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Evaluation of Yangon city tap water quality and the efficacy of household treatment

Shane Htet Ko and Hiroshi Sakai*

Department of Civil and Environmental Engineering, Tokyo Metropolitan University, 1-1, Minami-osawa, Hachioji-city, Tokyo 192-0397, Japan
*Corresponding author. E-mail: h_sakai@tmu.ac.jp

SHK, 0000-0002-2421-6151

ABSTRACT

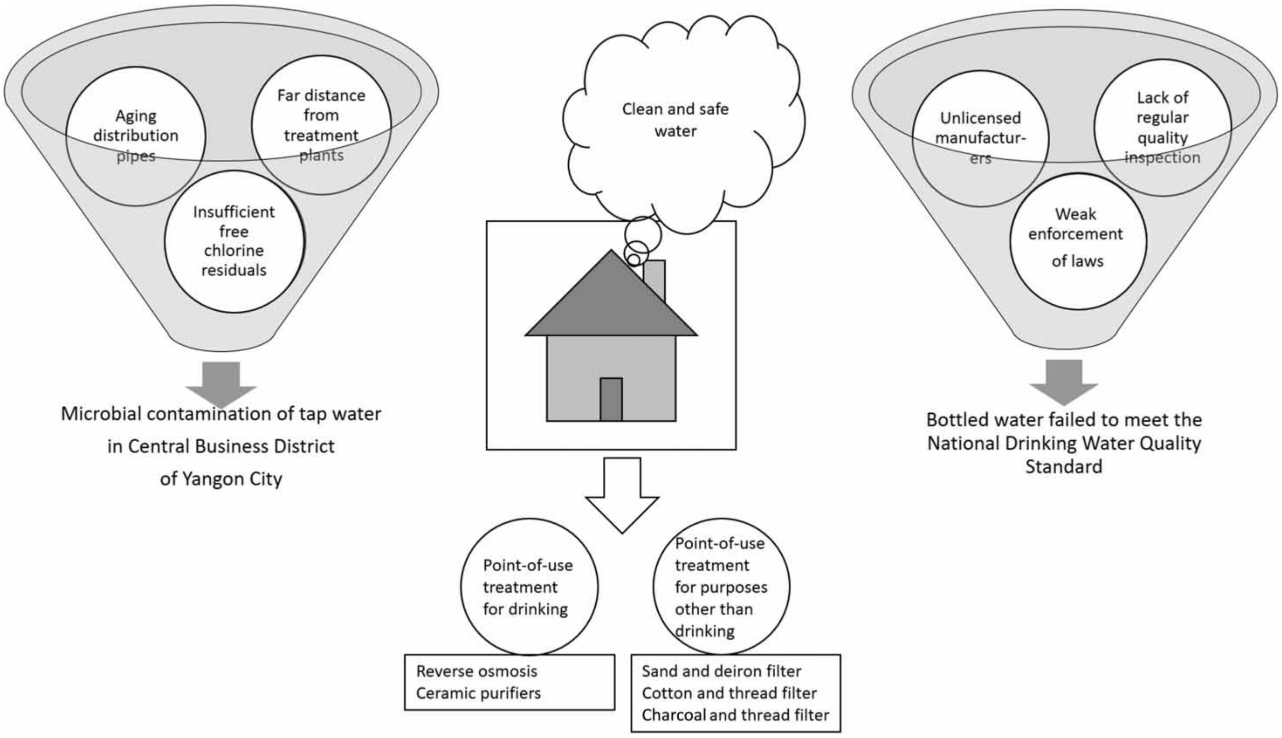
Yangon was one of the first cities in Asia to establish a tap water system. However, the city's water supply infrastructure now lags far behind those of other regions as a consequence of political instability over the last six decades. The installation of disinfection facilities in the tap water system and the enactment of the Myanmar National Drinking Water Quality Standard (MNDWQS) were accomplished only recently during the short period of democratic government. Due to the lack of reliable published information, the suitability of the tap water for drinking remains unclear to city residents. The quality of tap water and bottled water in the central business district was examined to assess compliance with the MNDWQS. The results showed that 95% of tap water delivered to homes was contaminated with *Escherichia coli* or coliform bacteria. Only 14% of bottled water was free of *E. coli* and coliform contamination. The efficacy of household treatment devices was tested, and ceramic purifiers (CPs) and reverse osmosis (RO) devices were found to be highly (>99%) effective for *E. coli* elimination. RO devices performed better in terms of dissolved organic carbon reduction at 60% compared with 43% reduction with CPs.

