

Diarrhea Prevention through Household-Level Water Disinfection and Safe Storage in Zambia

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ABSTRACT

A water quality intervention that consists of water treatment, safe storage, and community education was field tested in Kitwe, Zambia. A total of 166 intervention households were randomly selected from one community and 94 control households from another. Baseline surveys were conducted and the intervention distributed. Weekly active diarrhea surveillance, biweekly water testing, and a follow-up survey were conducted. Compliance was high in intervention households: 97% reported using disinfectant and 72 to 95% had measurable chlorine in their water in biweekly testing. The percentage of intervention households storing water safely increased from 41.5% to 89.2%. Stored water in intervention households was significantly less contaminated with *Escherichia coli* than water in control households ($p < 0.001$). Diarrheal disease risk for individuals in intervention households was 48% lower than for controls (95% confidence interval=0.3, 0.9). This intervention is a useful tool for preventing waterborne diseases in families in developing countries who lack access to potable water.

Tables and figures for this paper are not in HTML format yet and will be added in the future.

Introduction

Diarrhea is a leading cause of morbidity and mortality in children less than 5 years old in the developing world [1]. Consumption of fecally-contaminated water is an important route of transmission of enteric pathogens in many regions of the world lacking infrastructure to guarantee water quality and safe management of human waste [2,3]. In response to this problem, the Centers for Disease Control and Prevention (CDC) and the Pan American Health Organization developed a simple, inexpensive, and easy-to-disseminate intervention to improve drinking water quality and hygiene in developing countries [4]. This intervention has 3 elements: 1) point-of-use water disinfection with a sodium hypochlorite solution produced locally using appropriate technology; 2) 20-liter, durable plastic storage vessels with a lid and spigot, designed to prevent recontamination (referred to hereafter as the special vessel); and 3) community education about the causes and prevention of diarrhea and proper use of the intervention.

Field trials of this intervention in periurban and rural populations in Latin America have demonstrated that households using this safe water system have improved domestic water quality and reduced diarrheal disease incidence by 40% or more [5-7]. Through the use of this intervention, street vendors in Guatemala have improved the quality of water used to make beverages and wash utensils [8], and health workers in cholera wards in Guinea Bissau have prevented contamination of bulk supplies of oral rehydration solution [9].

As a result of the successful applications of this intervention, the Ministry of Health of Zambia invited the CDC to conduct a field trial to test its impact on water quality and health in the city of Kitwe. This paper describes the first community-based implementation of this project in Africa, and the willingness of residents of the project communities to pay for improved water storage containers.

Materials and Methods

Two peri-urban communities in Kitwe, Ipusukilo and Luangwa, were selected as project sites on the basis of two criteria: the lack of a piped water system and the presence of a local health center with community nurses to serve as a study team. Two zones in Ipusukilo and 1 in Luangwa, were chosen for the evaluation because a complete census had recently been completed in each, and each household had been assigned a number. A random sample of approximately 90 households was selected from each zone using a random numbers table.

To determine water handling practices and prevalent beliefs about the causes, treatment, and prevention of diarrhea, two focus groups were held with local women on March 11. This information was used to derive questions for the baseline survey, which the field team of nurses conducted in the study communities from 16 March through 21 March. The survey included demographic and socioeconomic information, household water sources and water handling practices, knowledge and beliefs about diarrhea, and breastfeeding practices. The relative asset value of each household was estimated by asking which of 4 non-essential household goods (radio, television, refrigerator, and automobile) they owned, determining the average local value for each item, and summing the values for each family.

During the weeks of 30 March and 6 April, a team of laboratory workers from the Kitwe Food Laboratory and the Tropical Diseases Research Center (TDRC) of Ndola, Zambia conducted tests of microbiologic quality of stored household water samples from 25% of participating families, which were selected using a random numbers table. The lab team also tested source water from a random sample of 50% of houses where stored water was tested. The water was collected in sterile 500-ml plastic bags, placed in coolers on ice packs, and transported to a water laboratory established at the Kitwe Food Laboratory. Water samples were processed within 3 hours of collection by the membrane filtration technique using M-coli Blue media (Hach Co., Loveland, CO) with *Escherichia coli* as the indicator organism [10].

