Stanford | King Center on Global Development

Environment and Climate Change

Health

Urbanization and Infrastructure

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The Power of Passive Technology

Evidence on how to improve water quality and health in low-resource settings

Summary

Poor water quality contributes to diarrheal disease and high rates of child mortality in many low-income countries. In places without clean piped water, people are encouraged to treat their water with chlorine at home. However, not enough people use these products consistently, and evidence indicates this approach has led to lower-than-expected improvements in child health.

Researchers looked at existing studies to understand to what extent people manually treat their water with chlorine and what the evidence says about "passive" chlorination, in which water is automatically treated before it is collected. Through rigorous field studies, researchers examined the impact of passive chlorination systems in low-resource settings.

When used correctly, manual chlorination can improve health but relying on individuals to manually treat their water is unlikely to lead to widespread public health benefits.

However, passive chlorination dramatically reduced E. coli levels in drinking water supplies in rural Nepal and reduced diarrhea by nearly 25 percent in urban Bangladesh.

In some settings, reducing the dose may increase adoption of chlorinated water by improving the taste, while still providing effective disinfection.

Overall, passive chlorination technologies are an effective and potentially scalable strategy to treat water in rural and urban low-income settings.

Background

Having access to safe, accessible, and affordable water is a basic human right and foundational to living a life of dignity.[1] Yet, globally, more than 2 billion people—mostly from rural areas of low-income countries—lack access to clean water.[2] Unsafe water contributes to diarrheal disease, which is estimated to be the eighth leading cause of death globally.[3] Given the scale of the problem, attaining universal access to safe and affordable drinking water is a global priority, codified in the United Nation's Sustainable Development Goals (SDGs), 17 goals formulated by the UN General Assembly in 2015 that constitute a global development agenda. SDG Goal 6.1 is to "achieve universal and equitable access to safe and affordable drinking water for all" by 2030.

In places without good water infrastructure, government and non-governmental organizations have encouraged people to safely treat their water at home using various methods, including household filters, solar disinfection, boiling, or manually adding chlorine products. Treating drinking water with chlorine, in particular, is extremely low-cost.

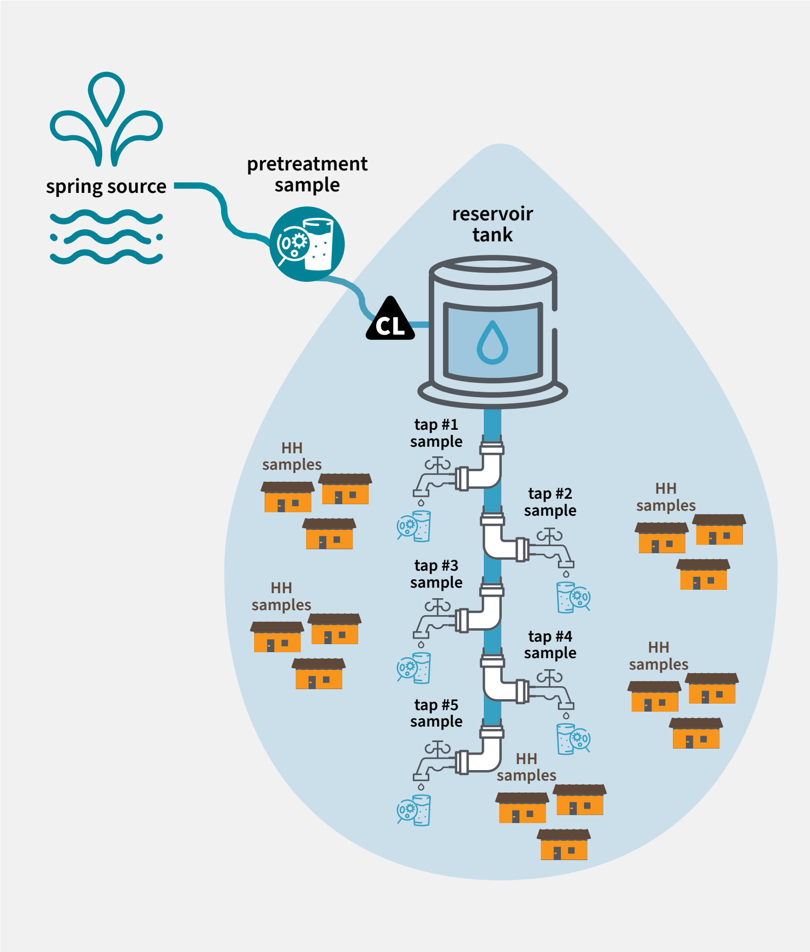
While effective at improving water quality, these "point-of-use" approaches to treating water are far from perfect. One challenge is changing human behavior: unlike "passive" water treatment systems that provide people

1 UN Water. "The Human Right to Water." https://tinyurl.com/f3xz84hj

2 WHO. Joint Monitoring Programme. Safely Managed Drinking Water - Thematic Report on Drinking Water 2017; World Health Organization, UNICEF, 2017.

