Influence of container cleanliness, container disinfection with chlorine, and container handling on recontamination of water collected from a water kiosk in a Kenyan slum

Regula Meierhofer, Basil Wietlisbach and Carol Matiko

ABSTRACT

The study assessed whether using clean containers that had been disinfected with chlorine at a water kiosk in the Kangemi slum in Nairobi reduced recontamination of treated water during drinking transport and storage. At the same time, the impacts of container handling and hygiene conditions at the household level on water quality changes during storage were evaluated. Data were collected during interviews with 135 households using either new, clean Maji Safi containers (MSCs) that had been disinfected with chlorine or normal uncleaned jerrycans (NJCs). Bacteriological water quality and free chlorine levels in both types of containers were measured after container filling at the kiosk and in the same containers after 24 h storage in households. The use of MSCs significantly reduced the risk of recontaminating the treated water. After water filling at the kiosk, none of the MSCs contained *Escherichia coli* bacteria, and 2.8% were contaminated after 24 h storage. In contrast, 6.2% of NJCs were contaminated after filling, and 15.2% after 24 h storage. Multivariate logistic regression indicated that the use of a clean water container and sufficient chlorine and the frequency of cleaning the container in the household mitigated recontamination. We suggest further investigation of water container designs that facilitate cleaning.

Key words | chlorination, drinking water quality, drinking water treatment, low-income country, recontamination, safe storage

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INTRODUCTION

Sustainable Development Goal 6 calls for universal and equitable access to safe and affordable drinking water for all by 2030 (UN 2015). Water kiosks are increasingly being established as a strategy to improve access to safe drinking water at community level in marginalized regions, such as urban slums and remote rural areas (Thompson *et al.* 2000; McGranahan *et al.* 2006; Opryszko *et al.* 2009; Sima & Elimelech 2013). Several studies have shown that water quality in kiosks is mostly high at the point of distribution (Huttinger *et al.* 2015; Peter-Varbanets 2015; Patrick *et al.* 2017) but is likely to be subject to recontamination and regrowth of pathogens during transport and storage. In their study on water kiosks in Ghana, Opryszko *et al.* (2013) found that even though 91% of water samples at the tap of the kiosk met WHO Guidelines for drinking water quality, only 40% of samples collected at households had no detectable levels of *Escherichia coli* per 100 mL sample.

As documented by Wright *et al.* (2004) in their meta-analysis, microbiological water quality often deteriorates during transport and storage. A number of other studies

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have investigated potential mechanisms and sources of recontamination and regrowth during transport and storage of drinking water: In Sub-Saharan Africa, Harris *et al.* (2013) found that levels of fecal indicator bacteria increased immediately after storage containers were filled and water extracted from the container in the home. Certain extraction methods, such as decanting from the container and using a cup or ladle, were related to higher levels of fecal bacteria. Deterioration immediately after filling collection containers has also been observed by other authors (Trevett *et al.* 2005; Meierhofer *et al.* 2017). Contact of hands and utensils with drinking water has been identified as an important source of contamination (Trevett *et al.* 2005; Pickering *et al.* 2010).

The design of the container has been found to have a significant impact on risks of recontaminating water during storage (Mintz *et al.* 1995; Reed *et al.* 2011). In observational studies, Mintz *et al.* (1995) identified a wide container opening and water extraction with utensils and hands as contamination sources. They found that water in containers with a narrow neck, tightly fitting lid, and faucet was less contaminated during one month of use. Mellor *et al.* (2013) similarly found higher levels of regrowth of total coliforms in containers with wide openings than in narrow-neck containers. In contrast, Levy *et al.* (2014) did not find a statistically significant difference in water safety between containers with small openings (<8 cm) and containers with large openings (>8 cm). Roberts *et al.* (2001) evaluated the impact of water containers with covers and spouts on recontamination during transport and storage in a refugee camp in Malawi and found an average of 53.3% fewer fecal coliforms in the improved buckets than in unimproved buckets without a cover and spout. The greatest difference between buckets was found at the time of water collection. Children below the age of five in families using improved buckets had 31% less diarrhea, but the difference was statistically not significant.

