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# End-User Preferences for and Performance of Competing POU Water Treatment Technologies among the Rural Poor of Kenya

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Household point-of-use (POU) water treatment technologies targeted at vulnerable populations are microbiologically effective and, in small trials, improve health. We do not understand the factors that influence preference for and adoption of these technologies by target end-users. We cycled 400 rural subsistence farm households in western Kenya through three randomly ordered two-month trials of three POU products: dilute hypochlorite solution, porous ceramic filtration, and a combined flocculant-disinfectant powdered mixture to compare relative end-user preferences and usage. Households reported higher usage of both dilute hypochlorite and filters than the flocculant-disinfectant. Averaged among all participating households, *Escherichia coli* reductions in treated water were generally higher among those that received dilute hypochlorite solution than among those receiving either of the other two products. Among those households that self-reported product usage, the *E. coli* reductions achieved by dilute hypochlorite and the flocculant-disinfectant are statistically equivalent to one another and higher than the reductions achieved by filters. At the same time, households ranked filters most frequently as their most preferred product.

## Introduction

Microbially contaminated drinking water is one of the main contributors to the deaths of some 1.8 million infants and children under the age of five each year from diarrheal illness and typhoid fever (*1*). Treatment of drinking water at the point-of-use (POU) has been documented to reduce exposure to indicators of microbial pathogens (*2*−*6*). Meanwhile, though there remains some debate as to the ability of water quality improvement interventions to achieve disease reductions without improved sanitation and hygiene (*7*), numerous studies do find an array of POU products reduce disease independently of other measures (*8, 9*).

Despite these findings, household treatment of water is not widely practiced among low-income populations of developing countries (other than boiling in a few nations) (*10*). Market penetration of Asian and Latin American middle- and high-income households by higher-priced POU treatment devices is significant (*11*), but widespread and sustained adoption of POU technologies or behaviors among the vulnerable poor remains elusive (*12*).

One attempt has been made to rank several available products targeted at low-income populations on the basis of their potential for scaled distribution and sustained adoption (*13*). Sobsey and collaborators base their rankings of sustained use on scattered documentation from published studies of microbiological efficacy and health outcomes of various POU approaches. Lantagne et al. critique the methodology (*14*). We appreciate the attention this paper and the published comment bring to the need to understand preferences for different POU products among poor populations.

Conversely, we lament the attention the lay press gives to supposedly pro-poor drinking water innovations that are never adopted at meaningful scale. For example, the LifeStraw Personal device, a halogenated resin-packed pipe filter manufactured by the Switzerland-based company Vestergaard-Frandsen, received numerous design awards and was described by the *New York Times* in 2006 as a "straw that saves lives" (*15*). Three years later, this product is not in widespread use anywhere on earth, and a randomized controlled trial published in 2009 found only 13% self-reported usage of the device among over 300 Ethiopian households to whom it had been provided at no charge and who were visited every two weeks by field enumerators (*16*).

In this research, we analyze the POU products that low-income consumers in Nyanza Province, Kenya, use and prefer. Claims about POU product usage in the developing world are frequently based on anecdote, and this is the first attempt of which we are aware to generate robust evidence of the choices rural householders make when multiple POU products are made available.

## Materials and Methods

**POU Products.** This study examines adoption preferences and usage of three products: dilute hypochlorite solution (branded locally as WaterGuard), combined flocculant-disinfectant (branded as the PUR Purifier of Water by its manufacturer, Procter & Gamble, Cincinnati, OH), and gravity-driven filtration using silver-coated porous ceramic "candle" elements (branded as Sterilaqua, manufactured by Cerâmica Stéfani of São Paolo, Brazil; Figure S1, see Supporting Information). Each of these products dramatically reduces the concentrations of pathogen indicators in drinking water and reduces disease levels in intervention households in randomized (though unblinded) trials (*8*). Waddington et al. (*12*) and Schmidt and Cairncross (*17*) raise questions about the potential bias of these randomized trials.

Both WaterGuard and PUR are commercially distributed by the U.S.-based nonprofit organization Population Services International (PSI) at subsidized prices and are locally available in our study area.

The candle filters we used in this study are distributed through a number of retailers in Kenya. We produced a low-cost version by employing locally sourced plastic buckets for the delivery system, with two candle filters mounted in the upper bucket and draining into the lower vessel for storage and dispensing. The filter devices had a filtration rate of 1−2 L/h (declining with the head loss of a dropping water level in the upper bucket, and varying with turbidity level of the feedwater). By comparison, the recommended wait-time for treatment using WaterGuard is 30 min for 20 L, while the PUR treatment process requires roughly 30 min for 10 L.

