Research Paper

Field trial of an automated batch chlorinator system at shared water points in an urban community of Dhaka, Bangladesh

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ABSTRACT

Point-of-use water treatment with chlorine is underutilized in low-income households. The Zimba, an automated batch chlorinator, requires no electricity or moving parts, and can be installed at shared water points with intermittent flow. We conducted a small-scale trial to assess the acceptability and quality of Zimba-treated municipal water. Fieldworkers collected stored drinking water over a 10-week period from control ($n = 24$ households) and treatment ($n = 30$ households) compounds to assess levels of free chlorine and *E. coli* contamination. Overall, 80% of stored drinking water samples had a safe chlorine residual among treatment households, compared to 29% among control households ($P < 0.001$). Concentrations of *E. coli* were lower (mean difference $= 0.4$ log colony-forming units/100 mL, $P = 0.004$) in treatment compared to control households. Fifty-three percent of mothers ($n = 17$), thought the Zimba was easy to use and 76% were satisfied with the taste. The majority of mothers mentioned that collecting water from the Zimba took more time and created a long queue at the handpump. The Zimba successfully chlorinated household stored drinking water; however, further technology development is required to address user preferences. The Zimba may be a good option for point-of-collection water treatment in areas where queuing for water is uncommon.

Key words | automated chlorine dispenser, Bangladesh, chlorination, household water treatment, urban, water quality

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INTRODUCTION

Each year, more than 800,000 children <5 years old, mostly from low-income countries, die of diarrhea (Liu *et al.* 2012). Evidence from randomized controlled trials suggests that point-of-use (POU) water treatment with chlorine reduces reported diarrheal disease (Fewtrell *et al.* 2005; Arnold & Colford 2007; Clasen *et al.* 2007), but POU techniques have been poorly adopted and inconsistently used among low-income households (Rosa & Clasen 2010). Two major barriers to uptake of POU technologies are the formation of new habits and the amount of time required each day for water treatment (Luby *et al.* 2008; Luoto *et al.* 2011). For example, one reason for low adoption of POU chlorine technologies might be the requirement to add chlorine each time drinking water is collected, which requires personal motivation, knowledge and behavior change. If these criteria are not met, inconsistent and inaccurate chlorine dosage could result.

An additional limitation of current POU chlorination is that treatment of varying batch sizes requires customized

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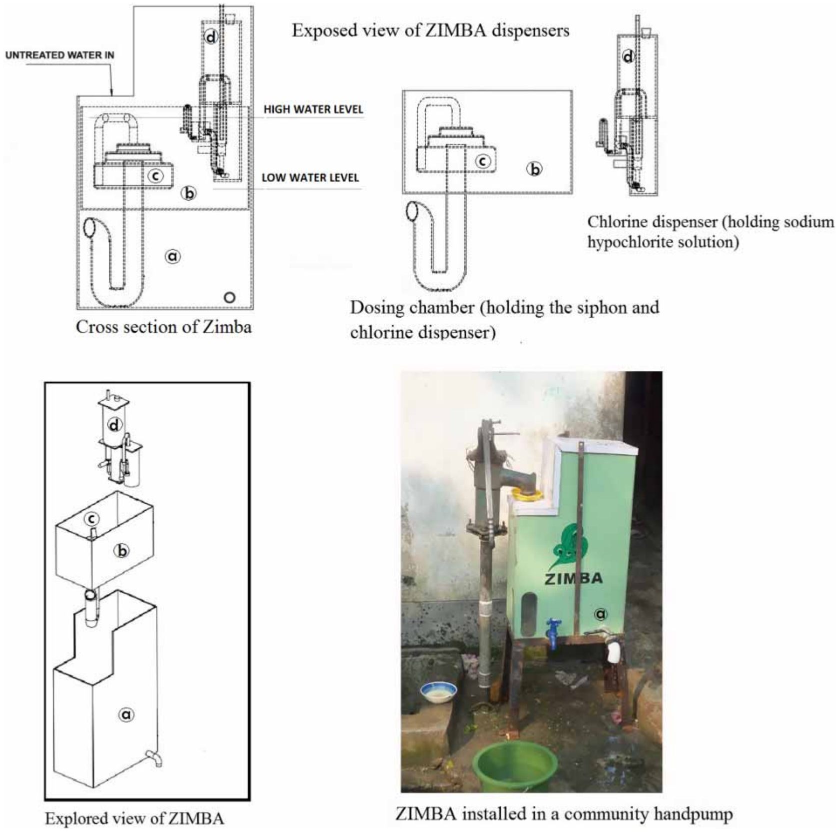
dosage volumes (i.e., for 5, 10 or 20 L) (Clasen & Edmondson 2006; Kremer *et al.* 2011a, 2011b), and users may not know how to measure out different sized chlorine doses. There are limited options for low-cost, accessible water treatment for larger (>10 L per day) quantities of water. Similarly, smaller amounts (i.e., one glass or jug) are not easily dosed with the same products used for more common larger collection volumes.