3 Troeger, C.; Blacker, B.; Khalil, I. A.; Rao, P. C.; Cao, J.; Zimsen, S. R. M.; Albertson, S. B.; Deshpande, A.; Farag, T.; Abebe, Z.; et al. Estimates of the Global, Regional, and National Morbidity, Mortality, and Aetiologies of Lower Respiratory Infections in 195 Countries, 1990–2016: A Systematic Analysis for the Global Burden of Disease Study 2016. Lancet Infect. Dis. 2018, 18, 1191–1210.

with clean water at the tap, point-of-use methods require that households manually treat their water, which requires habit formation and remembering to take that action all the time. Another challenge is that many people strongly dislike the smell of high concentrations of chlorine. Furthermore, these approaches impose a gendered burden, since the task of ensuring water is safe to drink tends to fall on women and girls.



Studies have found actual use of point-of-use water treatment products to be low in many settings. This is a concern since correct and consistent use is required to get the health benefits.[4] Recent randomized controlled trials found little to no impact of these products on child health outcomes. [5, 6, 7]

In contrast, new technologies that make treatment "passive," or automatic, have the potential to provide safe water and reduce reliance on individual behavior change until better infrastructure exists. Until recently, few studies had evaluated the performance and costs of these technologies over time in rural areas.

Using both field experiments and literature reviews, King Center postdoctoral fellow Dr. Yoshika Crider and her co-authors sought to answer several key questions around water treatment technology:

- To what extent are people using point-of-use chlorine? What does the existing evidence say?
- What does existing evidence say about "passive" techniques? Which technologies appear to work best?
- What is the impact of passive chlorination systems in low-resource settings such as rural Nepal and urban Bangladesh?

4 Brown, J. and Clasen, T., 2012. "High adherence is necessary to realize health gains from water quality interventions." *PloS one*, 7(5), p.e36735.

5 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 Global Health* 6(3):e302–e315, PMID:29396217,https://doi.org/10.1016/S2214-109X(17)30490-4.8.

6 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)30005-6.9.

7 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 Global Health* 7(1):e132–e147, PMID:30554749,https://doi.org/10.1016/S2214-109X(18)30374-7.10

The Context

In many low-income countries, contaminated water is a major problem for human health. One major contributor is a lack of clean and safe sanitation infrastructure; in these settings, fecal contamination is not properly contained and, as a result, dangerous microbes make their way into drinking water. According to the World Health Organization, approximately 2 billion people's drinking water sources are contaminated with feces, causing nearly half a million deaths each year.[8]

Another challenge in these settings is a lack of functioning infrastructure. Unlike in high-income countries, where water is treated at central facilities and then safely piped to households, low-income countries and rural areas especially lack this infrastructure. In these settings, water sources can include rivers, lakes, or unprotected wells and springs, which are often contaminated. Protected springs and covered wells are much safer, but not always accessible. In rural Nepal, researchers found that 68 percent of water sources and 81 percent of samples of stored water in people's homes had fecal contamination, yet only 12 percent of households were treating their water prior to drinking.

The Research

Dr. Yoshika Crider and co-authors conducted systematic reviews and field evaluations to understand levels of adoption of point-of-use chlorination and the effectiveness of passive chlorination methods.

1. **A review of literature on household point-of-use chlorination.** Researchers conducted a systematic review of studies, completed from 1990 through 2021, that looked at household point-of-use chlorination interventions and programs. To be included in the review, studies had to a) report a quantitative measure of adoption, b) be conducted in a low- or middle-income country, c) include data collection at households, and d) reported the intervention start date. The researchers identified 36 studies of household drinking water chlorination products that met prespecified eligibility criteria, covering 46 interventions with a range of types of products and locations.

2. **A review of literature on passive chlorination.** In this review, an interdisciplinary team of researchers led by Dr. Megan Lindmark and Dr. Katya Cherukumilli synthesized evidence from evaluations of passive chlorinators (in 19 articles, 3 NGO reports, and 5 theses) conducted across 16 countries in communities, schools, health care facilities, and refugee camps. The team identified 27 passive chlorinator technologies in these reports.

A shared water tap in rural Nepal (photo credit: Yoshika Crider)

8 https://www.who.int/en/news-room/fact-sheets/detail/drinking-water

3. **An evaluation of chlorine detection and acceptability of taste and smell for two common types of chlorine in Dhaka, Bangladesh.** The study was conducted with 50 adults. Each participant received three samples of water: two that contained no chlorine and one that contained a precise concentration of chlorine. The respondent was asked to identify which sample they believed contained chlorine. The test was repeated two more times at the same chlorine concentration, for a total of three sets per round, and the concentration was increased at each new round. Respondents were then asked questions about the acceptability of the taste and whether they would seek out an alternative source of water if the water at their primary drinking water source tasted like the sample.

