Effectiveness of Groundwater Boiling as Household Water Treatment in Metro and Bekasi Cities, Indonesia

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Abstract. Groundwater serves as a major drinking water source due to inadequate piped supplies in Indonesia. To eliminate the health risks associated with groundwater consumption, boiling appears as the most suitable and cost-effective treatment technique and widely practiced in Indonesia. Despite treatment efforts, inappropriate water storage and handling practices pose a higher risk of recontamination after treatment. The objective of this study was to analyse the effectiveness of groundwater boiling and treated water recontamination in Metro and Bekasi cities, Indonesia. Groundwater at the source and point of use samples were surveyed and assessed from a total of 116 households, resulting in 60% and 35% *E. coli* contamination, respectively. Paired testing involving boiling observed a reduction in microbial risk for 45% of households. However, 12% samples had an increase in risk even though boiling was reported. Furthermore, *E. coli* concentration at source prior to boiling and point of use after boiling showed a statistically significant difference (N=111, P<0.01). This study demonstrated the effectiveness of boiling in reducing contamination, although recontamination was evident in some cases, likely due to unsafe water storage and unhygienic environment.

1 Introduction

The World Health Organization (WHO) defines a safe drinking water source as one without any significant health risk [1]. In addition, access to safe consumption is also contained in the Sustainable Development Goals (SDGs). This global initiative considers availability of water that is free from faecal contamination as an important national objective for developing countries, specifically Indonesia [2]. Based on the 2018 National Socio-Economic Survey by Badan Pusat Statistik (BPS), the percentage of families with available improved water sources remained 72.04%. Also, no particular province obtained was rated 100% [3]. There is a consistent national shortage in a piped distribution system. In 2020, service coverage persisted at 20.29% [4]. This situation reportedly generated a

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negative stigma in certain communities, in terms of non-continuous supply, yellow coloration and mud sediment content [5]. As a consequence, most households tend to improvise with other alternatives, including groundwater, refill and bottled sources. Also, the use of self-supply measures in the form of dug wells and boreholes appears widespread, without any government support. These options are mainly preferred by low to middle income families due to affordable technology and simpler operation [6].

Unfortunately, groundwater in Indonesia demonstrates a high contamination risk from solid waste, animal excretion, and polluted environment [7]. A previous study in Lampung Selatan reported 28 out of 40 dug wells were polluted with *E. coli* at a concentration above 50 MPN/100 ml [8], while a study in Bekasi detected *E. coli* with more than 10 MPN/100 ml in 60% of dug wells and boreholes (N=254) [9]. Therefore, to counter this negative effect, boiling is extensively applied, with government support over the past decades. Furthermore, research in Guatemala showed an *E. coli* reduction by 13.7 $\log_{10}$ using the boiling method [10], while in South Sulawesi, Indonesia, a lower *E. coli* count (0.8 MPN/100 ml, N=204) was obtained in the boiled water, compared to untreated grades (29.9 MPN/100 ml, N=36) [11]. However, improper boiling is not able to completely eliminate the pathogens [12].

Apart from water source, recontamination possibly occurs after treatment, due to inadequate storage [13]. A systematic review of 310 water quality studies found that stored water was more likely to be contaminated than water at the source [14]. In Indonesia, studies that investigates the effectiveness of boiling in peri-urban settings and the influencing factors that contributes to recontamination events are still lacking. This study is conducted to assess microbiological effectiveness of boiling as a domestically preferred treatment method while analysing the influencing factors of water quality change from the source to point of use.

2 Materials and Methods

2.1 Study setting

This study was conducted over a 4-week period in two cities, Bekasi and Metro, between February-March and October-November, 2020, respectively. Households in Bekasi and Metro cities have a limited coverage of piped water connection. Consequently, both regions have a high use of groundwater as a water source. Three peri-urban districts in Bekasi, including Jatiluhur, Sumur Batu, and Jatirangga were chosen, while five districts were selected in Metro. These locations were preferred due to high poverty rate, high population density, reliance on groundwater, and limited access to piped utility supply. The total number of households surveyed in this study was 563, but point of use water sampling was only done in 176 households. Of those 176 households, only 116 uses groundwater as a drinking water source, with 51 situated in Bekasi and 65 in Metro. The focus of this study covers households using groundwater and boiling as a primary water treatment method.

