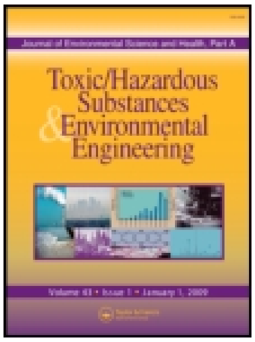

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The impact of hygiene and localised treatment on the quality of drinking water in Masaka, Rwanda

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The worldwide prevalence of waterborne diseases has been attributed to the lack of safe water, inadequate sanitation and hygiene. This study evaluated socio-demographic factors, microbiological quality of water at source and point of use (POU) at households, water handling and sanitation practices in a rural Rwandan community. Thirty five water samples from the source, Nyabarongo River, and water at point of use (POU) treated with the Slow Sand Filter (SSF) and Sûr'Eau methods, were analysed for total coliform and faecal coliform counts. Turbidity was measured in household samples. A structured questionnaire regarding water collection, storage, usage and waterborne disease awareness was administered to 324 women. Despite the significant reduction in coliforms and faecal coliforms from the Nyabarongo River following treatment using either SSF or Sûr'Eau, the water at point of use was found to be unsafe for human consumption. The frequency of diarrheal diseases were significantly higher among people who did not wash hands before food preparation ($P = 0.002$) and after using a toilet ($P = 0.007$) than among those who did. There was a statistically significant association between education levels and water treatment practices at the households ($P < 0.05$). Participants had limited knowledge regarding water storage practices for prevention of household water contamination. A combination of treatment methods with appropriate water handling should be considered. In addition, education is a fundamental precursor to advocating water treatment at POU.

Keywords: Microbiological water quality, waterborne diseases, SSF, Sûr'Eau.

Introduction

Every year, contaminated drinking water contributes to the death of millions of the poorest people of the world from diseases related to waterborne illnesses.[1,2] Two million children are reported to die annually from waterborne diseases.[3] The Millenium Development Goal (MDG) 4 aims to reduce the under-five mortality by two-thirds between 1990 and 2015. This is particularly critical for Rwanda, which has one of the highest under-five mortality rates in the world; one in 10 children die before reaching the age of five.[4] Children are particularly susceptible to waterborne diseases and an inadequate water supply coupled with poor water hygiene and sanitation may contribute to the high mortality rate. A report released in 2010 stated that just 30% of the rural population and 43% of the urban population in Rwanda have access to an improved water source.

In addition, nearly one third of all households consume unsafe water from unprotected sources.[4] Rwanda has a target of providing safe water and sanitation to all its citizens by 2020.[5] However, the country still has a long way to go as many rural areas have insufficient water to meet the most basic drinking and household needs. Lack of access to safe water and sanitation has significant health impacts and may contribute to the spread of waterborne diseases such as cholera, dysentery, hepatitis A and E, giardiasis, and Haemolytic Uremic Syndrome.[6]

Interventions to improve microbiological quality of drinking water at POU in developing countries such as Zambia, Bolivia and South Africa have been effective to an extent. Treatment methods used included boiling, sedimentation, filtration, exposure to ultraviolet radiation from sunlight and disinfection with sodium hypochlorite solutions coupled with safe storage and community education.[7–9] Although some studies have reported that the use of chlorine-based solutions improved the microbiological quality of drinking water and reduced the risk of diarrheal disease, others have reported inconclusive results on the effectiveness of such methods. [7,8,10–12]

The source and turbidity of raw water may impact on the efficacy of these methods. Furthermore, knowledge, attitude and practices of communities regarding water handling, storage and purification are important variables to consider in any intervention strategy. People living in the rural Masaka Sector of Rwanda are given two options to

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treat raw water; the SSF (Slow Sand Filtration) and a locally distributed chlorine-based solution locally known as Sûr'Eau. Even though the Sûr'Eau treatment has been marketed extensively throughout Rwanda, uptake in rural areas has been limited.[13] The purpose of this study was to evaluate socio-demographic factors, microbiological quality of water at source and POU at households, water handling and sanitation practices in a rural Rwandan community.