Because of the barriers to POU water treatment, manual chlorine dispensers have been promoted to encourage households to treat their water at the time they collect it (Kremer *et al.* 2011a, 2011b). Manual chlorine dispensers are designed to add 3 mL of diluted chlorine to 10–20 L of water (depending on the concentration) with the turn of a knob. These dispensers are installed next to communal water points (Kremer *et al.* 2011a, 2011b). Manual dispensers have certain advantages over POU treatments with liquid chlorine at the household level (Lantagne 2008), since the dispenser provides the correct dosing if the collection container is a standard size (no need to measure chlorine) and also takes advantage of peer-effects when installed at public sources (Kremer *et al.* 2011a, 2011b). Nevertheless, the manual chlorine dispenser still requires users to add chlorine during each water collection event, and to calculate the number of turns necessary for their vessel size (International Centre for Diarrhoeal Disease Research, Bangladesh icddr,b 2012).

The Zimba automated batch chlorinator was invented to reduce barriers to water treatment by focusing on automated treatment at the community level. The Zimba attaches to handpumps and dispenses a dose of 3 mL of NaOCl solution into a mixing chamber for every 10 L-batch of water that flows through the device. After chlorination, water is flushed by an automatic siphon into a storage reservoir



Exposed view of ZIMBA dispensers

Cross section of Zimba

Dosing chamber (holding the siphon and chlorine dispenser)

Chlorine dispenser (holding sodium hypochlorite solution)

Explored view of ZIMBA

ZIMBA installed in a community handpump

Figure 1 | Zimba automated chlorine dispenser. Figure provided by inventor Suprio Das. Figure showing (a) Outer box: upper part of outer box holds dosing chamber and lower part acts as a secondary tank which water flushes into after chlorination. (b) Dosing chamber: this chamber holds an automatic siphon and the chlorine dispenser. As untreated water from the handpump starts filling up this chamber, 3 mL of sodium hypochlorite solution is ejected from the chlorine dispenser into this water. When the water level reaches the high water level (10 L) the automatic siphon is triggered and this 10 L of treated water is flushed into the secondary tank. (c) Siphon: water from the dosing chamber flushes into the secondary tank through the siphon. (d) Chlorine dispenser: this consists of a chlorine reservoir and a combination of interconnected pipes and tubes. Dimensions of the Zimba are 76 × 45 × 25; the outer casing, dosing chamber and the siphon are made of fiberglass and the dispensers are made of acrylic.

and dispensed via a tap (Figure 1). The Zimba does not require custom-sized water collection vessels or manual addition of chlorine. We conducted a small-scale trial to assess acceptability, accuracy, and consistency of chlorine dosing by the Zimba, and to assess the microbial water quality of Zimba-chlorinated municipal water.