Key words: ceramic purifier, chlorine, coliform, *Escherichia coli*, reverse osmosis

HIGHLIGHTS

- This study was conducted in a developing country with a 178-year-old public tap water system.
- The failure to meet the minimum effective concentration of chlorine led to microbial contamination of tap water.
- The quality of bottled water did not meet national standards.

GRAPHICAL ABSTRACT



INTRODUCTION

The city of Yangon has one of the first tap water systems established in Asia, as public water-supply service began in 1842. Yangon is the former capital of and largest city in Myanmar, with a population of 5.21 million comprising about 10% of the country's population, according to the 2014 census (DOP 2015). The Yangon City Development Committee (YCDC) is the governmental organization responsible for the city's water infrastructure, including planning and the management and operation of the water supply. In this city in one of the world's least-developed countries, the committee faces challenges in the provision of sufficient quantities of clean and safe water to all residents due to the age of the water distribution system. Access to safe water is essential to promote health and reduce poverty in developing countries. According to researchers from the city's Health Research Department, acute diarrhea in children under the age of 5 years due to drinking-water contamination is prevalent in Yangon, occurring in 4.74% of 211 households examined (Sulatt *et al.* 2015). Previous studies (Sakai *et al.* 2013; Senda *et al.* 2014; Sulatt *et al.* 2015) have revealed the presence of fecal coliforms in tap water, bottled water, groundwater, and water from reservoirs in the Yangon region. A study team from Japan recommended the dilution of contaminated water with a low-contamination water source as a potential approach to the treatment of drinking-water supplies (Senda *et al.* 2014). Tube well water (groundwater) has been used to augment the insufficient water supply from reservoirs in some areas of the city. However, no disinfection system was used for Yangon's tap water until 2016. Tap-water disinfection facilities were installed in 2016, providing urgently needed improvement of the city's water-supply system (JICA 2017). However, no upgraded tap-water quality data have been published. This study was conducted to examine the quality of tap water and bottled water in Yangon, assessing its compliance with the Myanmar National Drinking Water Quality Standard (MNDWQS) enacted in 2014 (MOH 2014).

According to a multiple indicator cluster survey (UNICEF 2011), 39% of the urban population and 33% of the rural population in Myanmar use household water-treatment practices such as boiling, filtering, adding chlorine or bleach, and solar disinfection. In the Yangon region, around 35% of people employed some form of household water treatment. The World Health Organization (WHO) reported that a small percentage of the population practiced in-home water treatment, and that additional water safety actions were needed in Myanmar (WHO 2015). In contrast to the situation in developed countries, much improvement is required to supply tap water to all regions in Myanmar (Senda *et al.*

2014). As part of the National Strategy for Rural Water Supply, Sanitation and Hygiene (GRUM 2016), the Government of the Republic of the Union of Myanmar encourages the use of household water treatment in areas without access to safe water. Household water treatment practices have been recommended as a strategy to comprehensively control diarrhea (WHO 2009a). Household treatment is common in developing countries, even in urban areas where tap water is available (Do *et al.* 2014; Shrestha *et al.* 2018). Several studies have been conducted to examine the efficacy of locally available point-of-entry and point-of-use household treatment devices in other countries (Brown & Sobsey 2010; Mahlangu *et al.* 2012; Do *et al.* 2014; Li *et al.* 2014; Lothrop *et al.* 2015; Shrestha *et al.* 2018). However, the efficacy of household water treatment devices available in Myanmar has not been investigated. This study aimed to provide such information.

MATERIALS AND METHODS

Study area

The total capacity of YCDC water treatment plants is about 215 million gallons water per day (0.97 million m^3/d) (JICA 2017). Currently, four reservoirs (Gyobyu, Phugyi, Hlawga, and Ngamoeyeik) and 442 tube wells are the water sources for Yangon City. The YCDC public water supply covers 34 townships in Yangon. The city's central business district (CBD) is located centrally and has the highest population density. Many pipes used for the YCDC water distribution network in the CBD are more than 100 years old, dating to the colonial period, and the average age of the entire pipeline network is about 80 years (JICA 2017). The CBD is composed of the townships of Lanmadaw, Latha, Pabedan, Kyauktada, Botahtaung, and Pazuntaund, and receives its tap water supply from the Gyobyu and Hlawga reservoirs (Zaw *et al.* 2014; JICA 2017). In accordance with the recommendation of the YCDC water-supply authority, Kuauktada Township, where the YCDC and other important government offices are located, and the adjacent Botahtaung Township were selected as the study area (Figure 1). Kyauktada is the township with the second highest population density in Yangon, with 41,913 people per square kilometer, whereas Botahtaung has the lowest population density among townships in the CBD, with 16,498 people per square kilometer. The townships of Kyauktada and Botahtaung receive tap water from the Gyobyu and Hlawga reservoirs, respectively. The tap-water quality in these two townships is representative of that in the entire CBD, which comprises the heart of Yangon and has the oldest tap-water supply pipes. Considering the high water demand and age of the distribution system, this assessment conducted in the CBD reflects weaknesses in the YCDC's public water supply system in general.