Materials and methods

Study area and population

This study was approved by the Durban University of Technology (DUT) research committee. Permission to conduct the study was obtained from the Department of Health and local authorities of Kicukiro District and Masaka Health Centre in Rwanda. Informed consent was signed by all participants. The study was carried out in two communities (Rusheshe and Ayabaraya) which are located in rural Masaka Sector, Kicukiro District in Rwanda. Rusheshe and Ayabaraya are rural communities with 1095 households and a total of 7,774 residents. These two cells are situated along Nyabarongo River and are occupied by informal settlements. The Nyabarongo River is used as a source of water for drinking, cooking and bathing by residents.[12]

A total of 324 households were systematically sampled. One hundred and ninety three (193) households representing 60% of the population in Rusheshe and 131 (40%) in Ayabaraya were selected. The first household of each day of data collection was chosen randomly, thereafter every third household was selected. Women aged between 18 and 55 years old were invited to participate. Women are the primary caregivers involved in domestic duties such as fetching water, cooking, hygiene and sanitation.

Data collection

Triplicate samples of water were collected during January 2011 from five sites on the Nyabarongo River for microbiological examination. These sites were located at approximately 2 km from each other and included 3 areas, upstream and downstream of the water collection point and at the point of water collection. Twenty water samples were collected for microbiological and turbidity analysis from 10 randomly selected households. At each household, samples were collected on two different days of the week. Of the 20 water samples collected at POU, 8 samples of Sûr'Eau treated water and 12 samples of water treated by SSF were collected. Water samples were analysed at the Kigali Water Laboratory (KWL) in Rwanda.

Data for the women's knowledge, attitude and practices regarding water usage was collected using a questionnaire. Interviewers administered structured questionnaires to one adult female in each household. Information collected included basic demographic details, treatment methods for drinking water, storage and handling practices, sanitation and knowledge regarding causes of diarrhoea.

Water quality analysis

Total coliforms and faecal coliforms were used as indicator organisms to assess the microbiological quality of river and household water samples. Water samples were analysed in triplicate using the most probable number of colony forming units (CFU) per 100 mL for total coliform (TC) and faecal coliform (FC). The turbidity of each household water sample was determined in Nephelometric Turbidity Units (NTUs) using a portable H193703 Microprocessor turbidity meter (HANNA Instruments, Ann Arbor, MI, USA).

Data analysis

Statistical analysis was performed using SPSS Predictive Analytic Software (PASW) Statistics version 18.0 (IBM, Somers, NY, USA) and STATA (Version 11.0, College Station, TX, USA). Descriptive statistics were used to summarise and compare the quality of water from different sampling points. The Student's *t*-test and the One-way Analysis of Variance (ANOVA) tests were used to compare the means of microbial counts.

Data from the questionnaire describing water handling, hygiene and sanitation practices and waterborne disease awareness at the household level was summarised using frequency distributions, proportions and cross-tabulations. The Pearson's chi-square test was used to evaluate bivariate associations between independent variables (water treatment practices, storage container cleaning and ways of cleaning the storage container, hand-washing practices) and dependent variables (diarrhoea, practice of washing hands). Logistic regression models were used to determine the relationship between binary outcome variables adjusted for relevant covariates. Statistical significance was set at 0.05.

Results and discussion

Demographics of the study population are shown in Table 1. Women were aged between 18–55 years, with 42% between the ages of 26–35 years. The majority of participants (64%) had some level of primary schooling as their highest education, while only 2% had some secondary education. A total of 1570 people lived in the 324 interviewed households and the average number of people per household was 4.8. In these households, children below 5 years accounted for 18% of the study population. The community's main source of water was the Nyabarongo River and most participants had to walk a long distance to collect water from the river. Approximately one third of participants walked between 100–500 m to the river.

Table 1. Summary of household characteristics in rural areas of Masaka ($n = 324$).