METHODS

Study site

The study was conducted from February to April (before the rainy season) in 2012 among compounds in low-income neighborhoods in the Mirpur neighborhood of Dhaka. A low-income urban compound in these communities consists of multiple households that share common cooking areas, toilets, and water collection points, typically all owned by a single landlord. In our study area, water was extracted through a motorized pump attached to network pipes that connect to a deep borewell maintained by the Dhaka Water Supply and Sewerage Authority (DWASA). The borewell was also equipped with a broken chlorine injector; the operator of DWASA did not know when it would be repaired. Regular interruptions in the pump's electricity supply cause the distribution system to become unpressurized. DWASA also intentionally distributes water intermittently in some areas because demand exceeds supply. When the system becomes unpressurized, sewage can be sucked into damaged pipes that pass through the open drainage system (Kumpel & Nelson 2013).

Each of the water collection points (handpumps) in our study area was located within a compound and was used for drinking and other household uses. All study compounds met the following eligibility criteria: (1) the water point was located in a compound and shared by 5–30 households, (2) the water point delivered water from the DWASA distribution system, (3) the water was extracted by a manual handpump, and (4) the water point was the compound's primary drinking water source.

Sample frame

We selected Dhamalcot slum at Bhashantek, Mirpur, where the household compounds were divided by four separate streets. From these streets we purposively selected the two longest streets and randomly assigned one street to control and another street to treatment with the Zimba. We assigned treatment by street to avoid contamination between treatment and control groups. Fieldworkers used convenience sampling to enroll six eligible compounds from the street of treatment compounds and five eligible compounds from the street of control compounds. Fieldworkers also used convenience sampling to select five households from each treatment and control compound to participate in household surveys at baseline and end-line; mothers with at least one child under 5 years were given preference for enrollment (Figure S1).

Trained fieldworkers visited eligible households to describe the study prior to collecting baseline information. Fieldworkers introduced the Zimba to mothers in the compounds, explained its advantages and disadvantages, and showed how it worked using pictorial cue cards. The fieldworker provided a consent form written in Bengali and requested mothers to discuss the study and the device with other household members, then collected the signed consent on the following visit. Fieldworkers also obtained written consent from the landlord/compound managers. The study protocol was reviewed and approved by the Institutional Scientific and Ethical Review Committees at the International Centre for Diarrhoeal Disease Research, Bangladesh (icddr,b) (protocol number # PR-09048).

Baseline survey and household water testing

Fieldworkers conducted quantitative surveys with mothers (five surveys from each compound) to gather information on demographic characteristics of households, perceptions of drinking water quality, water collection and storage practice, water treatment practice and satisfaction with the current water supply. In each compound, a fieldworker then tested the existing water supply (handpump and stored water) from all households for water turbidity and free and total chlorine using a digital colorimeter (LaMotte Model 1200, LaMotte Company, Chestertown, Maryland) and turbidity meter (LaMotte Model 2020i, LaMotte Company, Chestertown, Maryland). The fieldworker then collected handpump and stored water samples from all households using 300 mL sterile sample collection bags containing a sodium thiosulphate tablet (Nasco Whirl-Pak®, 19 × 38 cm, Fort Atkinson, Wisconsin) to neutralize any chlorine that could be present. Samples were immediately placed into a cold box, maintained at $<10\,^{\circ}$C with ice packs, and sent to the Environmental Microbiology Laboratory at icddr,b to assess levels of *E. coli* and total coliform contamination.

Description of the Zimba

The Zimba is made of three parts: a dispenser containing diluted household bleach (NaOCl), a dosing chamber containing an automated siphon, and an outer box that holds the siphon tank and the dispenser (Figure 1). The handmade Zimba prototype cost about 100 US$ to produce, including labor costs; it works without electricity and has no moving parts. The Zimba's chlorine dispenser can treat approximately 8,000 L of water (~1 mg/L concentration of free chlorine in source water) between each chlorine refill. See supplemental information for additional details (available in the online version of this paper). The Zimba is mounted on an iron stand approximately 30 cm in height. A chlorine dispenser comprising a chlorine reservoir connected by tubes to two chambers (pressure chamber and constant level chamber) sits on the dosing tank. When untreated water from the handpump falls by gravity into the dosing tank, positive air pressure pushes the chlorine out from the trap through the ejection tube, where it mixes with water in the dosing chamber. After this, the water level in the dosing chamber rises until it reaches a water level of 10 L. Then, the treated water flows through the siphon to the secondary storage tank. When the water level goes down in the dosing chamber, the resulting negative pressure pulls chlorine up from the constant level chamber to fill the trap. The trap was designed to hold 3 mL of NaOCl.

