Implementation scientists aim to understand *how*, not merely *whether*, programs achieve anticipated gains. The deficient documentation of WASH intervention development and delivery and the lack of rigorous process evaluations that relate implementation outcomes to intervention effectiveness make it difficult to identify whether failures to achieve health gains are due to failures in implementation, theory, or both. In the case of several recent WASH and nutrition trials, intervention fidelity was high, but compliance by beneficiaries was inconsistent, so it is possible that the underlying theory of change, specifically for technology choice and behavior change strategies, for these interventions was flawed (Cumming et al. 2019; Pickering et al. 2019; Whittington et al. 2020). In addition, WASH studies may target populations or deliver interventions that lack external validity, meaning that they are not conducive to guide global policy. For example, the WASH-Benefits trial in Kenya worked in areas with higher sanitation access and little water scarcity, limiting its application to understanding an important programmatic and policy question: the impact of improved water quantity or sanitation in areas with lower overall access (Null et al. 2018).

Trial results are often more actionable if they incorporate findings on the implementation and translation processes (Glasgow et al. 2012). This methodology requires attention beyond individuals receiving the intervention, and an emphasis on intervention delivery, including documenting specific activities, implementing organizations, surrounding political/environmental/social settings, and effects on implementation outcomes over time. These details could be examined using different methods, such as pragmatic trial designs, process evaluation, comparative case study analysis, modeling, cost–effectiveness analysis, or qualitative data collection as part of the intervention delivery process.

For example, process evaluations document the intervention and assess basic implementation outcomes against clearly articulated delivery protocols. They can also help to validate the hypothesized theory of change, which is especially useful for explaining any null effects (Saunders et al. 2005). Validation does not necessarily mean to homogenize the specific components of interventions but to regiment their fundamental processes and functions for improved external validity of the intervention design across settings (Hawe et al. 2004). Few WASH studies use process evaluation for this purpose. Going back to an earlier sanitation example, the *Handbook on CLTS* stresses the importance of pragmatism, providing general guidance on the core components of the behavior-change program but few standards on how to deliver components, because those should depend on local context (Kar and Chambers 2008). This implementation variability makes it difficult to evaluate CLTS as a single program (Venkataramanan et al. 2018; Zuin et al. 2019); however, it is still possible to test the underlying theory of intervention components, evaluating them against their ability to effect implementation outcomes over time. Strengthening this type of evidence may improve the sector's capacity to design theory-driven interventions across contexts.

Optimizing delivery is especially relevant for scaling WASH interventions that are efficacious but costly to scale. There are several IS research designs used to specifically test and adjust implementation strategies for improved outcomes in cost, uptake, maintenance, etc. Pragmatic hybrid trial designs test the effectiveness of an intervention in the context of competing implementation strategies, which can also integrate cost-effectiveness evaluation (Brown et al. 2017; Peters et al. 2013; Theobald et al. 2018). For instance, health effects of point-of-use chlorination are only observed in trials that report daily to fortnightly contact between behavior-change promoters and study participants (Pickering et al. 2019). A hybrid trial could compare varying "doses" of promotion on implementation outcomes to design a more scalable intervention. Sequential multiple assignment randomized trial (SMART) designs are a way to adapt interventions and compare different intervention options during evaluation, particularly adjusting components or the intensity/dosage of an intervention depending on the study participants' response (Lei et al. 2012; Almirall et al. 2012).

Systems science also offers methods (e.g., network analysis, system dynamics, agent-based modeling) to examine nonlinear processes in changing interactions and implementation outcomes and simulate alternative implementation targets across myriad contexts (Truscott et al. 2017; Rosenthal et al. 2020). Quality improvement studies provide structured methods for involving all stakeholders to iteratively plan, execute, and analyze new ways of improving performance (Brown et al. 2017). This study type has proven to be useful for codesigning handwashing interventions with local service providers by rapidly piloting and optimizing protocols in health care settings (Kallam et al. 2018). These different methods may help bridge the translation gap between outputs and impacts, specifically in improving our understanding of how to change and sustain behaviors and generalizability of interventions.

Use IS theories, frameworks, and models throughout the research process. The use of systematic models, both the application of behavioral theory and action planning frameworks, is a hallmark of IS research. Their use and reference provide structure and a shared language to better design, adapt, and evaluate interventions and facilitate learning among organizations (Tabak et al. 2012). Numerous and competing theories, frameworks, and models have emerged from the field, making it difficult to choose just one to discuss. Below we introduce the taxonomy of IS approaches and provide several examples of how established IS approaches could be used in the WASH context.

IS approaches can be organized into three general overarching objectives of the field (Nilsen 2015): *a*) articulating the determinants or influences of process/implementation outcomes (determinant frameworks, classic theories, and implementation theories); *b*) evaluating implementation (evaluation frameworks); and *c*) describing or guiding the process of translating knowledge into practice (process models).

The Consolidated Framework on Implementation Research (CFIR), for example, is a widely used *determinant framework* that can inform intervention selection and systematically identify possible barriers and facilitators for sustainable delivery. The CFIR harmonizes concepts across implementation theories into five major domains, allowing researchers to select CFIR constructs that are most pertinent to understanding their unique implementation setting and the "contextual fit" of an intervention (Damschroder et al. 2009). The intervention domain of CFIR includes constructs that consider all types of characteristics of the intervention, such as its origins of development, technological quality, complexity, and cost, and its adaptability to be altered and tailored for local needs (Damschroder et al. 2009). The CFIR's *outer setting* domain touches on economic, political, and social forces that influence the implementation of the intervention. For example, project timelines could be too short to meet desired outcome or impact as a result of election or budgetary cycles. The feasibility to meet something like water quality standards could also depend on a jurisdiction's institutional and legal framework for assigning and enforcing liabilities among the mix of service actors. Outer-setting factors are sometimes beyond a local implementer's control, but they should at least be accounted for during program design.