Chlorination with a sufficiently high level of free residual chlorine (FRC) has been found to reduce recontamination risks in treated water handled under unhygienic conditions. WHO recommends that there should be a residual concentration of free chlorine of $\geq$0.5 mg/L after at least 30 min contact time at pH <8.0. At the point of delivery, the minimum residual concentration of free chlorine should be 0.2 mg/L. For household water treatment, WHO recommends dosage rates of 2 mg/L FRC for clear water (<10 Nephelometric turbidity units [NTUs]) and twice that concentration (4 mg/L) for turbid water (>10 NTUs) (Lantagne 2008; WHO 2017).

Declining residual chlorine concentrations during storage may allow regrowth if biochemical parameters in the water, such as dissolved phosphorus, nitrates, and adequate composition of assimilable organic carbon (AOC), provide growth conditions (LeChevallier *et al.* 1996; Vital *et al.* 2010). The influence of AOC on regrowth has been highlighted by several studies that found a significant correlation between regrowth and AOC concentrations above 60–100 μg/L (LeChevallier *et al.* 1996; Mellor *et al.* 2013).

The cleanliness of containers used for the transport and storage of drinking water may also impact recontamination. This can be due to the amount of pathogens attached to container walls and the formation of biofilm, including AOC. Jagals *et al.* (2003) analyzed the influence of biofilm attached to the walls of plastic water containers on water quality and found that counts of total coliforms and spores of *Clostridium perfringens* were significantly higher in water from containers containing biofilm. Murphy *et al.* (2009) quantified the biofilm in the storage containers of ceramic water filters and did not find a significant difference between containers that had or had not been cleaned in households, probably due to a small sample size, but the difference between containers undergoing controlled cleaning practice and those undergoing improper cleaning practice was significant. Mellor *et al.* (2013) looked at contamination mechanisms during water storage at household level and found that hands and biofilm layers on containers' inner walls were important contamination sources.

The material of water containers has been suggested to have an impact on water quality changes during storage. Several studies have found a higher chlorine demand for households using clay pots than those using plastic containers (Ogutu *et al.* 2001; Lantagne 2008; Murphy *et al.* 2016), although Lantagne (2008) observed the effect only in pots that had been fired at low temperatures. Murphy *et al.* (2016) found a higher odds ratio for *E. coli* contamination in clay containers and attributed this to the higher chlorine demand of the clay material. However, new plastic containers were used during that study. Biofilms and other types of contamination in the clay pots may also have led to their higher chlorine demand and higher contamination levels.

The goal of our study was to assess whether using clean containers that had been disinfected with chlorine at the water kiosk reduced recontamination risks during drinking water transport and storage in households in the Kangemi slum in Nairobi. The study also assessed the impact of container handling and hygiene conditions in households on water quality changes during storage.

METHOD

Context of the study

Water treatment kiosks are increasingly being established in Kenya to provide clean drinking water to communities in marginalized rural regions and informal urban settlements. The water kiosk at the Resource Center in the Kangemi slum of Nairobi, was established in 2013. It serves a population of about 150 households and 50 schools. The water delivered to the kiosk by the Nairobi City Water and Sewerage Company sometimes contains chlorine. At the kiosk, the water is treated with Skyjuice ultrafiltration modules. The maintenance of these modules includes monthly disinfection of the membranes with chlorine. The water provided from the kiosk therefore contains fluctuating levels of FRC. The treatment process at the water kiosk does not include any additional chlorination.

A majority of the kiosk's customers use 20 L recycled normal jerry cans (NJCs) to collect water and transport it to their homes. To reduce the risk of recontamination of treated water in NJCs, Siemens Stiftung (Munich, Germany) introduced the Maji Safi Container (MSC) in November 2014. This is a white 10 L jerry can with a design similar to normal jerry cans that is sold to water customers for 100 KES (1 USD). The normal jerry cans are available in the market for 150 KES (1.5 USD). The water kiosk operators clean and disinfect the Maji Safi containers (MSCs) before each refilling with treated water, while the NJCs are not cleaned. Customers do not have to pay extra for the cleaning of an MSC.

The MSC cleaning instructions are: 'Put some treated water inside the container. Add about 1 mL of chlorine solution (0.4% liquid hypochlorite) from the chlorine dispenser unit in the kiosk to the water container, close the lid and shake it well, clean the lid and the outlet of the container, pour the chlorine-water mix out of the container (if possible into a sink) and rinse the container with treated water at the sink.'