Characteristic	*N (%)*
Participant age (n = 324)	
18–25 yrs	43 (13)
26–35 yrs	135 (42)
36–45 yrs	97 (30)
46–55 yrs	49 (15)
Educational level (n = 324)	
No schooling	46 (14)
Some primary school	208 (64)
Standard 6–9	64 (20)
High school graduate	6 (2)
Age of people living in households	
<5 yrs	278 (18)
6–10 yrs	279 (18)
11–18 yrs	301 (19)
> 18 yrs	712 (45)
Water source:	
Nyabarongo River	254 (78)
Public tap	52 (16)
Other	18 (6)
Distance travelled to water source	
Nyabarongo River	
<50 m	8 (3)
50–100 m	102 (32)
100–500 m	115 (36)
Public tap	
<50 m	0 (0)
50–100 m	3 (1)
100–500 m	4 (1)
Diarrheal symptoms experienced by participant or family member in the previous 6 months	
Watery stool	89 (28)
Bloody stool	9 (3)
Vomiting	27 (8)
More than 4 loose stools within 24 h	52 (16)
Drinking water treatment	
Boiling	46 (14)
Sûr'Eau	92 (29)
Filtration (SSF)	65 (20)
No treatment	121 (37)

This is particularly relevant as water transported manually over long distances is prone to increased contamination.[14] One hundred and twelve women (35%) reported diarrheal symptoms in their households in the 6 mo prior to the interview. Of these, 75 cases were children under the age of 5. Treatment at the local clinic was only sought for 55% of these episodes, while the others (39%) preferred to treat themselves at home or use a traditional healer (6%).

Water quality

Faecal coliform (FC) counts were used in this study to indicate the presence of potential pathogenic microorganisms that is transmitted through the faecal-oral route.[15] High faecal coliform counts in river water samples indicate contamination due to direct faecal contamination from animals/humans and runoff from human settlements lacking proper sanitation.[16] Total coliforms (TC) comprise of a heterogeneous group of bacteria from the genera *Escherichia, Citrobacter, Enterobacter, Klebsiella*, *Serratia* and *Rahnella*, some of which are of faecal origin.[17]

High total coliform counts in water increases the health risk associated with waterborne diseases such as gastroenteritis, dysentery, cholera, typhoid fever and salmonellosis.[15] The high FC and TC counts in water samples from the Nyabarongo River and household storage containers indicated that the water was not fit for drinking (Table 2). TC in excess of 100/100 mL and FC in excess of 20/100 mL are associated with a significant and increased risk of infectious disease transmission.[15,17]

There were no statistically significant differences between means for counts of TC and FC [$P = 0.51$ (TC) and $P = 0.78$ (FC)] for samples taken from different sampling points on Nyabarongo River. There are many rural settlements along the Nyabarongo River, and it is likely that domestic activity such as washing, bathing and defecation may contribute to the high bacterial loads in this river.

Water treatment at POU

To our knowledge, this is the first study to document the effectiveness of household treatments (Sûr'Eau and SSF) with highly turbid raw water in rural Rwanda. These methods are two of the most common, low-cost and easily maintained water treatment systems for surface water usage in developing countries.[18] Previous studies have shown that sodium hypochlorite solutions effectively reduced the numbers of indicator microorganisms to undetectable counts in drinking water.[9,19–20] Unlike other technologies, chlorine disinfection has a residual effect which prevents recontamination of water over a period of time.[21,22]

Sûr'Eau (0.5% sodium hypochlorite) has been available in Rwanda since 2002, and is currently sold through health centres and commercial outlets throughout the country. However, its use in rural areas of the country is limited.[13] An important finding was that 37% of participants did not treat their water at all. About 60% of participants who did not treat their water had no schooling. It should be noted that only 49% of all participants adopted either SSF or Sûr'Eau as treatment methods for their water while 14% preferred boiling water before use (Table 1).