The CFIR's inner setting domain, in contrast, describes much of the operational constructs of the service provider. Here, one can think of characteristics of the provider such as the experience, maturity, culture, and skills capacity. Implementation scientists may also further assess institutional capacity by using other frameworks based on organizational theory regarding "readiness for change" (Helfrich et al. 2011). During effectiveness trials, interventions are sometimes delivered by a highly trained team with ample resources for monitoring and ensuring high fidelity to the intervention (Alonge et al. 2019; Brown et al. 2017). For example, the Sanitation Hygiene Education and Water Supply in Bangladesh (SHEWA-B) program aimed to improve WASH behaviors for 20 million rural Bangladeshis. Although SHEWA-B's design was proven effective in rigorous pilot studies, the scaled program was able to improve only a few targeted behaviors and did not significantly improve child health (Huda et al. 2012). Program evaluators speculated that the program's shortcomings were in operational delivery, because contracted NGO promoters did not have sufficient training and practical monitoring strategies were underdeveloped (Huda et al. 2012). Use of the CFIR or readiness assessments could support predictions of organizational shortcomings.

Implementation theories are especially useful for designing interventions. COM-B (Capacity-Opportunities-Motivation-Behavior), a widely used tool, adapts 19 behavioral theories from multiple disciplines into one instrument for planning behavior-change innovations (Michie et al. 2009). COM-B has been applied in the WASH sector to guide formative research and design novel WASH innovations for improving behavior outcomes in caregiving practices, safe feces management, and hygiene (Caruso et al. 2019; Delea et al. 2019; Freeman et al. 2020). There are also some established behavioral models specifically developed in the WASH sector, including the Integrated Behavioral Model for WASH (IBM-WASH) (Dreibelbis et al. 2013), RANAS (risks, attitudes, norms, abilities, and self-regulation) (Mosler 2012), and the Evo-Eco approach (Aunger and Curtis 2014). Determinant frameworks and implementation theories could be more widely used and documented in sector research, specifically to inform intervention development and to sufficiently detail an intervention's proposed theory of change.

Evaluation frameworks identify possible indicators for objectively measuring successful implementation. In an attempt to systematize process outcomes, Proctor et al. (2011) outline eight dimensions of implementation outcomes that include acceptability, adoption, appropriateness, feasibility, fidelity, implementation cost, penetration, and sustainability, each with potential units of analysis and methods for measurement. RE-AIM (an acronym for Reach, Effectiveness, Adoption, Implementation, and Maintenance) is a frequently used evaluation framework that is more operationally focused (Glasgow et al. 1999). These frameworks are possibly convenient for designing program checklists/diagnostics, monitoring and evaluation methods, and performance-based contracts for implementing partners.

Process models attempt to illustrate the steps needed for disseminating and translating knowledge. They may be valuable for knowledge mapping and planning organizational research agendas and scientific communication. We have not found an example of a process model used by a WASH implementer or funder; however, there are a few examples used by related research organizations. The U.S. Centers for Disease Control and Prevention (CDC) promotes the Knowledge to Action (K2A) framework for achieving individual and organization uptake of an evidence-based intervention (Wilson et al. 2011). The three distinct phases are the research/discovery, translation, and institutionalization phases, all of which have their own decision points and supporting structures for moving knowledge to action (Wilson et al. 2011). The U.S. National Institutes of Health integrate the Glasgow et al. (2012) translational phases of dissemination and implementation science research, which define the cyclical, interrelated process of moving research into policy. Figure 2 simplifies the primary objectives of the translational phases. The preliminary phase (T0) describes identification of the problem and new discoveries, including formative research, monitoring data, capacity assessments, and diagnostics. The first phase (T1) includes behavioral trials and rapid testing of an intervention in a new context. The second phase (T2) includes a set of studies and trials that extend along the intervention-impact chain, focusing on internal validity and efficacy. The third and fourth stages (T3 and T4) are on improving activity–output–outcome by focusing on fidelity of the intervention and testing effectiveness studies in different contexts to improve effectiveness and cost effectiveness.

Rather than recommending any particular IS framework, theory, or model when designing programs and studies, we instead advocate for WASH stakeholders to consider applying the structured IS approaches that are most contextually appropriate. We caution that IS was principally developed for clinical settings in high-income contexts, and adaptation to nonhealth system delivery and LMICs is just now emerging. Nevertheless, the approaches are still relevant to WASH, and its application is not merely an academic exercise. We believe the application is practical to integrate policy, program, and learning from stakeholders and to improve effective scale and replication of successful interventions and innovations. The application of these frameworks and models will require building capacity of stakeholders regarding their use. These tools can be applied from initial scoping of context and the use in formative evaluation describing the intervention components and fidelity and compliance of delivery.

Co-create knowledge with multiple stakeholders. Global health advocates of implementation science have underscored the necessity of collaboration among researchers, policymakers, implementers, and communities for building and using the knowledge base (Alonge et al. 2019; Theobald et al. 2018; Holt and Chambers 2017). Environmental health research generally supports this principle, such as in the promotion of community-based participatory research methods for addressing environmental exposure concerns of community residents (O'Fallon and Dearry 2002). Yet, a review on global health studies claiming IS applications found that efforts to involve diverse stakeholders were infrequent, with few examples of comprehensive discussions on policy implications (Alonge et al. 2019). This collaboration is critical for proposing relevant research questions on implementation, designing theory-driven and context-specific interventions, and increasing the probability of conducting research under real-world conditions that are not heavily influenced by research teams (Holt and Chambers 2017; Alonge et al. 2019). Involving the multitude of constituents in the entire research process may also importantly foster shared ownership and improve the transfer of scientific skills for building local research capacity and strengthening monitoring and management of information systems. The WASH sector

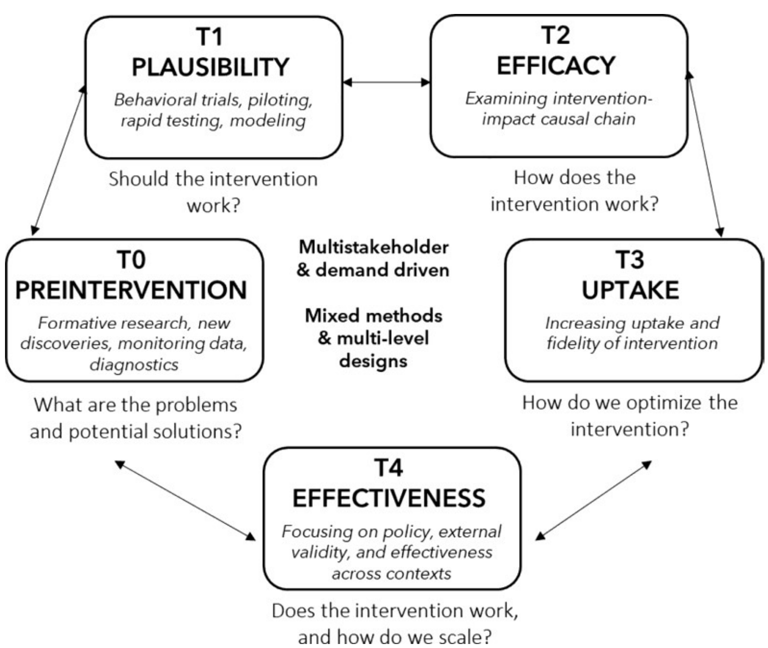

Figure 2. Translational Phases of Evidence to Practice (adapted from Khoury et al. 2010 and Glasgow et al. 2012).