Study design

The water quality in clean and disinfected MSCs was compared with the water quality in uncleaned, nondisinfected NJCs at the moment of filling the container and after 24 h of storage at household level. In addition to water quality tests, quantitative, structured household interviews took place with water buyers to determine the influence of water and container handling and hygiene conditions in the households on water contamination during storage.

Data were collected from 66 households using NJCs to collect drinking water from the water kiosk and from 69 households using MSCs. All customers visiting the kiosk during the data collection period were informed about the study. All households that provided informed consent and purchased water from the kiosk during the study period were included.

The study protocol was approved by the Ethics and Scientific Review Committee of the African Medical and Research Foundation in Kenya and the Kenya National Council of Science and Technology on 5 December 2014. Households were identified by name, a mobile phone number, and their GPS location. The registration was crosschecked with the kiosk operators' customer list. Each household was involved only once. Group attribution was not randomized, but was formed on the basis of purchasing an MSC. An MSC promotion campaign was implemented at the onset of the study. The MSCs assessed during the study were new. They were washed and disinfected at the kiosk in accordance with the procedure described above and handed out to customers immediately after disinfection. Normal jerry cans were not cleaned at the kiosk.

Water quality at the kiosk was measured over 12 days. Daily water samples were taken from the kiosk's tap after letting the water run for 3 seconds. A water sample was taken from each study participant's jerry can after it was filled at the kiosk. Interviewers filled the containers halfway and shook them for 10 seconds before taking the samples. The container was then marked, and interviewers accompanied participants to their households. They instructed the people not to completely empty the water container but to leave a little water in it until the interviewer's visit the next day. After 24 hours, the households were revisited and interviewed and another water sample was taken from the marked container. All water samples were put in Nasco Whirl-Pak Thiobags with sodium thiosulfate.

The water samples were kept inside cooler bags for transport to the field lab, which was located at the water kiosk. Water quality analysis of *E. coli*, total coliforms, and the measurement of FRC was conducted immediately after the samples collected at the households arrived at the field lab (the average walking time between the households and the lab was 4.5 minutes).

The contamination levels of total coliforms and *E. coli* were analyzed at the field site using membrane filtration techniques. The 100 mL water samples were passed through 0.45 μm Millipore cellulose membrane filters using sterilized filtration equipment, plated on Nissui Compact Dry Coliscan plates, and incubated for 24 hours at $35 \pm 2\,^{\circ}$C. Colonies were visually counted up to a maximum count of 600 CFU per plate. The concentration of FRC was identified at the field site by mixing 10 mL water samples with DPD power pillows HI93701-0 and measuring with a Hanna Instruments HI93414 Colorimeter.

Control experiments were conducted with five NJCs and MSCs to evaluate recontamination and potential regrowth in both types of containers without handling by local households. New MSCs containers were obtained from the water kiosk, while used, uncleaned NJCs were purchased from local households.

Quantitative information was collected from households through face-to-face interviews with the person in the household responsible for drinking water management. A structured questionnaire was used that incorporated closed, multiple choice questions mostly in categorical variables, Likert-scale answer categories, and some scale variables. The interviews were complemented by structured observations. The questionnaires were coded on tablets and contained questions on drinking water purchases (the time required to collect water from the kiosk, the frequency and volume of purchases per week), the use of containers for collecting water from different sources, the use and maintenance of containers for transporting and storing water, water treatment practices, the handling of water in the household, and hygiene indicators (type and cleanliness of handwashing station, type and cleanliness of the toilet, and frequency of handwashing).

Data analysis

Data were imported into SPSS for statistical analysis. General drinking water purchase and use patterns, the use and maintenance of containers for drinking water transport and storage, contamination levels with *E. coli* and total coliforms, and FRC levels were analyzed using descriptive statistics. The distribution of log-transformed coliform counts was not normal; therefore, the significance of differences between the two groups was assessed with a Mann–Whitney test. The difference between other variables was assessed using the *t*-test for variables with equal variances or the Mann–Whitney test for variables that violated the assumption of normality. Counts of zero *E. coli* or zero total coliforms were replaced by 0.5 to allow logarithmic transformations. Effect sizes of the differences between groups were calculated using the formulas proposed by Rosenthal & Roow (1991) and Rosnow *et al.* (2000).