Table 3 shows the distribution of bacterial contamination in ready to drink water from households. Mean TC counts were 284 CFU/100 mL for household filtered water (SSF) and 329 CFU/100 mL for Sûr'Eau treated water, while mean FC counts were 75 CFU/100 mL for household filtered water and 122 CFU/100 mL for Sûr'Eau treated water. Although both Sûr'Eau and SSF treatments showed a significant reduction of TC and FC colonies in POU water samples compared to river water, [$P < 0.05$ (TC) and $P = 0.004$ (FC)], treated water was still not suitable for

Table 2. Mean values (95% confidence intervals) for microbiological indicators in water samples collected from the Nyabarongo River.

Indicator		*Point of sampling on Nyabarongo River** *Before*	*At*	*After*	*Average*
Total coliforms (CFU/100 mL)	Max	1×10^4	2×10^4	1×10^4	2×10^4
	Min	2×10^3	3×10^3	3×10^3	2×10^3
	Std. dev	2864	7190	3082	4567
	Mean	5.8×10^3	8.2×10^3	7×10^3	7×10^3
Faecal coliforms[1] (CFU/100 mL)	Max	5×10^3	6×10^3	5×10^3	6×10^3
	Min	20	1×10^2	60	20
	Std. dev	2152	2724	2120	2288
	Mean	1164	2660	1232	1685

*n = 5 samples were taken at each sampling point; water samples were taken before, at and after the point of water collection.

human consumption. Ineffective disinfection may be, in part, due to high turbidity levels.

Filtered water had a mean turbidity value of 18 NTU, while Sûr'Eau treated water had a mean turbidity value of 191 NTU. The observed turbidity mean values for both filtered water and Sûr'Eau treated water in the study communities were well above the recommended upper limit guideline value of 5 NTU for drinking water.[22] Turbidity in excess of 5 NTU may protect microorganisms from the effects of disinfection, stimulate the growth of bacteria, and increase chlorine demand.[23] Pathogens may be encapsulated within flocs or particles in turbid water which decreases the efficiency of disinfection. A study in South Africa found that increased turbidity levels significantly decreased the efficiency of a sodium hypochlorite (3.5%) solution in the reduction of TC and FC.[9]

SSF was significantly more effective in reducing turbidity than Sûr'Eau ($P < 0.05$). A pre-treatment is thus imperative to remove large particles before adding Sûr'Eau. It has been reported that sedimentation or flocculation before chlorination leads to significantly higher free chorine residuals in stored water 24 h after treatment.[24,25] Treatment at POU of highly turbid water in this area would be improved by adopting a multifaceted approach which incorporates both a flocculation/sedimentation step followed by filtration and chlorination. Participants indicated that they either used SSF or Sûr'Eau, none of the households used these methods in combination. In addition, they poured the source water directly onto the filter, without allowing any time for sedimentation or settling. This indicated lack of knowledge regarding disinfection process.

Knowledge, attitude and practices regarding water storage and handling

The positive health impact of water quality improvements at POU through household water treatment and safe storage has been documented.[26] These strategies are regarded as an interim solution till reliable and improved water

Table 3. Mean values for microbiological indicators and turbidity values for water samples collected from household treated water (POU).

Water quality parameter		*Type of water treatment* *Filtered water using SSF(n = 12)*	*Water treated with Sûr'Eau (n = 8)*	*Rwandan standards[1]*
Total coliforms (CFU/100 mL)	Max	1×10^3	1×10^3	0 CFU/100 mL
	Min	10	1	
	Std. dev	348	433.4	
	Mean	284	329	
Fecal coliforms[2] (CFU/100 mL)	Max	7×10^2	4×10^2	0 CFU/100 mL
	Min	1	1	
	Std. dev	111.8	237.7	
	Mean	75	122	
Turbidity (NTU)	Max	52.1	426	0.1 NTU
	Min	5.24	4.45	
	Std. dev	15.5	171.9	
	Mean	18	191*	

[1]RBS [13] Results of <1 treated as 1 for calculation purposes.
*$P < 0.05$.

Table 4. Practices regarding water storage and sanitation and knowledge of diarrheal diseases ($n = 324$).