has many examples of multisectoral and multistakeholder collaboration, but the sector can strive to better institutionalize and document collaboration for its replication in other contexts. However, we stress that it is essential that researchers possess the competencies needed to work with communities, such as positive attitudes toward community engagement and willingness and capability to gain knowledge about the community and collaboratively conduct research (Shea et al. 2017).

Discussion

Water and sanitation are deemed to be human rights, and donor and government funds should rightly continue to support improvements in WASH access for the billions of people who remain underserved (WHO/UNICEF 2019). There are decades of experience implementing WASH interventions in resource-poor regions, yet approaches to adapting, scaling, and sustaining WASH access and behaviors remain elusive. Recent large-scale health impact studies have highlighted challenges in effectiveness of available interventions and potential health gains from WASH investments (Cumming et al. 2019; Pickering et al. 2019; Whittington et al. 2020). New discoveries for enhancing health slowly or seldom deliver their promised impact because their uptake is dependent on interactions between individuals and organizations housed in multifaceted social contexts (Aarons et al. 2011; Glasgow et al. 2012). Yet, donors and governments continue to invest in innovating new technology, despite the compelling argument that increasing uptake of existing evidence-based interventions—and a rigorous approach to learning—would be more cost-efficient and speed the reduction of health disparities (Glasgow et al. 2012; Woolf and Johnson 2005). This gap is partially explained by the lack of incentives to conduct implementation research in academia (Bromham et al. 2016).

But is the WASH sector ready for implementation science? Few would contest the strong biological plausibility that reduction in exposure to fecal pathogens improves health, and adequate WASH technologies and behaviors are key to that reduction. Yet it is reasonable to conclude that the empirical evidence for improvements to health are from higher-income settings (Cutler and Miller 2005), where WASH improvements have been successful at reducing transmission along a narrower set of transmission pathways than those faced by children in lower-resource settings. And as such, the WASH sector operating in these lower-resource settings is not yet ready for the tools of implementation science to document, adapt, and scale proven interventions. However, there have been successes in implementation and on the impact of WASH interventions on health, even if the evidence across all studies is mixed (Freeman et al. 2017; Prüss-Ustün et al. 2019; Wolf et al. 2018). Many countries were able to meet sector targets by 2015, nearly eliminating the dependence on lakes, rivers, and unprotected surface water sources for drinking and the once-widespread practice of open defecation (WHO/UNICEF 2019). There is evidence to suggest that WASH technologies in LMICs have the potential to provide health and social benefits when they are used and well-maintained. On-premise water connections do reliably reduce the prevalence of diarrhea when continuously available and free of fecal contamination (Wolf et al. 2018). Point-of-use filter interventions have been widely used and scaled for improvements in child health (Kirby et al. 2019; Wolf et al. 2018). Demand-based WASH programs can effectively change sanitation and hygiene behaviors at the community level (Garn et al. 2017). We assert that it is imperative that we study the processes and surrounding contexts that enabled these interventions to be effective.

We do not intend to diminish the importance of measuring health and well-being outcomes in WASH research. Untangling the relationship between WASH conditions and health is essential for setting agendas and for innovation. Rather, we can improve the frame and scope of our research questions to match the sector's complexity. We argue that improvements to and standardization of process documentation, application of behavioral theory for development of implementation strategies, the application of flexible design and evaluation approaches, purposeful approaches to adaptation, and awareness of organizational readiness for change could support both improvements to sustained delivery outcomes and measurable health gains at scale. Greater attention to improving uptake, functionality, and accessibility also supports the sector's multiple development end points past reduced diarrheal disease. WASH results in other health and nonhealth gains, including reduced respiratory infections and neglected tropical diseases and improved dignity and security, mental well-being, gender equity, and climate resilience, to name only a few (Prüss-Ustün et al. 2019; Sclar et al. 2018). A focus on implementation outcomes may have downstream impacts beyond specific health end points.

We recommend adapting more pragmatic research models by using the full suite of study designs—beyond traditional RCTS—to inform policy and practice and conduct these studies with rigor that appreciates the importance of external validity. In parallel, we recommend the use of systematic IS approaches throughout the design, documentation, and evaluation of interventions. Use of process models to guide research agendas may help to communicate and translate key learnings into practice [e.g., K2A, (Glasgow et al. 2012)]. Using established behavioral theory [e.g., COM-B, (Michie et al. 2009)] and determinant frameworks to map formative findings to proper intervention functions [e.g., the CFIR, (Damschroder et al. 2009)] may help to describe contextual fit of interventions and develop and test new innovations. Evaluation frameworks [e.g., RE-AIM, (Proctor et al. 2011)] can improve systematic assessment of program fidelity to report implementation success. Co-creating knowledge with multiple stakeholders will help focus research on local decision-making and needs of implementers and increase local research capacity.

The WASH sector can be seen equally as either a set of intervention outcomes (e.g., WASH access) searching for a health impact (e.g., diarrhea, stunting), or a set of human rights outcomes without the need for an infectious disease-related health impact. We believe at this moment that health-specific trials are not the highest priority to address the knowledge gaps in the sector; rather, nimble yet rigorous IS research could provide valuable actionable, policy-relevant guidance. We argue that a dedication to the fundamentals of IS in the sector would support the effective, context-specific application of evidence-based approaches and engender more policy- and programmatically relevant questions that focus on improving implementation outcomes in the WASH sector.