Sample collection

Sample collection was based on a previously described method (Shane & Sakai 2021). Advance consent for possible future sample collection for further research was sought during the previous study, and permission was granted by 19 households.

A total of 41 water samples, comprising 19 samples of tap water (arriving at consumers' homes), 15 samples of tap water treated with point-of-entry or point-of-use devices, and 7 samples of bottled water, were collected in the two townships. Nine tap-water samples were collected in Botahtaung (source: Hlawga Reservoir). In the Kyauktada Township, the YCDC used tube well water to supplement the insufficient supply from the Gyobyu Reservoir during the day (from 8:00 am to 12:00 pm and from 3:00 pm to 7:00 pm). Outside of these hours, the tap-water supply for Kyauktada Township was the Gyobyu Reservoir alone. In the Kyauktada Township, six tap-water samples were collected during mixed-supply hours, sourced from the Gyobyu Reservoir and tube wells, and four tap-water samples were collected outside of the mixed-supply hours. Samples of seven brands of bottled water (in 20-L bottles) available in the study area, identified in previous research, were collected to check compliance with the MNDWQS.

Samples of tap water and bottled water from residential apartments were collected in sterile 1-L plastic bags. Disposable sampling bottles (100 mL) containing a chlorine-removing agent (TG-4000; Eiken, Japan) were used for microbial sampling. The samples were stored on ice in a cooler for transport to the laboratory and were analyzed on the same day. Tap-water samples were collected from the taps of apartments after running the water for 1 min. Treated tap water was collected from the outlets of point-of-entry or point-of-use water purifiers. Bottled water samples were obtained from the taps of 20-L bottles, which are usually exchanged for new bottles when empty. All water samples were collected at a room temperature of approximately 28 °C.