Chlorine purchase and dilution

Two fieldworkers purchased household bleach (~5.25% NaOCl) from the local market and diluted it with distilled water to a concentration of 0.6% NaOCl to achieve 2 mg/L of free residual chlorine when added by the Zimba to source water. The concentration of chlorine was closely monitored before delivery. We eventually reduced the NaOCl concentration to 0.4% to achieve ~1.5 mg/L of free chlorine in source water because study participants complained about the strong smell of chlorine. The same two fieldworkers refilled all Zimba dispensers with chlorine twice a week.

Intervention delivery

At least one day prior to installation of the Zimba, an intervention promoter held compound-wide meetings with study participants to introduce chlorinated water and its potential health benefits and to give instructions for using the Zimba. During promotional activities, fieldworkers advised study participants to drink the treated water 30 minutes after collection to allow time for disinfection. The fieldworkers also requested that study participants share this information with other household members. With the help of a local handpump mechanic, fieldworkers increased the height of the handpump by 12 inches and installed Zimba chlorine dispensers in the six treatment compounds. The mechanic also maintained the handpumps throughout the study period.

Follow-up and end-line surveys

During twice-weekly follow-up visits and one end-line visit, fieldworkers collected two types of water samples from treatment households: treated Zimba water directly from its secondary tank, and household stored drinking water. From control households they collected handpump water and stored drinking water. At the end of the three-month intervention, fieldworkers conducted an end-line quantitative survey to assess satisfaction with the current water system and perceptions of water taste, smell, and water quality among control and treatment compounds enrolled at baseline. Fieldworkers also administered the survey to new households with children under 5 years old that moved into the compounds during the study period.

Qualitative in-depth interviews

Fieldworkers used convenience sampling to select two mothers with at least one child <5 years old from each treatment compound. A trained fieldworker used a written guide to conduct in-depth interviews focusing on how the Zimba chlorinator performed, how regularly they drank chlorinated water treated by the Zimba, perceptions (likes/dislikes and advantages/disadvantages) of chlorinated water and the Zimba device, and changes in taste and smell of treated water over the study period. Fieldworkers collected suggestions for making the Zimba more user-friendly.

Fieldworkers elicited perceptions among other family members, relatives, and neighbors regarding the Zimba. In-depth interviews were recorded using a digital audio recorder.

Microbial water quality testing

All water samples were filtered within 6 hours of collection. *E. coli* and total coliform concentrations were enumerated using membrane filtration following the United States Environmental Protection Agency (USEPA) Standard Method 1604 (USEPA 2002). In brief, 100 mL of each sample was filtered through a 0.45 micrometre filter, then the filter was placed on MI agar media and incubated at 35 °C for 24 hours. Blue-colored colonies were enumerated as *E. coli* and colonies that fluoresced under long-wave UV light (366 nm) were enumerated as total coliforms (*E. coli* were included in the total coliform count). Agar plates with $\geq$500 colony-forming units (CFU) were designated as too numerous to count (TNTC) which follows previous published protocols (Pickering *et al.* 2010; Peletz *et al.* 2012). One duplicate sample was analyzed for every 10th sample collected; one lab blank (100 mL distilled water) was filtered each day as a control. Plates with $>$500 CFU were not feasible to count because the colonies cannot be distinguished from each other; growth is also inhibited due to crowding.

