Point of Use Household Drinking Water Filtration: A Practical, Effective Solution for Providing Sustained Access to Safe Drinking Water in the Developing World

MARK D. SOBSEY,*
CHRISTINE E. STAUBER,
LISA M. CASANOVA, JOSEPH M. BROWN,[†]
AND MARK A. ELLIOTT

Department of Environmental Sciences and Engineering, CB#7431, University of North Carolina, Chapel Hill, North Carolina 27599-7431

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The lack of safe water creates a tremendous burden of diarrheal disease and other debilitating, life-threatening illnesses for people in the developing world. Point-of-use (POU) water treatment technology has emerged as an approach that empowers people and communities without access to safe water to improve water quality by treating it in the home. Several POU technologies are available, but, except for boiling, none have achieved sustained, large-scale use. Sustained use is essential if household water treatment technology (HWT) is to provide continued protection, but it is difficult to achieve. The most effective, widely promoted and used POU HWTs are critically examined according to specified criteria for performance and sustainability. Ceramic and biosand household water filters are identified as most effective according to the evaluation criteria applied and as having the greatest potential to become widely used and sustainable for improving household water quality to reduce waterborne disease and death.

Introduction

About 1.1 billion people worldwide lack access to improved drinking water supplies and use unsafe surface and groundwater sources. Even people who have access to "improved" water supplies such as household connections, public standpipes, and boreholes may not have microbiologically safe water. Improved supplies are often contaminated with pathogens causing infectious diseases such as cholera, enteric fever, dysentery, and hepatitis. Lack of access to safe water contributes significantly to the global burden of disease and death resulting from infectious diarrhea and other enteric illnesses, as well as their sequelae and indirect health effects, such as neurological syndromes, reactive arthritis, malnutrition, and arrested growth and development (*1*). The World Health Organization (WHO) estimates that diarrheal diseases kill 1.6 million people yearly, mostly children under five years of age. This disease burden falls disproportionately on those in developing countries, where children experience multiple episodes of diarrheal disease each year (*2*).

Recent systematic reviews of water, sanitation, and hygiene interventions suggest that the beneficial effects of improving household drinking water quality at the point of use (POU) to reduce diarrheal disease risks had been previously underestimated. Contemporary reviews estimate 30−40% reductions in diarrheal disease by improving household drinking water quality at the POU, making such treatment more effective than improvements at the source (*3*–*6*). The goal of POU household water treatment (HWT) and safe storage technologies is to empower people without access to safe water to improve water quality by treating it and storing it safely in the home. There are a number of different POU technologies which policy-makers, implementers, and users can select as appropriate for particular circumstances and populations (*5, 6*). Although a variety of POU technologies have been suggested, tested, and disseminated, not all have an evidence base of effectiveness and sustained use (*5, 6*). One of the challenges to making informed choices about widespread dissemination of these technologies is the lack of rigorous scientific evidence of sustained use, positive health impact, and water quality improvement over extended periods of use (*5*). This review focuses on those technologies for which performance efficacy and sustained use have been documented by microbiological efficacy and diarrheal disease reduction studies. The POU technologies to be critically reviewed are the following:

Chlorination with Safe Storage. POU free chlorine (hypochlorite) treatment has been widely promoted in recent years by the U.S. Centers for Disease Control and Prevention (CDC).

Combined Coagulant−Chlorine Disinfection Systems. Commercial technologies such as WaterMaker (Control Chemicals, Alexandria, VA) and PuR (Procter and Gamble, Cincinnati, OH) combine dry coagulant-flocculant and chlorine as tablets or sachets of granular particles that are added to water.

SODIS. Transparent polyethylene terephthalate (PET or PETE) bottles are filled with aerated source water and exposed to solar UV and heat energy outside during the sunlight hours of the day.

Ceramic Filter. Porous ceramic (fired clay) media are used to filter microbes from drinking water by size exclusion. Ceramic candle filters are made in more developed countries to exact specifications, and ceramic filters of either candle or pot design are made in developing countries, where production methods and filtration effectiveness can vary.

Biosand Filter. The biosand filter (BSF) was designed as a modification of the large-scale, continuously operated slow sand filter, and allows for intermittent water dosing for household use.

