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MASTER THESIS:
EVALUATION OF STRATEGIES TO ASSURE SAFE STORAGE AND REDUCE THE RISK OF RECONTAMINATION AT WATER KIOSKS IN UGANDA

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Abstract

Drinking water collected from water kiosks is recontaminated during transport and storage in rural Eastern Uganda. Three different strategies were investigated for their potential to reduce the risk of recontamination. For the first strategy, passive chlorination with an initial free residual chlorine (FRC) dose of 2 mg/l was installed at the water kiosk. The second strategy combined chlorination and an adequate cleaning process as it is known that biofilms, growing on the inner walls of the containers, are a possible source for recontamination. The last strategy combined chlorination, cleaning and the use of improved containers, because container design influences recontamination pathways. Additionally, household factors were investigated for their effect on recontamination. Recontamination was measured at two points in time, directly after filling, where contamination frequently occurs due to the detachment of the biofilm caused by the incoming water flow, and again after 24 hours of transport and storage. All three strategies significantly reduced recontamination within 24 hours. While an initial FRC dosage of 2 mg/l was sufficient to reduce E. coli recontamination after filling, the combination of cleaning and adequate chlorination was necessary to reduce E. coli recontamination during transport and storage. In contrast, cleaning was observed to increase counts of total coliforms. A common local practice for cleaning was adopted, where sand together with water is introduced in the containers and shaken to remove biofilms. As total coliforms also multiply in soil environments, the use of sand could explain the increase in number. The narrow opening of standard jerrycans impedes the complete removal of sand at the end of the cleaning procedure. Improved container with the feature of a larger opening can facilitate the cleaning procedure. However, the additional use of improved containers did not significantly reduce E. coli contamination compared to only cleaning and chlorination. Apart from the applied strategies, a higher hand-washing facility index was statistically significant correlated to lower counts of total coliforms, indicating the importance of decent hand–washing facilities to reduce recontamination.

Contents

List of Figures

List of Tables

Abbreviations

AWS Africa Water Solutions

CFU Colony forming unit

D Kolmogorov-Smirnov test statistics

E. coli Escherichia coli

F Levene's test statistics

FRC Free Residual Chlorine

GDM Gravity Driven Membrane

H Kruskal–Wallis test statistic

MAD Median absolute deviation

MDG Millennium Development Goals

NGO Non–governmental organisation

NSI Non standardised index

p Significance level

PCA Principal component analysis

r Effect size

SDG Sustainable Development Goals

SI Standardised index

SSA Sub–Saharan Africa

U Mann-Whitney test statistic

UN United Nations

VIF Variance inflation factor

WASH Water, sanitation and hygiene

WHO World Health Organisation

1 Introduction

In 2015, with the declaration of the 6th Sustainable Development Goal (SDG) the United Nations (UN) declared that the access to safe drinking water and sanitation should be achieved for all by the year 2030. Achieving SDG 6 is an integral component of the realisation of global human rights leading to good health and improved gender equality [WHO, 2015; UN, 2010]. Nonetheless, progress is slow and access to safe water for everyone is yet to be achieved. Annually 4 billion people suffer from diarrhoea, of which 88% is caused by unsafe water supply, unimproved sanitation and insufficient hygiene standards [WHO, 2007]. The infection with diarrhoea is often fatal, causing the death of more than 800 children per day, mostly below the age of 5 [WHO, 2015]. Sub–Saharan Africa (SSA) has one of the lowest rates of access to safe water and sanitation globally and 32% of the population in SSA lacked access to an improved water source in 2015 [Roche et al., 2017]. WHO defines improved drinking-water sources as "sources which by nature of their design and construction have the potential to deliver safe water" [WHO, 2019]. SDG 6 not merely calls for an improved water source but for a source conform with WHO standard of 0 E. coli CFU/100 ml. In Uganda, East Africa, 72% of the population were provided with access to safe water in 2015, in urban areas, the access to safe water is higher than in rural areas. However, the access to safe water in urban areas even decreased due to the rapid growth of cities. In rural areas the access increased strongly from 46% in 2001 to 68% in 2013. Nevertheless, about 30% of the population were still lacking safe water access in rural Uganda in 2015 [The Republic of Uganda, 2015]. In the districts along the shores of lake Victoria, people are using the lake as their drinking water source even tough the water is not considered safe. Little children collecting water from the lake are also facing the risk of being attacked by crocodiles. In contrast, bore–wells are improved water sources, but in the areas surrounding the Victoria lake, water from bore–wells is salty and not suitable for drinking (K. Wanyama, personal communication, October 25, 2018).

To provide an alternative safe water source Eawag, the Swiss Federal Research Institute, started a cooperation with Water School Uganda in 2015 to establish three water kiosks in the district of Busia, Eastern Uganda. In 2017, two more kiosks were built in the district of Namayingo. Today, five water kiosks are run in the villages Bulwande, Busime, Lugala, Bulundira and Bumeru, using lake Victoria as their water source. For the kiosk, the water is pumped by a solar pump (produced by Ennos AG) over a distance of 1–3 km from the lake into a water tank of 6000 l. In the tank, the water is treated by gravity driven ultrafiltration membranes (GDM) and collected in another clean water tank, where the water is stored for later consumption. The installed GDM technology is gravity driven, merely using the pressure difference between the water level in the tank and the outflow at 1/3 of the height of the tank. Up to 6000 l/day are filtered by the GDM. From the clean water tank the water flows through pipes to the taps where people collect the water. For operation and maintenance, a local engineer of Africa Water Solutions (AWS) was trained to check the technology on a regular basis and repair it in case of failure. Each of the kiosks is built next to a school, providing free access to safe water for pupils. People of the community fetch water and pay a monthly (UGX 3,000) or daily fee (UGX 100) in exchange. In Lugala, people can fill 5 jerrycans per day (=100 l), in Bulundira and

Bumeru 3 jerrycans (60 l) per day. Each of the kiosks is run by a local operator, who is supported by a committee consisting of local volunteers. Apart from selling water, each kiosk also serves as a store selling essential products to the community. The money gained from sales is used for repair and maintenance [Peter-Varbanets et al., 2017]. The water quality at the taps is systematically analysed and documented. It revealed that the GDM system is able to treat water to a good quality. [Peter et al., 2016]. A follow–up study to check the water quality from the water kiosks at household level, showed that water is recontaminated during transport and storage [Meierhofer et al., 2017].

Recontamination after collection is a frequently reported concern [Opryszko et al., 2013; Wright et al., 2004; Mellor et al., 2013]. Hygiene and sanitation play a major role for recontamination during transport and storage in the household [Trevett et al., 2005]. It was possible to identify hands, utensils to fetch water and transport and storage canisters as main sources for water deterioration [Trevett et al., 2005; Opryszko et al., 2013; Mellor et al., 2013]. Pickering et al. [2010] found a positive correlation between faecal contamination on hands of mothers and children and contamination in stored drinking water. Despite access to safe water, adequate sanitation and hygiene education are important factors to reduce recontamination [Ologe, 1989]. In rural Uganda around 30% of the population lacked access to improved sanitation facilities in 2015 [The Republic of Uganda, 2015]. "Improved sanitation facilities are those designed to hygienically separate human excreta from human contact" [WHO, 2019].

Several studies investigated measures to ensure safe storage of drinking water even under low hygienic conditions [Roberts et al., 2001; Steele et al., 2008]. One effective and cost–efficient method is the addition of chlorine. Chlorine provides protection against bacteria and viruses as long as a sufficient chlorine level is present [J. L. Murphy et al., 2016]. Chlorine degradation in water is influenced by the amount of organic pollutants, sunlight and pH value [Nowell & Hoigné, 1992]. Hence, correct dosage is a crucial factor to assure safe drinking water. WHO recommends to dose 2 mg/l of Free Residual Chlorine (FRC) for non turbid water to prevent contamination during transport and storage. At the point of consumption, a minimum concentration of 0.2 mg/l should remain in the water [WHO, 2017]. Meierhofer et al. (2019) found that a sufficient level of chlorine mitigates recontamination. Also Murphy et al. (2016) documented that water disinfected by chlorine was significantly less contaminated than source water up to 72 hours. As chlorine degrades over time point–of–use chlorination would assure sufficient chlorine levels. Nevertheless, a study in Guatemala showed that although efficacy of point of use treatment for improving water quality was proven and a sophisticated marketing strategy was run, only 5% of the people used point–of–use treatment [Luby et al., 2008]. Another study evaluated the impact of container material on chlorine degradation. Clay pots were found to consume more chlorine than plastic ones, because more organic materials were observed on the inner surface consuming chlorine [H. Murphy et al., 2009].

Apart from container material, the design can also affect water quality. Quite often, containers are kept at ground level, which makes them easily accessible for children and animals [Steele et al., 2008]. Hence, it is important to cover containers with lids. Storing containers higher than ground level and not next to windows, helps to prevent pollutants from entering. Water is often deteriorated

during extraction due to the common method of scooping water with a cup or hands. Cups are often polluted as they are stored without any coverage [Jagals et al., 2003]. To prevent hands from entering, integrating a spout for extraction like it was used in refugee camps in Malawi is a possible solution [Roberts et al., 2001]. Narrow neck containers also showed better water quality than broader ones, preventing hands from entering the canister [Mellor et al., 2013]. Reused containers from oil storage are precontaminated with oil residuals. Any contamination by nutrients offers food for bacteria to grow [Jagals et al., 2003]. Meierhofer et al. (2019) proved better water quality by using new containers. Drinking water was shown to recontaminate immediately after filling due to a biofilm, which forms on the inner walls of the transport canister. The biofilm detaches, caused by the incoming water flow and transport, contaminating the water[Harris et al., 2013]. Hence, cleaning of the containers could be a method to avoid this type of deterioration. While narrow openings impede contact with possible contamination sources, they also hinder cleaning with a brush. Other methods like cleaning with sand and stones to remove the biofilm from the walls, disinfecting the container with chlorine or using Lantana kamara leaves are common practice [Steele et al., 2008]. Using sand and stones entails the risk to cause scratches in the walls, offering a niche for bacteria to grow [van der Merwe et al., 2012]. Also Lantana kamara leaves were related to a deterioration in water quality [Meierhofer et al., 2017]. In contrast, disinfecting with chlorine supports the prevention of recontamination during filling. However, only disinfecting the containers with chlorine does not protect the water during transport and storage [Steele et al., 2008].

As discussed above, household hygiene like contaminated hands, utensils and containers play a major role in recontamination pathways, therefore household factors have to be assessed for their potential to prevent deterioration. A study in Ghana found that increased education was not related to an improved drinking water quality and attributed this to a lack in WASH (water, sanitation and hygiene) training [Opryszko et al., 2013]. A study in India failed to find any statistically significant correlation of contamination and demographics, sanitation, or household practices of water handling and hygiene, but detected a slight correlation between increased contamination and increased number of household members as well as decreased average age [Eshcol et al., 2008]. Another study in Kenya was able to link a higher frequency of cleaning storage container to higher water quality [Meierhofer et al., 2019]. The practice of transferring water from smaller transport containers to larger storage containers revealed to introduce another point of contamination [Opryszko et al., 2013]. As discusses above preventing recontamination is a challenge, therefore this thesis evaluates strategies to assure safe storage and reduce the risk of recontamination at GDM kiosks in Eastern Uganda.