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**Setting.** We conducted this research in Nyawita, a largely rural administrative sublocation within a 6 km radius of the town of Bondo in Nyanza Province, Kenya (Figure S2, Supporting Information). The study area includes 28 distinct villages and is located approximately 60 km from the regional capital of Kisumu in one of the poorest rural districts in the poorest province in Kenya. The area has moderate topographic relief and lies south of the Yala River, approximately a dozen miles from Lake Victoria. Because the study population consists overwhelmingly of subsistence farmers, we did not measure income directly, although average daily wages for an informal laborer in the nearby town of Kisumu range from $1 to $1.25/day (*18*). Homes in our study area are constructed either of mud (77%) or concrete (20%), and 63% of the households have corrugated metal roofing (with the remainder being thatch). Liquidity constraints are significant, with nearly 60% of the population reporting that they would find it "very difficult" or "impossible" to raise 500 Kenyan shillings (~$7.33 in the middle of 2008) in cash within 24 h.

Water sources include small artificial surface reservoirs (known locally as earthpans), the Yala River, public and privately owned standpipes, harvested rainwater, and a very small number of boreholes, shallow wells, and springs (comprising <3% of the observations). Households' choice of water source is complex and seasonally dependent (as discussed in the Results section).

Rainfall patterns in the area follow a bimodal distribution, with monthly average peaks of ~160 mm occurring in April and August, respectively, separated by a moderately dry May-August period with monthly rains of ~100 mm in June. Precipitation then drops precipitously from September onward, reaching a monthly average of under 40 mm in January (*19*). These patterns bear strongly on water sourcing patterns, as discussed below.

**Experimental Design.** At baseline, a census identified all homes with children under the age of 5 years old in Nyawita. We then randomly selected 400 households and conducted interviews on basic assets, water supply, water treatment, sanitation, and hygiene behaviors. During the same baseline visit, enumerators provided detailed presentations of the three POU products in randomized order. Households were asked to rank their product preferences based on the enumerator presentations.

At the end of the interview, enumerators provided one of the three products for a two-month trial. The order of the trials was randomly assigned. Households assigned to receive PUR also received two locally procured 15 L plastic buckets with lids to execute the PUR treatment process (one of which had a tap), and households assigned to receive WaterGuard received a single 20 L bucket with a lid and tap.

Enumerators visited a randomly selected subset of the participating households over the course of the following two months for short spot checks to objectively verify product usage.

At the end of the two-month period, enumerators visited each household for a follow-up survey to determine updated product preferences and to measure water quality in stored untreated and treated water. Each household was then assigned a new product in random order. This cycle was repeated twice, so each household had a two-month trial of each POU product. It is worth noting here that most households had an uninterrupted two months to reveal their usage and preference patterns, as compared to the more frequent enumerator visits conducted in other published studies of POU product impacts on diarrhea morbidity. Visits to collect water samples were unannounced, although respondents were generally aware that approximately two months after receiving a product they would be revisited.

**Sample Size, Enrollment, and Attrition.** To detect differences in rates of product usage of 10 percentage points with 80% power at 95% confidence required a sample size of approximately 100 households per product-trial for a total of 300 households. We sampled 133 households per product-trial to account for expected attrition. The sole selection criterion for inclusion in the study was presence of a child under five in the household.

The study began in July 2008 with 400 participating households and was completed in February 2009 with 370 participating households, resulting in an overall retention rate of 93%. The most common reason for a household to drop out of the study was migration to an urban area. Our estimates of usage are therefore most representative of a persistently rural population. Attrition does not appear related to a household's assigned product or other randomized treatment assignments. ($\chi^2$ test p-value is 0.16 on a probit regression that predicts dropout as a function of all treatment assignments.)

**Water Quality Analysis.** We tested source waters, stored untreated water (if available), and stored treated water (if available) for turbidity and *Escherichia coli*. We tested turbidity using a portable turbidimeter (Model 2100P, Hach Company, Loveland, CO).

In heavily contaminated source waters, we measured *E. coli* using Petrifilm *E. coli*/Coliform Count Plates (3M, St. Paul, MN). In household samples anticipated to have lower (<2400 CFU/100 mL) concentrations, we used the Colilert Quantitray-2000 assay (IDEXX Laboratories, Westbrook, ME).

**Data Analysis.** Household survey results were recorded in hardcopy forms and entered into digital forms using Excel (Microsoft Corp., Redmond, WA). Digital data tables were then exported into Stata (StataCorp LP, College Station, TX).