From 16 March through 19 June 1998, the field team conducted active diarrhea surveillance, which consisted of weekly visits to all study households to obtain data on all episodes of diarrhea occurring in the household during the previous 7 days. Field workers used calendars to assist respondents in recalling episodes. Diarrhea was defined as 3 or more loose or watery stools in a 24-hour period.

The intervention phase of the study took place from 14 April through 19 June 1999. The 2 zones in Ipusukilo were designated as intervention communities because production and sale of disinfectant solution was established there and was made available to the general population. Luangwa was designated a control community.

For the intervention phase of the project, only 90 special water vessels (Tolco Corporation, Toledo, Ohio) were available and, by a decision of the Kitwe City Council, were sold to intervention households on a first-come, first-served basis at a

discounted price of \$1.25 per vessel, rather than given away free. Any special vessels not yet purchased after one week were made available to the rest of the Ipusukilo population. For intervention households who could not or did not want to purchase the special vessel, the field team recommended 3 types of inexpensive, second-hand, locally-available, narrow-mouthed cooking oil or milk containers, with volumes of 2.5, 5 and 20 liters (hereafter referred to as jerry cans).

For production of disinfectant, a SANILEC On-Site Hypochlorite Generator (Exceltech International Corporation, Sugarland, TX) was installed in Ipusukilo clinic on 9 April 1998. This equipment generates a solution of 0.5% sodium hypochlorite from a 3% solution of salt water and electricity by an electrolytic process. The solution was packaged in 250 ml reusable plastic containers with a cap that also served as a disinfectant dispenser. A dosing schedule of solution was developed for water stored in 2.5-, 5-, and 20- liter containers. Disinfectant solution was provided to intervention households at no cost as a benefit of their participation in the study. A microenterprise for the production and sale of disinfectant to other Ipusukilo residents was created at Ipusukilo Clinic as a self-sustaining activity.

The education of study households was carried out by community volunteers, who were assigned clusters of households to visit and motivate about the intervention. Volunteers were given special training in the causes and prevention of diarrhea, and in the treatment and safe storage of water. They also received training in communication skills and a behavior change technique known as motivational interviewing [11], which is derived from the stages of change theory of behavior change [12]. An educational brochure that explained proper use of the disinfectant with the special vessel or with appropriate, locally available containers was given to each intervention household.

All intervention households were visited once every 2 weeks by the field workers, for a total of 4 visits, to test the stored water in both groups for total and free chlorine residuals. At the conclusion of the study, testing for contamination with *E. coli* was conducted on source and stored water samples from the same households tested at baseline.

Epi Info, Version 6.02 software (USD, Inc., Stone Mountain, GA) was used for descriptive and univariate analysis. The Fisher two-tailed test was used to analyze categorical data, ANOVA was used for data that were continuous and normally distributed, and the Kruskal Wallis test was used for analysis of continuous data that were not normally distributed. SAS software (SAS Institute, Cary, NC) was used for multivariate analyses of data on diarrhea. Generalized estimating equations (GEE) were used for the analysis of repeated observations of diarrhea in families and individuals over time in intervention and control households, controlling for clustering within households [13].

The study protocol was approved by the CDC Institutional Review Board (protocol no. 1892) and the TDR Ethics Committee (protocol no. 98-1), and informed consent was obtained from all subjects. At the end of the study, all control households received one free bottle of disinfectant and were given the opportunity to buy one special vessel at the discounted price.

Results

Baseline studies

A total of 260 households with 1584 persons were present for the entire study, for a mean of 6.1 persons per household. The median age of the study population was 16 years (range, 0-79 years); 51% were female (Table 1). Of the 260 households, 166 were from Ipusukilo, and 94 were from Luangwa. Median estimated asset value was \$20 (range 0 to \$860). Only 11 (4%) of households had access to electricity. There were no statistically significant demographic or socioeconomic differences between intervention and control households (Table 1). Thirty households were excluded from the study, 28 (93%) because the family moved during the study, one (3%) because the only member died, and one because of a refusal to participate. Excluded families were significantly smaller than families included in the study (4.9 persons per family compared to 6.0 persons [$p=0.03$]); there were no other statistically significant differences between excluded and participant families.