2 Scope and Goal

The scope of this Master thesis was to evaluate strategies to assure safe storage and reduce the risk of recontamination of drinking water collected in jerrycans from GDM water kiosks in Uganda. Additionally, household factors were investigated for their impact of reinforcing or lowering the risk of drinking water deterioration. Based on these two approaches, the goal was to answer the hypothesis: "Technical measures are sufficient to reduce the risk of recontamination after filling the container and during transport and storage within 24 hours". Following research conducted by other scientists, three technical measures were chosen: chlorination of the water, cleaning canisters before filling and using an improved canister. To answer the hypothesis four research questions were phrased (see below).

Hypothesis: Technical measures are sufficient to reduce the risk of recontamination after filling the container and during transport and storage within 24 hours.

Research Question 1:Does chlorination of 2 mg/l at the point of collection reduce the risk of recontamination?

Research Question 2: Does an adequate process of cleaning the containers used for transport and storage of treated water in combination with chlorination reduce the risk of recontamination?

Research Question 3:Does the use of an improved container for transport and storage of treated water in combination with chlorination and adequate cleaning reduce the risk of recontamination?

Research Question 4: Which factors at household level influence the recontamination of drinking water (demographic factor, water handling, hygiene and behaviour and infrastructure)?

To answer research question 1 to 3, each of the measures formed one group of participants and additional one group served as a control group without any measure. The different groups are sampled at different sites to avoid interference within the different strategies. At each site between 40 – 50 people participated comprising a total sample size of 120–150. For research question 4, household factors were identified through interviews and observations in the participant's household. The exact tools and methods used in this research process are explained in the method section of this thesis.

3 Materials & Methods

This study was conducted at the water kiosks Lugala, Bulundira and Bumeru in the districts Busia and Namayingo, Uganda, from October till December 2018. A total sample size of 135 participants was obtained. In this section a detailed description of the different groups, the microbial water quality analysis, the measurement of free residual chlorine (FRC), the conduction of household interviews and observations and the statistical analysis of the data are explained.

3.1 Description of different strategies to reduce recontamination

To assess the potential of different measures on reducing recontamination, the study was structured in 4 groups. One group served as a control group, the other three groups represented different methods to reduce recontamination. An overview about the four groups, their implementation sites and the realised measures are shown in Table 1. The names in Table 1 will be used throughout this thesis to refer to those different groups. In the following, they will be explained in more detail.

Table 1: Overview of the study approach

Name	Site	Chlorination	Cleaning	Improved containers	Sample Size
Control group	Lugala	✗	✗	✗	43
Strategy I	Bulundira	✓	✗	✗	46
Strategy II	Bumeru	✓	✓	✗	23
Strategy III	Bumeru	✓	✓	✓	23

Lugala served as a control group. The water was only treated with GDM and filled in jerrycans, which are former oil canisters reused as water transport and storage containers, without any further treatment. The jerrycans used by the community can be seen in Figure 1 a). They are very stable with a handle on top and a narrow opening, which is covered by a lid. Frequently, the lid is not used and the opening not covered. It was also observed that some people cover the jerrycans with leaves to prevent water loss during transport (see Figure 1 b)). A total number of 43 samples in Lugala was used for the final analysis.

In Bulundira, strategy I was tested, where passive, continuous chlorination was introduced by a Venturi–Doser at one tap of the kiosk. The inline Venturi–Doser was developed by Standford University to dose a liquid chlorine solution with a concentration of 1.2% according to the prevailing flow based on the Venturi effect [PATH, 2018]. A sodium hypochlorite solution purchased in Kenia called Waterguard was used in this study. The dosage was set to 2 mg/l FRC with a standard deviation of +/– 0.3 mg/l. The exact dosed values can be seen in the digital attachment. For the analysis, 46 samples were collected in Bulundira.

Strategy II and III were both conducted in Bumeru. For strategy I, contamination could still be observed after 24 h, therefore it was decided to combine chlorination and cleaning. Consequently, strategy II is the combination of chlorination and cleaning of standard jerrycans. The chlorination in Bumeru was also done with a Venturi–Doser and a setting of 2 mg/l FRC like in Bulundira. A toilet

brush to clean the jerrycans proved itself unpractical due to the narrow opening of the jerrycans. Hence, a common practice of local people to remove the biofilm from the inner walls of the jerrycans was adopted: in each jerrycan a handful of sand located next to the kiosk was introduced and shaken for about a minute. Afterwards, the sand was rinsed out using about 5 l of water. In a second step, they were cleaned with one portion of a liquid soap dispenser and again about 5 l of water. For both steps, the chlorinated water from the kiosk was used. The jerrycans were always washed by the same person to avoid different washing practices. 23 samples were collected for the final analysis.
Strategy III combined chlorination, cleaning and improved jerrycans. The chlorination was conducted the same way as for the other Strategies. However, this time the water was not filled into the standard jerrycans, but into improved containers. These containers differed from the jerrycans in three ways. First, they had a bigger opening, providing access for cleaning. Second, they had a tap to release water. Releasing water from the tap instead of scooping it, should prevent contamination of water after filling. The third difference were two handles, one on each side of the canisters, instead of only one on top of the container. An improved container can be seen in Figure 1 c). Other than the standard jerrycan, the improved containers were cleaned without sand to prevent sand from clogging the tap. They where merely cleaned with one portion of the liquid soap dispenser, about 5 l of water and a brush to remove the biofilm. After cleaning, the improved containers were filled and the people were told to just release water through the tap. Contrary to the standard jerrycans, the improved containers were not precontaminated with oil. It also has to be considered in the results that the standard jerrycans had already been in use for a longer period, whereas the improved containers were distributed to 25 families in July 2018 and the samples were taken in December 2018. Thus, the improved containers had only been in use for 5 months. A standard jerrycans costs around UGX 40,00 and the improved container each UGX 20,000 and were both produced by the company Mukwano (K. Wanyama, personal communication, March 13, 2018).

(a) Standard jerrycan

(b) Opening covered by gras

(c) Improved container

Figure 1: Comparison of containers

3.2 Microbial water quality analysis

For the microbial water quality analysis, 100 ml water samples were taken at different points in time and analysed regarding Escherichia coli (E. coli) and total coliforms. The procedure is visualised in Figure 2: on the left, the different water sampling locations are shown, in the middle the tasks conducted in the field are presented and on the right the water quality analysis in the labour is explained. First, the water quality at the taps of the kiosk was measured at each site. Each day, one sample was taken at the tap, resulting in eight samples in Lugala and three samples each in Bulundira and Bumeru. The water was running for about 3 seconds before the probe was taken. Another sample was taken from each participant's jerrycan after filling. Before the sample was taken, the jerrycan was well shaken for around 10 seconds. Afterwards, the person was accompanied to their home and instructed to leave some water in the container for the household visit the next day. 24 hours later, the respective household was visited again and another sample was taken. All the samples were stored in 100 ml sterile whirl–paks, produced by Nasco, and cooled in ice–boxes until analysis in the lab after returning from the field. For chlorinated samples, thio–whirl–paks containing sodium thiosulfate were used.

The 100 ml water samples from the whirl-paks were first vacuum–filtered through 0.45 µm millipore cellulose membrane filters using sterilized filtration equipment and then placed on Nissui Pharmaceutical compact dry coli-scan plates. The dry plates were incubated at 35 +/– 2 °C for 24 hours. Due to occasional electricity lacks, body incubation was also conducted. Instead of storing the compact dry coli-scan plates in the incubator, they were kept in a bumbag attached to the body. The temperature was monitored with a thermometer and constantly remained at around 34–35 °C. After the incubation time, E. coli and total coliforms colonies were counted visually up to 2000 colony forming units (CFU). The dry plate producer recommends to count up to 300 CFU, but for a more detailed interpretation of the data, it was counted up to 2000 CFU. The more colonies were found, the higher the error rate of counted colonies. E. coli are important indicators for faecal contamination and cause several disease like urinary tract infections, bacteraemia and meningitis. Certain species can cause acute diarrhoea. Total coliforms are harmless for humans, but serve as another indicator for cleanliness, integrity of distribution systems and the potential presence of biofilms. They occur in soil and water and can survive and multiply in water systems. Especially for testing the disinfection potential of chlorine, total coliforms are an useful indicator [WHO, 2017]. To double check the water quality analysis regarding handling in the lab and sample collection, every 16th sample, a blank sample (negative control) and a duplicate of a study participant were analysed.

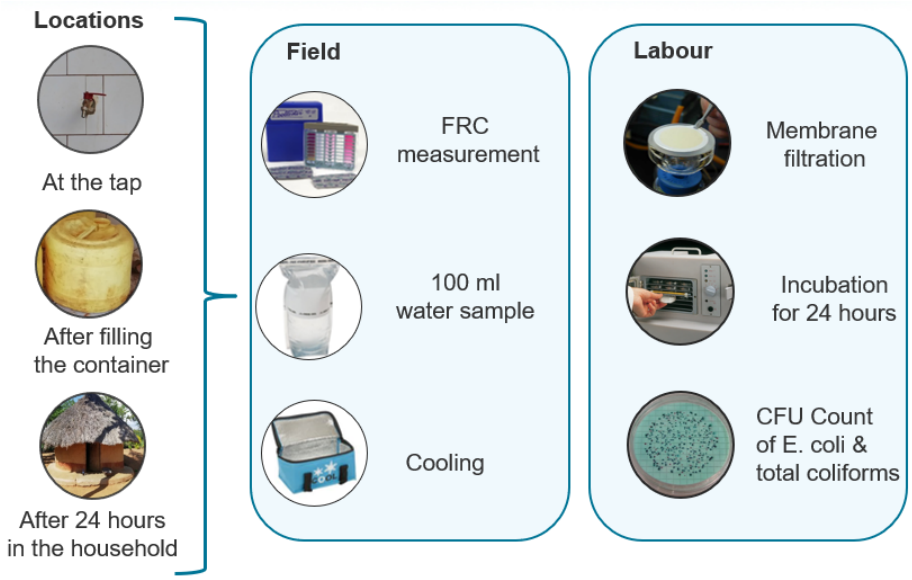


Figure 2: Work procedure [Meierhofer, 2018]

3.3 Testing of free residual chlorine

In the groups, where strategy I to strategy III was applied, a 1.2% sodium hypochlorite solution was added to the water with a Venturi–Doser, explained in section 3.1. The jerrycans were tested for their Free Residual Chlorine (FRC) concentration directly after filling the jerrycan, 30 minutes later and after 24 hours in the households. It was measured after 30 minutes, because by this time, the chlorine is expected to have reacted with the pollutants [WHO, 2017]. Two different devices were used to measure the FRC concentrations. At the taps and after filling the containers, FRC was measured using a colorimeter produced by LaMotte (see Figure 3a)). In the households after 24 hours, a pooltester from Palintest was employed (see Figure 3 b)). Both are visual methods, one rapid dissolving DPD No.1 tablet was added to the measuring chamber of the pooltester and a DPD No.1 instrumental grade tablet was added to the cuvette of the colorimeter. The tablet changes the colour of the water to pink, the intensity of the pink colour corresponds to a particular FRC concentration. The colorimeter determines the FRC concentration through the change in colour. For the pooltester the user has to determine the content himself by comparing the colour to a given scale. The pooltester has a measurement range of 0-6 mg/l, the colorimeter of 0-4 mg/l. The pooltester is more susceptible for subjective interpretation than a colorimeter.