All reported confidence intervals and statistical tests take into account the repeated nature of the sampling using the "cluster" sandwich estimator in Stata. Full details on the statistical analysis are included in the Supporting Information.

**Ethics.** This study was reviewed and approved by the Committee for the Protection of Human Subjects at the University of California, Berkeley, and local permissions were secured by CARE Kenya, which supervised the enumerator team. Participants were briefed as to the details of the study and afforded opportunity to ask questions and receive answers to those questions. Enumerators obtained informed, verbal consent from each respondent prior to inclusion in the study.

## Results

**Water Supply Behaviors and Source Water Characteristics.** We selected the field site because of an expectation that highly turbid surface waters (earthpans and the River Yala) represented dominant water supply sources for the local population. In fact, survey responses revealed complex water sourcing patterns.

At the baseline survey, conducted during the rainy period of July–August 2008, 46% of households reported relying on surface water (river or earthpan) sources when asked for their "main" drinking water source, far higher than the 8% reporting rainwater. However, only 14% said they collected their "currently stored water" from surface sources, while over half the respondents mentioned rainwater.

Rainwater harvesting increased to 68% of the respondents in Follow Up 1 (conducted in September–October 2008) and then declined with the onset of the dry season, as only 30% of the households reported collecting rainwater in Follow Up 3 during January–February 2009 (Table S1, Supporting Information). Meanwhile, surface water sourcing (earthpans or Yala River) for current drinking water increased to 25% by Follow Up 3.

Overall, 79% of the observations in our study are from homes which sourced their water from taps or rainwater. In

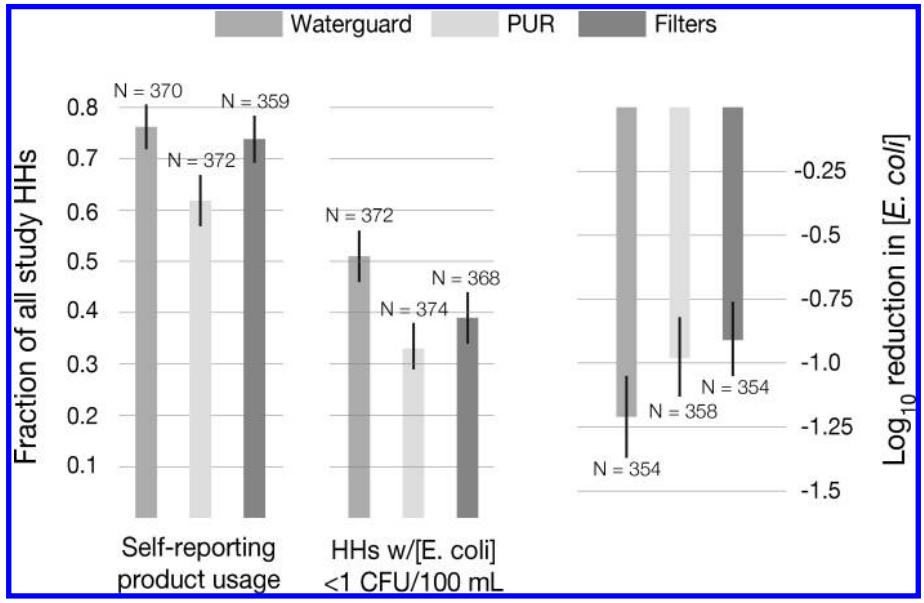


**FIGURE 1. Product usage and performance across all study waves and water supply sources. Error bars correspond to 95% confidence intervals. All postbaseline waves of data (excludes spot checks).**

contrast, only 18% sourced from more turbid surface water sources (earthpans and the Yala River).

The quality of untreated water stored in the home is largely as expected (Table S2, see Supporting Information). Surface waters (earthpan and river) have significantly more *E. coli* (means of 711 and 602 CFU/100 mL, respectively) than harvested rainwater and standpipe (tap) water (means of 231 and 248 CFU/100 mL, respectively; difference statistically significant at $p < 0.001$). The median is substantially lower than the mean for *E. coli* in rainwater and tap water because of right skewness (that is, a few large positive outliers).

Turbidity is also far higher for earthpan and river water (means of 117 and 47 NTU, respectively) compared to tap and rainwater (means of 13 and 16 NTU, respectively; difference statistically significant at $p < 0.001$). Harvested rainwater and tap water are not statistically significantly different from each other in terms of microbiological quality or turbidity.

The "wells and springs" category, consisting primarily of open hand-dug wells and both protected and unprotected springs, has water quality comparable to that of the surface water sources, with mean *E. coli* at 669 CFU/100 mL and mean turbidity at 69 NTU. We see comparable right skewness in the distributions of *E. coli* and turbidity in this category, with median *E.coli* at 201 CFU/100 mL and median turbidity at 25 NTU.