Quantitative data analysis

To compare the mean difference between groups, microbial water quality samples under the detection limit were assigned the value of 0.5 CFU/100 mL and samples above the detection limit were assigned the value of 500 CFU/100 mL. To compare the mean difference within groups and between control and treatment stored water samples we converted bacterial counts into $\log_{10}$ scale and performed regression modeling, adjusted for clustering at the compound level. We adjusted compound level clustering using robust standard error of the mean difference. See supplemental information for further details.

Qualitative data analysis

The fieldworker who recorded all in-depth interviews downloaded them and transcribed them in Bengali so thematic content analysis could be performed. The investigator, N.A., manually coded the transcripts according to our research objectives. After coding, he categorized the data under different themes and matched these themes to factors influencing acceptability and feasibility.

RESULTS

Two compounds (comprising 10 households each) in the treatment group withdrew from the study after installation of the Zimba and were not included in the analysis. One withdrew because the additional time required to pump the water into the siphon tank was inconvenient and the other because the amount of space that the device occupied interfered with cleaning utensils and washing clothes. Three households in treatment compounds moved out during the study period and were not included in the analysis. A total of 24 (96%) control households (one household decided not to participate following enrollment) and 30 (100%) treatment households were interviewed at baseline. During the end-line survey, fieldworkers conducted interviews with 24 (96%) control and 17 (57%) treatment households. Mothers from 12 treatment households (2 per compound) participated in qualitative data collection.

Baseline characteristics of control and treatment households

Demographic and socioeconomic

At baseline, the age, education of respondents, number of <5 years old children and other members per household, and monthly income were comparable across control and treatment households (Table S1).

Water collection and storage practice

Fourteen (58%) mothers in control households and 13 (43%) mothers in treatment households collected their drinking water using a plastic pitcher/jug (2–3 L). All control and treatment households (100%) stored their drinking water; 19 (79%) control households and 20 (67%) treatment households reported usually covering their stored water with a lid.

On average, water was available at handpumps for more than 20 hours per day in all households (Table S1). About 8 L of water per person was collected for cooking, storing and drinking in a typical day in both control and treatment households. Among all treatment and control households, only one treatment household reported treating their drinking water by boiling (Table S1).

Stored water quality

Stored water samples at baseline contained negligible amounts of free and total chlorine (mean free chlorine = 0.10 mg/L, SD = 0.06 in control compounds, and 0.08 mg/L, SD = 0.05 in treatment compounds). Microbial quality of stored water was similar in control (log-mean CFU of *E. coli* = 0.8) and treatment (log-mean CFU of *E. coli* = 0.6) households. At baseline, samples of stored water from two (7%) treatment households and one (4%) control household had free chlorine within the 0.2–2.0 mg/L range (Table S1).

Follow-up and end-line visits

Accuracy and consistency of chlorine dosing at treatment households

All water samples collected immediately after chlorination from the Zimba (100%) were within the 0.2–2 mg/L range for free chlorine (mean = 1.3 mg/L, SD = 0.54) and total chlorine (mean = 1.4 mg/L, SD = 0.58). Mean free and total chlorine levels in household stored water samples were significantly higher in treatment households compared to control households (mean difference of free chlorine = 0.33, $P < 0.001$). In treatment households, 16 (20%) stored water samples contained <0.2 mg/L of free chlorine (Table 1). Average free chlorine in water samples collected directly from the Zimba was 1.3 mg/L and in stored water was 0.5 mg/L (Table 1, Figure 2).

Microbial water quality in control and treatment households

All processed laboratory blanks were free from contamination with *E. coli.* After installation of the Zimba, levels of bacterial contamination in stored water samples were lower in treatment households compared to control households (log-mean difference *E. coli* count between treatment vs. control households = −0.43 CFU/100 mL, $P = 0.002$ of water; and log-mean difference total coliform count between treatment vs. control households = −0.61 CFU/100 mL of water, $P = 0.029$) (Table 1). In treatment households, 72% of stored water samples had <1 CFU/100 mL *E. coli*, compared to 51% in control households (proportion difference = 21%, $P = 0.004$) (Figure 3). In treatment households, stored water samples with free chlorine within the 0.2–2 mg/L range had less bacterial contamination (log-mean *E. coli* = −0.3CFU/ 100 mL) compared to samples with chlorine level <0.2 mg/L (log-mean *E. coli* = 0.5 CFU/100 mL; log-mean difference = 0.52, $P = 0.001$).