For all 260 households, the drinking water source was a shallow well; 240 (92.3%) households stored drinking water in their homes (Table 1). The remaining households fetched water for immediate use directly from the well. Of 235 households storing drinking water that reported the type of container they used, 101 (43%) exclusively used narrow-mouthed jerry cans ranging in volume from 2.5 to 20 liters (Table 1); the remainder used wide-mouthed containers. Only 92 (35.2%) of 260 respondents reported ever treating their drinking water, either by boiling or adding bleach, and only 10 (3.8%) had treated their water within the past day. Intervention households tended to be more likely to use jerry cans or to have ever treated their water than control households, although these differences were not statistically significant (Table 1). Despite the low frequency of water treatment behaviors, 240 (92.3%) respondents said they knew how to prevent diarrhea, and 194 (80.8%) of them knew that boiling water was one method.

Of 65 households visited to obtain baseline water samples, 60 (92.3%) had stored water available for testing; in addition, water samples from 36 wells were tested (Table 2). The median *E. coli* colony count was 34/100ml (range 0-20,000) for well water samples and 44/100ml (range 0-20,000) for stored water samples. Thirty-four (94.4%) of 36 well water samples, and 57 (95%) of 60 stored water samples yielded colonies of *E. coli*. There were no statistically significant differences in the degree of *E. coli* contamination in well or stored water samples between intervention and control households (Table 2).

Intervention phase studies

Of the 90 special vessels made available to the 166 intervention group households, 67 (74%) were purchased. Families that purchased a special vessel possessed household goods of significantly higher value (mean \$110) than families that did not purchase a special vessel (mean \$30) [$p=0.002$]. During the final round of water testing, of 157 families visited, 62 (39.5%) were using the special vessel, 78 (49.7%) were using jerry cans, and only 17 (10.8%) were still using wide-mouthed containers. When 94 respondents who did not buy the vessel were asked why, 70 (74.5%) said that they did not have the money at the time of the sale, 11 (11.7%) said the vessels ran out before they could buy one, 9 (9.6%) said they were out of town at the time of the sale, and 2 (2.1%) were ill. Of 161 respondents interviewed at the end of the study, 157 (97.5%) expressed an interest in purchasing a special vessel.

Sodium hypochlorite use was reported by respondents in 156 (96.9%) of 161 intervention households at the end of the study; all disinfectant users indicated that they intended to begin purchasing disinfectant. Those who did not intend to purchase chlorine said the reason was a lack of money; this group possessed household assets of significantly lower value (mean \$4) than households who intended to purchase (mean \$65; [$p=0.05$]). Of the 161 respondents, 153 (95%) said they knew the chlorine dose for their container and 150 (93%) stated the correct dose. When the 156 disinfectant users were asked why they use it, 99 (63.5%) said that they learned that chlorine kills germs, 77 (49.3%) that it prevents diarrhea, 27 (17.3%) that it cleans water, and 7 (4.5%) that their well water is contaminated and needs treatment. All respondents believed that they knew how to prevent diarrhea, and 95% named treating water with chlorine, boiling, or both as methods.

Testing for free and total chlorine residuals in stored water in intervention households revealed that compliance, defined as any detectable total chlorine residual in the water, ranged from 71.7% to 94.7% during four rounds of sampling (Figure 1). Free chlorine residuals at or above 0.2 mg/L, the threshold for disinfection effectiveness, were found in 55 to 80.5% of water samples (Figure 1). During the first sampling round, water samples from households using the special vessels were significantly more likely to have detectable levels of total chlorine and free chlorine residuals >0.2 mg/L than samples from households using jerry cans (Table 3). In subsequent sampling rounds, chlorine residuals in jerry cans were similar to the special vessels.

Median *E. coli* colony counts for well water samples obtained at the end of the study were 37 per 100 ml for intervention households and 5.5 for control households (Table 2). This difference was not statistically significant. Although median *E. coli* colony counts for stored water samples obtained at the end of the study were 0 for intervention households and only 3 for control households, *E. coli* colonies were detectable in stored water samples from only 12 (30.8%) of 39 intervention households and 21 (95.4%) of 22 control households. This difference was statistically significant. The median *E. coli* colony count was 0 for stored water samples in 15 households using special vessels and in 14 intervention households using jerry cans with lids. Stored water samples from 7 intervention households using jerry cans without lids, however, was 3 (range 0-800), compared to 0 (range 0-24) for 15 households using the special vessel ($p=0.009$).