**POU Product Usage and Performance.** We analyze self-reported product usage and several complementary measures of product usage. Due to widespread courtesy bias among respondents, it was important to objectively verify product usage to the greatest degree possible. Thus, in addition to self-reporting, we examined product performance in reducing contamination with *E. coli* - both because of its intrinsic value and as a proxy for product usage.

We measure product performance using the fractions of households whose treated water exhibited *E.coli* concentrations <1 CFU/100 mL (the WHO-recommended maximum for drinking water) and base 10 log reductions in measured *E. coli* concentrations between stored untreated water and stored treated (or drinking) water across all study waves and source water types.

We transform the data into log form because of the log-normal distribution of absolute *E. coli* counts. We assign all observations with no detectable *E. coli* a log value of −1 to retain them after the log transformation.

Some of the products evaluated in this study have shown >6 $\log_{10}$ (99.9999%) reduction of *E. coli* in the laboratory, the maximum detectable *E. coli* reduction observable here is 4.38 $\log_{10}$ because the maximum detection limit of the IDEXX Colilert Quantitray-2000 assay is 2419.6 CFU/100 mL when run without a dilution and we assign the sample with no detectable *E. coli* a $\log_{10}$ concentration value of −1.

When households had only untreated water, we assumed that water was also the drinking water (implying reduction in $\log_{10}$ *E. coli* = 0). When households had only treated water we imputed the untreated water's $\log_{10}$ *E. coli* concentrations based on out-of-sample predictions from a model of untreated $\log_{10}$ *E. coli* levels on a series of village, survey wave, and source type dummies and their interactions, using data from homes with both untreated and treated water.

Households visited later in a day in a village did not have better product performance than households visited earlier, alleviating fears that respondents treated water when they learned enumerators were nearby. Furthermore, spot check visits were unannounced, and our point estimates on product performance are very similar if we rely solely on the spot checks (although we lack statistical power to do so).

Figure 1 presents the core results of the paper, showing each product's self-reported usage and microbiological performance. Combining all study waves, households are more likely to self-report usage of WaterGuard (76%, 95% CI: 72−80%) and the filter (73%, 95% CI: 69−78%) relative to PUR (62%, 95% CI: 57−67%; $p < 0.001$). The difference in self-reported usage between WaterGuard and the filter is not statistically significant ($p = 0.40$).

WaterGuard proves significantly more likely than the other two products to produce *E. coli* concentrations under the detection limit of our assay across all water sources and all survey waves (Figure 1). When homes were assigned WaterGuard, 51% of their stored drinking water samples had <1 CFU/100 mL (95% CI: 46−56%). When these same households were provided PUR, 33% had *E. coli* concentrations <1 CFU/100 mL (95% CI: 29−38%, $p < 0.001$ on test of equality with WaterGuard), and when provided filters, 39% of the time (95% CI: 34−44%, $p < 0.001$ for Wald test of equality with WaterGuard and $p = 0.14$ for test of equality with PUR).

As in many other studies, each of the products exhibited solid microbiological performance, with an average log reduction value across all products and follow up waves of

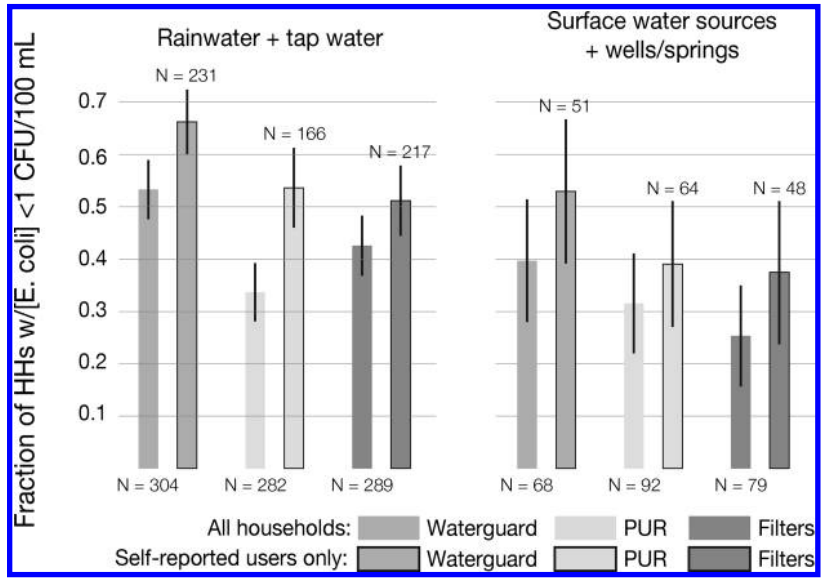


**FIGURE 2. Fraction of households with <1 CFU/100 mL *E. coli* observed in treated water across all waves. Error bars correspond to 95% confidence intervals.**