Only 6% of *E. coli* samples were TNTC so this did not meaningfully affect *E. coli* analysis, but it may have affected the total coliform analysis.

End-line surveys

Acceptability and perception of water supply in control and treatment households

At end-line, 3 (12%) mothers from control households stated that they were not satisfied with their water due to its poor quality, and 5 (29%) mothers from treatment households mentioned that they were not satisfied with their water due to the bad smell (chlorine). In control and treatment households 100% of mothers mentioned that the drinking water from their current water source is safe to drink (Supplemental information Table S2).

Acceptability of Zimba

At end-line, only one (4%) respondent from a control household and five (29%) respondents from treatment households reported a bad (chlorine) smell in their drinking water. Among the Zimba users who kept using the Zimba for 12 weeks, only half (53%) the mothers thought the device was easy to use, but most (88%) were satisfied with it. Thirteen (76%) mothers were satisfied with the water taste, and 12 (71%) were satisfied with the smell. Fourteen (85%) mothers believed that drinking Zimba chlorinated water was healthier for their families.

Table 1 | Water chlorine residual, turbidity, and fecal indicator bacteria concentration among control and treatment households during bi-weekly follow-up household visits, Mirpur, 2012

	Control group *n* (%)		**Treatment group *n* (%)**			**Mean difference between control vs. treatment households (*P*-value)**	
Water quality	**Source water ($n = 23$)**	**Stored water ($n = 96$)**	**Source water at baseline ($n = 24$)**	**Zimba water ($n = 23$)**	**Zimba stored water ($n = 82$)**	**Untreated source water**	**Stored water**
Turbidity (NTU)							
<5	23 (100)	96 (100)	24 (100)	23 (100)	82 (100)		
Mean (SD)	1 (0.52)	0.72 (0.47)	0.73 (0.39)	1 (0.33)	0.73 (0.34)	−0.30 (0.006)	0.02 (0.724)
Free chlorine (mg/L)							
<0.2	14 (61)	69 (72)	21 (88)	0	16 (20)		
0.2–2	9 (39)	27 (28)	3 (12)	23 (100)	66 (80)		
Mean (SD)	0.18 (0.17)	0.17 (0.12)	0.12 (0.08)	1.3 (0.54)	0.5 (0.5)	−0.06 (0.054)	0.33 (0.001)
Total chlorine (mg/L)							
<0.2	13 (57)	57 (59)	17 (71)	0	9 (11)		
0.2–2	10 (43)	39 (41)	7 (29)	19 (83)	71 (87)		
>2	0	0	0	4 (17)	2 (2)		
Mean (SD)	0.22 (0.17)	0.2 (0.12)	0.16 (0.09)	1.4 (0.58)	0.55 (0.52)	−0.06 (0.102)	0.35 (0.001)
Log-mean *E. coli* CFU/100 ml (SD)	0.45 (1)	0.54 (1.1)	0.4 (1)	−0.16 (0.4)	0.11 (0.84)	−0.05 (0.773)	−0.43 (0.002)
Log-mean total coliforms CFU/100 ml (SD)	1.3 (1)	1.6 (1.1)	1.2 (1)	0.5 (0.9)	1 (1.2)	−0.09 (0.029)	−0.61 (0.002)

