40th WEDC International Conference, Loughborough, UK, 2017

LOCAL ACTION WITH INTERNATIONAL COOPERATION TO IMPROVE AND SUSTAIN WATER, SANITATION AND HYGIENE SERVICES

Membrane filtration reduces recontamination risk in chlorinated household water containers

R. Meierhofer, P. Rubli, K. Dreyer, H. Ouma, K. Wanyama & M. Peter-Varbanets (Switzerland / Uganda)

PAPER 2595

The study was conducted in the catchment area of two Gravity Driven Membrane Filtration (GDM) water kiosks in Uganda. It assessed if the cleaning and disinfection of jerrycans with chlorine can reduce risks for regrowth and recontamination of treated water during storage in undisturbed containers, as well as at the household level. In addition, the impact of water handling, household hygiene and safe storage determinants on water quality was evaluated. Results indicate that the cleanliness of the water storage container has a critical impact on water quality changes during storage. Safe drinking water at the point of consumption after 24 hours of storage at the household level can be achieved with a combination of ultrafiltration and subsequent chlorination.

Introduction

Sustainable Development Goal (SDG) number six calls for universal and equitable access to safe and affordable drinking water for all by 2030 (UN 2015). The establishment of water kiosks to treat contaminated water at the community level in rural areas or in marginalised urban settlements contributes to efforts to reach SDG 6.

Our study was conducted in a context where community water treatment systems, using flatsheet ultrafiltration membranes, were established to provide safe drinking water for three schools and the surrounding community in Uganda. Schools, as well as individual customers, collect the treated water at a kiosk tap and transport it home with their own water containers, mostly 20L jerrycans that originally had been used to store vegetable oil.

Even if safe water is provided at the tap, unhygienic conditions in low-income areas often lead to the recontamination of water during transport and storage. In a meta-analysis of 57 studies, Wright found that the microbiological quality of water often deteriorates during transport and storage (Wright *et al.* 2004). Also, bacterial regrowth has been observed in containers used for water storage at the household level. Mellor discussed the formation of biofilm on the walls of water containers as a source of regrowth and recontamination (Mellor *et al.* 2013). Also, Jagals measured biofilm in plastic water containers used by households and found that biofilm contributed substantially to the deterioration of water in the storage containers (Jagals *et al.* 2003).

Chlorination that provides sufficiently high levels of free residual chlorine could reduce recontamination risks in treated water. WHO recommends a range of free residual chlorine of 0.2 mg/L to 1.0 mg/L to sufficiently protect treated water (WHO 2004). Declining residual chlorine concentrations during storage may influence regrowth if various water biochemical parameters, such as dissolved phosphorus, nitrates and adequate composition of AOC (assimilable organic carbon), support regrowth conditions (LeChevallier *et al.* 1996; Vital *et al.* 2010).

The goal of our study was to assess if the cleaning and disinfection of jerrycans with chlorine can reduce or prevent regrowth and recontamination of treated water during storage in undisturbed containers at the household level. In addition, we wanted to assess which water handling, household hygiene and safe storage determinants could have a significant influence on maintaining or reducing water quality.

Methods

The study was carried out in Busia District in Uganda in the catchment area of GDM water kiosks in Lugala and Bulwande in April and May 2016. Data was collected from 60 households in Bulwande and from 70 households in Lugala. At each location, half of the randomly selected households used jerrycans that had been cleaned inside with sand – as cleaning with a brush did not work properly - and disinfected with chlorine, while the other half of the randomly selected households used uncleaned, non-chlorinated jerrycans. During the water quality analysis, there was evidence of contamination in the clean water tank of the water treatment system in Lugala. It did not deliver clean water at the kiosk tap. The evaluation is, therefore, focussing on the four following conditions: a) water treated by ultrafiltration filled into cleaned and disinfected jerrycans (FCL), b) water treated by ultrafiltration filled into uncleaned jerrycans (F0), c) contaminated water filled into cleaned and disinfected jerrycans (NFCL), and d) contaminated water filled into uncleaned jerrycans (NF0).