1.03. The mean $\log_{10}$ reduction value for *E. coli* when households were provided with WaterGuard (1.21, 95% CI: 1.05−1.37) was greater than when they had PUR (0.98, 95% CI: 0.82−1.13) or filters (0.91, 95% CI: 0.76−1.05; $p = 0.013$ on three-way test of equality), with no statistically significant difference between filters and PUR ($p = 0.52$) (Figure 1).

These results are for all households *assigned* a product and, therefore, include nonusers of products. If we restrict the sample to those homes that report use of a product (so we lose the true experiment), PUR performs equally well as WaterGuard (mean $\log_{10}$ reduction value of 1.40 and 1.45, respectively, $p = 0.73$ on Wald test of equality), while the filters are less effective (mean $\log_{10}$ reduction value of 1.10, p-value = 0.019 on joint test of equality across three products).

We anticipated that users of surface water would use PUR (which removes turbidity) more than users of less-turbid rain or tap water, but did not find that pattern. In Figure S3 (see Supporting Information), we present self-reported product usage among households relying on relatively high quality waters (rainwater and tap water) as compared to those relying on relatively poor quality waters (surface waters, shallow wells, and springs). In the high quality category, the difference between reported usage of WaterGuard and the filters is not statistically significant (76%, 95% CI = 72−81% vs 77%, 95% CI = 72−82%; $p = 0.9$). In contrast, households in this category are less likely to report usage of PUR (59%. 95% CI = 53−65%) than either WaterGuard or filters ($p <$ 0.0001). Among households relying on poor quality waters, 75% (95% CI = 65−85%) report WaterGuard usage, as compared to 70% (95% CI = 60−79%) for PUR and 62% (95% CI = 51−73%) for filters, but these differences are not jointly statistically significant at the 5% level.

We were interested in whether WaterGuard was less microbiologically effective in turbid waters. Measuring product effectiveness by source is complicated because we could not randomize sources, and there is suggestive evidence that users selected cleaner source waters in response to being assigned the filter or WaterGuard instead of PUR. The median *E. coli* concentration for untreated water among self-reported PUR users is 47 CFU/100 mL, as compared to 26 and 15 CFU/100 mL for WaterGuard and the filter, respectively ($p$ = 0.001 in a Wilcoxon rank sum test of medians for PUR vs. WaterGuard and filters; we cannot reject that log *E. coli* counts of untreated water at WaterGuard and the filter homes are equal with $p = 0.24$).

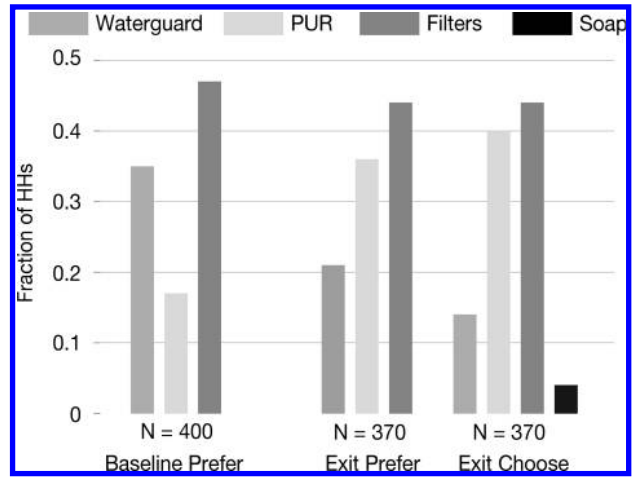


**FIGURE 3. Initial vs final product preference and choice.**

In Figures 2 and 3, we first present results for all households receiving a given product. We then present results for the subsample of households self-reporting use of that product. As with examination by source, restricting our analysis to self-selected users removes the benefits of randomization. Specifically, any observed differences may be, in part, the result of household characteristics correlated with product usage. This concern with self-selection bias is amplified because fewer households self-report usage of PUR than the other two products ($N = 284$ for WaterGuard, 233 for PUR, and 270 for filters).