To analyze the impact of water handling and hygiene conditions at household level on recontamination, a binary variable was formed with households with recontamination (*E. coli* or total coliforms $\geq$1 CFU/100 mL) and households without recontamination (*E. coli* or total coliforms = 0 CFU/100 mL) between container filling and 24 hours of storage. Bivariate analysis between the outcome variable and various water handling and hygiene factors were calculated using Chi-square. The factors considered were the number of people in the household, the number of school-age children, the time required to collect water from the kiosk, the number of water purchases per week, the amount purchased, the use of additional sources of drinking water, whether the same container was used to collect water from different sources, whether the same container was used for the transport and storage of the drinking water, various materials used for the cleaning of containers, the number of times hands were washed per day with soap, the type of handwashing station used by the household, and the type and condition of the toilet used by the household.

Variables that had a significant relation with the outcome variable were further analyzed using a binary multivariate logistic regression model. Power calculations using G*Power 3.1 revealed that a sample size of 137 households detects an odds ratio of 0.1 with a power of 100% and an odds ratio of 0.4 with a power of 98% at a two-tailed alpha of 0.05 in logistic regression (Faul *et al.* 2009).

The concentration of FRC was normally distributed. Linear regression was used to analyze the relation between FRC at the kiosk and FRC after filling the MSCs and NJCs. Once more, *t*-tests were used to analyze the difference between the two groups. Spearman's rho was used to calculate the correlation between FRC and the log-transformed counts of *E. coli* and total coliforms after container filling and after 24 h of storage.

RESULTS AND DISCUSSION

Water handling and hygiene conditions

Observations showed that the 69 households in the MSC group had slightly better sanitary infrastructure than the 66 households in the NJC group: 6% more households in the MSC group had a handwashing station, 11.5% more had a private latrine, and 15% more had access to toilets that looked clean.

According to the answers received during the interviews, the groups did not differ in the frequency of handwashing. While 70% of the NJC group used their container to collect water from other, potentially unsafe drinking water sources, only 40% of the MSC group did so. The practice of storing safe and unsafe water in the same container may lead to higher contamination of the insides of the containers used by NJC households.

Interviews also showed that the NJC group purchased significantly more water from the kiosk, but the MSC group perceived the quality of water to be better. Both groups cleaned their containers about once per week in the household. There was no difference between the groups in the frequency of cleaning their drinking water containers in the household, but in contrast to the MSC group, the NJC group did not have their containers disinfected at the kiosk. Further details of water handling and hygiene conditions in both groups are presented in Table A, Supplementary material (available with the online version of this paper).

Recontamination and regrowth in disinfected and non-disinfected containers

None of the samples taken at the tap of the kiosk contained *E. coli* ($N = 20$), while two samples contained 1 CFU/100 mL of total coliforms ($N = 20$).

E. coli counts and counts of total coliforms were significantly different between MSCs and NJCs both after filling the containers and after 24 h of storage. The difference in *E. coli* counts after filling corresponded to a small effect, with Mann–Whitney U = 2,104.5, $p = 0.053$ (1-tailed), $r = -0.18$. The difference of total coliform counts was more pronounced, corresponding to a medium effect with Mann–Whitney U = 1,863.0, $p < 0.001$, $r = -0.31$ (Table 1).

A similar difference between containers was observed after 24 h of storage at household level. The difference in *E. coli* counts in NJCs and MSCs corresponded to a small effect, with Mann–Whitney U = 1,999.0, $p = 0.009$, $r = -0.21$, while the difference in total coliform counts corresponded to a medium effect, with Mann–Whitney U = 1,863.0, $p < 0.001$, $r = -0.31$.

In contrast to the MSCs used by local households, no recontamination or regrowth was observed in MSCs in the control experiment during the 24 hours of storage. However, increased levels of total coliforms were found in the NJC after 24 h of storage (Table 1), indicating that the use of contaminated containers can contribute to the regrowth of bacteria during storage even if direct reintroduction of bacteria through contact with contaminated hands or other materials is prevented.

Our findings suggest that the use of clean and disinfected MSCs reduced the risk of recontaminating treated water during transport and storage.

Bacterial contamination is presented in Table 1 as the percentage of water samples found in correspondence with WHO risk categories for *E. coli* in drinking water (WHO 1997).