Although other POU technologies are available, they lack scientifically sound evidence documenting their ability to improve water quality and reduce waterborne infectious disease. Therefore, they can not be assessed here on the basis of these measures of effectiveness and sustainability. These five household POU technologies have an evidence base from laboratory and intervention studies, which provides a timely opportunity to compare them on the basis of key criteria for effectiveness and sustainability. This review examines these POU technologies based on available evidence in a rigorous framework for holistic comparisons of their microbial efficacy, health impacts, and sustainability.

* Corresponding author phone: (919) 966-7316; e-mail: sobsey@unc.edu.

[†] Departments of Biological Sciences and Civil, Construction, and Environmental Engineering, University of Alabama.

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TABLE 1. Estimates of Baseline and Maximum Effectiveness of POU Technologies against Microbes in Water

treatment process	pathogen group	baseline LRV[a,b]	maximum LRV[c]	factors influencing performance efficacy
porous ceramic filtration	bacteria	2	6	varies with pore size/structure, tortuosity, flow rate, filter medium composition, augmentation with silver or other chemical agents that enhance microbe inactivation or retention (*7–10*)
	viruses	0.5	4	
	protozoa	4	6	
biosand filtration (BSF)	bacteria	1	3	varies with filter maturity, dosing conditions, flow rate, pause time between doses, grain size, filter bed contact time, other design and operation factors; POUs may differ in microbial removal from conventional SSF (*11–13*)
	viruses	0.5	3	
	protozoa	2	4	
SODIS	bacteria	3	5.5+	depends on water oxygenation, sunlight intensity, exposure time, temperature, turbidity, and size of vessel (depth of water) (*8, 14–18*)
	viruses	2	4+	
	protozoa	1	3+	
free chlorine	bacteria	3	6+	turbidity and chlorine demand reduce efficacy; concn × contact time predicts efficacy; [d] (*19–21*)
	viruses	3	6+	
	protozoa[d]	3	5+	
coagulation/chlorination	bacteria	7	9	possible physical removal of chlorine-resistant pathogens by coagulation-flocculation; turbidity may inhibit performance; reductions differ among viruses (*22*)(*23*)
	viruses	2−4.5	6	
	protozoa	3	5	

[a] LRV: $\log_{10}$ reduction value = $\log_{10}$ (pretreatment concn) − $\log_{10}$ (post-treatment concn). [b] Baseline LRV: LRV typically expected in actual field practice when done by relatively unskilled persons who apply the treatment to waters of varying quality and where there are minimum facilities or supporting instruments to optimize treatment conditions and practices. [c] Maximum LRV: LRV possible when treatment is optimized by skilled operators who are supported with instrumentation and other tools to maintain the highest level of performance in waters of predictable and unchanging quality. [d] Minimally effective against *Cryptosporidium parvum* oocysts.

TABLE 2. Diarrheal Disease Reduction by POU Technologies in Controlled Studies

technology	diarrheal disease reduction estimate (95% CI)	compliance (estimates of self-reported and/or measured % user compliance)
SODIS (solar UV radiation + thermal effects)	31% (26%−37%) (*5*)[a]	78% compliance during study (*24*); however, poststudy compliance rates may drop as low as 9% (*25*)
free chlorine and safe storage	37% (25%−48%) (*5*) 29% (*26*)[b]	60−73% of households were self-reported users, but only approximately 30−40% of those who reported use had detectable free chlorine levels (*27–29*)
coagulation/chlorination	31% (18%−42%) (*5*) 29% (*26*)	usage rates may drop to as low as 10% after intervention ends (*30*)
ceramic filtration through candle filters	63% (51%−72%) (*5*)	high until filter breaks; in a trial in Bolivia, compliance was 88% over 6 months (*31*)
ceramic filtration through ceramic water purifiers	46% (29%−59%) (*9*)	dependent on filter breakage rates (*9, 10*)
biosand filtration	47% (21%−64%) (*32*)	>85% post-implementation (*33, 34*)

[a] Summary estimates stratified by type of intervention (from a meta-analysis of drinking water quality interventions and diarrheal disease reductions). [b] Summary estimate from meta-analysis on POU chlorination (includes both free chlorine disinfection and combined coagulation-disinfection).