WaterGuard's overall superior microbiological performance persists when we divide by water supply source type (Figure 2): 53% of high quality water-reliant households receiving WaterGuard exhibited *E. coli* concentrations <1 CFU/100 mL (95% CI: 48−59%), as compared to 34% (95% CI: 28−39%) of those that received PUR and 43% (95% CI: 37−48%) of those that received filters, with all differences significant at the 5% level. WaterGuard's superiority in the higher quality water category (66% of samples <1 CFU/100 mL, 95% CI = 60−72%, vs 54%, 95% CI = 46−61% for PUR and 51%, 95% CI = 44−58% for filters) is also statistically significant ($p < 0.01$) when looking at self-reported users only. Among self-reported users, however, there is no statistically significant difference in performance of PUR as compared

to filters ($p = 0.63$) among households accessing higher quality source waters.

When we turn to households relying on low-quality waters, more households receiving WaterGuard had no detectable *E. coli* than households receiving the other products, but none of the differences are significant at the 5% level. The advantage of WaterGuard (and its lack of statistical significance) also held among the subset of self-reported users (Figure 2).

The $\log_{10}$ reductions in *E. coli* achieved by the products offers a similar picture (Figure S4, see Supporting Information). In the high-quality source water category, the mean $\log_{10}$ reduction in *E. coli* between treated and untreated water observed in households provided with WaterGuard (1.1, 95% CI = 0.97−1.3) is higher than those of PUR (0.8, 95% CI = 0.64−0.97) and filters (0.91, 95% CI = 0.74−1.1), with differences significant at the 5% level. There is no significant difference between PUR and filters in this category. Among self-reported product users relying on high quality source waters, however, $\log_{10}$ reductions achieved by WaterGuard (1.3, 95% CI = 1.1−1.5) and PUR (1.25, 95% CI = 1.0−1.5) are statistically similar. WaterGuard achieves higher $\log_{10}$ reductions than those achieved by filters (1.0, 95% CI = 0.8−1.2) at the 5% level.

The same pattern remains among households relying on low quality source waters, with WaterGuard.(1.5, 95% CI = 1.1−1.9) and PUR (1.4, 95%: CI = 1.1−1.8) achieving statistically similar results, both superior to those achieved by the filters (0.9, 95% CI = 0.6−1.2) at the 5% level. Among self-reported product users, the only statistically significant difference ($p = 0.05$) is between the reductions achieved by WaterGuard (−2, 95% CI = 1.5−2.5) and filters (1.3, 95% CI = 0.9−1.8).

**Stated and Expressed Product Preference.** In Figure 3, we present households' self-reported product preferences at baseline and at the final household visit following two-month trials with each of the three products. Recall our baseline survey was conducted at the end of the short rainy season while the final survey was conducted in the middle of the long dry season. Thus, any change from baseline to the exit survey may be a product of both experience and of the shift in seasons.

Our analysis of households' relative valuation of the sampled products is offered in the Discussion section.

At the final household visit, we also offered each household their choice of a filter, 100 sachets of PUR, or three bottles of WaterGuard. Importantly, the PUR option included two buckets, one with a cover and tap, and the WaterGuard option included a single safe storage bucket with a cover and a tap. The quantities of WaterGuard and PUR provided homes with access to improved drinking water for approximately 6 months.

We also offered households an outside health good, soap, in case households did not care for any of the POU products. Bars of soap are a commonly purchased item among these households and the same bar of soap is often used for washing dishes, bathing, and cleaning. We therefore anticipated it to hold value among respondents. The results of this choice are also presented in Figure 3.

Filters were reported most preferred at both baseline (45% of homes) and after trying each product (44%) and were most frequently selected in the choice experiment (44% of households).

Interestingly, the fraction of households identifying PUR as their preferred choice remained fairly constant over the first four months of the study, with 16% at baseline, 17% at Follow Up 1, and 20% at Follow Up 2. The fraction increased to 35% at the final visit.

Meanwhile, 34% of households identified WaterGuard as their preferred choice at baseline, but only 21% at the final visit. This decline occurs in spite of the higher usage rates of WaterGuard relative to the other two products.

In the choice experiment at exit, PUR did even better compared to WaterGuard, coming in a close second to filters (we fail to reject a null hypothesis that they were chosen at the same rate with $p = 0.36$), while WaterGuard fared even worse, with less than 15% of households choosing it from among the products and a two-month supply of soap.

We equalized the total access to safe water across the three products in giving out approximately 6 months' worth of supplies of PUR and of WaterGuard. However, this approximate equalization of days meant the market values of the three POU choices were markedly different, with WaterGuard worth approximately \$0.80 plus one bucket compared to PUR's value of \$9.33 plus two buckets and the (used) filter's value of approximately \$10−12. The filter would typically treat well over six months worth of water.