(a) Colorimeter [LaMotte, 2019]

(b) Pooltester [Hygiene4Less, 2019]

Figure 3: FRC measurement devices

3.4 Household interviews and observations

Prior to the beginning of the study, a community meeting took place in each of the communities, where the communities were informed about the content and the procedure of the study. Here, the participants with improved containers were instructed to only draw water from the tap of the container and the importance to cover the container was highlighted. For the household interviews, a questionnaire was prepared to assess factors that could have an influence on water quality changes during transport and storage. The questionnaire included structured questions mostly with categorical and likert-scale answer categories regarding information on household demographics, access to water, water handling practice, hygiene behaviour and wealth indicators. In rural Busia, few people speak English and the local languages are Samia and Luganda. For this reason, two interviewers were trained on 13/10/2018 how to approach participants, ask questions, deal with ambiguous answers and avoid mistakes in conducting interviews. Furthermore, safety rules were explained and the handling of the tablets were tested. The interviews were conducted in the households with a digital questionnaire using a tablet with ODK software. On the 14th of October 2018, a first field training was conducted in the town of Busia. After the training ambiguous questions were improved and adjusted. For strategy III, questions regarding the acceptance of the improved containers were added to the questionnaire. The questionnaire is included in the appendix A. The person mainly responsible for water handling in the household was informed about the goal, purpose and methodology of the study, asked for consent and was interviewed. Apart from interviews, observations in the household were conducted regarding the condition and existence of storage and transport canisters, hand–washing and sanitation facilities as well as available treatment methods in the respective household. The study was reviewed and approved by the ethical committees of Makere University, Uganda and Eawag, the Swiss Federal Research Institute.

3.5 Analysing data

All data was managed using Excel and IBM SPSS Statistics 25 and plots were created in Matlab R2016. The contamination levels of E. coli, total coliforms, and FRC were analysed using descriptive statistics. Since the distribution of bacteria was not normal, median and median absolute deviation were used to assess central tendencies. In a first step, the status quo of recontamination was assessed, therefore only the control group was investigated for the degree of contamination according to the WHO risk categories and its occurrence in time. The recontamination immediately after filling and after 24 hours of storage was compared to identify whether contamination mostly aroused during filling or during transport and storage. In a second step, different strategies were investigated for their potential to reduce the risk of recontamination. Counts of E. coli and total coliforms were measured in the field at different sampling points. The difference between water quality at the tap and water quality immediately after filling the container, the difference immediately after filling and water quality after 24 hours of storage and the difference between water quality at the tap and water quality after 24 hours of storage was calculated to get information about the degree of recontamination. For

each tap, a constant value was used, determined by the mean of all days.
To test if there is a significant difference in recontamination between the strategies and the control group, a non-parametric Kruskal–Wallis test was conducted. In order to see where the difference lies and how big the effect is, five non-parametric Mann–Whitney tests were carried out: for the control group and strategy I, for the control group and strategy II, for the control group and strategy III, for strategy I and strategy II and finally for strategy II and strategy III. A Bonferroni correction was applied and the effects are reported at a .01 level of significance. From the results of the Mann–Whitney test the effect size (r) was calculated according to formula 1 , where Z is the Z–score and N the total sample size [Rosenthal, 1991]. Non–parametric tests were used as the assumptions of normal distribution and homogeneity of variance for the parametric ANOVA test were not fulfilled. ANOVA is robust to the violation of assumptions for groups with the same sample size, but for groups with different sample sizes, it can create errors [Field, 2009]. The normal distribution was investigated with the Kolmogorov–Smirnov test. The homogeneity of variance was tested with the Levene's test. Because these tests revealed non–normality and heterogeneity of variance, a log–transformation was applied to the data. Negative values were defined as zero recontamination. For all zero recontamination values, 1 was added to allow logarithmic transformations. The log–transformed data was again checked for normal distribution and homogeneity of variance, again the tests showed non–normality and heterogeneity of variance (see appendix C).

$$r = \frac{Z}{\sqrt{N}} \tag{1}$$

The difference between the FRC concentration after filling and after 30 minutes contact time as well as the difference between the FRC concentration after filling and after 24 hours of storage was calculated to get the FRC degradation. The degradation within 30 minutes and 24 hours was investigated statistically for the differences between groups. Kolmogorov–Smirnov and Levene's tests were conducted to test for normal distribution and homogeneity of variance. The degradation within 30 minutes of strategy I showed a non normal distribution. All other groups were normal distributed and all groups fulfilled homogeneity of variance (see appendix E). Due to the not normal distributed group, the non-parametric Kruskal–Wallis and Mann–Whitney test were used to test the difference between groups. A Bonferroni correction was applied and the effects are reported at a .025 level of significance. For better interpretation, the effect size of the Mann–Whitney test was calculated according to formula 1.
To investigate the impact of household factors on water quality a wealth index and hand–washing index was determined. The wealth index and hand–washing index were calculated using principal component analysis (PCA) with orthogonal rotation (varimax). Households' wealth is hard to measure, therefore the assumption is made that assets available in the household are related to the relative economic position [Rutstein, 2008]. The wealth index was based on questions asked during the interview: education–level, money spent per week, items owned: solar panel, radio, TV, phone, bicycle, motorbike, car, fridge, watch, type of fuel used, owner of the house, number of rooms, wall,

roof and floor type of the house. Likewise, a hand–washing facility index was calculated for each household, including: the presence of a hand–washing facility, the condition of the facility (not damaged), soap available, cleanliness and water availability. Items owned and the hand–washing variables were included as dichotomous variables (0= not owned, 1= owned; 0=not present, 1=present) and the other variables were included as continuous variables. For the wealth index, some variables were excluded due to the result of the anti–image matrix. "Diagonal values should be greater than 0.5 if the sample is adequate for a given pair of variables" [Field, 2009]. Hence, money spent per week, education level, owning a fridge, car, type of fuel used and owner of the house were excluded. Apart from that, it was a reasonable choice to exclude the first two values as they are susceptible for reporting bias. The other four indicators provide less information, because the answers were the same for almost all participants. Hardly no families owned a fridge or a car and almost all use wood as fuel and own their houses. The PCA decomposes a large number of variables into a smaller set of uncorrelated factors, the principal components [Krishnan, 2010]. Based on the scree test, the components for the wealth index were chosen [Catell, 1966]. For the chosen components, the scores of each participant were calculated in SPSS by the Anderson–Rubin method. From the factor scores the Non-standardized index (NSI) was calculated for each participant according to the following formula [Krishnan, 2010].

$$NSI = factor\ 1 \times \frac{variance\ explained\ by\ factor\ 1}{total\ variance\ explained} + factor\ 2 \times \frac{variance\ explained\ by\ factor\ 2}{total\ variance\ explained} + factor\ n \times \frac{variance\ explained\ by\ factor\ n}{total\ variance\ explained} \quad (2)$$

Finally, the NSI was standardised according to the following equation [Krishnan, 2010]:

$$SI = \frac{NSI\ of\ particpant\ n\ -\ Minimum\ NSI}{Maximum\ NSI\ -\ Minimum\ NSI} \quad (3)$$

To answer research question 4 "Which factors at household level influence the recontamination of drinking water?" Two multivariate regression models were developed, one for E. coli and one for total coliforms recontamination during transport and storage as a dependent variable. Independent variables were received from household interviews. Among all household factors the most important ones were included in the model based on literature and bivariate correlation. Former studies reported the influence of cleaning containers, FRC concentration and improved containers on recontamination, therefore they were included as independent variables. The practice of cleaning with sand and Lantana kamara leaves was identified to influence water quality [Meierhofer et al., 2017]. Apart from the cleaning practice, also the frequency of cleaning the containers was observed to influence recontamination [Meierhofer et al., 2019]. As faecal contamination on hands is a frequent reported source for water deterioration, the hand–washing facility index was included in the analysis [Trevett et al., 2005; Opryszko et al., 2013; Mellor et al., 2013]. The local NGO AWS regularly trains

households in WASH topics. To evaluate the impact of the training, the number of household visits within the last years was included as a independent variable in the analysis. As socioeconomic characteristic, the wealth index was assessed. This results in nine independent variables for the final multivariate regression model: cleaned before filling, FRC content after 24 h, use of improved containers, practice of cleaning with sand, practice of cleaning with Lantana kamara leaves, hand–washing facility index, wealth index, number of household visits and frequency of cleaning the transport canister.

It was decided to use a multivariate generalised linear model for E. coli as neither the residuals of the original nor of the log-transformed data were normally distributed in multivariate linear regression. Hence, E. coli recontamination was grouped into the WHO risk categories and assessed in a generalised linear model with poisson distribution and identity link function. Total coliforms were also classified in WHO risk categories, but different to E. coli the resulting data was not poisson distributed. For this reason, logistic regression was assessed for total coliforms. A multivariate binary logistic regression model was developed for total coliforms, contamination values were classified in low contamination (total coliform counts < 11 CFU/ 100 ml) and high contamination (total coliform counts > 10 CFU/100 ml). The dependent variable was expressed in a dichotomous variable (0= low contamination, 1 = high contamination). As the study was conducted at three different sites, the site was included as a random intercept in both models. To respect outliers in the model, the robust regression method of SPSS was applied. The classification of data in dichotomous variables or the WHO risk categories is a crucial step as it is a loss of information. It is important to interpret the results of the model with caution.

4 Results and discussion

This chapter will show and discuss the results of the conducted research focusing on the water quality, the status quo, the effects of the strategies, the FRC degradation as well as the community and household characteristics and finally the relation between household factors and water quality.

4.1 Water quality at the taps

The water quality results at the taps of the kiosks are displayed in Table 2. None of the samples taken at the tap of the kiosks at the three sites contained E. coli (N=14). Total coliforms were detected in Lugala (N=8) with a median of 11 and a median absolute deviation (MAD) of 7. The chlorinated taps in Bulundira and Bumeru contained no total coliforms (see Figure 2). Total coliforms are only used as another indicator for cleanliness and integrity of the distribution systems as they are harmless to humans, unlike E. coli which can cause severe food–borne diseases [WHO, 2017; WHO, 2019]. The WHO groups E. coli contamination in four categories. Conform with the WHO standards are 0 CFU/100 ml, low risk are 1–10 CFU/100 ml, 11–100 CFU/100 ml are intermediate risk and >100 CFU/100 ml are high to very high risk [WHO, 2017]. In the final evaluation report of the GDM technology, water quality at all taps was measured systematically from November 2015 to December 2016, showing that at least 36.8 % were conform to the WHO's risk categories [Peter et al., 2016]. During this study, 100% of the results in the control group were conform with the first of the WHO's risk categories. The low sample size and the short time period of this study are less representative than the results of 2015–2016. However, the results prove the assumption of the thesis that safe water quality is ensured at the point of delivery during the study period.

Table 2: Water quality at the tap of the kiosks

	Lugala not chlorinated [CFU/ 100 ml]	Bulundira chlorinated [CFU/ 100 ml]	Bumeru chlorinated [CFU/ 100 ml]
Median E. coli	0	0	0
MAD E. coli	0	0	0
Median total coliforms	11	0	0
MAD total coliforms	7	0	0

4.2 Status quo without strategies

Figure 4 shows the total recontamination after 24 hours of the control group (N=43). Water quality results in the control group after 24 hours are distributed over all four risk categories. With a sample size of 43, 14% are conform, 37% are low risk, 37% are intermediate risk and 12% are in the high risk category according to the WHO standards (see Figure 4). The WHO recommends urgent actions, if high risk values are detected [WHO, 2017]. As the water quality deteriorates from the tap until 24

hours later, protection of the drinking water to the point of use is needed.