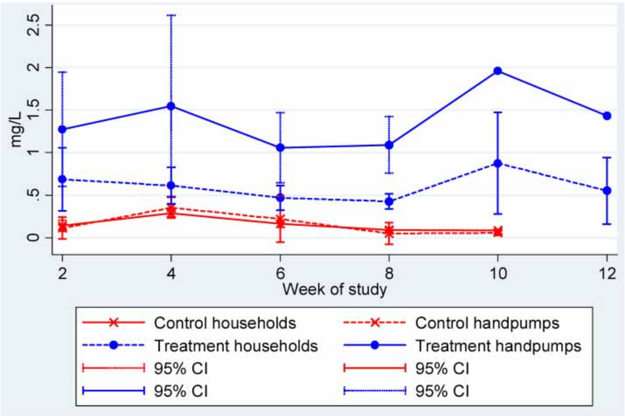


Figure 2 | Free chlorine level in control ($n = 24$) and treatment ($n = 23$) handpumps, and in stored water at control ($n = 83$) and stored water at treatment ($n = 96$) households over time during follow-up visits, in Mirpur, Dhaka, 2012.

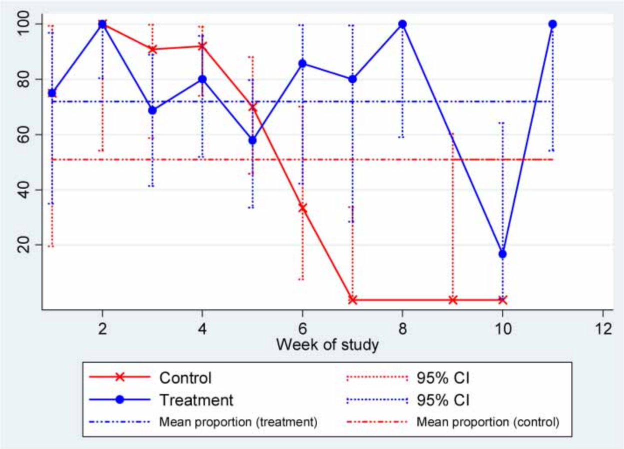


Figure 3 | Percentage of household on y-axis (control $n = 83$ and treatment $n = 96$) with 0 *E. coli* per 100 mL in stored water over time during follow-up visits, in Mirpur, Dhaka, 2012.

Qualitative assessment

During the qualitative in-depth interviews ($n = 12$) in treatment households, most of the mothers (9 out of 12) mentioned that the machine purified the water by killing germs. Some respondents also described the Zimba as a water filter. All mentioned that the water had a medicinal smell, but they became accustomed to it during the course of the study. All mothers also mentioned that they obtained all drinking water from the Zimba because it was safe for their children. Most mothers (10 out of 12) mentioned that the first few weeks after installation of the Zimba they noticed a strong smell of chlorine but only two respondents complained of bad taste. All mothers also mentioned that they considered drinking chlorinated water to be safer than drinking untreated water and that treating water with chlorine could prevent diseases. Most users (9 out of 12) reported that they liked the Zimba but collecting small amounts of water (i.e., one glass or one jug [2–3 L]) took more time and created a long queue. One mother said, 'Before installing the machine (Zimba) we did not need to wait for water, but now we have to wait for water which makes a long queue.' Some (3 out of 12) mentioned that the increased height of the handpump made it difficult to pump water, particularly for children. Mothers also mentioned that they would not be able to refill the Zimba chlorine dispenser because of its complexity. They also requested technical assistance for repair and refilling of the Zimba dispenser.

DISCUSSION

The concentration of free residual chlorine in water samples collected directly from Zimba automated chlorine dispensers was consistently observed to be within the World Health Organization (WHO) recommended range (0.2–2 mg/L). Over a 10-week period, the percentage of households with stored water with a safe level of free chlorine was 80% in treatment households, while it remained low (28%) in control households. Despite the apparent dosing success of the Zimba, 20% of stored water samples from treatment households did not contain the WHO-recommended chlorine level, and 28% were contaminated (>1 CFU/100 mL) with *E. coli*. Possible explanations for the absence of detectable free chlorine include collecting water from other sources, undetected Zimba dosing inconsistencies, or consumption of free chlorine as a result of water handling that leads to re-contamination (Quick *et al.* 1996).