**Interaction with Turbidity.** PUR, unlike WaterGuard, greatly reduces turbidity. While the filter also removes turbidity, highly turbid source water can clog the filter. Thus, we hypothesized that source water turbidity would increase the product preference for and choice of PUR.

In Table S3 (see Supporting Information), we present product preference results across all study waves and results of the final choice experiment stratified by the turbidity of the household's water source. Contrary to our hypothesis, there was no strong relationship between the turbidity of water and preference for PUR. PUR is preferred more frequently by respondents with >100 NTU turbidity source water (30%, 95% CI = 20−40%) than by respondents with <100 NTU turbidity source water (21%, 95% CI = 19−24%), although this difference is not significant ($p = 0.104$). There is no consistent relationship between use of PUR and the turbidity of untreated water in the household.

**Sustained Usage.** Because of the small size of our enumerator team relative to the sample size and frequency of visits, each set of household visits was staggered over several weeks. This, combined with the spot-check visits made to a subset of households during each product rotation, enabled us to examine the relationship between time exposure to products and various measures of product usage. In Figure S5 (see Supporting Information), we present results of a locally weighted regression (using Stata's lowess command) of the fraction of homes having treated and untreated water with *E. coli* concentrations <1 CFU/100 mL, across all three products tested.

The probability of treated water *E. coli* concentrations <1 CFU/100 mL were highest immediately after the household received the POU product, at over 60%. This probability drops steadily over the first month of exposure to the product, and then stabilizes at approximately 40%. Meanwhile, the probability of *E. coli* < 1 CFU/100 mL in untreated water fluctuates between 9% and 18%. At any given point in the studied time period, treated water is at least 2.9 times more likely to exhibit *E. coli* < 1 CFU/100 mL than untreated water. However, we powered our study to look at differences at the mean, where we find differences to be statistically significant. Other differences typically are not statistically significant. We therefore interpret with caution.

## Discussion

The rural poor we study use a complex mix of water sources, with the mix varying enormously by seasons. Often households will use one water source for cleaning and bathing, a second source for cooking and yet another source for drinking. The results in Table S1 (see Supporting Information) illuminate both the dependence of water sourcing on seasonal climate patterns, as well as the care that must be taken to get reliable information on where households extract water for different purposes.

With respect to product usage, performance, and choice, our main results are as follows:

- WaterGuard and ceramic filtration were generally used more than PUR, though among households relying on relatively low-quality source waters, PUR was more widely used than filters (though less than WaterGuard).
- Households provided with WaterGuard showed larger improvements in water safety (as measured by presence of *E. coli*) than did the same households provided with the other products.
- WaterGuard's advantage over PUR came from higher usage, while both WaterGuard and PUR were a bit more effective than the filter when used. At the same time, all of the products improved water quality substantially when used.
- In contrast to the results on usage, PUR and the filter were each chosen more than twice as often as WaterGuard as the parting gift. The filter was the most preferred product across all waves of the study ($p < 0.001$).

Branded dilute hypochlorite solutions, such as WaterGuard, were designed for bacteria and virus removal and not for particle removal. WaterGuard's success against *E. coli* when employed on low-turbidity waters such as tap water and harvested rainwater was expected, but we hypothesized that WaterGuard would be less effective in turbid water. Thus we were surprised to see how well WaterGuard performed among homes relying on surface water sources where turbidity of stored water was high (stored untreated samples from earthpans across all waves had a mean turbidity reading of 132 NTU).

Despite our locating this study site specifically to examine households reliant on turbid water, our study was underpowered in the surface water category, thereby preventing inference about the relative performance and usage of PUR as compared to filters.

Despite its superior performance and usage rates, WaterGuard is not the product most preferred or most frequently selected by households in our study. Conversely, filters are not the most effective of the products, but they are the most popular.

The objectionable taste and odor of chlorinated water is sometimes identified as a limit on adoption of chlorine-based products such as WaterGuard and PUR, and this would normally be a reasonable explanation for the popularity of the filters. Yet chlorine odor and taste did not prevent WaterGuard from being the most used and effective product.

We asked households to explain their reasons for naming a product as their most preferred, and 67% of those that preferred the filter did so because it was "easiest to use" (across all waves), while less than 4% cited the filter's superior taste and odor. At the same time, 20% of of those households that ranked WaterGuard or PUR as their *least* preferred product listed objectionable odor and taste among their reasons, while 27% mentioned difficulty of use, 24% mentioned failure to remove turbidity, and 20% mentioned the duration of the treatment process.