Data	*N (%)*
Container storage conditions	
Open	216 (67)
Closed	108 (33)
Storage of water container	
Outdoors	14 (4)
Indoors	310 (96)
How water is obtained from the storage container	
Mug	297 (92)
Tap	0 (0)
other	27 (8)
Number of times the storage container is cleaned	
Daily	28 (9)
Weekly	74 (23)
Monthly	137 (42)
Rarely or not all	85 (26)
Separate container for drinking water	
Yes	265 (82)
No	59 (18)
Importance of washing hands	
To be clean	260 (80)
To prevent diseases	148 (46)
To be healthy	96 (30)
Hand washing practices**	
Before eating	315 (97)
Before food preparation	65 (20)
After using a toilet	140 (43)
After waking up in the morning	93 (29)
After cleaning the baby's buttocks	100 (31)
Causes of diarrheal episodes (N = 112)	
Contaminated water	67 (60)
Eating stale food	10 (9)
Dirty hands	12 (11)
Dirty surrounding	21 (18)
Religious belief	2 (2)

supplies can be provided to those who lack access to improved water supplies.[27] However, it must be accompanied by continual health education and hygiene promotion in order to achieve a sustained behavioural change. A summary of water storage and treatment practices is shown in Table 4.First, 67% of participants indicated that they did not cover their water storage containers.

Nearly all participants (96%) kept their water storage containers indoors. In terms of the method of drawing water from the storage container, most women (92%) used a mug or a small container to transfer water from the storage container. All participants dipped into the storage vessel with a cup held in their hands. This increases the risk of contamination by contact. The use of cups with longer handles should be encouraged in this community. Only 9% of all participants reported cleaning the water storage container daily, while 26% rarely cleaned the storage containers. Most of the participants (82%) indicated that they used separate containers for drinking purposes and for cooking, washing hands and cleaning of kitchen utensils.

Basic hygiene practices, especially hand washing, are an effective intervention in the reduction of waterborne diseases in developing countries.[9,27,28] Human faecal contamination from children and adults who do not wash their hands after using the toilet may contribute to secondary contamination of household stored drinking water. Several studies have indicated that *E. coli* can survive for 10 minutes, *Klebsiella spp* for 2.5 hours and *Shigella sonnei* for up to 3 hours on unwashed hands.[9] Almost all participants (97%) indicated that they washed hands before eating, 43% washed hands after using a toilet, while only 20% of women washed hands before they prepared food (Table 4). This lack of basic hygiene adversely affects water quality as the women dip their hands into storage containers to access water for household tasks.

When questioned about the possible causes of diarrhoea, 60% of participants identified contaminated water as a possible cause, while 9% believed that it was caused by eating stale food and 29% of women thought that it was related to unsanitary hands and environment. Pearson's chi-square tests were performed to determine whether water handling practices, hand washing practices, knowledge of waterborne diseases and their prevention was dependent on educational level of participants. Table 5 shows that people who went to school were more likely to cover their storage containers than those who did not have any schooling. There was no significant association between storage container cleaning practices and level of education of women. The number of participants with schooling, who washed hands after using a toilet and after cleaning baby's buttocks, was significantly higher compared with those who did not have schooling ($P < 0.05$).

Similarly, results indicated that awareness of waterborne diseases was significantly associated with the level of education of the respondent ($P < 0.05$). Multivariate logistic models indicated a significant association between levels of schooling and diarrhoea experienced (Table 6). Participants with primary or secondary schooling reported a significantly lower risk of diarrheal episodes than those with no schooling [(OR = 0.35, CI: 0.15–0.85, $P = 0.02$); (OR = 0.36, CI: 0.14–0.96, $P = 0.04$)].

It is anticipated that persons who have attended school are aware of susceptibility to waterborne diseases and are therefore more likely to pursue preventive measures.[29,30] Rana [31] found that prevalence of waterborne diseases was significantly higher among illiterate women caregivers in rural Bangladesh ($P < 0.001$). A recent study in Pakistan by Arif and Naheed [32] found no significant relationship between a mother's age and the occurrence of diarrhoea among under-five children; however, the prevalence of diarrhoea decreased with increased education. These studies are in agreement with the findings of this study. No significant association was found between the women's age with

Table 5. Water handling practices among participants stratified by level of education ($n = 324$).