Microbial Efficacy, Health Impacts, and Sustainability

Microbial Efficacy. Laboratory studies provide guidance for decisions about which technologies show potential for field application. Microbial removal can vary by microbe type, and depends in part on the characteristics of the source water. Comparative levels of microbial reduction achieved by specific POU technologies are shown in Table 1.

Health Impacts. Some of the technologies achieving microbial reductions in the laboratory and field have also been evaluated for efficacy in reducing rates of diarrheal disease. The highest quality of epidemiological evidence for diarrheal disease reductions comes from randomized controlled trials (RCTs) and prospective cohort studies. In RCTs and cohort studies, chlorination and safe storage, combined coagulation/chlorination systems, SODIS, ceramic filtration, and biosand filtration have been shown to reduce diarrheal disease rates by varying but significant amounts, as shown in Table 2.

Chlorination has been demonstrated to significantly reduce diarrheal disease by an average of 29% (*26*). There was a trend of decreased efficacy in reducing diarrheal diseases with increasing intervention length (*26*). The reasons for this observation are uncertain, but they could be due to increasing lack of interest among participants, leading to lower intervention compliance or abandonment (as evidenced by decreased proportions of households with detectable free chlorine in their water) or variable chlorine effectiveness across different seasons. RCTs using PuR in several countries report diarrheal disease reductions ranging from 19 to 59% (*35–38*).

SODIS treatment was reported to significantly decrease diarrheal disease in children in Africa and India, with reductions of 26−37% (*24*, *39*, *40*). RCTs of ceramic “candle” filters document reduced diarrheal disease risks in user versus nonuser households (*41–44*). Diarrheal disease reductions associated with locally produced low-cost ceramic filters were approximately 50% in two field trials in rural Cambodia (*9*, *10*).

Until recently, there was only anecdotal evidence of positive health impact by the BSF (*45*, *46*). In recent RCT and prospective cohort studies in the Dominican Republic and Cambodia, respectively, diarrheal disease reductions were about 45% (*33*, *34*).

Sustainability. Although POU technologies may demonstrate effectiveness both in laboratory and field studies, this does not necessarily mean that they will do so over long periods of time in actual use. The effectiveness of POU technologies will be seriously undermined and waterborne disease risks and burdens will remain high if people treat water intermittently, go for long periods without treating, treat only some of the water they consume, or provide treated water to only some household members while others consume contaminated water. People must be sufficiently motivated and committed to integrate POUs into their daily lives long after intensive study interventions have ended. The overarching need for *any* POU technology is that it is sustainable: it becomes a part of the daily routine of every household member, who uses it for drinking and other high level purposes (e.g., food preparation and handwashing) all of the time. Key features of a sustainable POU technology are as follows:

1. Able to consistently produce sufficient quantities of microbiologically safe water to meet daily household needs.
2. Effective for treating many different water sources and quality levels including turbid and high organic content waters.
3. Requires relatively small user time to treat water, thereby not significantly contributing to already substantial household labor time burdens.
4. Low cost; relatively insensitive to income fluctuations, not causing households to stop treating water because they cannot afford to purchase the technology or continuously replace it.
5. Have a reliable, accessible and affordable supply chain for needed replacement units or parts for which consumers are willing and able to pay.
6. Maintain high post-implementation use levels after cessation of intensive surveillance and education efforts, as in field trials and marketing campaigns.

Here we present and apply a scoring system to rate and compare POU technologies based on five of these six sustainability criteria: water quantity produced, ability to treat a range of water qualities, ease of operation and time to treat, cost per liter, and supply chain requirements. For each criterion, a technology is assigned a performance score of 1 to 3, with 1 for low, 2 for fair, and 3 for good performance.