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References

Aarons GA, Hurlburt M, Horwitz SM. 2011. Advancing a conceptual model of evidence-based practice implementation in public service sectors. Adm Policy Ment Health 38(1):4–23, PMID: 21197565, https://doi.org/10.1007/s10488-010-0327-7.

Abebe TA, Tucho GT. 2020. Open defecation-free slippage and its associated factors in Ethiopia: a systematic review. Syst Rev 9(1):1–15, PMID: 33143715, https://doi.org/10.1186/s13643-020-01511-6.

Alexander KT, Tesfaye Y, Dreibelbis R, Abaire B, Freeman MC. 2015. Governance and functionality of community water schemes in rural Ethiopia. Int J Public Health 60(8):977–986, PMID: 25926341, https://doi.org/10.1007/s00038-015-0675-x.

Almirall D, Compton SN, Gunlicks-Stoessel M, Duan N, Murphy SA. 2012. Designing a pilot sequential multiple assignment randomized trial for developing an adaptive treatment strategy. Stat Med 31(17):1887–1902, PMID: 22438190, https://doi.org/10.1002/sim.4512.

Alonge O, Rodriguez DC, Brandes N, Geng E, Reveiz L, Peters DH. 2019. How is implementation research applied to advance health in low-income and middle-income countries? BMJ Glob Health 4(2):e001257, PMID: 30997169, https://doi.org/10.1136/bmjgh-2018-001257.

Aunger R, Curtis V. 2014. The Evo–Eco approach to behaviour change. In: *Applied Evolutionary Anthropology*. New York, NY: Springer, 271–295.

Barreto ML, Genser B, Strina A, Teixeira MG, Assis AM, Rego RF, et al. 2007. Effect of city-wide sanitation programme on reduction in rate of childhood diarrhoea in northeast Brazil: assessment by two cohort studies. Lancet 370(9599):1622–1628, PMID: 17993362, https://doi.org/10.1016/S0140-6736(07)61638-9.

Bauer MS, Damschroder L, Hagedorn H, Smith J, Kilbourne AM. 2015. An introduction to implementation science for the non-specialist. BMC Psychol 3:32, PMID: 26376626, https://doi.org/10.1186/s40359-015-0089-9.

Berwick DM. 2008. The science of improvement. JAMA 299(10):1182–1184, PMID: 18334694, https://doi.org/10.1001/jama.299.10.1182.

Biran A, Schmidt WP, Varadharajan KS, Rajaraman D, Kumar R, Greenland K, et al. 2014. Effect of a behaviour-change intervention on handwashing with soap in India (SuperAmma): a cluster-randomised trial. Lancet Glob Health 2(3):e145–e154, PMID: 25102847, https://doi.org/10.1016/S2214-109X(13)70160-8.

Bromham L, Dinnage R, Hua X. 2016. Interdisciplinary research has consistently lower funding success. Nature 534(7609):684–687, PMID: 27357795, https://doi.org/10.1038/nature18315.

Brown CH, Curran G, Palinkas LA, Aarons GA, Wells KB, Jones L, et al. 2017. An overview of research and evaluation designs for dissemination and implementation. Annu Rev Public Health 38:1–22, PMID: 28384085, https://doi.org/10.1146/annurev-publhealth-031816-044215.

Caruso BA, Sclar GD, Routray P, Majorin F, Nagel C, Clasen T. 2019. A cluster-randomized multi-level intervention to increase latrine use and safe disposal of child feces in rural Odisha, India: the Sundara Grama research protocol. BMC Public Health 19(1):322, PMID: 30885158, https://doi.org/10.1186/s12889-019-6601-z.

Clasen T, Boisson S, Routray P, Torondel B, Bell M, Cumming O, et al. 2014. Effectiveness of a rural sanitation programme on diarrhoea, soil-transmitted helminth infection, and child malnutrition in Odisha, India: a cluster-randomised trial. Lancet Glob Health 2(11):e645–e653, PMID: 25442689, https://doi.org/10.1016/S2214-109X(14)70307-9.

Crocker J, Saywell D, Bartram J. 2017. Sustainability of community-led total sanitation outcomes: evidence from Ethiopia and Ghana. Int J Hyg Environ Health 220(3):551–557, PMID: 28522255, https://doi.org/10.1016/j.ijheh.2017.02.011.

Cumming O, Arnold BF, Ban R, Clasen T, Esteves Mills J, Freeman MC, et al. 2019. The implications of three major new trials for the effect of water, sanitation and hygiene on childhood diarrhea and stunting: a consensus statement. BMC Med 17(1):173, PMID: 31462230, https://doi.org/10.1186/s12916-019-1410-x.

Cutler D, Miller G. 2005. The role of public health improvements in health advances: the twentieth-century United States. Demography 42(1):1–22, PMID: 15782893, https://doi.org/10.1353/dem.2005.0002.

Damschroder LJ, Aron DC, Keith RE, Kirsh SR, Alexander JA, Lowery JC. 2009. Fostering implementation of health services research findings into practice: a consolidated framework for advancing implementation science. Implement Sci 4:50, PMID: 19664226, https://doi.org/10.1186/1748-5908-4-50.

Delea MG, Snyder JS, Belew M, Caruso BA, Garn JV, Sclar GD, et al. 2019. Design of a parallel cluster-randomized trial assessing the impact of a demand-side sanitation and hygiene intervention on sustained behavior change and mental well-being in rural and peri-urban Amhara, Ethiopia: Andilaye study protocol. BMC Public Health 19(1):801, PMID: 31226957, https://doi.org/10.1186/s12889-019-7040-6.

Dreibelbis R, Winch PJ, Leontsini E, Hulland KR, Ram PK, Unicomb L, et al. 2013. The integrated behavioural model for water, sanitation, and hygiene: a systematic review of behavioural models and a framework for designing and evaluating behaviour change interventions in infrastructure-restricted settings. BMC Public Health 13:1015, PMID: 24160869, https://doi.org/10.1186/1471-2458-13-1015.

Eccles MP, Mittman BS. 2006. Welcome to *Implementation Science*. Implement Sci 1(1):1, https://doi.org/10.1186/1748-5908-1-1.