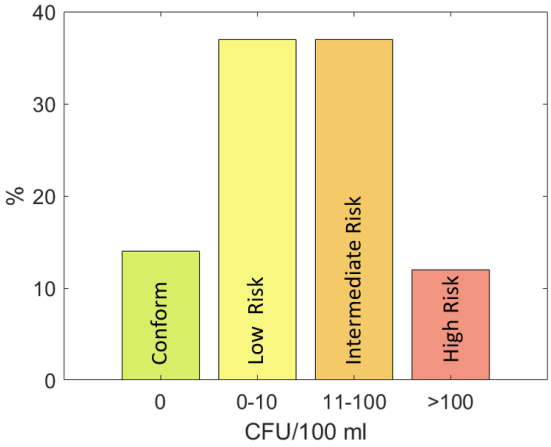
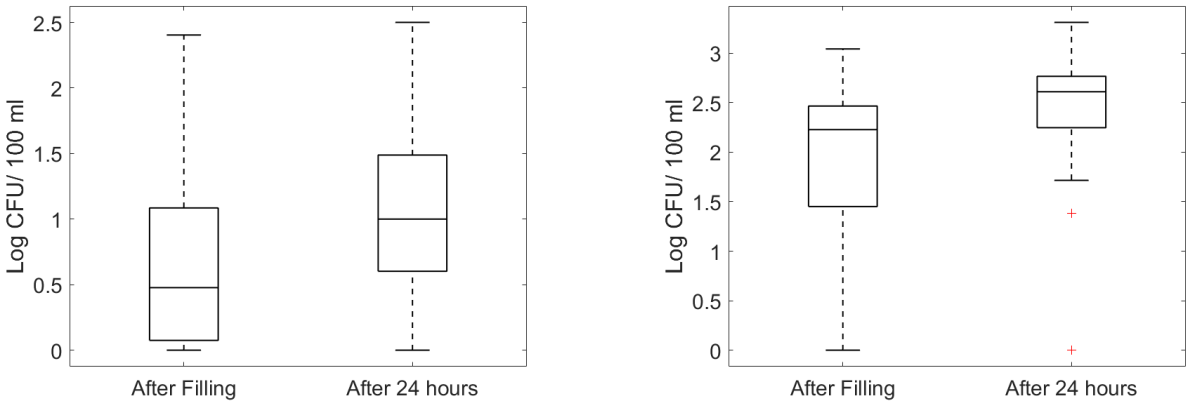


Figure 4: Distribution of E. Coli within the WHO risk groups of the control group

The recontamination after filling the jerrycans (difference of E. coli number in the jerrycan after filling and the tap) and the total recontamination after 24 hours (difference of E. coli number in the household and the tap) of the control group are compared in Figure 5. The values are displayed in logarithmic scale for better visualisation. For both E. coli and total coliforms, higher contamination was observed after 24 hours than immediately after filling. E. coli showed a median of 1 CFU/100 ml (MAD =0.53) and total coliforms of 2.61 CFU/100 ml (MAD=0.49) after 24 hours. In contrast, E. coli after filling revealed a median of 0.48 CFU/100 ml (MAD=0.52) and total coliforms of 2.23 CFU/100 ml (MAD=0.71). A Mann–Whitney test between the recontamination after filling and after 24 hours showed that water quality significantly deteriorated during transport and storage. As recontamination immediately after filling was observed, the storage container can be identified as a recontamination source. This agrees with findings in the literature [Trevett et al., 2005; Opryszko et al., 2013; Mellor et al., 2013].

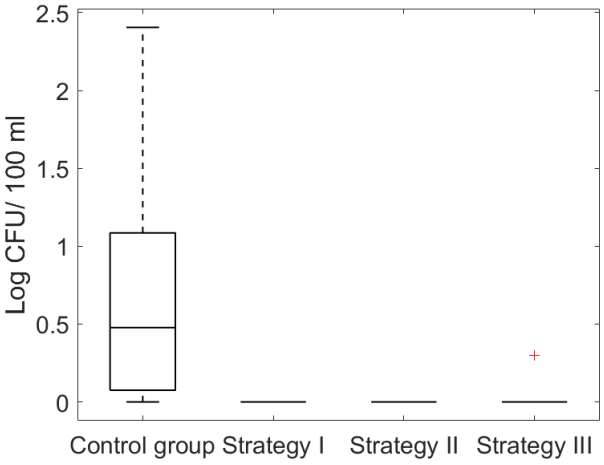


(a) E. coli recontamination

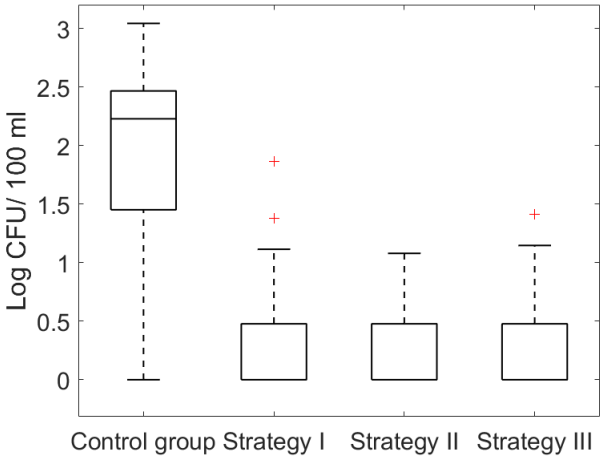
(b) Total coliforms recontamination

Figure 5: Comparison of the recontamination after filling and after 24 hours

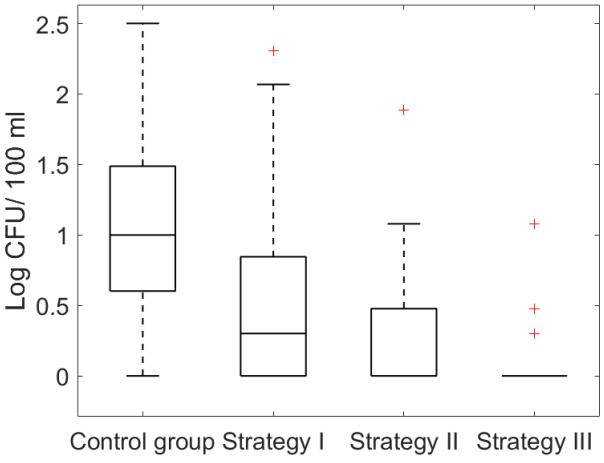
4.3 Effect of strategies



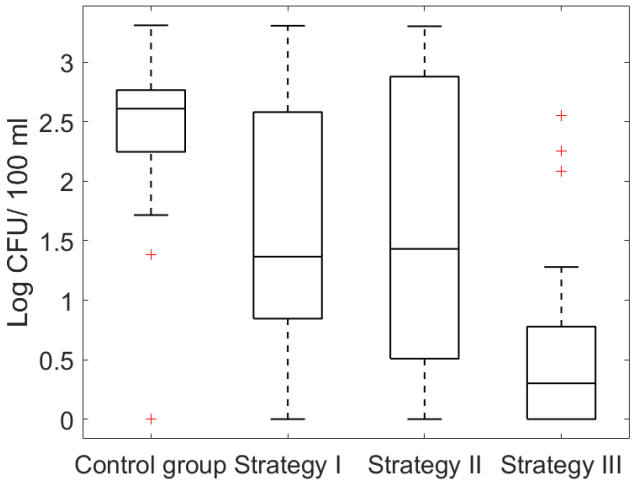
(a) E. coli recontamination after filling



(b) Total coliforms recontamination after filling



(c) E. coli recontamination after 24 hours



(d) Total coliforms recontamination after 24 hours

Figure 6: Log recontamination after filling and after 24 hours for E. coli and total coliforms

In Figure 6 a) and b) recontamination immediately after filling is compared for the different groups. For better visualisation, the values are presented on a logarithmic scale. The boxplot of the control group revealed a median of 0.48 CFU/100 ml (MAD= 0.52) for E. coli. After chlorination was introduced, the median and MAD of E. coli dropped to 0 for all strategies (see Figure 6 a). For total coliforms, the median of the control group was 2.23 CFU/100 ml (MAD=0.71) after filling. For all three strategies the median also dropped to 0 CFU/100 ml, but the MAD is 0.34 CFU/100 ml for strategy I, 0.29 CFU/100 ml for strategy II and 0.32 CFU/100 ml for strategy III (see Figure 6 b).
The results of the recontamination of E. coli after 24 hours (difference between jerrycan after 24 hours and tap) are visualised in boxplots in Figure 6 c). The control group showed a median of 1 CFU/100 ml (MAD=0.53) for E. coli. For strategy I the median was lower with 0.30 CFU/100 ml (MAD=0.52). For strategy II and III the median was 0 with MAD of 0.36 for strategy II and 0.14 for strategy III. Also, the maximum contamination of each group decreased with additional measures.

The results of the total recontamination after 24 hours between the different groups are displayed in Figure 6 d). The control group revealed a median of 2.61 CFU/ 100 ml (MAD=0.49). Strategy I dropped to a median of 1.37 CFU/100 ml (MAD=0.88). The median of strategy II was slightly higher, namely 1.43 CFU/100 ml (MAD=1.02). Strategy III showed the lowest median of 0.30 CFU/100 ml (MAD=0.57). Compared to the E. coli, the recontamination after 24 hours for total coliforms did not decrease with increasing measures. Although the median was lower for all strategies compared to the control group, strategy II showed a slightly higher median than strategy I. Strategy III showed by far the lowest recontamination.
The boxplots indicate that all strategies reduced recontamination for E. coli and total coliforms after filling, because the median dropped to 0 CFU/100 ml. Therefore, strategy I with only chlorination is sufficient to eliminate recontamination after filling, additional measures are not necessary. As chlorination already reduced recontamination to a median of 0 CFU/100 ml after filling, most recontamination within 24 hours occurred during transport and storage. To test which strategy is significantly different to the control group, the results of Mann-Whitney tests are shown in Table 3 and 4. Additionally, the results of Mann-Whitney tests between strategy I and strategy II and between strategy II and III are displayed to test the effect of combining different measures. Apart from the performance of the different strategies for recontamination after filling and after 24 hours, this was also evaluated for recontamination during transport and storage. U is the test statistic for the Mann–Whitney test, p shows the significance of a test reported with a Bonferroni correction (significant if $p < .01$), Z is a data point expressed in standard deviation units and r is the calculated effect size. Values marked green were significantly different. Values marked in red showed an effect (light red= small effect, medium red = medium effect, dark red = large effect).
In table 3 the results of the Mann–Whitney tests for E. coli are shown. As already indicated in the box plots all strategies are significantly different to the control group. Comparing the Strategies within each other reveals that their performance is not significantly different from each other. The middle column presents the results for contamination during transport and storage. The observation revealed that chlorination alone is not sufficient to reduce recontamination during transport and storage. When additional cleaning and improved containers were applied, the results differed significantly from the ones of the control group. The use of additional improved containers in addition to chlorination and cleaning did not reveal a significant difference. Nevertheless, the combination of all three measures showed a medium effect, whereas strategy I and strategy II only showed a small effects. The total recontamination, consisting of contamination during filling and during transport and storage is shown in the right column. For total contamination all strategies were significantly different to the control group. The effect of strategy III was the highest.