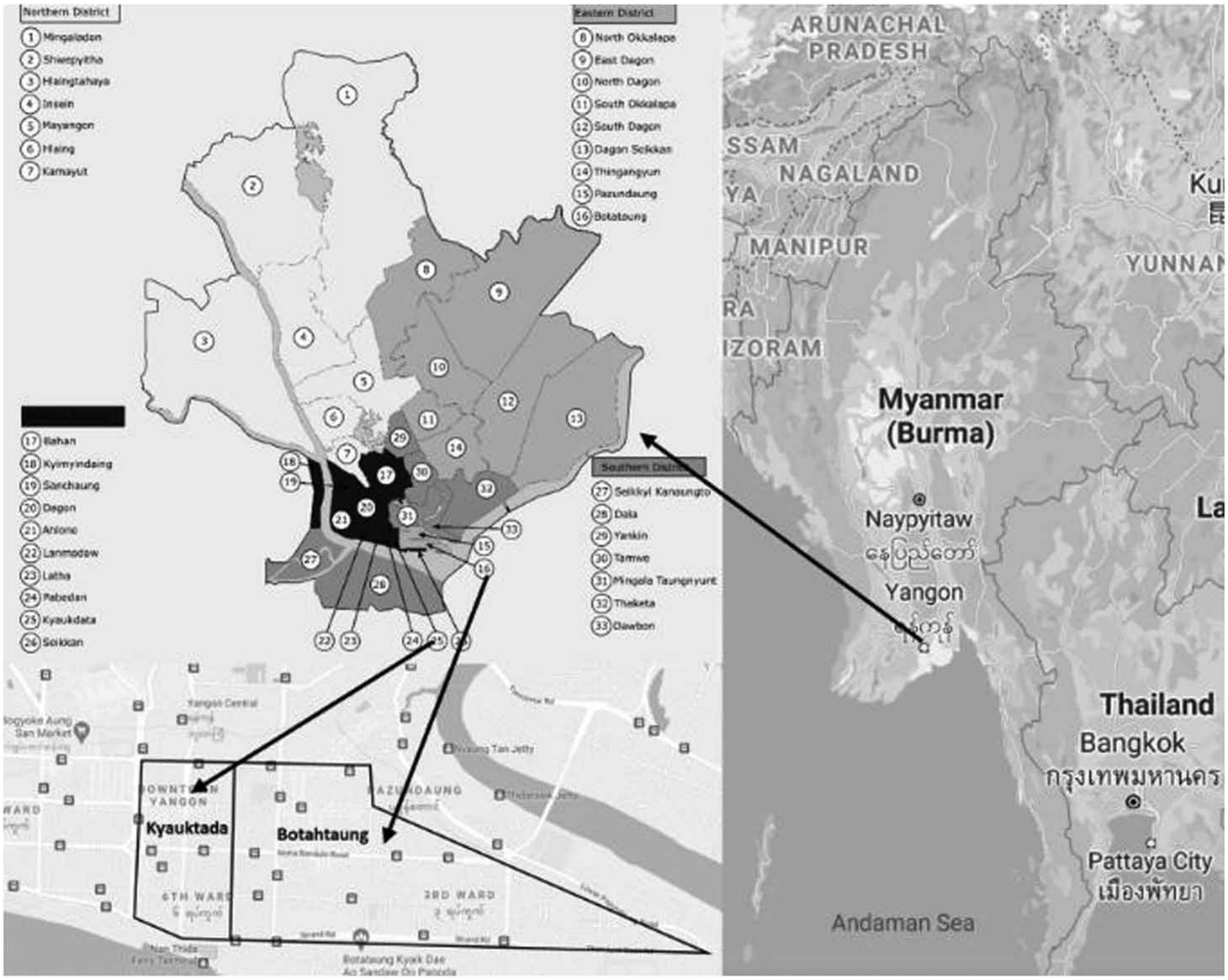


Figure 1 | Map of the study area.

Quality parameters

Microbial contamination is the primary concern addressed with drinking-water quality standards (Fawell & Nieuwenhuijsen 2003; Sorlini *et al.* 2013). In this study, the heterotrophic plate count (HPC), *Escherichia coli* count, and total coliform count were obtained, along with the measurement of other water quality parameters [pH, turbidity, total iron, dissolved organic carbon (DOC), and hardness]. The WHO (2011a) recommends the measurement of residual chlorine at least once per week to ensure protection from waterborne pathogens. The concentration of free chlorine in YCDC tap water was measured to assess compliance with the WHO (2017) guidelines. The MNDWQS and WHO (2017) guideline values for drinking water quality were used as references in this study. The Japan Drinking Water Quality Standard was used for parameters not covered by the MNDWQS and WHO guidelines, as the YCDC receives technical support from the Japan International Cooperation Agency.

Laboratory analysis

The onsite analysis of free and total residual chlorine was conducted using a DR900 colorimeter (Hach, USA) with a detection limit of >0.01 mg L^{-1}. Other parameters were analyzed in the laboratory. pH was measured using a pH meter (LAQUA; Horiba, Japan). The concentration of total iron was measured using the Hach DR900 colorimeter. Turbidity and hardness were measured using the attenuated radiation and metallphthalein methods, respectively, with a spectrophotometer (SpectroDirect; Lovibond, UK). DOC was measured with a total organic carbon (TOC) analyzer (TOC-V; Shimadzu, Japan) after filtering through a 0.45-μm pore size PTFE DISMIC membrane filter (25 mm; Advantec, Japan). Sterile single-use Nalgene vacuum filter units (165-0045; Thermo Fisher, USA) were used for membrane filtration with a manual vacuum pump. Heterotrophic bacteria were examined using Petrifilm plates (AQHC; 3M, USA) with an incubation period of 48 h at 37 °C. Compact dry plates (EC; Nissui, Japan) were used for the enumeration of *E. coli* and coliform bacteria, with an incubation period of 24 h at 37 °C. The buffer solution was prepared in accordance with the Association of Official Analytical Collaboration (2016) standard for microbial analysis. Serial dilution was used for the heterotrophic bacterial counts, and the membrane filtration method was used for the *E. coli* and coliform analyses.

The number of heterotrophic bacteria (N) was calculated using the following formula (ISO 2007):

$$N = \frac{\sum c}{V \times 1.1 \times d'}$$

where $\sum c$ is the total number of colonies counted on all dishes retained from two successive dilutions, at least one of which contains 10 colonies; V is the volume of inoculum applied to each dish, in milliliters; and d is the dilution factor corresponding to the first dilution retained.

RESULTS AND DISCUSSION

Tap water quality

Tap water quality data are provided in Table 1. The source of tap water in Botahtaung Township is the Hlawga Reservoir. The source of Kyauktada Township tap water is the Gyobyu Reservoir, sometimes supplemented with tube well water. The Myanmarese, Japanese, and WHO guideline values for drinking water are provided in Table 2.

