Comparison of Drinking Water Quality Following Boiling, Household Filtration and Water-Refill in Urban-Slum Area

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Abstract

Safe drinking water availability remains crucial problem in urban-slum areas. Boiling and household filtration are the most frequent water-treatment methods; water-refill is a growing industry providing affordable drinking water for low-middle income households in developing countries. This study compared the efficacy and annual infection risk after boiling, filtration, and water-refill methods to determine the best method for urban-slum dwellers. It was quasi-experimental pre-post design, data were collected by purposive sampling from urban-slum area in Bandung municipality between January-February 2017.

Water samples were examined from 55 households using boiling and filtration method and 55 households using water-refill. Coliforms and E.coli contaminations were examined using membrane filter method. The removal efficacy of Coliforms, log removal reduction (LRR) and annual risk infection were calculated. The efficacy of filtration for removing Coliform/E.coli was 99.84% and 100%, boiling was 98% and 96%, respectively. Only 54.5% of water-refill samples were Coliform-negative. Safe LRR for Coliforms/E. coli using filtration was 76.63% and 100% whereas using boiling was 40% and 96.36%, respectively. Only household filtration demonstrated no annual risk infection.

Household filtration is the most effective method to eliminate microorganisms from raw water. Health education and proper water-treatment method promotion are warranted to prevent waterborne disease in urban-slum areas.

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Introduction

Globally, 4% of all deaths and 5.7% of the total preventable disease burden are associated with health impacts of poor water, sanitation, and hygiene (WaSH).[1] WaSH is a prerequisite to human development and health. Furthermore, clean water is essential for daily living, especially for drinking. Millions of people in developing countries still do not have access to adequate and safe water supplies. Rapid urbanization in developing countries during the last decade, much of which occurred in peri-urban and slum areas, has led to a sharp increase in the number of people without access to safe water.[2] The United Nations projected a rapid population growth in urban areas between 2000 and 2030, suggesting that 6 out of 10 people will live in cities. Therefore, accessible and adequate safe drinking water and sanitation in urban areas, particularly for urban-slum dwellers, should be a priority of policy makers to decrease the risk of water-related diseases.[3]

In developing countries, the primary treatment methods for converting group and tap water into safe drinking water include boiling and household filtration. It is estimated that 1.1 billion people or 21.6% of a sample of low-middle income populations still use boiling.[4] This conventional water-treatment method requires that the water is heated at 60–100°C to ensure the inactivation of microbiological pathogens; however, this method does not effectively remove all chemical contaminations.[5] Household

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filtration is becoming increasingly popular as it is more practical and effective for purifying highly turbid water and more effectively eliminates pathogens compare with ultraviolet, coagulation, or chemical disinfection methods.[6] However, the use of bottled drinking water as an alternative source of drinking water has increased due to convenience and affordability. With branded bottled drinking water being relatively expensive for low-middle income populations, water-refill has become an alternative choice as it is three times cheaper than branded bottled water.

This study was conducted in Bandung city, the capital city of West Java Province, Indonesia, which is a densely populated area. The local water company responsible for tap water distribution in Bandung city only supplies 46.91% of the public with clean water; the remaining 53% have to independently find alternative safe water sources.[7] The Taman Sari sub district is a slum area in the center of Bandung city, with insufficient safe drinking water, high reported diarrhea cases, and high population density, which has been designated as a priority by a development project targeting urban-slum areas in five large cities in Indonesia. This slum area is located on the Cikapundung River basin. The Cikapundung River is the main river among 15 rivers that cross the city and empties into Citarum River. The Cikapundung River is heavily contaminated by household waste and latrine disposal from settlements along the riverbanks, as the majority of households preferred to dispose the human waste from their latrine directly to the river, while the Citarum River, in the south part of the city, contains industrial waste contamination.

The quality of drinking water is influenced by the efficacy of the water-treatment method used. Thus, this study aimed to analyze the efficacy of various water-treatment methods that are used by urban-slum dwellers by comparing the quality of drinking water obtained after boiling and household filtration as well as that obtained from a water-refill station.