2.2 Household Data collection

An online questionnaire was developed with Qualtrics, using information on water source, storage and treatment practices. The survey was composed in English and translated to Bahasa Indonesia. Local interviewers from Bekasi and Metro were adequately trained and equipped with sufficient resources for water sampling such as Whirl-Pak® sample bags, thermometer, and cooler box. In Metro city, strict health protocols were observed, due to COVID-19 pandemic.

2.3 Water sample collection and analysis

Samples were obtained from a primary water source (kitchen tap) and point of use (water-filled glass), after the field survey. In addition, alternative supplies such as from bathroom tap, yard tap, or directly from the well (if no tap were available) were also considered. A Whirl-Pak® bag was used to store 100 ml of each sample and subsequently placed in a cooler sack at a temperature of ≤4°C to be delivered to field laboratory within 6 hours.
Furthermore analysis involved the use of IDEXX Colilert-18® test, comprising quanti-tray of 48 small and 49 large wells, with 100 ml reagent. These plates were then incubated for 18-22 hours, followed by the evaluation of total coliform (TC), using the number of stained wells. Subsequently, the trays were placed under a UV lamp to quantify the fluorescent wells, and determine the *E. coli* count in most probable number (MPN)/100 ml, ranging between <1 to 2420/100 ml. Therefore, to prevent external contamination, laboratory and field blanks, as well as other duplicates were assessed on a daily basis.

2.4 Data analysis

The questionnaire and laboratory data were analysed using Microsoft Excel and STATA IC 16.1 (StataCorp LP, College Station, TX, USA). Also, $\log_{10}$ was applied to transform *E. coli* MPN count, while <1 MPN was converted to 0.5, in order to account for left-censored data. Water quality analysis involved the use of binary variable to indicate the presence or absence of microbes. Moreover, log reduction from source to point of use samples was calculated from the mean difference between the respective *E. coli* MPN counts. As a result of abnormal data distribution, non-parametric assessment was employed in this research. Furthermore, Wilcoxon signed-rank test was used to evaluate *E. coli* count variation, prior and after boiling. Meanwhile, the correlation between water storage and *E. coli* contamination was achieved with Spearman model. Paired sample analysis incorporated the use of a graph to represent the percentage change between each risk category.

3 Results and Discussion

3.1 Respondent characteristics

Table 1 outlines the overall respondent characteristics data. The majority of households in Bekasi and Metro employed boreholes (54%) as a primary drinking water source, followed by unprotected dug wells (41%) and protected dug wells (4%). At the source, 60% of source samples were contaminated with *E. coli*, while at the point of use, 35% contamination was observed. Unprotected wells had the largest percentage of contamination at the point of use with 44% samples contaminated.

About 96% of households in both cities employed boiling as a primary treatment method. Meanwhile, 3% do not treat their water at all under the assumption that they are already safe to drink without treatment. The samples from these households were found to be 25% contaminated. Conversely, for residents using boiling method to treat the groundwater (N=111), 36% were found to be contaminated. This result suggests boiling was not sufficient to completely eliminate the pathogens, due to improper boiling practices [12].

Bekasi and Metro households use a wide variety of water containers, although the most common is a jug (41%). However, 19 out of 47 (40%) samples from jugs were contaminated, other vessels had a moderate concentrations of *E. coli* ranged from 29 – 100%. The proportion of respondents who reported using closed water containers was 97%, but *E. coli* was detected in 36% of these. In contrast, open vessels were without pathogens, probably due to minimal sample size (N=3) needed for a robust analysis. Furthermore, the most common storage duration was estimated between 1-5 days (51%) and the least contaminated sources had storage times of <1 day, implying an immediate consumption after treatment or collection. This report showed consistent results with previous finding, where prolonged stagnation provided sufficient period for *E. coli* regrowth [15].