Water Quantity Produced. For all members of a household to use only treated drinking water, the ability of a household water treatment technology to produce sufficient volumes is critical. The number of units needed or doses applied increases user processing time and the risk that the user will rely on additional untreated sources of water for drinking. We score water quantity production based on producing 20 L within 4 hours of applying the treatment, a sufficient quantity to meet all critical drinking water needs of a 5-member household (*47*). Technologies producing 20 L of water in 4 h by using one unit (in the case of chemicals) or applying one dose of water (in the case of filters) receive a score of 3. Such technology produces sufficient quantities of treated water to meet all daily needs. A technology receives a score of 2 if 2−4 units of the technology or 2−4 doses of water have to be applied to provide 20 L in 4 h. The technology will receive a score of 1 if 5 or more units or doses of water have to be applied to meet the criterion.

Chlorination. Chlorine is supplied as concentrated liquid or tablets, designed for treatment of large quantities of water with a small volume of chlorine (5−10 mL or 1 tablet per 20 L of water), allowing users to treat multiple unit volumes. Score: 3.

Coagulation/Chlorination System. PuR comes in sachets for a 10 L volume of water. Score: 2.

SODIS. Uses 1−2-L PET bottles, requiring 10−20 bottles per day for 20 L of daily household water. The limited amounts of water treated per bottle may result in people using and possibly consuming both SODIS-treated and untreated water (*24, 48*). Score: 1.

Ceramic Filter. Flow rates are about 1−3 L per hour, but decline with use and accumulation of impurities on filter element surfaces. At optimal flow rates, a filter can produce approximately 8 L in 4 h and 20 L in about 10 h. Score: 2.

Biosand Filter. Water flow rates from BSFs are 0.25−1 L per minute, easily allowing for the production of tens to hundreds of liters of water per day. Score: 3.

Application of the Technology to a Wide Range of Water Qualities: Treatment Robustness. The applicability of the treatment technology to a wide range of water qualities is key because of differences in water sources and spacio-temporal and seasonal fluctuations in water quality. Technologies that improve water quality and reduce microbes under a wide range of source water quality conditions provide households with high quality water regardless of source water quality. Technologies that can provide consistent microbial reductions in waters with high turbidity and organic matter are scored higher in treatment robustness. Technologies that reduce turbidity and/or organic matter and provide similar or higher microbial reductions as for water of higher quality score a 3. Technologies not removing organic mater and turbidity but still maintaining effective microbial reductions comparable to those for higher water quality conditions score a 2. Technologies unable to remove turbidity and/or organic matter and providing less microbial reduction efficiency under poorer water quality conditions score a 1.

Chlorination. Waters with high organic matter and particles can interfere with chlorine disinfection efficacy, cause production of compounds with objectionable taste and odor, and create consumer scepticism about effectiveness due to the unchanged appearance of the water. Score: 1.

Coagulation/Chlorination Systems. These can remove turbidity, organic matter, and microbes through flocculation and settling, aesthetically improving waters and facilitating chlorine effectiveness. Score: 3.

SODIS. Due to decreased penetration of UV light, SODIS is less effective in waters having high turbidity and color and in bottles that become scuffed from daily use. Users have inadequate guidance on how to determine when raw water is too turbid or colored or bottles are too worn for adequate UV light penetration. Score: 1.

Ceramic and Biosand Filters. Can remove turbidity, organic matter, and microbes. These filters are simple to clean manually to restore efficacy and flow rate if too much particulate matter accumulates. Score: 3.

Ease of Process Use and Time Treating Water. Adoption and consistent use of POU technology by households is influenced by both ease of treatment process performance and the time required of the household member tasked with treatment. The more straightforward the operation and maintenance of the technology, the greater the likelihood that it will be adopted and used successfully. This criterion is based on the sum of scores for three elements: process ease, process duration, and process maintenance requirements. Treatment processes having a single step score a 1 and those having multiple steps score a 0. Technologies providing 10 L of water within 30 min score a 1 and those taking longer score a 0. Technologies requiring periodic maintenance beyond cleaning the water storage container score a 0 whereas those not requiring maintenance score a 1.

Chlorination. The user need only measure out the liquid or dispense the tablet, add it to the water, mix briefly and allow for some contact time. Many liters of water can be batch treated within 30 min. Except for keeping the water

TABLE 3. Scoring of POU Treatment Technologies Based on Sustainability Criteria

technology	quantity	quality	ease of use	cost	supply chain	overall score
free chlorine	3	1	3	3 (liquid) 2(tablets)	1	11 10
coagulation/chlorination	2	3	1	1	1	8
SODIS	1	1	1	3	3	9
ceramic filters	2	3	2	3	2	12
biosand filters	3	3	2	2	3	13

vessel clean and protected from contamination, no maintenance is required. Score: 3.