For water quality tests, 100ml water samples were taken at the water taps of both water kiosks. 100ml water samples were taken from the jerrycans of the individual customer after they were filled and shaken, as well as after 24 hours of water storage in the same jerrycans at the household level. The 100ml water samples were sampled into sterile whirlpacks either directly at the kiosk tap after letting the water run for three seconds, or they were sampled by the interviewers by pouring water from the container directly into the whirlpacks. The water samples were kept inside cooler bags for transport between the sample collection location and the field lab. Water quality analysis was conducted within one hour after the collection of the samples. The contamination levels of total coliforms and *E. coli* were analysed at the field site using standardised membrane filtration techniques. 100ml were passed through 0.45 μm Millipore cellulose membrane filters, plated on Nissui Compact Dry Plates (EC) and incubated for 24 hours at 35 +/- 2°C. Colonies were counted visually up to a maximum count of 2000 CFU per plate.

After filling the container, interviewers accompanied the participants to their homesteads and instructed them not to use up the water completely. After 24 hours, the respective households were revisited. Quantitative information was collected from households during face-to-face interviews with the person responsible for drinking water management in the household, using a structured questionnaire with closed ended, multiple choice questions mostly in categorical variables, as well as with Likert-scale answer categories and some scale variables. The questionnaires were coded on tablets and dealt with: utilisation of different sources, utilisation and maintenance of containers for drinking water transport and storage, water treatment practices, the handling of water in the household and hygiene indicators (type and cleanliness of handwashing station and type and cleanliness of the toilet, as well as frequency of handwashing). The interviews were complemented with structured observations.

A control experiment was conducted with undisturbed containers to observe regrowth of coliform bacteria in containers that were not stored at the household level. Two used and uncleaned jerrycans were purchased from households, filled with water filtered at the water treatment station and kept for 24 hours at the field laboratory. At the same time, water was filled into two PET bottles and also kept for 24 hours. 100ml water samples were taken after filling the containers, after 6 hours of storage and after 24 hours of storage.

Data was imported into SPSS for statistical analysis. General water handling practices and hygiene conditions were analysed using descriptive statistics. The significance of differences of log-transformed mean coliform counts in four groups at three different times of measurement were assessed by ANOVA and the difference in the mean of free residual chlorine were assessed by t-Tests. The counts of zero *E.coli* or zero total coliforms were replaced by 0.5 to be able to do logarithmic transformations. Bivariate correlations between different factors were calculated using Pearson's r and Spearman's rho. The influence of water handling practices, container cleaning and household hygiene on water quality was assessed by multivariate linear regression.

Results & discussion

Water quality

The mean of coliform counts at different times of measurement, Log Removal Rates (LRV) between the kiosk tap and the filling of the jerrycan, as well as between after filling the jerrycan, and after 24 hours of storage, and concentrations of free residual chlorine, are displayed in Table 1.

Table 1. Coliforms and free residual Chlorine in 4 groups after filling jerrycan and after 24h of storage