During the 5-week baseline period from 16 March 1998, through 17 April 1998, 103 episodes of diarrhea were detected; 64 episodes (6.4%) among 1003 persons in intervention households, and 39 (6.7%) episodes among 578 individuals in control households. The incidence rates of the two groups were not significantly different. Over the 8-week period following the launch of the intervention, from 20 April through 12 June 1998, 22 episodes of diarrhea (2.2%) were reported among 1003 persons in Ipusukilo, and 28 (4.8%) among 578 Luangwa residents. Despite the steady decline in diarrhea cases over the course of the study (Figure 2), univariate GEE analysis revealed a statistically significant difference in household diarrhea rates (estimated OR 0.53, 95% CI 0.3, 0.98) and individual diarrhea rates (estimated OR 0.52, 95% CI 0.3, 0.9) between the intervention and control groups in the post-launch period. The low number of cases did not permit an age-stratified analysis of diarrhea incidence. Multivariate GEE analysis did not reveal an independent association between diarrhea incidence and variables other than the statistically significant difference observed between intervention and control households.

Discussion

Households using the simple and inexpensive water quality intervention tested in this study had improved water quality and fewer episodes of diarrhea than households using traditional water handling and storage practices. Findings of this study were consistent with other studies testing similar interventions in Bolivia [7], Uzbekistan [14], Peru (Centro Panamerica de Ingeneria Sanitaria, unpublished data), and in a refugee population in Malawi [15]. The results of this study were obtained despite having taken place after the end of the rainy season, when diarrhea rates were decreasing in both intervention and control households, which, consequently, reduced the power of the study to detect a difference between intervention and control groups. A statistically significant difference in diarrhea rates between the intervention and control groups was detected, however, because of the magnitude of the difference in diarrhea incidence rates between the two groups.

Water treatment behaviors improved substantially during the course of this study. At baseline, only 35% of respondents reported ever treating their water and less than 4% claimed to have treated their water during the previous day, while in the follow-up survey, 97% of intervention households reported using sodium hypochlorite. The high rates of reported disinfectant use were corroborated by objective observations of high rates of compliance with water treatment recommendations. Stored water in intervention households showed detectable total chlorine residuals in 72 to 94% of samples and free chlorine residuals > 0.2 mg/L in 55 to 80% of samples. Microbiological results at the end of the study were consistent with these findings, showing that 69% of water samples from intervention households had no detectable growth of *E. coli*.

Water storage behaviors were also positively impacted by this project. Of 90 vessels made available at a discounted price to this impoverished population, 67 (74%) were purchased. Most of those who did not purchase the vessel expressed a desire to own the vessel but indicated that money was the main barrier to purchasing it. Despite this economic barrier, water storage in narrow-mouthed vessels promoted by study personnel increased from 48.0 to 89.2% in the intervention population. Improved water storage practices enabled intervention households to maintain the quality of their treated water, as shown by the lower degree of *E. coli* contamination of stored water in intervention households as compared to control households.

There are at least four possible explanations for the striking improvement in water treatment and storage behaviors exhibited by the study population. First, at the beginning of the study, a high percentage of respondents, 92%, felt they knew how to prevent diarrhea, and 81% named boiling water as one method. This population therefore believed in their ability to prevent diarrhea and knew how to do it, which suggests that they possessed a sense of self-efficacy, a characteristic that encourages the process of behavior change [16-17]. Second, behavior change in this primed population was facilitated by easy access to simple water treatment and storage technology. Prior to the study, the only locally available method for water treatment was boiling. Aside from being time-consuming, boiling water was expensive, requiring the purchase of charcoal, which, for one day's supply, cost more than a one-month supply of sodium hypochlorite disinfectant. Third, by the end of the study, 100% of the intervention group believed that they knew how to prevent diarrhea, 95% named water treatment as a preventive method, 93% were able to state the correct dose of disinfectant, and 89% were using a safe storage technique. These findings suggest that the communication/behavioral component of the project,