By including buckets with each of the product offerings in the choice experiment, we attempted to control for the advantage that the filter units possess as a durable good (as opposed to the consumables, WaterGuard and PUR). Even so, the highest number of households selected the filter (although we cannot reject equality between the rates at which filters and PUR were chosen). This result could suggest that their aspirational characteristics may exceed those of the chemical products, even when WaterGuard and PUR are offered with buckets. Another important caveat with respect to the choice experiment is that many users likely recognized that with proper care, a filter unit would function far longer than the six month supply offered with PUR and WaterGuard. On the one hand, 52% of the 163 households that chose the filter listed as one of their reasons: "It will last." On the other hand, 90% of filter-choosing households also listed "easiest to use" as a reason for their choice.

We initially hypothesized that the increase in preference for PUR (at the expense of WaterGuard) between baseline and exit could be a function of increasing use of turbid surface sources as the study progressed out of the rainy season into a dry period. Indeed, the fraction of households reporting their stored water to be from a turbid water source (earthpan or the Yala River) did increase from 14% at baseline to 25% at exit ($p < 0.0001$ on test of equality), and average turbidity levels of stored untreated samples from all source types increased from 21 NTU at baseline to 38 NTU at exit ($p \leq 0.005$). Meanwhile, rainwater declined from 54% to 29% over this period (see Table S1, Supporting Information). At the same time, many households reported shifting their water source to taps at the exit interview (from 30% to 41%).

We now suspect a combination of factors bearing on PUR's relative popularity at exit, including the reduced use of nonturbid rainwater, PUR's second bucket, and an awareness among the study population that in the local market town a 6-month supply of PUR cost more than ten times a 6-month supply of WaterGuard ($9.33 versus $0.80). We have no evidence on the relative importance of these (or other) factors.

Meanwhile, though we produced the filter units from locally available buckets, the filter elements themselves are available only in Kisumu (some 60 km away), and thus, information on the filter price was not available to study participants. Instead, they would have to estimate product market or resale value.

We also hypothesized that source water turbidity would have an influence on product preference. The effects we observed were not nearly as pronounced as we expected. There is weak evidence that preference for PUR increases with increasing turbidity of source water.

**Extensions.** Our main analysis discusses the three products we studied. This section discusses alternative means that may help improve water quality for the rural poor: improved harvesting of rainwater and more effective outreach.

Our measurements of *E. coli* loads in the various water sources yielded a notable result with respect to rainwater collection. Untreated rainwater had the lowest median *E. coli* contamination level (11 CFU/100 mL) of all source types (see Table S2, Supporting Information). The superior quality of harvested rainwater stored in households using rudimentary collection and storage techniques offers support to efforts to expand rainwater harvesting. This result suggests that, at least in rural settings, promotion of rainwater harvesting and safe storage may be a cost-effective means to improve water quality in addition to an obvious water supply augmentation approach.

In systematic meta-analyses, Arnold and Colford (*9*) and Hunter (*20*) find that POU-driven reductions in diarrhea risk decline over time, with study durations ranging from 10 to over 80 weeks. Thus, the stabilizing of adoption near 40% that we observe is encouraging. At the same time, the maximum duration with a product that we report here is only about 10 weeks; we provided the safe water products at zero cost; and some respondents may have used the product to avoid embarrassment at follow-up surveys. Thus, future declines in usage are very possible, especially outside of the experimental setting.

Against the backdrop of an extensive literature asserting health benefits from POU interventions, this study was intentionally not powered to examine health outcomes, focusing instead on user preference and product performance. Well after our research for this paper was begun, several papers were published arguing that estimates of POU water treatment's beneficial effects on diarrheal disease rates are biased (*12, 17, 20*). Hunter argues that ceramic filtration

is the only POU treatment category whose health impacts can be reasonably accepted (*20*). In the same paper, Hunter asks whether the comparative failure of disinfection techniques are more attributable to poor effectiveness or to poor user compliance. In this particular setting in Kenya, we observe one disinfection technique to be definitively *more* effective than filters at reducing pathogen indicators, while its reported user compliance was indistinguishable from that of filters. Here, the striking advantage of the filter is instead that users prefer it.

Our focus on product adoption reflects our concern that microbiologically effective POU products have not been adopted by large numbers of the vulnerable poor. POU product dissemination at scale to the poor will not occur until we better understand the preferences, choices, and aspirations of the at-risk populations. We hope that similarly rigorous investigations will occur in other regions, using other study designs, examining longer time periods, and testing other products.

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## Supporting Information Available

Details on the experimental design and data analysis. This material is available free of charge via the Internet at http://pubs.acs.org.

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