One important contribution to the low adoption rates of POU water treatment using NaOCl is the unpleasant taste and/or smell in treated water (Clasen & Edmondson 2006; Albert *et al.* 2010; Luoto *et al.* 2012). A study in southeast Africa suggested that participants in Ethiopia did not taste the chlorine residual at 1.0 mg/L (sodium hypochlorite), noticed the presence of chlorine at 2.0 mg/L, and found the taste objectionable at 3.0 mg/L. But in Zambia participants found the taste of chlorine to be too strong at 2.0 mg/L (Lantagne 2008). In our study, the average free residual in stored water was low (0.5 mg/L, SD = 0.5, range = 0.07–1.8 mg/L), but 29% of Zimba users had not become accustomed to the chlorine taste and smell after three months of use. It is possible that the combination of chlorine compounds with organic materials in the water affects taste perceptions, which would vary by geographic location, highlighting the importance of adjusting the dose of NaOCl in future studies according to participant preferences. A higher dose of free chlorine could improve disinfection, but it is unlikely that users in this study would have accepted a dose higher than 1.0 mg/L.

The DWASA pump supplying the study area was equipped with a broken chlorine injector. The spike of chlorine in the stored water of control households during the 3rd to 5th weeks of the study (Figure S2) may have been due to the chlorine injector being activated by DWASA. The chlorine level of Zimba treated water did not go beyond the WHO recommended range of free chlorine when the injector was on. These results suggest that even though DWASA was attempting to chlorinate the municipal water, it did not provide safe water consistently, as has been found in municipal systems in India (Brick *et al.* 2004; Kumpel & Nelson 2013).

The Zimba dispensers dose in 10 L batches, so if the secondary tank empties then users need to fill the 10 L tank even when only a small quantity of water is required. To pump 10 L of water using a typical handpump in Dhaka takes an average of 60 seconds (range = 32–117 seconds, *n* = 18) if pumped continuously (Yoshika Crider, unpublished data). Since mothers already spend substantial time collecting water and carrying out other household tasks (Hanchett *et al.* 2003), they might be unwilling to spend the additional time for pumping 10 L water when they require only 2–3 L. Since the water sources were close to the households, the users did not collect or store large volumes. A smaller batch chlorination volume could make water collection from the Zimba more efficient in this setting.

Several design changes could improve the Zimba. The Zimba dispenser occupies significant space (45 × 25 cm) when installed, thus installation may not always be possible due to space limitations in urban slums. Future iterations of the Zimba could be more compact. The Zimba required frequent visits from trained field staff to refill the dispensers, which is an issue for its sustainability. The reservoir capacity could be increased so that the need for refilling is less frequent. In addition the Zimba used a low concentration NaOCl solution (0.4%), which is non-standard and requires dilution before filling the Zimba dispenser. Future models of the Zimba could aim to use a higher concentration of NaOCl to reduce the need for dilution (Lantagne *et al.* 2011).

Some limitations to this study should be acknowledged. No other similar technologies were available at the time of this study to compare the efficacy of the device. Further studies should aim to compare the effectiveness of the Zimba with other chlorine water treatment options. Technical assistance with the technology for the first few weeks might have increased adoption rates. In addition, the study population was drawn from a small geographic area in a low-income community in Mirpur, Dhaka; thus, the acceptability and uptake results may not be generalizable to other low-income urban communities.

The Zimba automated dispenser overcomes some of the most important barriers to low-cost decentralized chlorination of drinking water. First, it eliminates the extra step of adding chlorine after water collection, which saves time for other household work (Luby *et al.* 2008). Second, the Zimba is attached/locked to the handpump and automatically treats water without the active participation of users. Since household members cannot choose whether to chlorinate, they may be more likely to adjust to the smell and taste of the consistently chlorinated water. Third, users do not need to consider the size of their water collection vessel since the collected water is passively dosed with a safe residual chlorine level before they collect it in their vessels. Although the Zimba was able to successfully and consistently chlorinate household stored drinking water, further work must be done to take this technology or other similar technologies to scale. Essential next steps include improving the user experience (Ahuja *et al.* 2010) and developing an appropriate business model for refilling chlorine and maintenance of the device.

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