Ercumen A, Pickering AJ, Kwong LH, Arnold BF, Parvez SM, Alam M, et al. 2017. Animal feces contribute to domestic fecal contamination: evidence from E. coli measured in water, hands, food, flies, and soil in Bangladesh. Environ Sci Technol 51(15):8725–8734, PMID: 28686435, https://doi.org/10.1021/acs.est.7b01710.

Fixsen DL, Naoom SF, Blase KA, Friedman RM, Wallace F. 2005. *Implementation Research: A Synthesis of the Literature*. Tampa, FL: University of South Florida, Louis de la Parte Florida Mental Health Institute National Implementation Research Network.

Freeman MC, Ellis AS, Ogutu EA, Caruso BA, Linabarger M, Micek K, et al. 2020. Impact of a demand-side integrated wash and nutrition community-based care group intervention on behavioural change: a randomised controlled trial in western Kenya. BMJ Glob Health 5(11):e002806, PMID: 33234528, https://doi.org/10.1136/bmjgh-2020-002806.

Freeman MC, Garn JV, Sclar GD, Boisson S, Medlicott K, Alexander KT, et al. 2017. The impact of sanitation on infectious disease and nutritional status: a systematic review and meta-analysis. Int J Hyg Environ Health 220(6):928–949, PMID: 28602619, https://doi.org/10.1016/j.ijheh.2017.05.007.

Garn JV, Sclar GD, Freeman MC, Penakalapati G, Alexander KT, Brooks P, et al. 2017. The impact of sanitation interventions on latrine coverage and latrine use: a systematic review and meta-analysis. Int J Hyg Environ Health 220(2 pt B):329–340, PMID: 27825597, https://doi.org/10.1016/j.ijheh.2016.10.001.

Glasgow RE, Vinson C, Chambers D, Khoury MJ, Kaplan RM, Hunter C. 2012. National Institutes of Health approaches to dissemination and implementation science: current and future directions. Am J Public Health 102(7):1274–1281, PMID: 22594758, https://doi.org/10.2105/AJPH.2012.300755.

Glasgow RE, Vogt TM, Boles SM. 1999. Evaluating the public health impact of health promotion interventions: the RE-AIM framework. Am J Public Health 89(9):1322–1327, PMID: 10474547, https://doi.org/10.2105/ajph.89.9.1322.

Haque SS, Yanez-Pagans M, Arias-Granada Y, Joseph G. 2020. Water and sanitation in Dhaka slums: access, quality, and informality in service provision. Water Int 45(7–8):791–811, https://doi.org/10.1080/02508060.2020.1786878.

Harter M, Mosler H-J. 2018. Determining the Effectiveness and Mode of Operation of Community-Led Total Sanitation: The DEMO-CLTS Study. Dübendorf, Switzerland: Eawag Aquatic Research.

Hawe P, Shiell A, Riley T. 2004. Complex interventions: how "out of control" can a randomised controlled trial be? BMJ 328(7455):1561–1563, PMID: 15217878, https://doi.org/10.1136/bmj.328.7455.1561.

Helfrich CD, Blevins D, Smith JL, Kelly PA, Hogan TP, Hagedorn H, et al. 2011. Predicting implementation from organizational readiness for change: a study protocol. Implement Sci 6:76, PMID: 21777479, https://doi.org/10.1186/1748-5908-6-76.

Hickey MD, Odeny TA, Petersen M, Neilands TB, Padian N, Ford N, et al. 2017. Specification of implementation interventions to address the cascade of HIV care and treatment in resource-limited settings: a systematic review. Implement Sci 12(1):102, PMID: 28784155, https://doi.org/10.1186/s13012-017-0630-8.

HLPW (High Level Panel on Water). 2016. Statement of the High Level Panel on Water Addressing the Drinking Water, Sanitation and Hygiene (WASH) Challenges. September 2016. New York, NY: United Nations and World Bank.

Holt CL, Chambers DA. 2017. Opportunities and challenges in conducting community-engaged dissemination/implementation research. Transl Behav Med 7(3):389–392, PMID: 28884305, https://doi.org/10.1007/s13142-017-0520-2.

Huda TM, Unicomb L, Johnston RB, Halder AK, Yushuf Sharker MA, Luby SP. 2012. Interim evaluation of a large scale sanitation, hygiene and water improvement programme on childhood diarrhea and respiratory disease in rural Bangladesh. Soc Sci Med 75(4):604–611, PMID: 22197292, https://doi.org/10.1016/j.socscimed.2011.10.042.

Hueso A, Bell B. 2013. An untold story of policy failure: the Total Sanitation Campaign in India. Water Policy 15(6):1001–1017, https://doi.org/10.2166/wp.2013.032.

Humphrey JH, Mbuya MNN, Ntozini R, Moulton LH, Stoltzfus RJ, Tavengwa NV, et al. 2019. Independent and combined effects of improved water, sanitation, and hygiene, and improved complementary feeding, on child stunting and anaemia in rural Zimbabwe: a cluster-randomised trial. Lancet Glob Health 7(1):e132–e147, PMID: 30554749, https://doi.org/10.1016/S2214-109X(18)30374-7.

Jerneck M, Van der Voorden C, Rudholm C. 2016. Sanitation and Hygiene Behaviour Change at Scale: Understanding Slippage: Primarily Based on Experiences from the Global Sanitation Fund-supported programme in Madagascar. Geneva, Switzerland: Water Supply and Sanitation Collaborative Council (WSSCC).

Kallam B, Pettitt-Schieber C, Owen M, Asante RA, Darko E, Ramaswamy R. 2018. Implementation science in low-resource settings: using the interactive systems framework to improve hand hygiene in a tertiary hospital in Ghana. Int J Qual Health Care 30(9):724–730, PMID: 29788245, https://doi.org/10.1093/intqhc/mzy111.

Kar K, Chambers R. 2008. *Handbook on Community-Led Total Sanitation*. London, UK: Plan UK.

Kemp CG, Weiner BJ, Sherr KH, Kupfer LE, Cherutich PK, Wilson D, et al. 2018. Implementation science for integration of HIV and non-communicable disease services in sub-Saharan Africa: a systematic review. AIDS 32(suppl 1):S93–S105, PMID: 29952795, https://doi.org/10.1097/QAD.0000000000001897.