	Filtered Not chlorinated (n=30)		Filtered Chlorinated (n=30)		Contaminated Not chlorinated (n=35)		Contaminted Chlorinated (n=35)	
	Mean	***SD***	**Mean**	***SD***	**Mean**	***SD***	**Mean**	***SD***
E.coli tap of the kiosk CFU/100ml	0.0	*0.0*	0.0	*0.0*	186.8	*107.5*	202.9	*96.8*
E.coli after filling jerrycan CFU/100ml (0h)	1.3	*2.6*	0.0	*0.0*	179.9	*109.6*	0.0	*0.0*
E.coli after 24h storage (CFU/100ml) (24h)	41.8	*126.9*	0.3	*1.1*	225.4	*362.4*	131.2	*339.9*
Total coliforms tap of the kiosk (CFU/100ml)	30.6	*26.8*	28.2	*24.3*	939.4	*421.7*	971.3	*372.3*
Total coliforms after filling jerrycan (CFU/100ml)	438.3	*665.6*	0.0	*0.0*	1698.2	*739.9*	0.1	*0.5*
Total coliforms after 24h storage (CFU/100ml) (24h)	698.6	*880.4*	0.4	*1.1*	2054.8	*931.1*	897.4	*1264.5*
LRV E.coli (tap-after filling)	-0.2	*0.3*	0.0	*0.0*	-0.1	*0.3*	2.2	*0.8*
LRV Total coliforms (tap-after filling)	-0.4	*1.1*	1.2	*0.8*	-0.2	*0.3*	3.0	*0.3*
LRV E.coli (after filling-after 24h storage)	-0.4	*0.8*	0.0	*0.2*	-0.1	*0.7*	-1.1	*1.1*
LRV Total coliforms (after filling-after 24h storage)	-0.4	*1.5*	-0.2	*0.6*	-0.1	*0.4*	-2.5	*1.1*
Residual chlorine after filling mg/L	0.0	*0.0*	1.7	*0.5*	0.0	*0.0*	1.8	*0.8*
Residual chlorine after 24h storage mg/L	0.0	*0.0*	0.2	*0.2*	0.0	*0.0*	0.0	*0.0*

SD=Standard Deviation; n= number of households

The comparison of water quality changes during storage at the household level in the four groups FCL, F0, NFCL, and NF0 is displayed in Figure 1, and revealed significant differences between the groups. No recontamination or regrowth of *E.coli* or of total coliforms were observed in water that had been passed through ultrafiltration membranes and chlorinated during 24 hours of storage (FCL).

In water that had been passed through ultrafiltration, but had not been chlorinated (F0), recontamination and/ or regrowth of coliforms was observed. Mean counts of *E.coli* at the tap, after filling the container and after 24 hours of storage in group F0, were significantly different with $t(40)=5$, $p=0.000$ and $t(40)=2.2$, $p=0.03$. The mean counts of total coliforms were different between the tap and time of container filling $t(85)=4$, $p=0.000$, but not between filling the container and after 24 hours of storage $t(85)=1$, $p=0.2$.

High contamination levels were measured in group NF0, where water was contaminated and not chlorinated. In this group, counts of *E.coli* and of total coliforms remained high at the tap, after filling the container and after 24 hours of storage. No statistically significant difference was found between the mean at different times of measure with $t(49)=0.8$, $p=0.4$ and $t(61)=0.7$, $p=0.5$ for *E.coli*. For total coliforms, mean counts at the tap and after filling the container were different with $t(95)=4.6$, $p=0.000$, but not after filling the container and 24 hours storage $t(95)=1.5$, $p=0.1$.

In group NFCL, that filled contaminated water into chlorinated jerrycans, no *E.coli* or total coliforms were measured after filling the container, but high recontamination or regrowth was observed in these containers with LRV of -1.1 (SD=1.1) for *E.coli* and LRV of -2.5 (SD=1.1) for total coliforms after 24 hours of storage. Differences in the mean were statistically significant with $t(61)=-11$, $p=0.000$ and $t(33)=6$, $p=0.000$ for *E.coli* and for total coliforms with $t(37)=-17$, $p=0.000$ and $t(27)=11.6$, $p=0.000$.

The mean concentration of free residual chlorine in groups FCL and NFCl after filling the containers were not significantly different with 1.7 mg/L (SD=0.5) in FCL and 1.8 mg/L (SD=0.8) in NFCL ($t(63)=-0.5$; $p=0.6$). No chlorine was measurable after 24 hours of storage in NFCL, while a concentration of 0.2 mg/L (SD=0.2) was found in FCL.