Materials and methods

This study was quasi-experimental research with pre and post design which was conducted from January to February 2017. The study population included households along the Cikapundung River basin in the Taman Sari sub district. Minimal samples were calculated using sample size estimations for unpaired two-sample t-tests with 5% alpha and 80% power levels. Water samples were collected using purposive sampling and divided into two groups according to the water purification method used: 55 households that used to boil the water were given a household filtration unit containing a ceramic filter and 55 households that used a water-refill station as the drinking water source.

For the boiling and household filtration group, water samples were collected pre and post water treatment, while those for the water-refill group were collected from the water dispenser only. Water samples from the field were collected using sterile plastic and then stored inside a cooler box before being transported to laboratory, where processing was performed within 6–8 h after retrieval. Bacterial identification was conducted using a membrane filtration technique with 100 mL of sample filtered through a nitrocellulose membrane filter (47 mm in diameter, 0.45 µm pore size; Merck Millipore, Merck KGaA, Darmstadt, Germany) and cultured on chromocult Coliform agar (Merck Chromocult, Merck KGaA, Darmstadt, Germany) as the culture media. The membrane filter and culture media was then incubated in 37°C for 24 h until colonies formed. The sample was reported as E. coli-positive if a purple-bluish colored colony was found and coliform-positive if a red-colored colony was found. E. coli and Coliform bacteria were expressed in colony forming units (CFU) per 100 mL water sample. According to the World Health Organization (WHO) and Indonesian guidelines, drinking water should contain 0 CFU/100 mL for Coliforms and E. coli. Microbiological identification was conducted in the Laboratory of Microbiology and Parasitology, Faculty of Medicine, Padjadjaran University.

Water quality was defined based on the WHO standards. For this, the efficacy of point-of-use water-treatment methods was examined by comparing water samples pre and post treatment. The ability to reduce the indicator pathogen was analyzed by comparing the mean reduction of Coliforms and E. coli based on the percentage of removal efficacy and log removal reduction. Drinking water is considered safe if the decimal elimination minimal equals 4 ($4\log_{10}$), which is defined as having 99.99% removal efficacy.

The data was further analyzed using a quantitative microbiological risk assessment

(QMRA) approach in order to compare infection risk from the three different types of drinking water by focusing on the microbiological quality of drinking water sources. The equations used in this study are as follows:

$$d = V \times c \quad (1)$$

$$P_I = 1 - [1 + (d/N_{50})]^{-\alpha} \quad (2)$$

$$P_{annual} = 1 - (1 - P_{infection})^{365} \quad (3)$$

In equation (1), *d* is the ingested dose per day, *V* is the volume of water consumed per day, and *c* is the concentration of microorganisms in the water. The volume of water consumed per day was defined as 1.1 L per person, as derived from a previous study [8]. In equation (2), P_I is the infection probability, α is the parametric slope, N_{50} is the average dose required to cause an infection (*E. coli*: $N_{50} = 8.6 \times 10^7$, $\alpha = 0.1778$). In equation (3), P_{annual} is the annual infection probability and $P_{infection}$ is the calculated daily infection rate.[9-11]

Informed consent was provided prior to sample collection and ethical approval was obtained from the Ethical Committee of the Faculty of Medicine Padjadjaran University, Bandung, Indonesia (No.1149/UN6.C1.3.2/KEPK/PN/2016).

Results

Figure 1 illustrates boiling and household filtration unit (with a ceramic filter) that were used in the study. Figure 2 compares the efficacy of boiling with that of household filtration and shows that when using the same raw water source, household filtration is more effective than boiling in reducing Coliforms and E. coli. Moreover, only 54.5% of the water-refill samples were found to be Coliform-negative.

Figure 1. Illustration of the boiling method and that of household water filtration using a ceramic filter.