Khoury MJ, Gwinn M, Ioannidis JPA. 2010. The emergence of translational epidemiology: from scientific discovery to population health impact. Am J Epidemiol 172(5):517–524, PMID: 20688899, https://doi.org/10.1093/aje/kwq211.

Kirby MA, Nagel CL, Rosa G, Zambrano LD, Musafiri S, Ngirabega JD, et al. 2019. Effects of a large-scale distribution of water filters and natural draft rocket-style cookstoves on diarrhea and acute respiratory infection: a cluster-randomized controlled trial in Western Province, Rwanda. PLoS Med 16(6): e1002812, PMID: 31158266, https://doi.org/10.1371/journal.pmed.1002812.

Kotloff KL, Nataro JP, Blackwelder WC, Nasrin D, Farag TH, Panchalingam S, et al. 2013. Burden and aetiology of diarrhoeal disease in infants and young children in developing countries (the Global Enteric Multicenter Study, GEMS): a prospective, case–control study. Lancet 382(9888):209–222, PMID: 23680352, https://doi.org/10.1016/S0140-6736(13)60844-2.

Lei H, Nahum-Shani I, Lynch K, Oslin D, Murphy SA. 2012. A "SMART" design for building individualized treatment sequences. Annu Rev Clin Psychol 8:21–48, PMID: 22224838, https://doi.org/10.1146/annurev-clinpsy-032511-143152.

Luby SP, Rahman M, Arnold BF, Unicomb L, Ashraf S, Winch PJ, et al. 2018. Effects of water quality, sanitation, handwashing, and nutritional interventions on diarrhoea and child growth in rural Bangladesh: a cluster randomised controlled trial. Lancet Glob Health 6:e302–e315, PMID: 29396217, https://doi.org/10.1016/S2214-109X(17)30490-4.

Luoto J, Shekelle PG, Maglione MA, Johnsen B, Perry T. 2014. Reporting of context and implementation in studies of global health interventions: a pilot study. Implement Sci 9:57, PMID: 24886201, https://doi.org/10.1186/1748-5908-9-57.

Madon T, Hofman KJ, Kupfer L, Glass RI. 2007. Public health. Implementation science. Science 318(5857):1728–1729, PMID: 18079386, https://doi.org/10.1126/science.1150009.

Michie S, Fixsen D, Grimshaw JM, Eccles MP. 2009. Specifying and reporting complex behaviour change interventions: the need for a scientific method. Implement Sci 4:40, PMID: 19607700, https://doi.org/10.1186/1748-5908-4-40.

Mosler HJ. 2012. A systematic approach to behavior change interventions for the water and sanitation sector in developing countries: a conceptual model, a review, and a guideline. Int J Environ Health Res 22(5):431–449, PMID: 22292899, https://doi.org/10.1080/09603123.2011.650156.

Nilsen P. 2015. Making sense of implementation theories, models and frameworks. Implement Sci 10:53, PMID: 25895742, https://doi.org/10.1186/s13012-015-0242-0.

Null C, Stewart CP, Pickering AJ, Dentz HN, Arnold BF, Arnold CD, et al. 2018. Effects of water quality, sanitation, handwashing, and nutritional interventions on diarrhoea and child growth in rural Kenya: a cluster-randomised controlled trial. Lancet Glob Health 6(3):e316–e329, PMID: 29396219, https://doi.org/10.1016/S2214-109X(18)30005-6.

O'Fallon LR, Dearry A. 2002. Community-based participatory research as a tool to advance environmental health sciences. Environ Health Perspect 110(suppl 2):155–159, PMID: 11929724, https://doi.org/10.1289/ehp.02110s2155.

Patil SR, Arnold BF, Salvatore AL, Briceno B, Ganguly S, Colford JM Jr. et al. 2014. The effect of India's total sanitation campaign on defecation behaviors and child health in rural Madhya Pradesh: a cluster randomized controlled trial. PLoS Med 11(8):e1001709, PMID: 25157929, https://doi.org/10.1371/journal.pmed.1001709.

Penakalapati G, Swarthout J, Delahoy MJ, McAliley L, Wodnik B, Levy K, et al. 2017. Exposure to animal feces and human health: a systematic review and proposed research priorities. Environ Sci Technol 51(20):11537–11552, PMID: 28926696, https://doi.org/10.1021/acs.est.7b02811.

Peters DH, Adam T, Alonge O, Agyepong IA, Tran N. 2013. Implementation research: what it is and how to do it. BMJ 347:f6753. https://doi.org/10.1136/bmj.f6753.

Pickering AJ, Djebbari H, Lopez C, Coulibaly M, Alzua ML. 2015. Effect of a community-led sanitation intervention on child diarrhoea and child growth in rural Mali: a cluster-randomised controlled trial. Lancet Glob Health 3(11):e701–e711, PMID: 26475017, https://doi.org/10.1016/S2214-109X(15)00144-8.

Pickering AJ, Null C, Winch PJ, Mangwadu G, Arnold BF, Prendergast AJ, et al. 2019. The WASH benefits and shine trials: interpretation of wash intervention effects on linear growth and diarrhoea. Lancet Glob Health 7(8):e1139–e1146, PMID: 31303300, https://doi.org/10.1016/S2214-109X(19)30268-2.

Platts-Mills JA, Babji S, Bodhidatta L, Gratz J, Haque R, Havt A, et al. 2015. Pathogen-specific burdens of community diarrhoea in developing countries: a multisite birth cohort study (MAL-ED). Lancet Glob Health 3(9):e564–e575, PMID: 26202075, https://doi.org/10.1016/S2214-109X(15)00151-5.

Powell BJ, Haley AD, Patel SV, Amaya-Jackson L, Glienke B, Blythe M, et al. 2020. Improving the implementation and sustainment of evidence-based practices in community mental health organizations: a study protocol for a matched-pair cluster randomized pilot study of the Collaborative Organizational Approach to Selecting and Tailoring Implementation Strategies (COAST-IS.). Implement Sci Commun 1(1):, PMID: 32391524, https://doi.org/10.1186/s43058-020-00009-5.

Powell BJ, McMillen JC, Proctor EK, Carpenter CR, Griffey RT, Bunger AC, et al. 2012. A compilation of strategies for implementing clinical innovations in health and mental health. Med Care Res Rev 69(2):123–157, PMID: 22203646, https://doi.org/10.1177/1077558711430690.