Table 1. Groundwater user characteristics (N=116).

	Total samples	Contaminated	
	N	N	%
Water source			
Borehole	63	19	30%
Protected dug well	5	1	20%
Unprotected dug well	48	21	44%
Treatment method			
Boiling	111	40	36%
Chlorination	1	1	100%
Not treated	4	1	25%
Water container			
Bottle	6	2	33%
Bucket	8	3	38%
Gallon/dispenser	12	5	42%
Jug	47	19	40%
Barrel	1	1	100%
Kettle	35	10	29%
Pot	7	2	29%
Water container lid			
Closed	113	41	36%
Not closed	3	0	0%
Water storage duration			
0 day	54	18	33%
1 – 5 days	59	22	37%
>7 days	2	1	50%
Don't know	1	0	0%

3.2 Boiling effectiveness

Among 116 households using groundwater source, 111 employed boiling as the main treatment method. Paired water samples were analysed, in a bid to determine the water quality change and log reduction of *E. coli* concentration. The geometric mean of point of use *E. coli* count in Metro was estimated as 1.48 MPN/100 ml (95% CI: 1.00-2.20) and Bekasi at 0.86 MPN/100 ml (95% CI: 0.58-1.29). The log reduction associated with boiling in Bekasi ($0.75 \pm 0.37 \log_{10}$) was greater than in Metro ($0.38 \pm 0.34 \log_{10}$), but with overall estimate of 0.53 $\log_{10}$ (95% CI: 0.29-0.79) or a reduction of 70,5% across both cities. This value of reduction is less than previous studies in Guatemala (82,2%), Vietnam (96%), and India (99%) [10,16], indicating an inadequate boiling practice in both cities. Furthermore, Wilcoxon signed-rank test was used to analyse the variation of *E. coli* concentration between normal and boiled paired samples, with 95% confidence level. In both locations there was a significant difference in *E. Coli* concentration (P<0.01 in Bekasi, P=0.04 in Metro, and P<0.01 for both).