	Educational level (n = 324)		
Water handling practices	*No schooling*	*Primary school*	*High school*
Method of cleaning storage container			
Water only	3 (6.5)	21 (10.1)	4 (5.7)
Soap and water	5 (10.9)	52 (25)	17 (24.3)
Sand and water	19 (41.3)	86 (41.4)	32 (45.7)
other	19 (41.3)	49 (23.6)	17 (24.3)
Method of drinking water treatment			
Boiling	2 (4.35)	36 (17.3)	8 (11.4)*
Sûr'Eau	3 (6.5)	67 (32.2)	22 (31.4)
No treatment	28 (60.9)	68 (32.7)	25 (35.7)
Filtration (SSF)	13 (28.3)	37 (17.8)	15 (21.4)
Washing hands before food preparation	3 (6.5)	47 (22.6)	15 (21.4)*
Washing hands after using a toilet	3 (6.5)	99 (47.6)	38 (54.3)*
Washing hands after waking up	16 (34.8)	56 (26.9)	21 (30)
Washing hands after cleaning the baby's buttocks	7 (15.2)	67 (32.21)	26 (37.1)*
Wash hands to be clean	39 (84.8)	166 (79.8)	55 (78.6)
Wash hands to prevent diseases	6 (13)	103 (49.5)	39 (55.7)*
Wash hands to be healthy	2 (4.4)	72 (34.6)	22 (31.4)*
Awareness of diseases	36 (78.6)	198 (95.2)	69 (98.6)*
Knows how to treat diarrhea at home	7 (15.2)	67 (32.21)	28 (40)*

*P value < 0.05 (chi-squared test).

the occurrence of diarrheal diseases in the study households. The number of people who washed hands after using a toilet was significantly higher among people who attended school ($P < 0.05$).

Similarly, the awareness of the importance of washing hands, awareness of waterborne diseases and reporting of symptoms to the clinic were significantly associated with the level of education of the respondent ($P < 0.05$). This suggests that level of education plays a major role in water handling practices and waterborne diseases prevention practices in rural communities. Furthermore, a "sophisticated" knowledge of water treatment in terms of educating the community about the influence of turbidity, retention times and dosage, is essential. In Rwanda, as in other countries in Africa, community health care workers (CHWs) are an essential part of the health care system. They are trained to educate the community on diarrheal prevention through water treatment, hand washing, and use of latrines. CHWs are well positioned, given their close relationship with the community, to promote health education and advocate proper use of disinfection techniques.

Table 6. Association of educational level and awareness of waterborne diseases with diarrhoea experienced in households.

Educational Level	*Adj. OR*	*95%CI*
No schooling	1.00	
Primary school	0.35	0.15–0.85*
Some high school	0.36	0.14–0.96*
Awareness of diarrheal diseases	Adj. OR	95%CI
No	1.00	
Yes	1.01	0.36–2.87

Logistic regression models adjusted for age and how often the water storage container was washed (daily, weekly, monthly, rarely or not at all).

*P value < 0.05.

Conclusion

Treated water at POU in this rural community was not acceptable for human consumption. In addition, a large number of participating households did not treat river water at all before use. The limited use of water treatment, poor handling and storage coupled with poor sanitation practices increases vulnerability to waterborne diseases in this community. Furthermore, women had limited knowledge regarding water storage practices, prevention of household water contamination and diarrheal diseases.

Conventional treatments like chlorination and filtration are inadequate to treat this highly turbid water with significant coliform contamination. The use of a multifaceted treatment technique, using sedimentation, followed by filtration and chlorination should be explored with consideration to correct application, duration and dose. However, this approach will not succeed without appropriate education on water storage, handling and sanitation. Educational interventions should consider the context and the target population. The overall effectiveness of these interventions will depend on acceptability to the community and feasibility in terms of implementation and cost. This should ideally be accompanied by social marketing and community mobilization to promote and sustain behavioural change.