4. **An evaluation of passive chlorination systems in Nepal.** Researchers conducted a non-randomized evaluation of two passive chlorination technologies for system-level water treatment in six gravity-fed, piped water systems in small communities in rural western Nepal. Researchers monitored water quality indicators upstream of the treatment and downstream, at shared taps and at households. They also looked at user acceptability and measured the costs of monitoring and maintaining the technology over one year.

Water and Development: A Gender Perspective

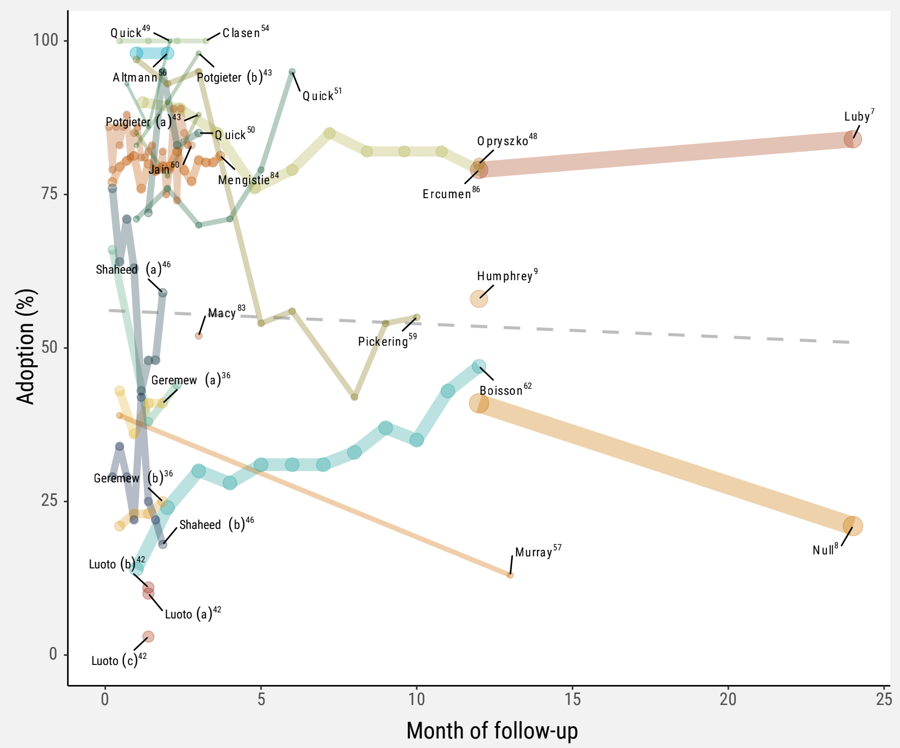
In a 2022 article in *Oxford Research Encyclopedia of Environmental Science*, Crider and co-author Dr. Isha Ray explore new directions in global development literature that acknowledge the breadth and complexities of gender and water in the world. Rather than simply calling for gender-disaggregated data, new scholarship seeks to take water research towards a recognition of gender justice as a foundation for water justice for all.

5. **Health impact evaluation of a passive chlorination system in Bangladesh.** This was a double-blind, cluster-randomized controlled trial led by Dr. Amy Pickering. One hundred shared water points in two low-income urban communities in Bangladesh were randomly assigned either to have their drinking water automatically chlorinated at the point of collection by a passive chlorinator (intervention group) or to be “treated” by a visually identical doser that supplied vitamin C (placebo group). The primary outcome was caregiver-reported child diarrhea.

The Results

The study that reviewed point-of-use chlorination found that the adoption of point-of-use chlorine was highly variable. Across all studies, the median level of adoption was just 47%, far lower than is required to realize the full health benefits of safe water. When combining all the available evidence, adoption declined over time. The review also found that higher chlorine use was correlated with more frequent contact between respondents and study staff, indicating that sustaining high use requires a lot of resources.

The review of the literature on passive chlorination technologies identified several limitations to current systems and identified research priorities. The limitations include local chlorine availability, cost, lack of technical expertise to maintain systems, time- and labor-intensive methods for (manually) checking systems, and dosing issues. Based on this, researchers outlined research priorities to address existing barriers, including strengthening local chlorine supply chains; validating context-specific business models and financial sustainability; leveraging remote monitoring and sensing tools to monitor real-time chlorine levels and potential system failures; and designing handpump-compatible passive chlorinators to serve the many communities reliant on handpumps as a primary drinking water source. They noted that only one high-quality peer-reviewed evaluation (by Pickering et al, see below) had measured health outcomes of passive chlorination, also highlighting the need for further research.