Powell BJ, Waltz TJ, Chinman MJ, Damschroder LJ, Smith JL, Matthieu MM, et al. 2015. A refined compilation of implementation strategies: results from the Expert Recommendations for Implementing Change (ERIC) project. Implement Sci 10(1):1–14, PMID: 25889199, https://doi.org/10.1186/s13012-015-0209-1.

Proctor E, Silmere H, Raghavan R, Hovmand P, Aarons G, Bunger A, et al. 2011. Outcomes for implementation research: conceptual distinctions, measurement challenges, and research agenda. Adm Policy Ment Health 38(2):65–76, PMID: 20957426, https://doi.org/10.1007/s10488-010-0319-7.

Proctor EK, Landsverk J, Aarons G, Chambers D, Glisson C, Mittman B. 2009. Implementation research in mental health services: an emerging science with conceptual, methodological, and training challenges. Adm Policy Ment Health 36(1):24–34, PMID: 19104929, https://doi.org/10.1007/s10488-008-0197-4.

Proctor EK, Powell BJ, McMillen JC. 2013. Implementation strategies: recommendations for specifying and reporting. Implement Sci 8:139, PMID: 24289295, https://doi.org/10.1186/1748-5908-8-139.

Prüss-Ustün A, Wolf J, Bartram J, Clasen T, Cumming O, Freeman MC, et al. 2019. Burden of disease from inadequate water, sanitation and hygiene for selected adverse health outcomes: an updated analysis with a focus on low- and middle-income countries. Int J Hyg Environ Health 222(5):765–777, PMID: 31088724, https://doi.org/10.1016/j.ijheh.2019.05.004.

Remme JH, Adam T, Becerra-Posada F, D'Arcangues C, Devlin M, Gardner C, et al. 2010. Defining research to improve health systems. PLoS Med 7(11):e1001000, PMID: 21124816, https://doi.org/10.1371/journal.pmed.1001000.

Robb K, Null C, Teunis P, Yakubu H, Armah G, Moe CL. 2017. Assessment of fecal exposure pathways in low-income urban neighborhoods in Accra, Ghana: rationale, design, methods, and key findings of the SaniPath Study. Am J Trop Med Hyg 97(4):1020–1032, PMID: 28722599, https://doi.org/10.4269/ajtmh.16-0508.

Rosenthal J, Balakrishnan K, Bruce N, Chambers D, Graham J, Jack D, et al. 2017. Implementation science to accelerate clean cooking for public health. Environ Health Perspect 125(1):A3–A7, PMID: 28055947, https://doi.org/10.1289/EHP1018.

Rosenthal J, Arku RE, Baumgartner J, Brown J, Clasen T, Eisenberg JNS, et al. 2020. Systems science approaches for global environmental health research: enhancing intervention design and implementation for household air pollution (HAP) and water, sanitation, and hygiene (WASH) programs. Environ Health Perspect 128(10):105001, PMID: 33035121, https://doi.org/10.1289/EHP7010.

Sanders D, Haines A. 2006. Implementation research is needed to achieve international health goals. PLoS Med 3(6):e186, PMID: 16729844, https://doi.org/10.1371/journal.pmed.0030186.

Saunders RP, Martin HE, Praphul J. 2005. Developing a process-evaluation plan for assessing health promotion program implementation: a how-to guide. Health Promotion Practice 6(2):134–147, PMID: 15855283, https://doi.org/10.1177/1524839904273387.

Satterthwaite M. 2014. On rights-based partnerships to measure progress in water and sanitation. Sci Eng Ethics 20(4):877–884, PMID: 24474242, https://doi.org/10.1007/s11948-014-9514-3.

Sclar GD, Penakalapati G, Amato HK, Garn JV, Alexander K, Freeman MC, et al. 2016. Assessing the impact of sanitation on indicators of fecal exposure along principal transmission pathways: a systematic review. Int J Hyg Environ Health 219(8):709–723, PMID: 27720133, https://doi.org/10.1016/j.ijheh.2016.09.021.

Sclar GD, Penakalapati G, Caruso BA, Rehfuess EA, Garn JV, Alexander KT, et al. 2018. Exploring the relationship between sanitation and mental and social well-being: a systematic review and qualitative synthesis. Soc Sci Med 217:121–134, PMID: 30316053, https://doi.org/10.1016/j.socscimed.2018.09.016.

Seppälä OT. 2002. Effective water and sanitation policy reform implementation: need for systemic approach and stakeholder participation. Water Policy 4(4):367–388, https://doi.org/10.1016/S1366-7017(02)00036-3.

Setty K, Cronk R, George S, Anderson D, O'Flaherty G, Bartram J. 2019. Adapting translational research methods to water, sanitation, and hygiene. Int J Environ Res Public Health 16(20):4049, PMID: 31652610, https://doi.org/10.3390/ijerph16204049.

Sharma A, Burn S, Gardner T, Gregory A. 2010. Role of decentralised systems in the transition of urban water systems. Water Sci Technol Water Supply 10(4):577–583, https://doi.org/10.2166/ws.2010.187.

Shea CM, Young TL, Powell BJ, Rohweder C, Enga ZK, Scott JE, et al. 2017. Researcher readiness for participating in community-engaged dissemination and implementation research: a conceptual framework of core competencies. Transl Behav Med 7(3):393–404, PMID: 28341897, https://doi.org/10.1007/s13142-017-0486-0.

Sinharoy SS, Schmidt W-P, Wendt R, Mfura L, Crossett E, Grépin KA, et al. 2017. Effect of community health clubs on child diarrhoea in western Rwanda: cluster-randomised controlled trial. Lancet Glob Health 5(7):e699–e709, PMID: 28619228, https://doi.org/10.1016/S2214-109X(17)30217-6.

Suchman E. 1968. *Evaluative Research: Principles and Practice in Public Service and Social Action Programs*. New York, NY: Russell Sage Foundation.

Sweetman C, Medland L. 2017. Introduction: gender and water, sanitation and hygiene. Gend Dev 25(2):153–166, https://doi.org/10.1080/13552074.2017.1349867.