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References

[1] World Health Organization (WHO). Microbial aspects. In *Guidelines for drinking water quality,* 3rd Ed.; Author: Geneva, 2006; Vol. 1, 22–36.

[2] Yongsi, H.B.N. Suffering for water, suffering from water: access to drinking-water and associated health risks in Cameroon. J. Health Popul. Nutr. **2010**, *28*(5), 424–435.

[3] McGarvey, S.T.; Buszin, J.; Reed, H.; Rahman, Z.; Andrzejewski, C.; White, M.J.; Smith, D.C.; Awusabo-Asare, K. Community and household determinants of water quality in coastal Ghana. J. Water Health **2008**, *6*(3), 339–349.

[4] Dusabe, G.C.; Raobelison, A.; Nzabonimpa, J.P.; Wilson, M. Scaling up Point-of-Use Water Treatment through Multiple Channels in Rwanda Point-of-Use Water Disinfection and Zinc Treatment Project: Bethesda, MD, 2010.

[5] Rwanda Ministry of Infrastructure (MININFRA). *National Policy and Strategy for Water Supply and Sanitation Services*. Author: Kigali, Rwanda, 2010.

[6] Montgomery, M.A.; Elimelech, M. (2007) Water and sanitation in developing countries: including health in the equation. Environ. Sci. Technol. **2007**, *41*, 17–24.

[7] Quick, R.E.; Kimura, A.; Thevos, A.; Tembo, M.; Shamputa, I.; Hutwagner, L.; Mintz, E. Diarrhoea prevention through household-level water disinfection and safe storage in Zambia. Amer. J. Trop. Med. Hyg. **2002**, *66*, 584–589.

[8] Sobsey, M.D.; Handzel, T.; Venczel, L. Chlorination and safe storage of household drinking water in developing countries to reduce waterborne disease. Water Sci. Technol. **2003**, *47*, 221–228.

[9] Potgieter, N.; Becker, P.J.; Ehlers, M.M. Evaluation of the CDC safe water-storage intervention to improve the microbiological quality of point-of-use drinking water in rural communities in South Africa. Water SA **2008**, *35*(4), 505–516.

[10] Rwanda Bureau of Standards (RBS). *East African Standards*. Available at: http://www.rwanda-standards.org (accessed June 2011).

[11] Semenza, J.C.; Roberts, L.; Henderson, A.; Bogan, J.; Rubin, C.H. Water distribution system and diarrheal disease transmission: a case study in Uzbekistan. Am J. Trop. Med. Hyg. **1998**, *59*(6), 941–946.

[12] Luby, S.P.; Mubina, A.; Robert, M.H.; Mohammad, R.; Ward, B.; Bruce, H.K. Delayed effectiveness of home-based interventions in reducing childhood diarrhoea, Karachi, Pakistan. Am J. Trop. Med. Hyg. **2004**, *71*(4), 420–427.

[13] Reller, M.; Mong, Y.; Hoekstra, R.; Quick, R. Cholera prevention with traditional and novel water treatment methods: An outbreak investigation in Fort-Dauphin, Madagascar. Am. J. Public Health **2001**, *91*(10), 1608–1610.

[14] Wright, J.; Gundry, S.; Conroy, R. Household drinking water in developing countries: A systematic review of microbiological contamination between source and point-of use. Trop. Med. Int. Health **2004**, *9*(1), 106–117.

[15] South African Department of Water Affairs and Forestry (DWAF). *South African Water Quality Guidelines,* 2nd Ed.; Author: Pretoria, South Africa 1996; Vol. 1, 1–61.

[16] World Health Organization (WHO). *Draft Research Agenda: International Network to Promote Safe Household Water Treatment and Storage*. Author: Geneva, 2004.

[17] World Health Organization (WHO). Microbial aspects. In *Guidelines for Drinking Water Quality,* 3rd Ed.; Author: Geneva, Switzerland, 2006; Vol. 1, 121–144.