Table 3: Results of Mann-Whitney test for E. coli

Comparison		After filling	After transport & storage	After 24 hours
Control group - Strategy I	U	253.000	752.000	539.000
	p	.000	.046	.000
	Z	-7.040	-1.999	-3.751
	r	-.606	-.172	-.323
Control group - Strategy II	U	126.500	263.000	167.000
	p	.000	.001	.000
	Z	-5.335	-3.244	-4.493
	r	-.459	-.279	-.387
Control group - Strategy III	U	134.500	180.500	99.500
	p	.000	.000	.000
	Z	-5.185	-4.492	-5.488
	r	-.446	-.387	-.472
Strategy I - Strategy II	U	529.000	399.500	399.500
	p	1.000	.073	.073
	Z	0.000	-1.793	-1.793
	r	.000	-.154	-.154
Strategy II- Strategy III	U	253.000	215.000	215.000
	p	.317	.132	.132
	Z	-1.000	-1.508	-1.508
	r	-.086	-.130	-.130

Bonferroni correction
significant p < .01

effect size:
small > .10
medium > .30
large > .50

Table 4 displays the Mann-Whitney test results for total coliforms. As for E. coli, chlorination is sufficient to reduce recontamination during filling and all three strategies showed large and medium effects of reducing recontamination during filling. In contrast, recontamination occurring during transport and storage was just significantly different to the control group if all three measures were applied. Strategy I showed a small effect, strategy II showed no effect and strategy III a medium effect. For total recontamination after 24 hours, strategy I and III were significantly different to the control group. Strategy II has the lowest effect of reducing recontamination for total coliforms, which agrees with the findings of the box–plots. Strategy III showed the highest effect on reducing recontamination.

Table 4: Results of Mann-Whitney test for total coliforms

Comparison		After filling	After transport & storage	After 24 hours
Control group - Strategy I	U	192.000	823.500	597.000
	p	.000	.174	.001
	Z	-6.689	-1.360	-3.219
	r	-.576	-.117	-.277
Control group - Strategy II	U	92.000	449.000	352.500
	p	.000	.540	.056
	Z	-5.465	-0.613	-1.911
	r	-.470	-.053	-.164
Control group - Strategy III	U	95.500	157.500	87.000
	p	.000	.000	.000
	Z	-5.410	-4.575	-5.497
	r	-.466	-.394	-.473
Strategy I - Strategy II	U	525.500	487.000	509.500
	p	.960	.593	.804
	Z	-0.050	-0.535	-0.248
	r	-.004	-.046	-.021
Strategy II- Strategy III	U	252.500	107.500	114.500
	p	.773	.000	.001
	Z	-0.288	-3.501	-3.314
	r	-.025	-.301	-.285

Bonferroni correction
significant p <0 .01

effect size:
small > .10
medium > .30
large > .50

The hypothesis of this thesis is: "Technical measures are sufficient to reduce the risk of recontamination after filling the container and during transport and storage within 24 hours". Research questions 1 asked: "Does chlorination of 2 mg/l at the point of collection reduce the recontamination risk?" This was confirmed for the recontamination immediately after filling. After introducing chlorination, deterioration of the water quality is significantly different from the control group with a median of 0 CFU/100 ml for E. coli and total coliforms. The schools next to the kiosk fetch their water in jerrycans, but in contrast to the households, they consume the water within the same day without long storage times. School children were observed to fill water directly from the taps into cups. Cups are expected to have a similar effect on worsening water quality as jerrycans. Due to the short storage time, high FRC levels can protect water against recontamination. Therefore, recontamination after filling is the main concern for schools. Accordingly, an important improvement can be reached through

chlorination. Nevertheless, children below the age of 5 are most vulnerable to waterborne diseases [WHO, 2007]. In Uganda, children start school at the age of 4 (P. Wafula, personal communication, March 26, 2018); so most children at a vulnerable age are consuming water merely at home and not at school. In contrast, only chlorination of 2 mg/l did not significantly reduce recontamination during transport and storage compared to the control group, which can be explained by FRC degradation over time. In Figure 5 it was shown that about 50% of recontamination occurs during filling and about 50% during transport and storage. Although, chlorination of 2 mg/l was not sufficient to reduce recontamination during transport and storage due to the elimination of recontamination during filling, total recontamination within 24 hours was sufficiently reduced by chlorination.

Research question 2 asked: "Does an adequate process of cleaning the containers, used for transport and storage of treated water, in combination with chlorination reduce the risk of recontamination?". A former study demonstrated that cleaning as such does not protect water from recontamination during transport and storage [Steele et al., 2008] As discussed above, chlorination alone is not sufficient to reduce recontamination during transport and storage. Hence, the potential of cleaning and chlorination in combination was investigated. Chlorination proved to be an effective measure to eliminate deterioration after filling the jerrycans. For this reason, no further measures like cleaning or improved containers are necessary. Cleaning effected recontamination during transport and storage different for E. coli and total coliforms. While cleaning improved water quality for E. coli, it worsened it for total coliforms. Consequently, the combination of chlorination and cleaning was proven to be sufficient for E. coli, however not for total coliforms. The improvement for E. coli can be explained, as it is likely that cleaning with sand removes the biofilm on inner walls. E. coli originate in faeces, whereas total coliforms occur everywhere in the environment, also in soil [WHO, 2017]. The standard jerrycans were cleaned with sand, which enabled total coliforms to enter together with the sand. It is likely that cleaning also removes total coliforms in biofilms. Due to the design of the jerrycan it is hard to wash the sand out and the possibility of sand remaining in the jerrycans can explain the high count of total coliforms. As total coliforms are harmless to humans and cleaning with sand reduces the risk of E. coli occurrence, cleaning can be an efficient method to reduce recontamination. It has to be paid attention not to scratch inner walls during the cleaning process, which offers niches for bacteria to grow [van der Merwe et al., 2012].

Research Question 3 stated: "Does the use of an improved container for transport and storage of treated water in combination with chlorination and adequate cleaning reduce the risk of recontamination?" Descriptive statistics, as well as effect size identified the best performance of combining chlorination, cleaning and improved container. Strategy II compared to strategy III for E. coli did not show a significant difference. As the improved container are 5 times the price of normal jerrycans, the benefit of using additional improved container has to be weighted against the high costs. In contrast, strategy III was the only one significantly different to the control group for total coliforms during transport and storage. The reason for this is, that no sand was introduced in the improved containers, because due to the wider opening a brush could be used to clean the inner walls. A long time study for the performance of improved containers is recommended, because they were just in use for 4

month, when the study was conducted. Regardless of the short time of usage, no biofilm growth is to be expected, as Budeli et al. [2018] showed that biofilms form already after 3 to 14 days.

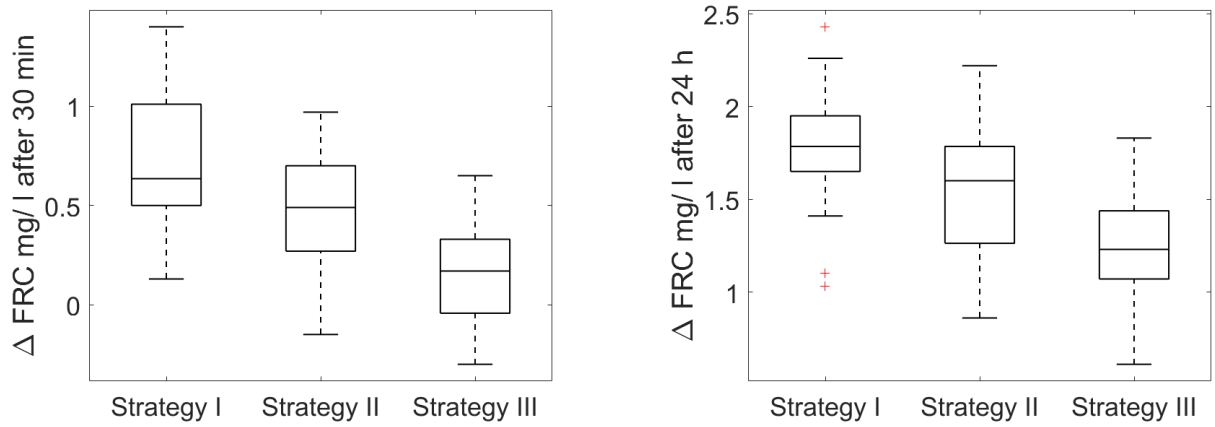
4.4 FRC degradation

In all of the groups, except for the control group, chlorine was added to the water to reduce recontamination. To compare the impact of the additional measures like cleaning and improved containers, FRC degradation also serves as an indicator as pollutants react with the FRC. High degradation indicates high pollution and lower degradation indicates the opposite. The initial dosage for the different strategies can be seen in Table 5. The dosage of strategy I was slightly lower with 1.9 mg/l compared to the other two with 2 mg/l. This difference can be a explained by the uncertainty of the measurement device.

Table 5: Initial FRC dosage for different strategies

	Mean FRC [mg/l]	Std FRC [mg/l]	Median [mg/l]
Strategy I	1.9	0.26	1.9
Strategy II	2.0	0.26	2.0
Strategy III	2.0	0.21	2.0

The degradation of the different strategies is displayed in Figure 7. Figure 7 a) shows the degradation within the first half an hour, Figure 7 b) shows the degradation over a period of 24 hours. Both figures reveal a decrease in degradation for strategy II compared to strategy I and the lowest degradation for strategy III. The median degradation for strategy I and II was around the same of 0.6 mg/l and 0.5 mg/l within the first 30 minutes. FRC degraded more than 50 % of the initial dosage of 2 mg/l within the first half an hour for strategy I. Strategy III had a much lower median of 0.2 mg/l than the other two Strategies. Over 24 hours, a median degradation of 1.8 mg/l was observed for strategy I, 1.6 mg/l for strategy II and only 0.8 mg/l for strategy III .



(a) FRC degradation over 30 minutes

(b) FRC degradation over 24 hours

Figure 7: FRC degradation after 30 min and 24 hours

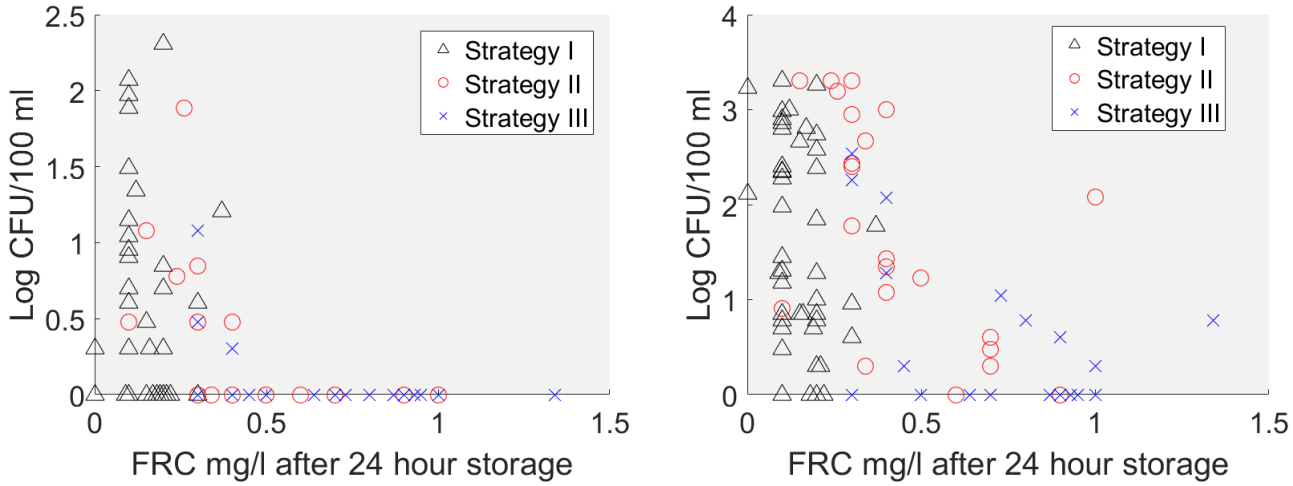
The results of the Mann–Whitney test for FRC degradation between strategy I and II and between strategy II and III are documented in Table 6. The groups are significantly different if p < .025 (Bonferroni correction). The Mann–Whitney test identified significance for both comparisons. Between all groups a medium effect (r > .30) could be observed.