Tabak RG, Khoong EC, Chambers DA, Brownson RC. 2012. Bridging research and practice: models for dissemination and implementation research. Am J Prev Med 43(3):337–350, PMID: 22898128, https://doi.org/10.1016/j.amepre.2012.05.024.

Theobald S, Brandes N, Gyapong M, El-Saharty S, Proctor E, Diaz T, et al. 2018. Implementation research: new imperatives and opportunities in global health. Lancet 392(10160):2214–2228, PMID: 30314860, https://doi.org/10.1016/S0140-6736(18)32205-0.

Trémolet S, Halpern J. 2006. Regulation of Water and Sanitation Services: Getting Better Service to Poor People. Washington, DC: World Bank.

Trémolet S, Rama M. 2012. Tracking national financial flows into sanitation, hygiene and drinking-water (No. WHO/HSE/WSH/12.05). Geneva, Switzerland: World Health Organization.

Trémolet S, Rama M, 2012. Tracking national financial flows into sanitation, hygiene and drinking-water. (No. WHO/HSE/WSH/12.05). Geneva, Switzerland: World Health Organization.

Truscott JE, Werkman M, Wright JE, Farrell SH, Sarkar R, Ásbjörnsdóttir K, et al. 2017. Identifying optimal threshold statistics for elimination of hookworm using a stochastic simulation model. Parasit Vectors 10(1):321, PMID: 28666452, https://doi.org/10.1186/s13071-017-2256-8.

Tulchinsky TH. 2018. Chapter 5 - John Snow, cholera, the broad street pump; waterborne diseases then and now. In: *Case Studies in Public Health*, 77–99. Cambridge, MA: Academic Press, https://doi.org/10.1016/B978-0-12-804571-8.00017-2.

Tumilowicz A, Ruel MT, Pelto G, Pelletier D, Monterrosa EC, Lapping K, et al. 2019. Implementation science in nutrition: concepts and frameworks for an emerging field of science and practice. Curr Dev Nutr 3(3):nzy080, PMID: 30864563, https://doi.org/10.1093/cdn/nzy080.

United Nations General Assembly. 2010. Resolution adopted by the General Assembly on 28 July 2010. *The Human Right to Water and Sanitation*. New York, NY: United Nations General Assembly.

USAID (United States Agency for International Development). 2020. USAID Water for the World: Implementation Research Agenda. Washington, DC: United States Agency for International Development.

Van Belle S, van de Pas R, Marchal B. 2017. Towards an agenda for implementation science in global health: there is nothing more practical than good (social science) theories. BMJ Glob Health 2(2):e000181, PMID: 28608872, https://doi.org/10.1136/bmjgh-2016-000181.

van den Broek M, Brown J. 2015. Blueprint for breakdown? Community based management of rural groundwater in Uganda. Geoforum 67:51–63, https://doi.org/10.1016/j.geoforum.2015.10.009.

Venkataramanan V, Crocker J, Karon A, Bartram J. 2018. Community-led total sanitation: a mixed-methods systematic review of evidence and its quality. Environ Health Perspect 126(2):026001, PMID: 29398655, https://doi.org/10.1289/EHP1965.

Victora CG, Habicht JP, Bryce J. 2004. Evidence-based public health: moving beyond randomized trials. Am J Public Health 94(3):400–405, PMID: 14998803, https://doi.org/10.2105/ajph.94.3.400.

Wagner E, Lanoix J. 1958. Excreta disposal for rural areas and small communities. Monogr Ser World Health Organization 39:1–182, PMID: 13581743.

Whaley L, Cleaver F. 2017. Can "functionality" save the community management model of rural water supply? Water Resources and Rural Development 9:56–66, https://doi.org/10.1016/j.wrr.2017.04.001.

Whittington D, Radin M, Jeuland M. 2020. Evidence-based policy analysis? The strange case of the randomized controlled trials of community-led total sanitation. Oxford Review of Economic Policy 36(1):191–221, https://doi.org/10.1093/oxrep/grz029.

WHO/UN Water (World Health Organization and United Nations Water). 2017. UN–Water Global Analysis and Assessment of Sanitation and Drinking-Water (GLAAS). Geneva, Switzerland: World Health Organization and United Nations Water.

WHO/UNICEF. 2017. Progress on Household Drinking Water, Sanitation and Hygiene 2000–2017: Progress on Drinking Water, Sanitation and Hygiene: 2017 Update and SDG Baselines. New York, NY: United Nations Children's Fund and World Health Organization.

WHO/UNICEF. 2019. Progress on Household Drinking Water, Sanitation and Hygiene 2000–2017: Special Focus on Inequalities. New York, NY: United Nations Children's Fund and World Health Organization.

Wilson KM, Brady TJ, Lesesne C, et al. 2011. An organizing framework for translation in public health: the Knowledge to Action Framework. Prev Chronic Dis 8(2):A46, PMID: 21324260.

Wolf J, Hunter PR, Freeman MC, Cumming O, Clasen T, Bartram J, et al. 2018. Impact of drinking water, sanitation and handwashing with soap on childhood diarrhoeal disease: updated meta-analysis and meta-regression. Trop Med Int Health 23(5):508–525, PMID: 29537671, https://doi.org/10.1111/tmi.13051.

Woolcock M. 2013. Using case studies to explore the external validity of "complex" development interventions. Evaluation 19(3):229–248, https://doi.org/10.1177/1356389013495210.

Woolf SH, Johnson RE. 2005. The break-even point: when medical advances are less important than improving the fidelity with which they are delivered. Ann Fam Med 3(6):545–552, PMID: 16338919, https://doi.org/10.1370/afm.406.

Woolf SH. 2008. The meaning of translational research and why it matters. JAMA 299(2):211–213, PMID: 18182604, https://doi.org/10.1001/jama.2007.26.

Yerian S, Hennink M, Greene LE, Kiptugen D, Buri J, Freeman MC. 2014. The role of women in water management and conflict resolution in Marsabit, Kenya. Environ Manage 54(6):1320–1330, PMID: 25167777, https://doi.org/10.1007/s00267-014-0356-1.

Zuin V, Delaire C, Peletz R, Cock-Esteb A, Khush R, Albert J. 2019. Policy diffusion in the rural sanitation sector: lessons from Community-Led Total Sanitation (CLTS). World Dev 124:104643, https://doi.org/10.1016/j.worlddev.2019.104643.