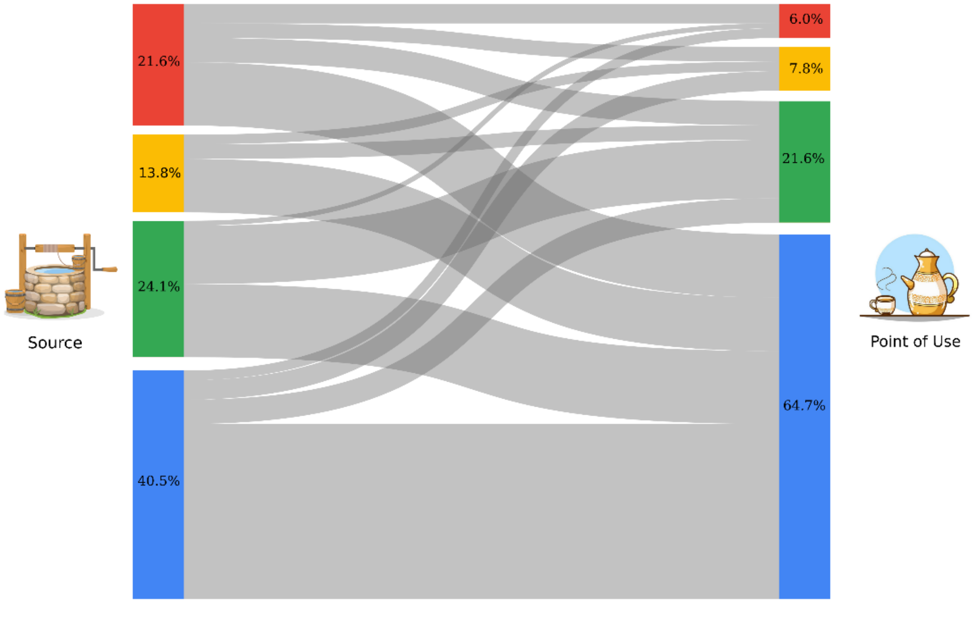
3.3 Water quality change

The water quality in the source and point of use samples was quantified by microbial risk, based on 2011 WHO Drinking Water Guidelines. The microbial (*E. coli*) risk was categorized into four levels, termed low (<1 MPN/100 ml), medium (1-10 MPN/100 ml), high (11-100 MPN/100 ml) and very high (>100 MPN/100 ml). This category was defined by the percentage of samples with varying risk levels from source to point of use.

Figure 1 represents the results of 40.5% low, 24.1% medium, 13.8% high and 21.6% very high risks in the source samples prior to treatment. Meanwhile, for point of use, 64.7% low, 21.6% medium, 7.8% high risk and 6.0% very high risks, were obtained. Overall, point of use samples achieved a safer condition with extensive low risk category, compared to source components (64.7% vs 40.5%).

Consequently, out of the source samples, 46% obtained a decreased risk, 43% showed no change, and 11% had deteriorated risk. Samples that had deteriorated risk suggests a recontamination or regrowth of *E. coli* between treatment and the time of sampling. Previous studies also showed a significantly deterioration in water quality after collection, due to dirty vessels [17,18] or unhygienic practices among residents [16]. Based on improved risk samples, 52% of very high risk sources were adjusted to a low category, indicating a minimum log reduction of 2. This was in accordance with previous studies, where boiled drinking water obtained a lower contamination, compared to the source samples [10,11,16].

The analysis of households with deteriorating water quality between source and point of use revealed a considerable shift from low to very high risk among 2 households. These households reported boiling the water prior to drinking with a close-lid jug as a container that were stored for less than a day. The finding also suggested a sudden recontamination, due to other factor(s), apart from water treatment and storage practices.



Risk level	Low	Medium	High	Very High
E. coli (MPN/100 ml)	<1	1-10	11-100	>100

Fig. 1. Sankey Diagram of Water Quality Change for Both Cities (N=116)

Spearman's rank correlation test for various water storage containers *E. coli* contamination showed no statistically significant relationship (Spearman's ρ = -0,06; P=0.43). This was consistent with previous study in Bekasi which found no correlation between water storage practices and *E. coli* contamination in drinking water [19]. Other possible recontamination source could be attributed to drinking cup, where previous studies reported 33% pollution with *E. coli* [13]. *E. coli* was detected in 34% of cup-acquired samples, compared to 24% that were acquired directly from the container. Furthermore, Wilcoxon signed-rank test with 95% confidence level was not able to indicate any significant *E. coli* contamination difference between cup-acquired and container-acquired samples (P=0.32). Moreover, Spearman also showed no correlation between cup and *E. coli* contamination (Spearman's ρ = 0,07; P=0.32).

4 Conclusion

Based on results and discussion, boiling treatment method in Bekasi and Metro demonstrated an improvement in water quality, however, failed to completely eliminate the microbial risk with only a log reduction of 0.53 (95% CI: 0.29-0.79), which corresponds to a 70.5% decline in *E. coli*. A statistically significant difference between presence/absence of *E. coli* in source and boiled water (P<0.01) was observed, confirming some degree of contamination reduction by boiling. Furthermore, water quality change analysis also revealed an improved risk category in 46% samples after treatment, further assuring the effectiveness of boiling in peri-urban settings. However, in 11% of cases, water quality deteriorated between source and point of use. This finding may be indicative of inadequate boiling processes or possible recontamination while water is stored. However, the study observed no statistically significant correlation between type of water storage vessel and presence/absence of *E. coli*. Future researches is needed to understand the mechanisms that result in faecal contamination at source and point of use, and also to better pinpoint why boiling practices in some households are inadequate.

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