[18] World Health Organization (WHO). *Draft Research Agenda: International Network to Promote Safe Household Water Treatment and Storage*. Author: Geneva, Switzerland, 2005. Available at www.who.int/household_water/resources/AnnualMtgChapelHill 2011.pdf (accessed June 2012).

[19] Firth, J.; Balraj, V.; Muliyil, J.; Roy, S.; Rani, L.M.; Chandresekhar, R.; Kang, G. Point-of-use interventions to decrease contamination of drinking water: A randomized, controlled pilot study on efficacy, and acceptability of closed containers, Moringaoleifera, and in-home chlorination in rural South India. J. Trop. Med. Hyg. **2010**, *82*(5), 759–765.

[20] Lantagne, D.; Quick, R.; Mintz, E. *Household Water Treatment and Safe Storage Options in Developing Countries: A Review of Current Implementation Practices*. Woodrow Wilson International Centre: Washington, DC, 2006; 1–16.

[21] American Water Works Association. *Water Quality and Treatment: A Handbook of Community Water Supplies, 5th Ed.*; McGraw-Hill, Inc.: New York, 1999.

[22] UNICEF. Promotion of Household Water Treatment and Safe Storage in UNICEF/WASH Programmes (online). 2008. Available at http://www.unicef.org/wash/files/Scaling_up_HWTS_Jan_25th_with_comments.pdf (accessed Oct 2011).

[23] World Health Organization (WHO). *World Health Report 2005*. Author: Geneva, 2005. Available at www.who.int/whr/2005/media_centre/facts_en.pdf (accessed June 2012).

[24] Lechevallier, M.W.; Evans, T.M.; Seidler, R.J. Effect of turbidity on chlorination efficiency and bacterial persistence in drinking water. Appl. Environ. Microbiol. **1981**, *42*(7), 159–167.

[25] Preston, K.; Lantagne, D.; Kotlarz, N.; Jellison, K. Turbidity and chlorine demand reduction using alum and moringa flocculation before household chlorination in developing countries. J. Water Health **2010**, *8*(1), 60–70.

[26] Cairncross, S.; Hunt, C.; Boisson, S.; Bostoen, K.; Curtis, V.; Fung, I.; CH.; Schmidt, W.P. Water, sanitation and hygiene for the prevention of diarrhoea. Inter. J. Epidemiol. **2010**, *39*, 193–205.

[27] Banda, K.; Sarkar, R.; Gopal, S.; Govindarajan, J. Water handling, sanitation and defecation practices in rural southern India: A knowledge, attitudes and practices study. Trans. Roy. Soc. Trop. Med. Hyg. **2007**, *101*(11), 1124–1130.

[28] Fewtrell, L.; Kaufmann, R.B.; Kay, D.; Enanoria, W.; Haller, L.; Colford, J.M. Water, sanitation, and hygiene interventions to reduce diarrhoea in less developed countries: A systematic review and meta-analysis. Lancet Infect. Dis. **2005**, *5*, 42–52.

[29] Qureshi, E.M.A.; Khan, Au.; Vehra, S. An investigation into the prevalence of water borne diseases in relation to microbial estimation of potable water in the community residing near River Ravi, Lahore, Pakistan. Afri. J. Environ. Sci. Technol. **2001**, *5*(8), 595–607.

[30] Hasuizume, M.; Wagatsuma, Y.; Faruque, As.; Hayashi, T.; Hunter, P.R.; Armstrong, B.; Sack, D.A. Factors determining vulnerability to diarrhea during and after severe floods in Bangladesh. J. Water Health **2008**, *6*, 323–332.

[31] Rana, A.M. Effect of Water, Sanitation and Hygiene Intervention in Reducing Self-Reported Waterborne Diseases in Rural Bangladesh. Available at: www.brac.net (accessed May 2012).

[32] Arif, A.; Naheed, R. Socio-economic determinants of diarrhoea morbidity in Pakistan. Acad. Res. Inter. **2012**, *2*(1), 490–518.