Coagulation/Chlorination Systems. The sachet or tablet needs to be added to 10 L of water, stirred vigorously for a few minutes, and allowed to sit for 30 min. A floc will form and settle at the bottom of the container. The water must be decanted and filtered through a cloth filter into another container, and settled floc must be properly disposed of. Containers and utensils for treatment must be available and in satisfactory condition. Score: 1.

SODIS. The process can be laborious due to the need to manage many bottles of water daily. Households must plan ahead to anticipate daily water needs. PET bottles, which hold only 1−2 L each, must be filled with water, shaken to aerate, placed in sunlight for a period of hours, recovered after exposure, and emptied. Sufficient bottles must be available to meet daily water needs and must be replaced when damaged. Score: 1.

Ceramic Filter. Water is poured into the top of the filter as needed and flows by gravity into a storage vessel for immediate use. Filter elements require periodic cleaning by manually scrubbing and rinsing to remove the accumulated impurities. Score: 2.

Biosand Filter. Same operation as ceramic filters; require periodic cleaning by manually scouring the top few centimeters of sand and then decanting and disposing of the overlying water. Score: 2.

Cost to Treat. Cost-benefit analyses of various household water treatment technologies have been done, but are beyond the scope of this review. However, POU technology cost is an important criterion for adoption and sustained use. For our purposes, we assume households treat 20 L of water per day for 365 days. For some technologies, this may require the purchase of multiple units of the technology to produce 20 L/day for a year (i.e., PuR sachets and chlorine bottles or tablets). The cost of each technology was calculated (in USD) as dollars/L/year. For technologies that are one time purchases this approach may overestimate the cost, but it does provide a consistent basis for comparison. Using this system, technologies are assigned the following scores: <0.001$/L = 3, 0.001− .01$/L = 2, and >0.01$/L = 1. This approach to calculating POU cost does not take into account many other cost-related factors but it does provide a simple, uniform basis for comparison.

Chlorination. A bottle of chlorine solution can treat >1000 L of water for about $1 and potentially lasts months. Chlorine tablets are more expensive than liquid chlorine at $0.01 to 0.001/L. Score: 3 for liquid chlorine or 2 for chlorine tablets.

Coagulant/Chlorine System. The cost of a PuR sachet ranges from $0.003/L (production cost) to >$0.010/L (end user cost without subsidy). Score: 1.

Sodis. Requires only a continuous supply of PET bottles, which can be collected as discarded bottles, or may need to be purchased at low cost. Score: 3.

Ceramic Filter. The cost of a filter unit is $8−10 and a replacement porous ceramic pot element is $4−5. Score: 3.

Biosand Filter. The typical BSF is a one-time cost of $25−100, depending on the country and implementer. Score: 2.

Supply Chain Requirements. Consistent use of a POU technology will also be affected by access. The need for a periodic or continuous supply can be a hindrance to sustained use of a technology, and currently available technologies have supply chain requirements. For this category, supply chain refers to logistical components the user requires to continue using the technology once received or introduced, not the logistical components necessary to make the technology available to the user by implementers. Technologies not requiring any type of supply chain for continued use score a 3. Technologies requiring periodic replacement or replacement parts score a 2. Technologies requiring a continuous supply of consumables to support continued use score a 1.

Chlorination. Requires a constant supply of consumable chemicals that consumers must be willing and able to purchase regularly. Free chlorine can be locally or regionally produced and distributed in bottles purchased by users that treat hundreds to thousands of liters before a repeat purchase is necessary. Chlorine tablets can be purchased in individual units or in multiple units (bottles and blister packs) and require regular or periodic repeat purchase. Score: 1.

Coagulation/Chlorination. Sachets or tablets are manufactured in few locations, imported to most countries, and require unit purchase for every 10−20 L of water. Score: 1.

SODIS. Requires no commercial supply chain as long as used PET bottles are available. Score: 3.