Reported adoption over time, with line weight scaled to study size. Full details in: Crider, Y. S., Tsuchiya, M., Mukundwa, M., Ray, I., & Pickering, A. J. (2023). Adoption of point-of-use chlorination for household drinking water treatment: A systematic review. *Environmental Health Perspectives*, 131(1), 16001.

In Dhaka, Bangladesh, users are okay drinking treated water in which they can detect the taste of chlorine. However, the concentration of chlorinated water they are okay tasting is well below the 2.0 mg/L that point-of-use chlorine water treatment products are often designed to dose.

In rural Nepal, passive chlorination dramatically reduced E. coli levels in the water. At the beginning of the study, over 80 percent of tap samples were contaminated with *E. coli*, an indicator of fecal contamination. After one year of system-level chlorination, only 7 percent of those taps had *E. coli* in water samples. However, 29 percent of household stored water was positive for *E. coli*, indicating there was recontamination during transport and storage at the home. Per cubic meter of treated water, the cost of chlorine was US$0.06–0.09, which was similar to the cost of labor to monitor and maintain the chlorination devices. This means that both the cost of the chlorine and the cost of ensuring the devices work properly need to be taken into account to operate these technologies effectively and ensure their long-term sustainability.

In Bangladesh, the passive chlorination system led to an almost 25 percent reduction in diarrhea. After having their water chlorinated for one year, caregivers in the treatment group were significantly less likely to report seeking medical care for their child due to illness, particularly gastrointestinal-related illnesses. Reported illness-related expenditures in the previous two months per child were significantly lower in the treatment group than in the control group; the average difference in medical expenditures per child between groups was 40 taka (approximately US$0.50). Caregivers in the treatment group were also less likely to report that their child had consumed antibiotics in the previous two months.

Policy Implications

- Chlorinated drinking water can improve health, but relying on individuals to manually treat their water is unlikely to lead to widespread public health benefits. Safe water programs should increasingly shift toward strategies that reduce treatment burdens on households.
- This research suggests that passive chlorination technologies at the point of collection are an effective and potentially scalable strategy in rural and urban low-income settings for achieving global progress towards Sustainable Development Goal 6.1 to attain universal access to safe and affordable drinking water. Developing reliable supply chains and financial models for maintenance will ensure they are sustainable.
- For some settings, reducing the dose may increase adoption of chlorinated water while still providing effective disinfection. In urban Bangladesh, using a low chlorine residual (<0.7 mg/L) in treated water can increase taste acceptability of chlorinated drinking water while still reducing the risk of diarrhea.

This brief is based on the following papers:

Crider, Yoshika S., and Isha Ray. "Water and Development: A Gender Perspective." In Oxford Research Encyclopedia of Environmental Science. (2022).

Crider, Yoshika, Sonia Sultana, Leanne Unicomb, Jennifer Davis, Stephen P. Luby, and Amy J. Pickering. "Can you taste it? Taste detection and acceptability thresholds for chlorine residual in drinking water in Dhaka, Bangladesh." Science of the Total Environment 613 (2018): 840-846.

Crider, Yoshika S., Sanjeena Sainju, Rubika Shrestha, Guillaume Clair-Caliot, Ariane Schertenleib, Bal Mukunda Kunwar, Madan R. Bhatta, Sara J. Marks, and Isha Ray. "Evaluation of System-Level, Passive Chlorination in Gravity-Fed Piped Water Systems in Rural Nepal." Environmental science & technology 56, no. 19 (2022): 13985-13995.

Crider, Yoshika S., Miki Tsuchiya, Magnifique Mukundwa, Isha Ray, and Amy J. Pickering. "Adoption of point-of-use chlorination for household drinking water treatment: a systematic review." Environmental Health Perspectives 131, no. 1 (2023): 016001.

Lindmark, Megan, Katya Cherukumilli, Yoshika S. Crider, Perrine Marcenac, Matthew Lozier, Lee Voth-Gaeddert, Daniele S. Lantagne et al. "Passive In-Line Chlorination for Drinking Water Disinfection: A Critical Review." Environmental science & technology 56, no. 13 (2022): 9164-9181.

Pickering, Amy J., Yoshika Crider, Sonia Sultana, Jenna Swarthout, Frederick GB Goddard, Syed Anjerul Islam, Shreyan Sen, Raga Ayyagari, and Stephen P. Luby. "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, no. 9 (2019): e1247-e1256.

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Author
Laura Burke

Featured Researcher
Yoshika S. Crider
King Center Postdoctoral Fellow 2021–2023

ABOUT THE FEATURED RESEARCHER

Yoshika S. Crider is a King Center Postdoctoral Fellow from 2021 to 2023. Her research agenda explores strategies to improve health in low-resource settings by reducing environmental exposures to enteric pathogens, with a particular interest in interventions that increase gender equity and water justice.