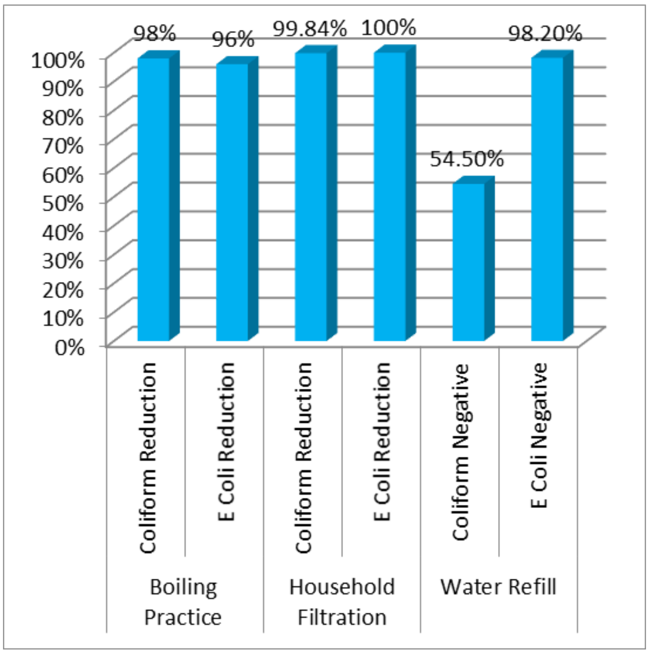

Figure 2. Comparison of water quality based on the reduction in Coliforms and E. coli in pre-and post-boiling and household filtration water samples and Coliform- and E. coli-negative refilled water.

Water contamination was identified in water samples subjected to all water-treatment methods used in this study (Table 1). Boiling and water-refill had a higher infection risk due to greater numbers of Coliforms and E. coli in the water samples. Water-refill was found to have higher Coliform contamination risk than the other two methods; only one sample demonstrated high E. coli contamination.

Drinking Water Quality	Boiling (n = 55)	Household Filtration (n = 55)	Water-refill (n = 55)
Coliform			
0	22 (40%)	43 (78.2%)	30 (54.5%)
Minimal risk[1]	12 (21.8%)	7 (12.7%)	1 (1.8%)
Moderate risk[2]	21 (38.2%)	5 (9.1%)	14 (25.5%)
High risk[3]	0 (0%)	0 (0%)	10 (18.2%)
E. coli			
0	53 (96.4%)	55 (100%)	54 (98.2%)
Minimal risk[1]	2 (3.6%)	0 (0%)	0
Moderate risk[2]	0 (0%)	0 (0%)	0
High risk[3]	0 (0%)	0 (0%)	1 (0.8%)

[1]Number of coliforms/*E. coli* < 10 CFU/100 mL; [2]Number of coliforms/*E. coli* 10–100 CFU/100 mL; [3]Number of coliforms/*E. coli* > 100 CFU/100 mL

Table 1. Comparison of drinking water quality after boiling, household filtration, and water-refill.

Comparison of the efficacy of boiling and household filtration is indicated in Table 2. Log4 and log5 reductions are defined as the indicators of effective practice, indicating 99.99% removal of the indicator pathogen from water samples. We found that household filtration was more efficacious compared with boiling, as 76.36% of household filtration samples reach log5 reduction, whereas only 40% of boiled samples reached this level. Observations made during sample collection indicated that only 20% of respondents washed the container before boiling and only 27% of them properly boiled the water; most of the respondents turned the stove of before the water was fully boiling.

Log Removal Reduction	Boiling (n = 55)	Household Filtration (n = 55)
Coliforms		
Log0	2 (3.64%)	0 (0%)
Log1	13 (23.64%)	4 (7.27%)
Log2	16 (29.09%)	8 (14.54%)
Log3	2 (3.64%)	1 (1.82%)
Log4	0 (0)	0 (0%)
Log5	**22 (40%)**	**42 (76.36%)**
E. coli		
Log0	2 (3.63%)	0 (0%)
Log1	0 (0%)	0 (0%)
Log2	0 (0%)	0 (0%)
Log3	0 (0%)	0 (0%)
Log4	0 (0%)	0 (0%)
Log5	**53 (96.36%)**	**55 (100%)**

Table 2. Comparison of log removal reduction after boiling and household filtration

Using Beta-Poisson model of QMRA, the infection probability can be calculated by incorporating foreknown values and the average dose of Coliform and fecal Coliform into equation (2). The probability of the occurrence of fecal Coliform infection after treatment using all three methods is shown in Table 3. The infection probability is then used to calculate the annual probability using equation (3).