Table 6: Results of Mann–Whitney test for degradation after 30 min and 24 hours

		Degradation 30 min	Degradation 24 hours
strategy I–II	U	309.500	329.500
	Z	-2.795	-2.540
	p	.005	.011
	r	-.241	-.219
strategy II–III	U	114.000	123.500
	Z	-3.309	-3.098
	p	.001	.002
	r	-.285	-.267

Bonferroni correction
significant p <.025

effect size:
small > .10
medium > .30
large > .50



(a) Log–transformed counts of E. coli versus FRC

(b) Log–transformed total coliforms versus FRC

Figure 8: Log–transformed counts of E. coli and total coliforms versus FRC after 24 hours

To find the optimal initial FRC dosage concentration, in order to prevent recontamination over 24 hours, the water quality (E. coli and total coliforms) vs. FRC concentration after 24 hours was evaluated and results are show in Figure 8. The range of measured FRC concentrations in the container after 24 hours varied between strategies. Strategy I showed no FRC concentrations higher than 0.4 mg/l after 24 hours, for strategy II concentrations of 1 mg/l were found and strategy III even showed 1.4 mg/l after 24 hours. In all of the three strategies no E. coli were found at FRC concentrations higher than 0.4 mg/l (see Figure 8 a)). In contrast, total coliforms were found for all FRC levels even up to 1.4 mg/l (see Figure 8 b).

The results of the water quality tests revealed that chlorination only was not enough to reduce the risk of recontamination during transport and storage. The reason for this is that the chlorine level recommended by the WHO, of 0.2 mg/l after 24 hours, is too low to protect the water at the sites against deterioration. [WHO, 2017]. More than 0.4 mg/l after 24 hours have to be present at the villages of the GDM water kiosks to ensure safe water quality. A study in Kenia showed the same result: FRC values greater than 0.4 mg/l after 24 hours were needed, to aim 0 CFU/ 100 ml of E. coli [Meierhofer et al., 2019]. The median degradation within 24 hours for strategy I was 1.8 mg/l (see Figure 7 b)). Therefore, a minimum dosage higher than 2.2. mg/l is required to assure 0.4 mg/l after 24 hours. Another study found a degradation rate of around 1.675 mg/l within 24 hours[Lantagne, 2008]. For the site of this study higher degradation values and higher values than 0.2 mg/l to ensure safe drinking water were found. One reason to explain the higher values is turbidity, which was observed in the group with only chlorination. Turbidity also consumes FRC [WHO, 2017]. The reason for turbidity was difficult to determine. An integrity test was conducted to ensure the proper function of the membranes. It is likely that turbidity is a result of rust formation in the pipes. The exact level of turbidity has not been measured as no device was available. Another explanation for higher degradation are high contamination levels in the jerrycans. Chlorination with an initial dosage higher than 2.2 mg/l without any further measures could be a solution to reduce recontamination also during transport and storage. This needs to be confirmed in another study. A higher chlorine dosage could cause a problem for the acceptance of taste. At the GDM water kiosk, a chlorine tasting was conducted to investigate the acceptance [Germann, 2019]. People accepted the taste of chlorine even at high concentrations. They linked the taste of chlorine to safe water, which is why higher dosage rates can be possible. The higher required FRC dosage indicates higher organic matter in the water. High natural organic matter in reaction with chlorine contains the risk of carcinogenic byproducts like trihalomethanes [Crittenden et al., 2012]. Hence, a combination of chlorination with another measure like cleaning or improved containers is recommended to reduce the occurrence of organic matter in the jerrycans.
The median FRC degradation of the combination of cleaning and chlorination was lower with 1.6 mg/l. Accordingly, a dosage of 2.0 mg/l was still not enough to ensure higher FRC concentrations than 0.4 mg/l after 24 hours. The lower degradation value supports the findings of the water quality results: cleaning could reduce the risk of recontamination significantly during transport and storage.

The median FRC degradation of combining chlorination, cleaning and improved containers was the lowest with 1.2 mg/l. An initial dosage of 2 mg/l and median degradation of 1.2 mg/l assures higher concentrations than 0.4 mg/l after 24 hours for median contamination. The combination of the three measures would allow a lower, initial FRC dosage of around 1.6 mg/l to ensure 0.4 mg/l after 24 hours, which could be a solution, if the acceptance of taste would be a problem. The other positive side effect of the low degradation values is that contamination higher than average could still be disinfected with a initial dosage of 2 mg/l. It was not possible to ensure disinfection for very high contamination and resulting high degradation (maximum 1.8 mg/l for strategy III), as this would lead to very high initial FRC dosage values. Due to the costs and the taste, the focus should be on disinfecting median contamination. The FRC degradation results support the water quality results. If the FRC concentration in the water drops below 0.4 mg/l, water quality is not conform to the WHO limit of 0 CFU/100 ml of E. coli. It was shown that the combination of different measures reduced the FRC degradation and therefore improve water quality.

4.5 Community and household characteristics

4.5.1 General

The interview results revealed that an average number of 7 people lived in each household, with 4 children among them, of which 2 are under the age of 5. 92% of the responsible persons for water in the household worked in agriculture. The average distance to the water kiosk was about 600 m and the average time to collect water everyday, including waiting time, was 130 minutes. 33% used other sources in addition to the water kiosk, the lake being the main additional source. Only 4 out of 135 interviewed people did not use the kiosk as their main drink water source. The customers of the kiosk ranked the water quality at the kiosk as safe and perceived the taste of the water as good.
The water handling is described in the following. Merely 11% use an additional method to treat the drinking water, mostly filtration with a cloth (shown in Figure 9 b)). Most of the households cleaned their water transport canister every second to third day. All 135 participants were asked for the type of material used to clean the transport canister. As Table 7 shows, the most common materials used are soap and a sponge.

Table 7: Materials used to clean transport canister

Material	Relative
Sometimes soap	0.19
Always soap	0.63
Chlorine	0.00
Sand	0.47
Lantana kamara leaves	0.20
Sponge	0.63
Stones	0.02
Ash	0.02

59 (43 %) people stated that they are using different containers for transport and storage. The most common storage container in use was a clay pot as shown in Figure 9 a). The drinking water was stored for 3–4 days until consumption. 40% of the households received a visit, regarding information on water handling and hygiene within the last year. Those 40% received an average of 2 household visits within the last year. A lot of the respondents, who did not receive household visits within the last year were new to the area, they were especially young women, who recently married and moved into the village of their husband. The exact number was not counted. 45% took part in community meetings regarding WASH within the last year, they attended about 2 meetings on average.

The results that the households perceive the water as safe and only 11% are using further treatment methods show that the people are not aware of the recontamination. It should be a goal in further WASH meetings to create awareness for this topic. The rebound effect that people perceive improved water sources as safe and treat it less, was also observed in another study [Lindskog & Lindskog, 1988]. 43% of the people transferred the water from the transport container to a storage container. This bears the risk of further recontamination from the storage container, which was identified as another contamination source [Harris et al., 2013]. Additional, clay pots were observed to consume FRC faster than plastic containers [J. L. Murphy et al., 2016]. Therefore, it should be a goal to avoid water transfer in the future and chlorinated water should not be stored in clay pots.
The results of this study did not look at the impact of transferring water into storage containers and only tested water quality after 24 hours of storage in the same container. The answers of the interviews showed that people stored the water for 3–4 days. An analysis of the point in time of recontamination occurrence, revealed that water quality is significantly worsened during transport and storage (see Figure 5). It is likely that storing water for more than 24 hours decreases water quality. Chlorination is not a measure to prevent recontamination after 24 hours as FRC degrades and very high FRC dosages would probably not be accepted due to their strong taste. For this reason, contact with contamination sources has to be prevented. Improved containers could be a good solution, as long as the lid stays closed and water is only drawn through the tap.

(a) Clay pot used for storage

(b) Cloth for filtration

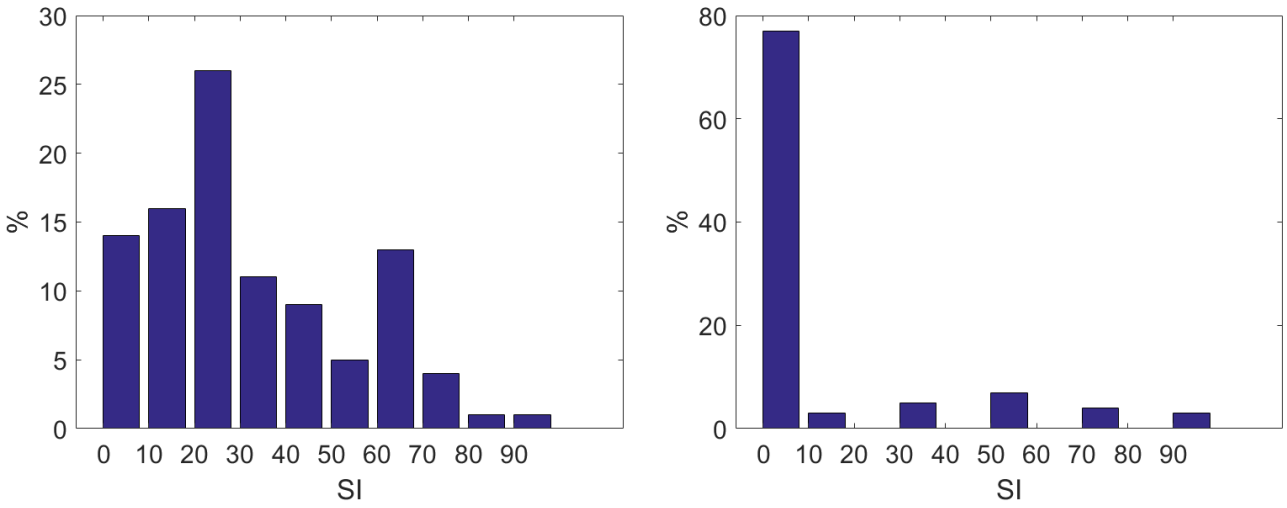
Figure 9: Household items for water handling

4.5.2 Wealth and hand–washing facility index

The wealh and hand–washing facility index based on results of specific interview questions and calculated with PCA are discussed in this section. The sampling adequacy for the PCA of the wealth index can be checked with the KMO criteria, which resulted in .754. A value between .7 and .8 represents good sampling adequacy [Hutcheson & Sofroniou, 1999]. Also Bartlett's test of sphericity χ^2 (55) = 335.699, p < .05 showed that correlations among items were sufficiently large for PCA. For the calculations of the wealth index, the first three factors were chosen from the component analysis according to the scree–plot. Factor 1 can be categorised as "house attributes" containing the wall, floor, roof type and the number of rooms. Factor 2 are rather "luxury goods" containing watch, motorbike, TV, solar panel and radio. Whereas factor 3 covers "basic goods" like bicycle, phone and solar panel. Factor 1 explains a variance of 25%, factor 2 of 16% and factor 3 of 13 %, resulting in a total explained variance of 54%. The wealth NSI was calculated according to the following formula:

$$NSI = 0.46 \times (\text{factor 1 score}) + 0.30 \times (\text{factor 2 score}) + 0.25 \times (\text{factor 3 score}) \tag{4}$$