combined with easy access to the intervention, succeeded in enhancing the sense of self-efficacy of the population and their knowledge of available treatment methods. Finally, this intervention, which involved the diffusion of an innovation into the community, had favorable qualities for 4 of the 5 characteristics that, according to diffusion research, influence the adoption of innovations by a population [18]. The water quality intervention had a relative advantage to the idea (boiling) that it superseded, it was compatible with the perceived needs of the target population, it was simple to understand and use and therefore of low complexity, and it had a high degree of trialability, that is, it could be easily experimented with. The fifth characteristic, observable results, was not exhibited by this intervention because its impact was to prevent an occurrence rather than create an observable event. The difficulty in observing the impact of the intervention could ultimately impact its sustainability unless the target population is able to appreciate decreased episodes of diarrhea in the household [18].

Another potential impediment to the sustainability of this intervention is the willingness of the target population to pay for its elements. Because of its low cost, purchase of the disinfectant solution presented a potential barrier for very few respondents. The cost of the special vessel, however, was an actual barrier that raised the question of whether the advantages of a more-expensive special vessel justify its introduction as an alternative to the use of locally available containers. The special vessel was designed to be more durable, easier to clean, more difficult to contaminate, and, with its spigot, more convenient to use than most water containers available in developing countries. Early in this study, the performance of the special vessel in maintaining adequate chlorine residuals appeared to be superior to locally-available jerry cans, but by the second sampling round the difference in chlorine residuals between the special vessel and jerry cans had narrowed, suggesting that continued promotion of proper storage led to improved water handling. The importance of proper storage was highlighted by the finding that intervention households that kept water in covered jerry cans had low rates of *E. coli* contamination that were similar to households with special vessels, while households that did not use a lid on their jerry cans had significantly poorer quality water. Thus, although the special vessel appeared to serve as a vehicle for improving water handling behavior, the locally-available jerry cans, when handled properly, were an acceptable alternative storage method for families unable to afford the special vessel. This finding is consistent with earlier studies suggesting that appropriate water vessel design and water handling can protect the microbiologic quality of stored water [15, 19-21]. The marginal benefits of the special vessel could be optimized by decreasing the price to a level similar to commonly used local containers. Increased access to the special vessel could also be achieved through subsidies, barter, or in exchange for work. Local production of the vessels could also help lower the price by decreasing shipping costs. The recognition by study participants of the superiority of the special vessel, as demonstrated by the almost universal desire to purchase it, justifies an attempt to make it more accessible.

This study had one major limitation. We were unable to randomize households into intervention and control groups within the same community because a microenterprise was established to promote and sell disinfectant in Ipusukilo, which meant that all households were exposed to the promotional activities and the product. It was, therefore, necessary to select another community from which to choose control households. This design created the problem of a one-to-one comparison (i.e., a study with an N of 2 communities) because diarrheal diseases among neighbors are not necessarily statistically independent events. This problem

was mitigated by 3 factors. First, both communities are quite similar demographically and socioeconomically, and both use similar water sources, water containers, and treatment practices. Second, both communities are large townships and the randomization procedure resulted in study households being scattered across a wide area, limiting the potential for disease clustering. Finally, the results of the study were of similar magnitude and direction of a Bolivian study in which households were randomized within the same population.

Given the likelihood that it will take decades and billions of dollars to provide piped systems of treated water to all needy populations in developing countries, there is an acute need to develop inexpensive, sustainable household level interventions to increase potable water coverage in the intervening years. Completed field trials in a variety of settings have shown that the intervention described in this paper is a potentially useful diarrhea prevention tool. A test of the sustainability of this intervention has now been launched in Zambia. Population Services International is conducting a social marketing project in which the disinfectant is being sold as a commercial product at an affordable price. The special vessels will be incorporated into the project when production in Africa begins in the near future. The goal of the project is to achieve a high degree of product penetration into the target communities and at least partial cost recovery. Future evaluations will provide important data about the sustainability of this intervention and its potential role in efforts to provide safe water for all.

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