Type of drinking water treatment	Concentration of fecal coliforms (CFU/100 mL)	Dose of fecal coliforms (CFU/person/day) (equation 1)	Probability of infection cause by fecal coliforms (equation 2)	Annual probability (equation 3)
Boiling	0.09	2.054	3.93×10^{-10}	1.43×10^{-7}
Household Filtration	0	0	0	0
Water-refill	2.46	27.09	5.60×10^{-8}	2.04×10^{-5}

Table 3. Comparison of annual infection risk after boiling, household filtration, and water-refill.

Discussion

The results of this study are similar to those reported by Basir and Farooqi, which state that 60% of drinking water after boiling was still positive for Coliform bacteria, including E. coli and was therefore unsuitable for consumption.[12] On the other hand, other study by Clasen et al stated that boiling is still effective for water treatment method.[13] However, although one of the oldest and most widely promoted and most frequently practiced water treatment method is boiling, study by Sodha et all showed the effectiveness of boiling in reducing contamination but overall impact on water quality was suboptimal.[14] In this study, proper boiling of water samples was not always conducted by all respondents; most of the respondents turn off the stove before the water is fully boiling in order to minimize the usage of gas. Moreover, recontamination may have occurred due to the use of a contaminated water container. Household filtration was the most effective method in reducing an indicator pathogen compared to boiling and the quality of refilled water. Previous studies have proven that the efficacy of water filtration depends on pore diameter as well as the thickness and width of the surface area of the filter unit.[15,17]

QMRA contains three steps: health hazard identification, followed by an exposure assessment, and then risk characterization. In the hazard identification phase, the description of the catchment to consumer system, selection of index pathogen, and selection of hazardous events are elaborated.[18] Although QMRA was previously intended for a specific pathogen, conducting QMRA for every pathogen that may be transmitted by water would be challenging; thus, microorganism indicators were used. In this study, both total Coliforms and fecal Coliform (E. coli) were selected as indicator bacteria because non-specific diarrhea is the most common type of waterborne disease that is reported in outpatient primary health centers in Indonesia.

The United States Environmental Protection Agency limits the annual infection probability at 10^{-4} per person; however, Blumental et al. stated that an annual infection probability of up to 10^{-3} per person can be tolerated, depending on different conditions in the country in which the study is being conducted. Currently, the tolerated range of annual infection probability had not been determined in Indonesia. Table 3 highlights that the annual infection probability due to the consumption of boiled or refilled water at the study site exceeds the tolerated limit and that household filtration was the only method that provided no infection risk.

The last step involved in QMRA is risk characterization, which aims to integrate exposure information using dose-response analysis to obtain overall risk estimates. High contamination rates after boiling and water-refill indicate that proper water-treatment education is crucial to prevent infection from consuming contaminated drinking water. Since half of the water-refill samples did not fulfill the WHO standards, the annual infection probability from drinking refilled water is higher than that from drinking water that has been boiled or undergone household filtration. This fact demonstrates that the possibility of recontamination during transportation or by inappropriate cleaning methods of water-storage containers among urban-slum dwellers is high.

Many studies in different cities have reported regarding the poor quality of refill drinking water and unsatisfactory compliance to regulations at some water-refill stations. Poor hygiene and sanitation conditions of water-refill stations indicate that many drinking water production sites are unable to meet the health and safety standards.[19-21] A previous study showed that using water from community-scale, water-refill kiosks can reduce the risk of childhood diarrhea[22]; however, if the quality of refilled water is not properly monitored, the community will still be at risk of consuming unstandardized drinking water. The lack of governmental control on the quality of water refilling is also an important factor; thus, the implementation of an integrated monitoring system for bottled water production is urgently needed.

Conclusions

High infection probability after boiling and consuming refilled water suggests that health education and promotion regarding suitable water-treatment methods for consumption of drinking water should be provided. Household filtration is the best water-treatment method for urban-slum dwellers compared with boiling and consuming refill water.

Declaration of Interest

The authors report no conflict of interest.

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