Table 1 | Contamination levels of *E. coli* and total coliforms and mean FRC in MSCs and NJCs after filling the containers and after 24 h of storage in households and laboratory

		Maji Safi containers (MSCs)		**Normal jerry cans (NJCs)**	
		0 h	**24 h**	**0 h**	**24 h**
Containers used by households	N	69	69	65	66
	E. coli CFU/100 mL				
	0 CFU	100%	97.1%	93.8%	84.8%
	1–10 CFU	0%	1.4%	6.2%	10.5%
	11–100 CFU	0%	1.4%	0%	3.0%
	101–1,000 CFU	0%	0%	0%	1.5%
	Total coliforms CFU/100 mL				
	0 CFU	100%	91.3%	83.1%	57.6%
	1–10 CFU	0%	4.3%	12.3%	15.1%
	11–100 CFU	0%	0%	4.6%	7.5%
	101–1,000 CFU	0%	4.3%	0%	19.7%
	Free residual chlorine (FRC) mg/L				
	Mean	0.49 (SD = 0.28)	0.37 (SD = 0.26)	0.39 (SD = 0.20)	0.19 (SD = 0.15)
	Mean (Δ 0–24 h)		0.13 (SD = 0.16)		0.2 (SD = 0.14)
Containers stored at laboratory	N	5	5	5	5
	E. coli CFU/100 mL				
	0 CFU	100%	100%	100%	100%
	1–10 CFU	0%	0%	0%	0%
	11–100 CFU	0%	0%	0%	0%
	101–1,000 CFU	0%	0%	0%	0%
	Total coliforms CFU/100 mL				
	0 CFU	100%	100%	100%	40.0%
	1–10 CFU	0%	0%	0%	20.0%
	11–100 CFU	0%	0%	0%	20.0%
	101–1,000 CFU	0%	0%	0%	20.0%
	Free residual chlorine (FRC) mg/L				
	Mean	0.61 (SD = 0.03)	0.47 (SD = 0.02)	0.60 (SD = 0.04)	0.20 (SD = 0.05)
	Mean (Δ 0–24 h)		0.14 (SD = 0.03)		0.40 (SD = 0.05)

The influence of water handling and hygiene conditions on water quality

Bivariate analysis revealed that most water handling and household hygiene factors were not significantly correlated with recontamination in the containers after 24 h of storage.

Table 2 shows that the risk of recontaminating treated water during transport and storage was significantly reduced by sufficiently high levels of FRC after 24 hours of storage ($OR = 0.001$, $p = 0.028$), the use of a clean container ($OR = 0.14$, $p = 0.035$), and the frequency of cleaning the inside of the transport container in the household ($OR = 0.43$, $p = 0.015$).

Except for the frequency of cleaning the inside of the water container in the household, none of the water handling, sanitation, and hygiene conditions in the households had a significant impact on recontamination during water storage. These findings are similar to results from a study conducted in an urban slum in Hyderabad, India, which found a 36% increase in fecal contamination in drinking water containers between point of supply and stored drinking water but failed to find a significant correlation between contamination and any household practice of water handling, hygiene, sanitation, or handwashing (Eshcol *et al.* 2009). This may indicate that bacterial transmission paths between the household environment and stored drinking water can vary greatly between households.

Container's influence on free residual chlorine

FRC levels at the water kiosk tap varied between 0.1 and 0.6 mg/L with an average level of 0.4 mg/L (SD = 0.17 mg/L).

Table 2 | Binary multivariate logistic regression of factors related to presence or absence of recontamination of total coliforms in water containers during 24 h storage

				95% confidence interval for odds ratio	
	B (SE)	***p*-value**	**Odds ratio**	**Lower**	**Upper**
FRC after 24 h storage	–6.544	0.028	0.001	0.000	0.489
Type of container used	–1.973	0.035	0.139	0.022	0.869
Frequency of cleaning containers inside at household level	–0.851	0.015	0.427	0.216	0.846
FRC after container filling	–3.007	0.151	0.049	0.001	3.001
No. of containers owned by household	–0.087	0.340	0.916	0.766	1.097
Frequency of getting container cleaned at the kiosk	0.330	0.550	1.391	0.471	4.107
Amount of water left in container after 24 h	–0.342	0.189	0.710	0.426	1.184
Constant	6.906	0.000	997.892		

$R^2 = 0.40$ (Cox and Snell), 0.58 (Nagelkerke). Model $\chi^2(7) = 68.4$, $p < 0.0001$.