Free and total chlorine

Free chlorine concentrations in the Hlawga and Gyobyu tap water ranged from 0.07 to 0.14 and 0.07 to 0.10 mg L^{-1}, respectively, with a mean value of 0.09 mg L^{-1} for both sources. After dilution with tube well water, no free chlorine was detected. Total chlorine concentrations in Hlawga-sourced water ranged from 0.09 to 2 mg L^{-1}, and those in Gyobyu-sourced water ranged from 0.12 to 0.18 mg L^{-1}, with both sources having a mean concentration of approximately 0.14 mg L^{-1}. Very little total chlorine (<0.01–0.02 mg L^{-1}, mean 0.01 mg L^{-1}) was detected after dilution with tube well water. Free chlorine levels at the point of consumer water collection should be between 0.2 and 0.5 mg L^{-1}, according to the WHO guideline; none of the tap-water samples contained this minimum required concentration.

pH

The pH values of the tap-water samples from all sources were similar. Samples from the mixed Gyobyu/tube-well source had pH values of 6.8–7.4, and those from the Gyobyu and Hlawga reservoirs had pH values of 6.8–7.8. All tap-water samples had pH values within the acceptable range according to the MNDWQS and WHO guidelines (6.5–8.5).

Total iron

The Hlawga tap water had total iron concentrations ranging from 0.04 to 0.08 mg L^{-1}, which did not differ greatly from the range of 0.05–0.10 mg L^{-1} for Gyobyu tap water; water from the two reservoirs had similar mean values of about 0.07 mg L^{-1}. After tube well water dilution, the tap water contained higher concentrations of iron, with a mean value of 0.32 mg L^{-1}. The total iron content of all tap-water samples was within the acceptable range of the MNDWQS (<1 mg L^{-1}); however, the content in some mixed samples containing tube well water exceeded the WHO guideline for drinking water (<0.3 mg L^{-1}).

Hardness

Water hardness can be classified using four categories: soft (<60 mg L^{-1}), moderately hard (60–120 mg L^{-1}), hard (120–180 mg L^{-1}), and very hard (>180 mg L^{-1}) (WHO 2011b). The tap water from the Gyobyu and Hlawga reservoirs was soft (<60 mg L^{-1}). However, most of the mixed samples containing tube well water were moderately hard, with a mean value of 112 mg L^{-1}. The hardness of all tap-water samples was within the acceptable limits for the total hardness of drinking water set by the WHO and the MNDWQS (<500 mg L^{-1}).

Table 1 | Tap water quality data

Parameters (units)	Source	*n*	Concentration		
			Lowest	Mean	Highest
Iron (mg L^{-1})	Hlawga	9	0.04	0.07	0.18
	Gyobyu	4	0.05	0.07	0.10
	Gyobyu + tube well	6	0.03	0.32	0.88
Hardness (mg L^{-1})	Hlawga	9	20	24	30
	Gyobyu	4	21	31	47
	Gyobyu + tube well	6	102	112	135
DOC (mg L^{-1})	Hlawga	9	1.97	2.58	3.07
	Gyobyu	4	1.78	1.97	2.17
	Gyobyu + tube well	6	0.73	1.18	1.65
pH	Hlawga	9	6.9	7.5	7.8
	Gyobyu	4	7.1	7.4	7.7
	Gyobyu + tube well	6	6.8	7.2	7.4
Free chlorine (mg L^{-1})	Hlawga	9	0.07	0.09	0.14
	Gyobyu	4	0.07	0.08	0.10
	Gyobyu + tube well	6	$<$0.01	$<$0.01	$<$0.01
Total chlorine (mg L^{-1})	Hlawga	9	0.09	0.13	0.20
	Gyobyu	4	0.12	0.14	0.18
	Gyobyu + tube well	6	$<$0.01	0.01	0.02
HPC (CFU mL^{-1})	Hlawga	9	1,800	8,000	17,000
	Gyobyu	4	900	3,400	6,500
	Gyobyu + tube well	6	350	1,500	3,600
E. coli (CFU 100 mL^{-1})	Hlawga	9	0	N/A	TNTC
	Gyobyu	4	0	2	8
	Gyobyu + tube well	6	0	8	32
Coliforms (CFU 100 mL^{-1})	Hlawga	9	182	N/A	TNTC
	Gyobyu	4	120	172	222
	Gyobyu + tube well	6	0	N/A	TNTC

N/A, not applicable; TNTC, too numerous to count; CFU, colony forming unit.