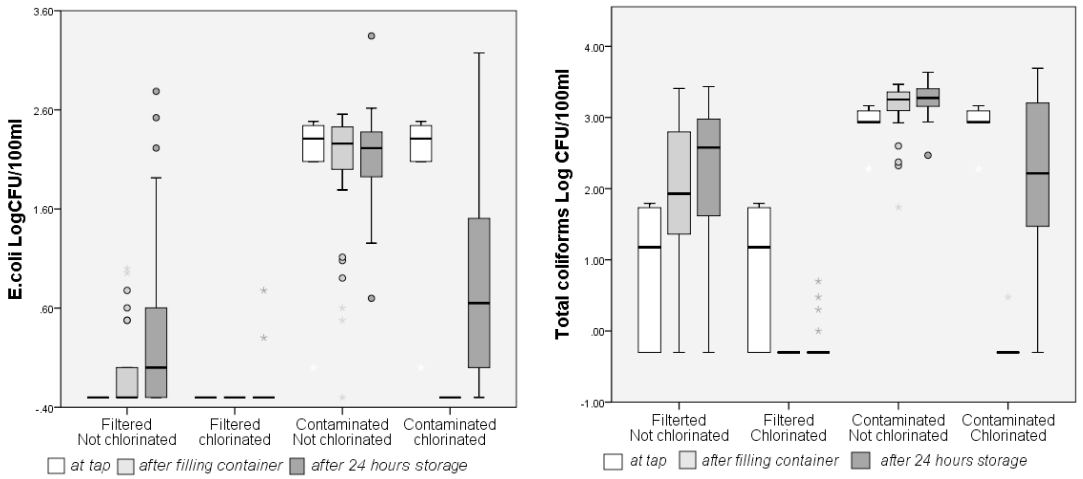

Figure 1. Boxplots of counts of E.coli and total coliforms in four groups

The findings in Figure 1 indicate that water, which had been passed through ultrafiltration membranes and chlorinated to a concentration of 1.7mg/L free residual Chlorine after filling the containers, was protected against recontamination and regrowth during 24 hours of storage at the household level in jerrycans.

Chlorination of contaminated water with the same concentration of free residual chlorine after filling the container as in FCL, however, did not protect the water sufficiently. Mean counts of *E.coli* after 24 hours storage were 131.2 CFU/100ml (SD=339.9mg/L) and 897.4 CFU/100ml (SD=1264.5mg/L) for total coliforms. A possible explanation for this might be that higher loads of organic materials, such as humic acid, may have led to a higher chlorine demand in contaminated water of NFCL than in FCL, thereby reducing the free residual chlorine in jerrycans of NFCL to a non-protective concentration.

Findings in group F0 indicate that, in the context of challenging hygienic conditions that include water transport and storage in non-disinfected jerrycans, water treatment based on ultrafiltration without subsequent chlorination to provide residual protection again recontamination is not sufficient to assure water safety over 24 hours of storage.

Figure 2 displays the results of the experiment with water that had been passed through an ultrafiltration membrane, stored in two types of non-chlorinated containers and kept undisturbed for 24 hours at the field laboratory. Findings reveal that the type of container used for water storage has an important influence on regrowth and recontamination. No regrowth of *E.coli* was found either in the jerrycans or in the PET-bottles. High levels of regrowth of total coliforms were found in jerrycans with a mean of 1144 CFU/100ml (SD=1211), while little regrowth of total coliforms was found in PET-bottles with 2 CFU/100ml (SD=0). This indicates that residual contamination and attached biofilm support the regrowth of coliforms in the uncleaned containers. It could also be that residuals from the oil that was previously stored in the containers provide nutrients for bacterial growth.

Household water handling and hygiene

Interviews with 130 households in the project area revealed that an average household contained 6.5 (SD=2.9) people, of whom an average of three (SD=2.2) were children attending school. The average distance of customers to the water kiosk is 400m, but five customers live further than 1km away.