FRC levels in NJCs directly after container filling did not differ much from the values measured at the kiosk tap. A linear regression of FRC in NJCs versus FRC at the kiosk tap resulted in a slope of almost 1, with R^2 close to 100% ($\mathrm{FRC_{NJC}} = 0.02$ mg/L + 0.96 * $\mathrm{FRC_{Kiosk}}$; $R^2 = 93\%$).

Because the quantity of chlorine used for cleaning the MSCs was not standardized, chlorine concentrations in these containers after filling were highly variable, with a low R^2 of 6% in linear regression. FRC in MSCs was only marginally influenced by the level of FRC at the kiosk ($\mathrm{FRC_{MSC}} = 0.34$ mg/L +0.44 * $\mathrm{FRC_{Kiosk}}$; $R^2 = 6\%$).

FRC levels after container filling were significantly different in NJCs and MSCs with $t(133) = –2.6$, $p = 0.011$, $r = 0.22$ (small effect), as well as after 24 h of storage with $t(133) = –4.8$, $p < 0.001$, $r = 0.38$ (medium effect). Mean levels of FRC are displayed in Table 1.

The use of NJCs led to a higher consumption of FRC than the use of clean MSCs. During 24 h of storage, FRC in NJCs decreased by an average of 0.2 mg/L (SD = 0.14), while in MSCs it decreased by 0.13 mg/L (SD = 0.16). This difference was significant: $t(133) = 2.75$, $p = 0.007$ (see Figure A in Supplementary material, available with the online version of this paper). It suggests that contamination present in uncleaned containers, including biofilms attached to NJCs, may have contributed to a higher chlorine demand in these containers. Therefore, a container-cleaning process that removes biofilms and so stabilizes chlorine concentrations may reduce the risk of bacterial regrowth during storage.

Our findings are supported by a study in Uganda that evaluated the impact of cleaning and disinfecting used jerry cans on the quality of stored water. The study found that in addition to the application of gravity-driven ultrafiltration, which also reduces organic matter in the water, the use of chlorine during the container-cleaning process at the kiosk and cleaning containers with sand in households reduced recontamination risks (Meierhofer *et al.* 2017). Looking at options for cleaning water containers, Shadbolt (2017) found that sand could be used effectively to clean containers with narrow mouths. However, the study also revealed that the use of scratched containers, possibly due to cleaning with sand, increased the rate at which biofilm developed on the internal surface of the container. Scratched containers with denser biofilm on the internal walls had an increased demand for FRC, which may be linked to higher deterioration of stored water quality.

The influence of chlorination levels on regrowth/recontamination

Figure 1 presents log-transformed counts of coliforms and FRC levels after 24 h of storage at household level. Counts of *E. coli* and total coliforms were significantly correlated with FRC ($r_s = –0.39$, $p < 0.001$ and $r_s = –0.58$, $p < 0.001$ respectively).

In our study, which used water treated by ultrafiltration with a turbidity of less than 10 NTUs, mean FRC levels of

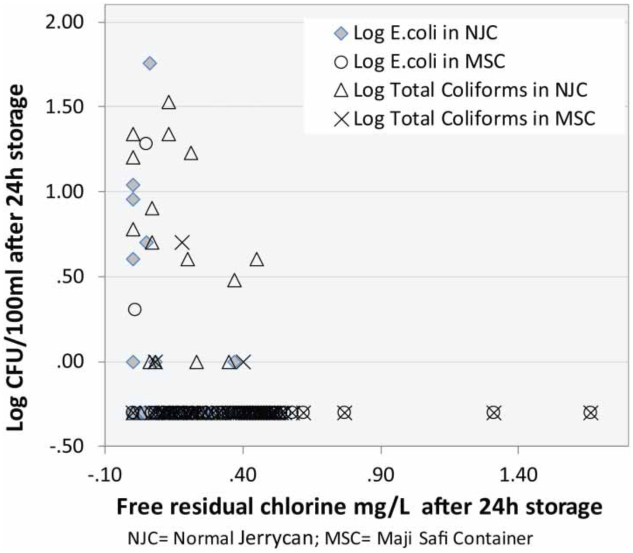

Figure 1 | Log-transformed counts of *E. coli* and total coliforms versus FRC in normal jerry cans (NJCs) and Maji Safi containers (MSCs) after 24 hours of storage in households.