Table 2 | Myanmarese, Japanese, and WHO guideline values for drinking water

Parameters	Units	MNDWQS	WHO Guideline values for drinking water (2017)	Japan Drinking Water Quality Standard
pH	No unit	6.5–8.5	6.5–8.5	5.8–8.6
Turbidity	NTU	5	5	N/A
Hardness	mg L^{-1}	500	500	N/A
Iron	mg L^{-1}	1	0.3	0.3
E. coli	CFU 100 mL^{-1}	0	0	0
Coliforms	CFU 100 mL^{-1}	0	0	N/A
Free chlorine	mg L^{-1}	N/A	0.2–0.5	N/A
HPC	CFU mL^{-1}	N/A	N/A	2,000
DOC	mg L^{-1}	N/A	N/A	3

N/A, not applicable; CFU, colony forming unit.

Dissolved organic carbon

The DOC concentration was higher in Hlawga tap water (mean, 2.58 mg L^{-1}) than in water from Gyobyu (mean, 1.97 mg L^{-1}) and samples diluted with tube well water (mean, 1.18 mg L^{-1}). No DOC or TOC requirement is set by the MNDWQS or WHO. The TOC must be <3 mg L^{-1} according to the Japanese drinking water quality standards. All tap-water samples except one sample from the Hlawga reservoir met this standard.

Turbidity

The turbidity of drinking water must be <5 nephelometric turbidity units (NTU) according to the MNDWQS and WHO guidelines. The turbidity of all tap-water samples was below the detection limit (<5 NTU).

Microbial quality

The MNDWQS contains no regulation regarding the number of heterotrophic bacteria in drinking water. According to the Japanese standard, heterotrophic bacterial abundance should be <2,000 CFU mL^{-1}. The heterotroph count was higher in water from the Hlawga reservoir (mean, 8,000 CFU mL^{-1}) than in water from the Gyobyu reservoir (mean, 3,400 CFU mL^{-1}). The Gyobyu and tube well mixed-source water had the lowest HPCs, with a mean value of 1,500 CFU mL^{-1}. The majority of tap-water samples failed to meet the MNDWS and WHO guidelines for drinking water due to *E. coli* and coliform contamination (Table 3).

In the study conducted by Kordach *et al.* (2018), <2% of tap-water samples were contaminated with *E. coli*. The authors reported that the tap water system in Bangkok was in compliance with WHO guideline levels due to regular water quality monitoring, including free residual chlorine measurement, in accordance with the WHO guidelines for quality and quantity. In contrast, the YCDC initiated drinking-water quality testing only in 2017, and no regular monitoring information is available. In addition, as the public water supply system in Bangkok was developed in 1967, the pipelines are younger than those in Yangon. In contrast to that in the neighboring country, the *E. coli* contamination level in the YCDC tap water was very high, possibly due to insufficient residual-free chlorine levels in the tap water system. Substantial effort is needed to improve the YCDC tap-water supply system, including frequent quality monitoring in the service area.

Differences in tap water quality among sources

Tap water from the Gyobyu and Hlawga reservoirs had similar ranges of free chlorine, total chlorine, and total iron concentrations, pH, hardness, and turbidity. However, the concentrations of DOC and heterotrophs in tap water from Hlawga were higher than those in water from Gyobyu. The Hlawga water also had more *E. coli* contamination, as eight of nine samples were contaminated, whereas only half of the Gyobyu tap-water samples were contaminated.

Significant changes in tap-water quality occurred when water from tube wells (groundwater) was mixed with water from the Gyobyu reservoir (surface water). Free chlorine was not detected in tap water from this mixed water source. The iron concentration and hardness were substantially higher, while the DOC and heterotroph concentrations were lower, than those in water sourced solely from the reservoir. The groundwater-sourced tap water contained fewer bacteria and less organic matter, but was harder and contained higher levels of minerals.