Ceramic Filter. Filter units provide long use periods with one-time purchase, but require a supply chain for replacement of broken parts (filter elements and container faucets). Score: 2.

Biosand filter. Filters are a one-time purchase and have no parts prone to breakage, so require no supply chain for replacement parts. Score: 3.

Scores for the four POU technologies are summarized in Table 3. The overall sustainability ratings from highest to lowest are biosand filtration, ceramic filtration, free chlorine disinfection, SODIS, and coagulation/chlorination.

Maintain High Post-implementation Use Levels after Cessation of Intensive Surveillance and Education Efforts, Such As Those of Field Trials and Marketing Campaigns. Although controlled interventions of POU technologies provide valuable information on water quality improvement and health impact, what happens subsequently with POU use and performance is important to understand and document. Evaluation of post-implementation use levels and performance is complex and not easily reduced to a single metric. However, continued POU technology use, consistent water quality improvement, and reduced risk of waterborne disease are obvious parameters to document as measures of sustainability. Some evidence for these sustainability measures is available from follow-up studies of POU technologies after RCTs and implementation programs, and is summarized in Table 4.

Chlorination. Sustained acceptance of POU chlorination has varied and has often been low. Studies document relatively low rates of sustained and successful use of household chlorination. In a survey of user-reported household chlorination and presence of chlorine residual in

TABLE 4. Post-Implementation Household POU Use and Sustainability

POU technology	sustainability evidence
free chlorine	Longest study lasted 20 months; attenuated effect of intervention found in longer trials (*26*). Assessing reasons for nonuse after a free chlorine social marketing campaign found 39% saying product was unavailable; 34% saying they could not afford it .
coagulation/chlorination	In follow-up studies, only 55% of those surveyed knew where to purchase product (*30*); in a separate survey, only 25% indicated willingness to pay the product's intended market price (*31*).
SODIS	Longest study lasted 12 months; even with high use during the study, 85% of study children also consumed non-SODIS treated drinking water during the study period (*24*); community use has varied from 20–80% (*48*).
ceramic candle filtration	Decline in use of approximately 20% after 9 months in Bolivia in the absence of replacement filters (*44*); susceptibility to ceramic candle breakage.
ceramic filtration - ceramic water purifiers	Filters became disused at rate of 2% per month, of which about 67% was due to breakage; susceptibility to filter pot and container faucet to breakage; mean time in use was 2 years (*9*).
biosand filtration	Continued filter use rates of >85% by households for up to eight years since introduction (*33, 34*).

household water of four Madagascar villages one year after an SWS implementation, 73% of households reported chlorine use but only 54% of these had detectable free chlorine levels (*27*). In a survey of rural Kenyan villages six months after introduction of the SWS, only 33.5% of households had detectable free chlorine residuals in stored water and only 18.5% were using modified safe water storage containers (*28*).

A use survey of a package of health interventions for adults and children with HIV in Uganda (including chlorine solution) reported 65% currently treating household drinking water, but only 36% of those having measurable chlorine residuals (*29*). Overall, sustained and effective use of household water chlorination was low relative to other health promotion/disease prevention interventions in a package; reasons for this are unclear and need to be better understood.

Coagulant/Chlorine Systems. The few studies on long-term sustained use of coagulant/chlorine systems show poor continued acceptance. A 6-month follow-up survey of 472 households from an intervention study found only 10% "confirmed users" (*30*). Barriers to sustainable coagulant/disinfectant access include not knowing where to purchase it (*30*), product unavailability, inability to afford its purchase when needed, and unwillingness to pay the market price (*50*). These barriers to sustainability apply to all POU technologies based on continuous supply and repurchase of consumables.

SODIS. Although sustainability of SODIS has only been evaluated over study durations ranging from weeks to months, continued use has been variable and often low. Following implementation in a Nepal village, only 9% of households routinely adopted SODIS a few months after implementation (*25*). There may be user acceptability problems due to the unchanged taste, smell, and appearance of treated water, and the time and effort required to treat water (*25*). Overall, sustainability of SODIS appears to be variable and may be governed primarily by attitudinal factors that need further study to address barriers to long-term use.