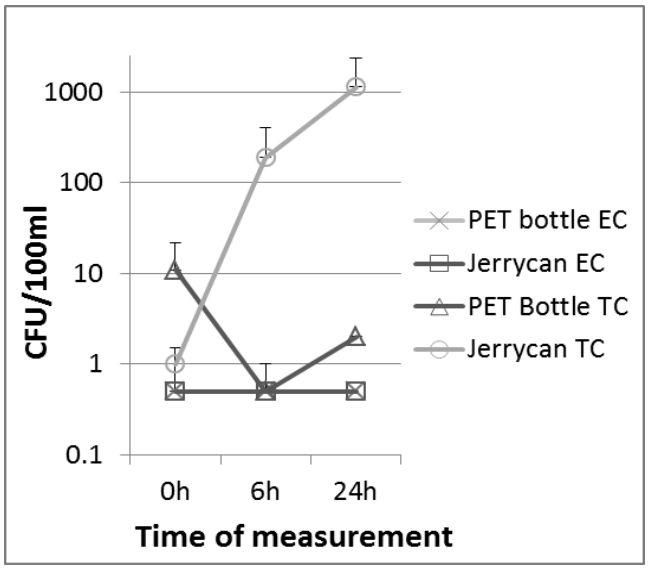

Figure 2. Regrowth of total coliforms in jerrycans and PET-bottles stored for 24 hours in undisturbed containers (n=2)

All households used 20L jerrycans to collect water at the kiosk and for transport to their homes. On average, these jerrycans are cleaned every second to third day. Materials used to clean the jerrycans are: sand (82%), Lantana kamara leaves (19%), sometimes soap (40%), always soap (48%), sometimes chlorine (1%), and sponges (57%). 50% of the households use a cup to take water out from the container, while 77% pour water out. 39% of household s use the same container for the transport and storage of water, while 49% use a clay pot and 7% use a big plastic container.

Household water treatment was used in 25.4% of households. 13.1% had a ceramic water filter, 0.8% used solar water disinfection, 6.9% had a chlorine product in the house and 4.6% said that they are boiling water.

The person interviewed washed his/her hands the day before the interview an average of four times with soap (SD=2.4). 24.6% did not have any infrastructure to wash their hands, while 72.3% used a small jerrycan with water and 3.1% installed a Tippy Tap. 61.5% had soap available at the handwashing station and 95% had water. 36% of the households did not have a private latrine on their compound, while 60.8% had their own pit latrine. 75% of the toilets looked clean during the observation.

A multivariate linear regression was calculated with log-transformed counts of total coliforms after 24 hours of storage as outcome and factors that had a significant correlation with the outcome in bivariate analysis. Included in the regression were: if water had been passed through an ultrafiltration membrane; the level of free residual chlorine after filling the container and after 24 hours of storage; the number of people in the household; the number of children attending school; the distance of the household to the water kiosk; the frequency of cleaning the container before water transport, of cleaning the container with sand, and of cleaning the container with Lantana kamara leaves; the availability of products for household water treatment in the house; the type of toilet on the compound; the type of handwashing station on the compound and the availability of soap at the handwashing station. Table 2 displays the B-values of factors that had a significant relation with the outcome in the model. The outcome is defined by:

$Y(\text{outcome})=(B_0+B_1X_1+B_2X_2+\ldots B_nX_n)$

Y=log-transformed counts of total coliforms after 24h of storage; X_1-X_n=factors included in the model, B_0(model constant)=3.69, B_1-B_n=coefficients of the factors

The B-values tell us to what degree each factor affects the outcome if the effects of all other factors are kept constant. The model revealed that water that been passed through ultrafiltration membranes was least likely to get contaminated during household storage. Other factors with a protective effect on stored water quality were chlorination, cleaning of containers with sand and the availability of soap at the handwashing station. The use of Lantana kamara leaves for the cleaning of containers increased contamination during storage.