For the hand–washing facility index, the KMO criteria resulted in .808 (see Appendix Table 14). A value between .8 and .9 represents great sampling adequacy [Hutcheson & Sofroniou, 1999]. Bartlett's test of sphericity χ^2 (10) = 448.272, p < .05, shows that correlations among items were sufficiently large for PCA (see Appendix Figure 12). For the calculations of the hand–washing index only one factor was chosen from the component analysis according to the scree–plot. The scree plots of both indexes are displayed in appendix B. This factor explains 68% of the variance. As for the wealth index, the NSI was calculated. The SI distribution for both indexes is shown in Figure 10:



(a) Histogram wealth index **(b)** Histogram hand–washing facility index

Figure 10: Results of PCA analysis

Both indexes represent the conditions for rural villages in Eastern Uganda, close to the Victoria lake. Included are only people buying water from the GDM water kiosk. It can be assumed that those people represent the wealthier class of this area as water is also freely accessible from the lake. A score of 100 indicates the presence of the following goods: solar panel, radio, TV, phone,bicycle, motorbike and watch present in the house. As well as a higher number of rooms in the house, and more expensive building materials used for the wall, roof and floor in the house. The specific materials are documented in the digital appendix. A score of 0 indicates the opposite. A hand-washing facility index of 100 indicates: the presence of a handâĂŞwashing facility, a good condition of the facility (not damaged), soap available, cleanliness and water availability. Again, a score of 0 means the opposite. Nearly 15% are in the lowest and 1% in the highest class of the wealth index. The distribution is left skewed and more than 50% have a score of 30 and lower (see Figure 10 a)). 77% of the people reached a hand–washing facility index score of 0, meaning no hand–washing facilities are present. This is a remarkable result and has to be considered for further measures to prevent recontamination. Several studies stated that hands with faecal contamination are a main source for deterioration of water [Trevett et al., 2005]. There is not only a need for measures that reduce the risk of contamination, but also for improved hand–washing facilities, which could eliminate one of the sources of contamination. Besides the lack of hand–washing facilities, for a lack of toilets 12% of the participants used bushes instead. 82% used pit latrines of which 33% shared it with other households.

Table 8: Wealth index and hand–washing index within the different groups

	Wealth		hand–washing	
	Mean SI	Std	Mean SI	Std
Control group	37	22	17	28
Strategy I	33	24	18	31
Strategy II	25	18	2	11
Strategy III	39	22	5	17

In Table 8, the wealth and hand–washing facility scores for each group are displayed. Surprising is, that the mean SI of the wealth shows the biggest difference between strategy II and strategy III, even though both were conducted at one site. The improved containers were distributed within families which regularly buy water from the kiosk. This could be a possible explanation for the different results, as people, who buy water regularly from the kiosk, are more likely to be wealthy. Nevertheless, most participants of strategy II and III said that they use the kiosk as their main drinking water source. However, this also might have been a reporting bias, as the participants knew that the interviewers were interested in them using the kiosk as a water source. The hand–washing facility score was higher for Lugala and Bulundira than for Bumeru. It has to be recognised though that for all the groups the hand–washing index is very low. In future WASH training, the importance of hand–washing facilities has to be emphasized.

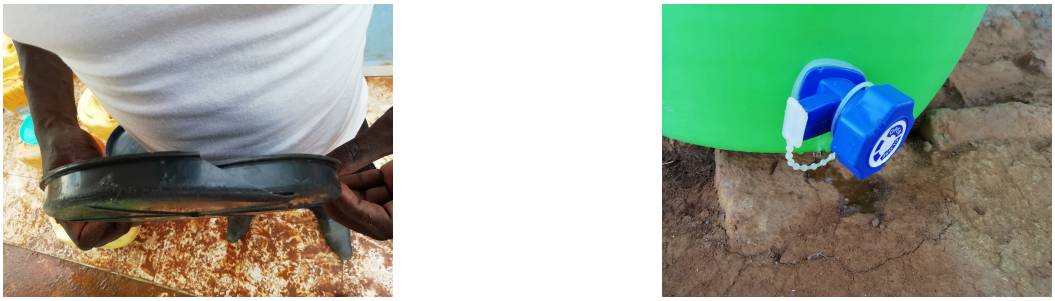
4.5.3 Acceptance improved containers

In Table 9 the results of the interviews with the participants using improved container are displayed (N=25).

Table 9: Results of the acceptance survey of the improved containers

	Absolute	Relative [%]
Preference of improved containers	23	96
Easy to carry	19	79
Use for storage & transport	16	67
Use for only storage	7	29
Use for only transport	1	4

96% of the people preferred the improved containers over the standard jerrycans, indicating a high acceptance. The following reasons were named by people for their preference of improved containers: easier to clean, good cover, tap and can be used to fetch water from the lake. The last reason does not serve the aim of the containers. Samples from the lake showed E. coli values of high risk and improved containers should not facilitate the access to lake water. 79% said the improved container are easy to carry, some people complained that they were heavier than normal jerrycans. This is true as the improved container can hold up to 23 l of water instead of only 20 l like standard containers. However, if the completely filled improved containers are too heavy to carry, less water could be filled into them. 29% are using the improved containers only for storage. This is not the aim of the containers, as the old, often contaminated containers, would still be used for transport. It was observed, that after the short period in use some of the canisters were already broken. Leaking taps, broken handles and lids were observed (see Figure 11). Especially the position of the tap is exposed to the risk of scratching the ground, if the improved container is not carried correctly. Due to those reasons and also the facilitated access to fetch lake water, a different container design should be considered in the future. The opening should be narrower, but at the same time large enough to allow hands to enter for cleaning. Additionally, handles, lids and taps need to be more stable.



(a) Broken lid **(b)** Leaking tap

Figure 11: Broken improved container

4.6 Relating household factors to water quality

In Table 10 the multivariate binary logistic regression model of the total coliforms recontamination during transport and storage is displayed. A p value <.05 indicates a significant correlation between the household factor and the degree of total coliform contamination. The FRC concentration after 24 hours, cleaned before filling, improved container and the hand–washing facility index significantly influence the counts of total coliforms. The coefficients indicate that high FRC concentrations after 24 hours (B=–7.176) and the use of improved container (B=–1.533) reduce the number of total coliforms. While cleaning before filling (B=2.489) increases the number. This agrees with the results of the sections 4.3 and 4.4.

A higher hand-washing facility index (B=–0.006) was significantly related to lower total coliform contamination. This supports the finding of other studies, that contamination on hands are a possible contamination pathway [Trevett et al., 2005]. In 77% of the households no hand–washing facilities were present. Further research on hand–washing facilities as a strategy to reduce recontamination is recommended.

The other household factors could not be related to water quality. The model result supports the hypothesis that technical measures are sufficient to reduce recontamination. Nevertheless, hand–washing facilities influence water quality as well. The influence of hand–washing facilities (B=–0.006) compared to the technical measures (e.g. FRC B=–7.176) is low.

Table 10: Multivariate binary logistic regression model of total coliforms

				95 % Confidenc Interval of odds ratios	
	B	Sig.	Odds ratio	Lower	Upper
Intercept	1.474	.248	4.367	0.353	54.037
FRC concentration after 24 hours	-7.176	.000	0.001	0.000	0.003
Cleaned before filling	2.489	.000	12.055	6.399	22.710
Use of improved containers	-1.533	.000	0.216	0.176	0.266
Use of sand to clean	-0.294	.191	0.745	0.479	1.160
Use of Lantana kamara leaves to clean	-0.375	.549	0.687	0.200	2.362
Household visits	-0.044	.291	0.957	0.881	1.039
Wealth index	0.005	.528	1.005	0.989	1.022
Hand-washing facility index	-0.006	.001	0.994	0.990	0.997
Frequency of cleaning containers	0.051	.847	1.052	0.626	1.767

Table 11 displays the multivariate generalised linear model of the E. coli recontamination during transport and storage. The model has to be interpreted with caution as the sign of the coefficient for improved containers (Coefficient=0.085) is positive. In the descriptive analysis and Mann-Whitney tests in section 4.3, cleaning before filling was observed to reduce recontamination and not support it. Including only improved containers as a independent variable in the model, showed that improved container improved counts of E. coli. Including the other independent variables caused a sign reverse of the coefficient for improved container. Possible reasons for the reversed sign are multicollinearity

of the independent variables and interactions effect [Field, 2009]. Multicollinearity was tested with the tolerance value, values less than 0.1 almost certain indicate collinearity problems [Menard, 1995]. Also variance inflation factors (VIF) greater than 10 indicate concern regarding multicollinearity [Myers, 1990]. The results of both tests did not indicate multicollinearity. Interaction was tested by including interaction effects between cleaned before filling and the use of improved containers and between FRC after 24 hours and the use of improved containers. The interactions effects were not significant. Likely, the reverse sign aroused due to information loss as the E. coli data was grouped in WHO risk categories. However, improved containers are not a significant variable. Significant are FRC concentration after 24 hours, cleaned before filling, use of sand to clean, use of Lantana kamara leaves leaves and the number of household visits regrading WASH training within the last year. The signs of the significant values were reasonable. Due to the concern of the performance regarding improved container, the findings of E. coli related to household factors can not be generalised.

Table 11: Multivariate generalised linear model with poisson distribution of E. coli

				95% Confidence Interval	
	Coefficient	Std. Error	p	Lower	Upper
Intercept	1.059	0.1386	.000	0.784	1.333
FRC after 24 hours	-1.253	0.0402	.000	-1.333	-1.174
Cleaned before filling	-0.063	0.0238	.010	-0.110	-0.015
Use of improved containers	0.085	0.0543	.119	-0.022	0.193
Use of sand to clean	0.188	0.0663	.005	0.057	0.319
Use of Lantana kamara leaves to clean	-0.235	0.1030	.024	-0.439	-0.031
Household visits	-0.119	0.0224	.000	-0.163	-0.074
Wealth index	0.003	0.0029	.386	-0.003	0.008
Hand-washing facility index	-0.003	0.0019	.188	-0.006	0.001
Frequency of cleaning container	-0.013	0.0476	.782	-0.107	0.081

5 Conclusion

The study proved that technical measures are sufficient to reduce the risk of recontamination even in an environment with unfavourable hygienic conditions. All three strategies significantly reduced recontamination within 24 hours.

Recontamination within 24 hours was classified into recontamination during filling and recontamination during transport and storage. Evaluating recontamination during filling, identified container as a contamination source. An initial FRC dosage of 2 mg/l is sufficient to prevent recontamination during filling and reduce counts of E. coli to a median of 0 CFU/100 ml. However, only chlorination of 2 mg/l was not sufficient to significantly reduce recontamination during transport and storage. The combination of chlorination and adequate cleaning of the containers with sand, soap and chlorinated water, significantly reduced recontamination for E. coli also during transport and storage. It is likely that cleaning removed the biofilm, which protects the bacteria and provides nutrition. In contrast, cleaning showed an increase of total coliform counts. As total coliforms occur in soil, the cleaning practice is likely to introduce total coliforms and the narrow opening of standard jerrycans impedes the complete removal of sand after.