Ceramic Filter. Acceptance and continued ceramic filter usage has been observed to be high. However, breakage of ceramic filter elements and container faucets results in declining use if replacement parts are not available, highlighting the importance of a supply chain to replace broken parts. Overall, ceramic filters provide long periods of effective use for a modest one-time purchase cost and no ongoing costs except those for occasionally replacing broken parts (*9, 10*).

Biosand Filters. Recent post-implementation surveys document >85% continued use of household BSFs as long as 8 years after introduction (*33, 34*). The BSF has very low rates of breakage and disuse over time. Therefore, BSFs appear to have high potential for sustained use to improve household water quality and reduce disease burdens.

Discussion

Laboratory and field evidence documents that free chlorine, coagulation/chlorination, solar disinfection, ceramic filtration, and biosand filtration are effective for improving water quality and reducing diarrheal disease burdens in households and communities of developing countries. However, the controlled intervention studies that document such positive impacts typically last only months and do not address critical issues of long-term sustainability and continued technology performance in homes and communities. It is essential to establish the key criteria for sustained access to and use of microbiologically safe water, and to rigorously evaluate and compare technologies in meeting these requirements.

Free chlorine, coagulation/chlorination, and solar disinfection can in principle improve the microbiological quality of water and reduce diarrheal disease, but the available evidence suggests that they do not achieve sustainable, long-term, continuous use by populations once intervention studies end. For chlorination and coagulation/chlorination, the need to continuously repurchase a consumable product may cause households to forego treating water when financial resources are inadequate. Once interrupted, it may be difficult for households to start treating water again. For technologies producing relatively small quantities of water, such as solar disinfection and coagulant-disinfectant products, the required time and effort to treat sufficient water quantities for all daily household uses may contribute to declining use rates and consumption of both treated and untreated water, undermining their overall effectiveness.

Field studies suggest ceramic and biosand filters are able to overcome these sustainability obstacles by requiring only one-time purchase, producing sufficient water for daily household use with little time and effort, and achieving large scale adoption and continued, long-term use. Both filters have been shown to improve water quality and reduce diarrheal disease in rigorous epidemiological studies, and follow-up studies document sustained, effective performance long after implementation, with filter usage rates remaining high years post-implementation. Ceramic and biosand filter technologies have also shown the potential for large scale adoption, as they are used by over 500,000 and 1.5 million people, respectively. Other household water filtration technologies also deserve consideration, but they need to be evaluated for performance and sustainability according to the criteria identified and applied here to ceramic and biosand filters.

Adoption of filtration technologies can also be accelerated by further improving their production and distribution systems. For BSFs, lightweight, stackable plastic filter housings and centralized facilities for bulk production of filter sand and gravel media are being developed. For ceramic filters, increased production is being achieved with additional new production facilities. Technical improvements are also being made to both ceramic and biosand filters by adding iron oxides to enhance microbial reductions and remove toxic chemicals such as arsenic.

Understanding the human behavioral factors that drive people to adopt and continue using household POU technologies is also crucial for widespread adoption and continued effective use. Much work is needed to better understand and incorporate into improved practice the role of education, behavior change, individual and group perceptions and attitudes of the aesthetic qualities of water, and the social−cultural drivers that influence household water treatment choices and practices of individuals, households, and communities.

Expanding filter production, marketing, distribution for effective and sustained use also requires knowledge of economic factors. Better information is needed on factors that influence filter uptake and continued use by communities and households. The roles of expanded investment in and different strategies for production, marketing, and distribution on large-scale sustainable uptake and use need to be investigated and understood. Business models and other economic factors such as costs of production, distribution and implementation, pricing, subsidy, microfinance, microcredit, willingness-to-pay, and contingent valuation need further investigation and testing to inform and facilitate scaled-up production, marketing and distribution, consumer and community acceptance and uptake, high level coverage, and sustained, effective use.

Going a day without safe water means being at risk. Practicing POU water treatment and safe storage should be like practicing safe sex and brushing your teeth: they need to be done at all times in order to minimize or prevent health risks. POU technologies such as ceramic and biosand filters have promise as effective, affordable ways to achieve sustained access to sufficient quantities of safe drinking water for those people worldwide who most need it.

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