Bottled water quality

In our previous study (Shane & Sakai 2021), all respondents in the CBD indicated that they were satisfied with the quality of bottled water and 65% of respondents consumed this water. However, we did not examine the quality of bottled water in that study. In the present study, the quality of all available brands of water was examined (Table 4). As the turbidity was <5 NTU

Table 3 | *E. coli* and coliform concentrations in tap water from various sources

Source	Total number of samples	Number of samples contaminated with *E. coli*	Number of samples contaminated with coliforms	Number of samples with no coliforms or *E. coli*
Hlawga	9	8	9	0
Gyobyu	4	2	4	0
Gyobyu + tube well	6	3	5	1
Total	19	13	18	1

Table 4 | Quality of bottled water

Sample	*E. coli* (CFU 100 mL^{-1})	Coliforms (CFU 100 mL^{-1})	HPC (CFU mL^{-1})	pH	Hardness (mg L^{-1})	Total iron (mg L^{-1})	DOC (mg L^{-1})
BW1	4	147	1.9×10^3	7.7	30	0.03	0.61
BW2	200	TNTC	6.2×10^3	7.4	3	0.02	0.32
BW3	0	0	6.4×10^2	7.6	6	0.16	0.50
BW4	0	2	1.0×10^5	7.7	<2	<0.01	0.38
BW5	65	75	1.2×10^2	8.0	2	0.03	0.34
BW6	7	14	1.4×10^3	7.4	10	0.03	0.56
BW7	2	2	1.5×10^2	8.4	<2	0.03	1.38

CFU, colony forming unit.

in all bottles tested, this parameter was excluded from the table. Two of seven bottled-water samples contained no *E. coli*, and one sample contained no coliform bacteria. The HPCs of three of the seven bottled waters exceeded the Japanese standard threshold ($<$2,000 CFU mL^{-1}). Aside from microbial quality, other parameters (pH, turbidity, hardness, and total iron concentration) were within the acceptable ranges of the MNDWQS. In previous studies, nearly half of samples of bottled water available in markets failed to meet the WHO standards (Kyaw *et al.* 2015; Phyo *et al.* 2019). Frequent findings of bottled water from unlicensed manufacturers in markets have drawn the attention of Yangon consumers to the risk of unsafe drinking water (MOI 2018). The presence of *E. coli* indicates that immediate measures are needed to ensure that commercially available bottled water available in markets is safe for drinking.

Household water treatment

Household water treatments used in the study area can be divided into two groups according to purpose: for drinking and for other purposes (cooking, washing, showering, hygienic activities, and pretreatment prior to treatment for drinking). Residents employed reverse osmosis (RO) devices and ceramic water purifiers (CPs) to treat water for drinking. They used sand- and iron-removing filters, cotton and thread filters, and charcoal and thread filters to treat water for other purposes.

The pH, turbidity, hardness, and total iron concentrations in water treated for drinking with RO devices and CPs met the MNDWQS requirements. However, *E. coli* and coliform elimination was effective for only 88 and 38% of samples, respectively. Thus, only 38% of water treated for drinking met the MNDWQS requirements.

None of the household treatments of water for other purposes exhibited good efficacy in the elimination of *E. coli* and coliforms. Changes in the abundance of microbiological contaminants and chemical quality of output water varied substantially, making treatment efficacy difficult to assess. This difficulty may be related to the failure to replace cartridge filters when needed, as visible color changes in some cotton and thread filters were observed during sample collection. The quality parameters for water treated for drinking and for other purposes are provided in Supplementary Material, Tables A1 and A2, respectively.

Efficacy of RO devices and CPs

The structures of RO devices and CPs are summarized in Supplementary Material, Table A3.

The treatment efficacy and percent concentration changes of contaminants are presented in Figure 2 and Table 5. According to a previous study conducted in Vietnam, household RO and CP treatments can reduce iron concentrations by $>$45% (Do *et al.* 2014). However, a study conducted in the USA showed that household RO devices did not effectively remove iron (Lothrop *et al.* 2015). Total iron concentrations in the source water in our study ($\leq$0.05 mg L^{-1}) were much lower than levels in those studies, most of which exceeded the WHO guideline of 0.3 mg L^{-1}. In our study, the mean iron removal efficacy of RO devices was approximately 34% and that of CP treatment was 20%. However, effectiveness varied substantially, and the iron concentration in one effluent was higher than the pretreated concentration. This finding could be related to the very low iron concentration in the pretreated water, as one sample had no detectable iron prior to treatment.