Conclusion

The results of this study showed that water treated by ultrafiltration membranes was subjected to recontamination if filled into unclean containers. Chlorination with a concentration of free residual chlorine of 1.7mg/L was not able to protect water from Lake Victoria from regrowth or recontamination if the water was filled into uncleaned water containers (jerrycans) and stored at the household level for 24 hours. Only those containers with ultrafiltration membranes for the water to pass through and that were cleaned and disinfected with chlorine, resulting in a concentration of 1.7 mg/L of free residual chlorine after container filling, were protected from regrowth and recontamination. This indicates that, besides providing residual protection through chlorinating the water, ultrafiltration also provided additional protection against regrowth or recontamination. A combination of the two treatments is, therefore, recommended to assure safe water at the point of consumption. At the household level, recontamination risks were additionally reduced if households used sand to clean the containers and if they had soap available at the handwashing station. Container cleaning at the kiosk, further contributed to improved water quality during storage. This may be due to the removal of residual contamination in the containers, as well as of the biofilms attached to container walls.

The experiment with filtered, non-chlorinated water that was filled into different types of containers and stored at the field-laboratory, revealed that the regrowth of total coliforms was highest in uncleaned household containers which had been used for oil storage, while only minor regrowth of total coliforms was observed in PET-bottles. This indicates that the cleanliness of the container used for water storage determines water quality changes during storage. Yet, many households in low-income areas use containers for household water transport and storage that have narrow openings and a square shape, which impede proper cleaning of their insides. To enhance safe storage at the household level, we recommend further work on the development of a better designed safe water storage container that will permit thorough cleaning, and which is also equipped with a type of water outflow that prevents the introduction of contamination.

Table 2. Factors related with log total coliforms after 24 hours storage in household containers

	B Unstandardized Coefficient	Std. Error (B)	Beta Standarized Coefficient	P Significance
Water passed through UF-membrane	-1.660	.191	-.552	.000
Free residual chlorine after filling the containers	-.769	.107	-.488	.000
Sand used for container cleaning	-.541	.238	-.141	.025
Soap available at handwashing stations	-.572	.262	-.183	.031
Lantana kamara leaves used for container cleaning	.501	.245	.125	.044

R^2=0.71; F(13)=17.3, p=0.000

Acknowledgements

The authors would like to extend thanks to the Water School Uganda for the excellent and fruitful collaboration in the GDM activities and the school's management, kiosk operators and households in the project area for their participation in the study.

References

JAGALS P., JAGALS C. and BOKAKO T. C. 2003. *The effect of container-biofilm on the microbiological quality of water used from plastic household containers.* Journal of Water and Health 1(3), 101-8.

LECHEVALLIER M. W., WELCH N. J. and SMITH D. B. 1996. *Full-scale studies of factors related to coliform regrowth in drinking water*. Applied and Environmental Microbiology 62(7), 2201-11.

MELLOR J. E., SMITH J. A., SAMIE A. and DILLINGHAM R. A. 2013. *Coliform sources and mechanisms for regrowth in household drinking water in Limpopo, South Africa*. Journal of Environmental Engineering (United States) 139(9), 1152-61.

UN (2015). *Resolution adopted by the General Assembly on 25 September 2015. Transforming our world: the 2030 Agenda for Sustainable Development,* United Nations General Assembly.

VITAL M., STUCKI D., EGLI T. and HAMMES F. (2010). *Evaluating the growth potential of pathogenic bacteria in water*. Applied and Environmental Microbiology 76(19), 6477-84.

WHO (2004). *Guidelines for Drinking-Water Quality, 3rd Edition. Vol. 1: Recommendations.* WHO, Geneva.

WRIGHT J., GUNDRY S. and CONROY R. (2004). *Household drinking water in developing countries: A systematic review of microbiological contamination between source and point-of-use.* Tropical Medicine and International Health 9(1), 106-17.

Contact details

Regula Meierhofer
Eawag/ Sandec,
Ueberlandstrasse 133, 8600 Dübendorf, Switzerland.
Tel: +41 58 765 50 73
Email: regula.meierhofer@eawag.ch
www.eawagc.h; www.sandec.ch

Maryna Peter-Varbanets
University of Applied Sciences and Arts,
Northwestern Switzerland (FHNW),
Gründenstrasse 40, 4132 Muttenz, Switzerland.
Tel: +41 77 409 27 38
Email: maryna.peter@fhnw.ch