0.5 mg/L (SD = 0.28) at the time water was put into clean, new MSCs were sufficient to prevent recontamination with *E. coli* for 97.1% of the households during 24 h of household storage.

In the NJC group, mean FRC levels at the time of filling the containers were 0.39 mg/L (SD = 0.20) and 0.19 mg/L (SD = 0.15) after 24 h of storage. After 24 h of storage, 10 households (15.2%) in the NJC group versus two households in the MSC group (2.9%) had *E. coli* in their stored drinking water. Eleven of these households had FRC concentrations of <0.08 mg/L in their water. Higher initial chlorine dosages – in line with WHO recommendations – are required to protect water from recontamination if the treated water is filled into uncleaned containers that have been in use in households for an extended period of time.

No total coliforms were found in the water after 24 h of storage if concentrations of FRC after 24 h were above 0.6 mg/L.

The importance of chlorine residuals in water storage containers sufficiently high to reduce recontamination risk was also highlighted by Null & Lantagne (2012), who found that 77% of households with a total chlorine residual (TCR) above 0.2 mg/L after 24 h of storage had water free of *E. coli* in their ceramic pots, in contrast to just 31% of households with TCR below 0.2 mg/L.

Limitations

A major limitation of our study is that the attribution of households to the MSC and NJC groups in our study was not randomized. MSCs were sold to customers willing to pay a subsidized price of 100 KES for the MSC. The study team decided against a randomized distribution of MSC containers free of cost to avoid future disturbance of the market for MSCs. This step could have created a bias of more wealthy households in the MSC group. Another data set looked at the wealth and education levels of the two groups and found that households in the MSC group had a median monthly income of 15,000 KES and expenditures of 10,000 KES, compared to a median monthly income of 17,000 KES and expenditures of 9000 KES in the NJC group. This difference was statistically not significant: $U = 120$, $p = 0.8$ (2-tailed) and $U = 99$, $p = 0.28$ (2-tailed) respectively. Further, the three principal components of the wealth index were not statistically different in either group. The number of years of formal education was almost identical in both groups, with $Mdn = 12.0$, $U = 169.5$, $p = 0.96$. Therefore, we do not expect the results to be affected by a wealth- or education-related bias.

CONCLUSIONS

Our study showed that significantly lower levels of recontamination with *E. coli* and total coliforms were observed if clean containers that had been disinfected with chlorine at the kiosk before filling with treated water were used for water transport and storage. The use of contaminated containers led to a higher consumption of FRC than the use of clean MSCs. This suggests that contamination present in uncleaned containers, including biofilms attached to container walls, may have contributed to a higher chlorine demand in these containers.

The use of chlorine during the cleaning of water containers led to high variations in concentrations of FRC in water storage containers. To achieve a more consistent level of free chlorine in the containers we recommend chlorinating water at the point of distribution, instead of using it during the cleaning process.

In addition to using a clean container and providing residual disinfection, more frequent container cleaning in households contributed to better water quality during storage. This is in line with other studies' findings that regular mechanical cleaning of containers preserves higher water quality in water containers by reducing contamination attached to container walls and efficiently removing biofilms (Walden *et al.* 2005; Steele *et al.* 2008; Meierhofer *et al.* 2017; Shadbolt 2017).

Currently, the use of containers with small openings and taps to prevent the immersion of hands or utensils in the containers is recommended to prevent the introduction of pathogens during water extraction (Trevett & Carter 2008). Several studies have demonstrated the positive impact of using such containers (Mintz *et al.* 1995; Roberts *et al.* 2001; Reed *et al.* 2011; Mellor *et al.* 2013). However, the use of narrow-mouthed containers poses a challenge to effective cleaning. We suggest the investigation of water storage containers that have a small opening or tap, preventing contact with contaminated utensils or hands when extracting water, but that also have an opening large enough to enable effective container cleaning.

Except for the cleaning of the container, none of the water handling or hygiene behaviors in households influenced stored water quality in this study. This indicates that the use of a clean water storage container, together with sufficiently high levels of FRC, may protect water from recontamination during 24 h of storage even if the water is stored in an environment with unfavorable hygienic conditions.

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