The combination of chlorination, cleaning and improved container performed the best. Nevertheless, the additional use of improved container did not significantly reduce E.coli counts compared to only cleaning and chlorination. Hence, the additional benefit of improved containers has to be weighted against the cost. Improved container cost UGX 20,000, which is about the monthly expenditure of a household. However, cleaning is not practical as it consumes a lot of high quality water and standard jerrycans are hard to clean due to the narrow opening. The combination of only chlorinated water and improved container could be a further study.

Additionally, it was found that people store water longer than 24 hours, in average about 4 days. The study only measured recontamination over 24 hours, observations for the complete storage period are recommended. Even though technical measures were proven to be sufficient to reduce recontamination, the importance of household factors for contamination was also identified. The majority of participants had no access to hand–washing facilities even though hands are known to be one of the main contamination sources [Trevett et al., 2005]. An increased hand–washing facility index was related to a lower count of total coliforms.

Sustainable Development Goal 6 aims at assuring access to safe drinking water for all by 2030 [WHO, 2015]. Especially rural areas lack access to safe water sources, where water distributions networks are rare. As all three measures are easy to apply, they can serve as a possible solution to assure access to safe water in rural areas and support SDG 6.

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A Questionnaire

A– General information
Name of interviewer
Name of the village
Enter this households jerry can number
What kind of jerrycan does the household use now?

B – Access to water
How far away is the water kiosk located from you home?
How much time does it take you each day to collect water from the water kiosk including waiting time?
How much water do you buy from the water kiosk per day?
Can you get the amount of drinking water from the kiosk you would like to have?
Apart from the kiosk, do you use any other sources to collect drinking water?
Which other source do you use?
Which source is your main source of drinking water?
How safe is the water you buy from the water kiosk?
How do you like the taste of the water from the water kiosk?

C – Water handling & hygiene
Do you use any additional method to treat your drinking water?
Which methods for water treatment do you use?
How often do you clean the container for water transport?
What kind of materials do you use to clean the container for water transport?
Do you use the same container for transport and storage?
What kind of containers do you use to store the drinking water?
How long do you store the water until consumption ?
How often do you clean the container for water storage?
What kind of materials do you use to clean the container for water storage?
What utensils did you use to take out water from the jerrycan since yesterday?
How many times did you wash your hands yesterday with soap?
Have you received any household visit in the last year on WASH?
How many household visits did you receive in the last year?
Have you attended any community meeting on WASH?
How many community meetings did you attend in the last year?
How many of your children suffered from diarrhoea in the the past seven days?
How many of your children suffered from respiratory diseases in the past seven days?

D – Wealth index
What is your education level?
How much money do you spend per week?
Household items:
Does anyone from your household own one of the following items?
Solar panel
Radio
TV
Mobile phone
Bicycle
Moterbike
Car
Fridge
Watch
What kind of fuel do you use mainly for cooking?
Are you the owner of your house?
How many rooms does your house have ?
What type of walls does the main house have?
What type of roof does the main house have?
What type of floor does the main house have?

E – Observation through the interviewer (your own observation)
Are water treatment devices or products visibly available in the house?
What kind of container is used to store drinking water?
Please specify other:
In which condition is the water transport container?
In which condition is the water storage container?
What kind of toilet does the HH have on the compound?
In which condition is the toilet?
What kind of hand–washing facilities does the HH have?
Condition of the hand washing facilities:
In which conditions are the hand washing facilities?
Are the hand–washing facilities in good condition (nothing damaged)?
Is soap available?
Are the hand–washing facilities clean?
Is water available?

B Principal component analysis

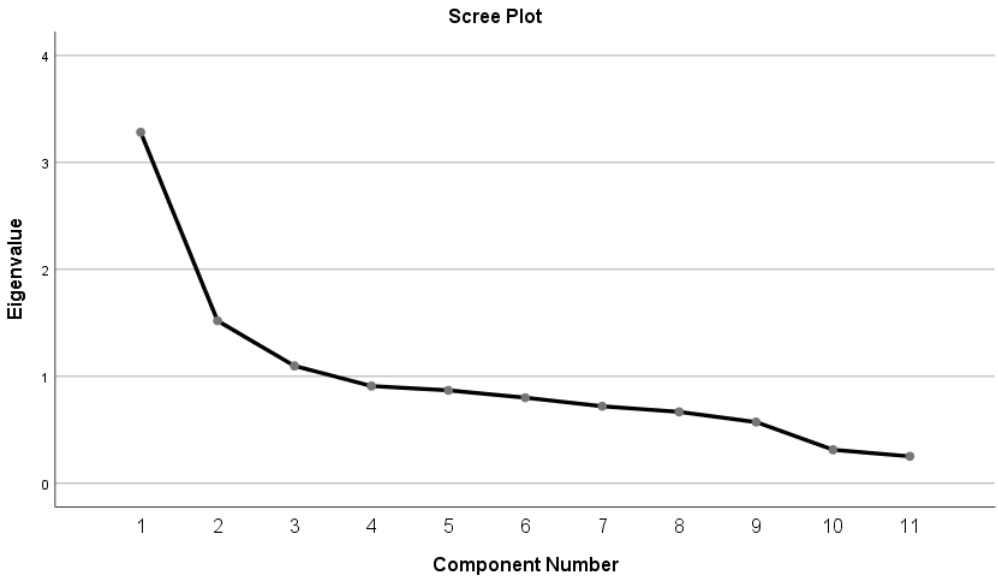

Figure 12: Screeplot of PCA analysis wealth index

Table 12: KMO results wealth index

Test		
Kaiser–Meyer–Olkin measure of sampling adequacy		.754
Bartlett's test of sphericity	Approx. Chi–Square	335.699
	df	55
	p	.000

Table 13: Components of wealth index

	Component 1	Component 2	Component 3
Wall type	0.867		
Number of rooms	0.791		
Floor type	0.768		
Roof type	0.753		
Watch		0.676	
Motorbike		0.628	
Radio		0.607	
TV		0.445	
Bicycle			0.859
Phone			0.509
Solar panel		0.435	0.479

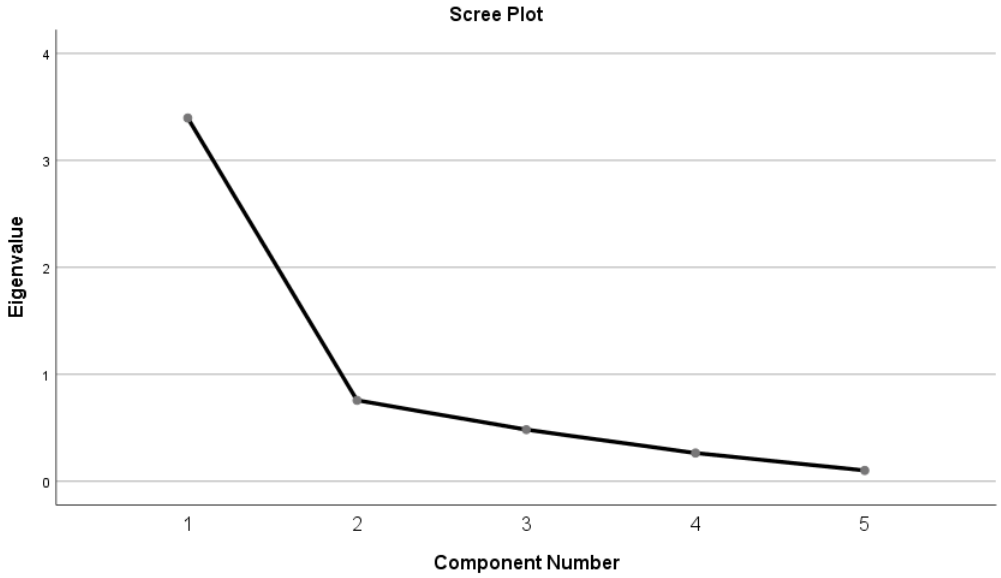

Figure 13: Screeplot of PCA analysis hand–washing facility index

Table 14: Results KMO hand–washing index

Test		
Kaiser–Meyer–Olkin measure of sampling adequacy.		.808
Bartlett's test of sphericity	Approx. Chi–Square	448.272
	df	10
	p	.000

C Test for normality and homogeneity of variance water quality

Table 15: Kolmogorov-Smirnov and Shapiro-Wilk test for normality of E.coli and total coliforms

	Kolmogorov-Smirnov			Shapiro-Wilk		
	D	df	p	Statistic	df	p
After filling E. coli	0.418	135	.000	0.210	135	.000
After filling total coliforms	0.363	135	.000	0.498	135	.000
After transport and storage E. coli	0.340	135	.000	0.442	135	.000
After transport storage total coliforms	0.291	135	.000	0.597	135	.000
After 24 hours E. coli	0.365	135	.000	0.410	135	.000
After 24 hours total coliforms	0.252	135	.000	0.679	135	.000

Table 16: Levene's test for homogeneity of variance of E.coli and total coliforms

	F	df1	df2	p
After filling E. coli	12.868	3	131	.000
After filling total coliforms	35.642	3	131	.000
After transport and storage E. coli	4.721	3	131	.004
After transport storage total coliforms	11.376	3	131	.000
After 24 hours E. coli	8.743	3	131	.000
After 24 hours total coliforms	10.477	3	131	.000

Table 17: Kolmogorov-Smirnov and Shapiro-Wilk test for normality of log E.coli and log total coliforms

	Kolmogorov-Smirnov			Shapiro-Wilk		
	D	df	p	Statistic	df	p
After filling E. coli	0.430	135	.000	0.529	135	.000
After filling total coliforms	0.213	135	.000	0.790	135	.000
After transport and storage E. coli	0.291	135	.000	0.780	135	.000
After transport storage total coliforms	0.111	135	.000	0.914	135	.000
After 24 hours E. coli	0.261	135	.000	0.808	135	.000
After 24 hours total coliforms	0.148	135	.000	0.911	135	.000

Table 18: Levene's test for homogeneity of variance of log E.coli and log total coliforms

	F	df1	df2	p
After filling E. coli	12.868	3	131	.000
After filling total coliforms	35.642	3	131	.000
After transport and storage E. coli	4.721	3	131	.004
After transport storage total coliforms	11.376	3	131	.000
After 24 hours E. coli	8.743	3	131	.000
After 24 hours total coliforms	10.477	3	131	.000

D Kruskal–Wallis test water quality

Table 19: Results of Kruskal-Wallis for different recontamination of log E. coli and log total coliforms

	E. coli			Total coliforms		
	After filling	After transport and storage	After 24 hours	After filling	After transport and storage	After 24 hours
F	134.500	180.500	99.500	95.500	157.500	87.000
W	410.500	456.500	375.500	371.500	433.500	363.000
Z	-5.185	-4.492	-5.488	-5.410	-4.575	-5.497
p	.000	.000	.000	.000	.000	.000

E Test for normality and homogeneity of variance for FRC data

Table 20: Komogorov-Smirnov test for normality of FRC data

	strategy	D	df	p
Delta 30 min	1	0.146	46	.015
	2	0.104	23	.200
	3	0.088	23	.200
Delta 24 h	1	0.097	46	.200
	2	0.112	23	.200
	3	0.108	23	.200

Table 21: Levene's test for homogeneity of variance of FRC data

	F	df1	df2	p
Delta FRC after 30 min	0.631	2	89	.534
Delta FRC after 24 h	2.438	2	89	.093

F Kruskal–Wallis test FRC degradation

Table 22: Kruskal-Wallis test for FRC degradation

	Degradation after 30 min	Degradation after 24 h
H	36.77	33.94
df	2	2
p	.00	.00