Point-of-use RO devices have been reported to reduce water hardness by an average of 97% (Lothrop *et al.* 2015). In this study, RO devices reduced the water hardness by 75–99%, with an average efficacy of 91%. Like the iron concentration, the hardness of influent tap water in our study was relatively low (mean, ~40 mg L^{-1}). The treated water was very soft

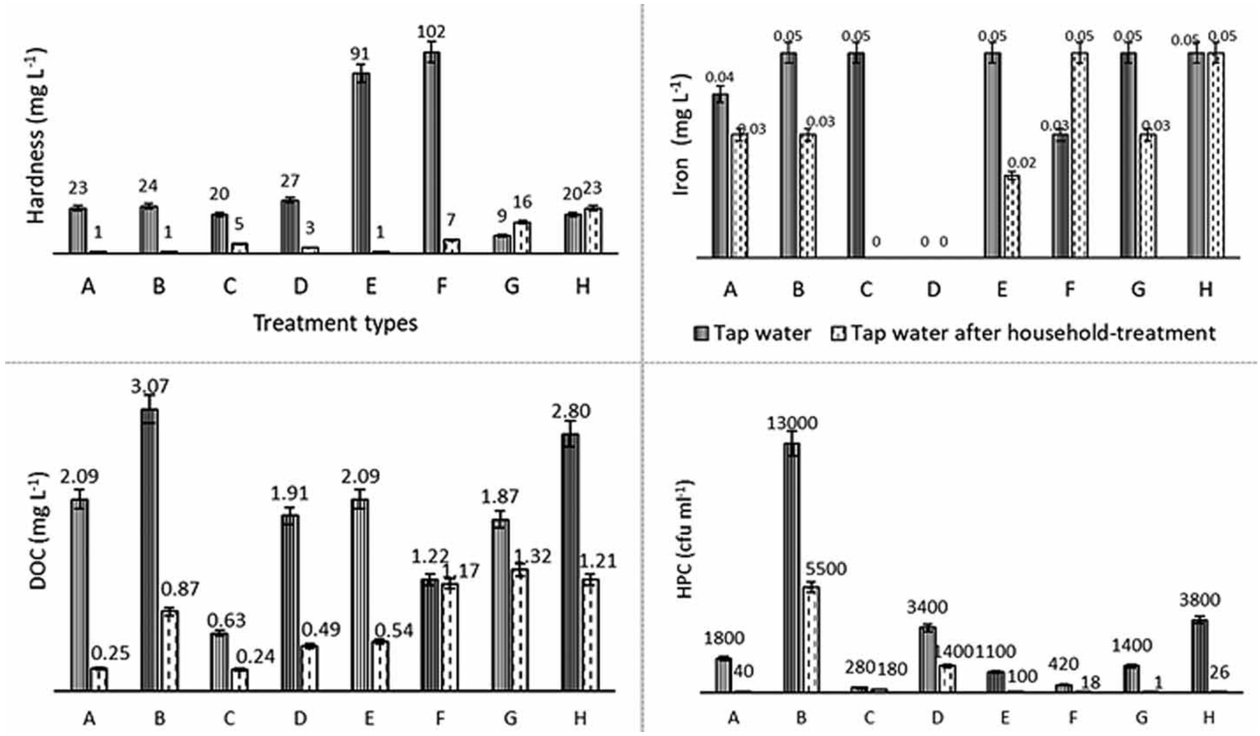


Figure 2 | RO (A–F) and CP (G, H) treatment efficacy.

Table 5 | Removal of contaminants by RO and CP treatments

			Reduction efficacy (%)		
Contaminant	**Treatment**	***n***	**Minimum**	**Mean**	**Maximum**
Iron	RO	6	−67	+34	+100
	CP	2	0	+20	+40
Hardness	RO	6	+75	+91	+99
	CP	2	−78	−49	−15
DOC	RO	6	+4	+60	+88
	CP	2	+29	+43	+57
HPC	RO	6	+36	+73	+98
	CP	2	+99	+99	+99
E. coli	RO	6	+99	+99	+100
	CP	2	+100	+100	+100

($<$10 mg L^{-1}). Point-of-use RO devices can remove minerals and several types of potential trace contaminant, yielding drinking water devoid of minerals (WHO 2011b). Water that is too soft ($\leq$90 mg L^{-1}) provides no benefit to cardiovascular or skeletal health and no protection against certain cancers. Residents in homes with very soft water may consider supplementing their magnesium or calcium intake to support good health (WHO 2009b). On the other hand, CP treatment increased the water hardness by 15–78% (mean, 49%). This increase could be an effect of the mineral support layer in the CP cartridges.

RO filters effectively reduce the DOC concentration, according to Li *et al.* (2014). In this study, the DOC concentration in raw water was about 4.3 mg L^{-1}, and RO treatment reduced it to $<$0.6 mg L^{-1}. The mean DOC removal efficacy of RO treatment was 60%. The average DOC concentration in influent was about 1.8 mg L^{-1} and that in RO-treated water was 0.6 mg L^{-1}. The mean DOC reduction efficacy of the CPs was 43%, and the mean DOC concentration in CP-treated water was 1.2 mg L^{-1}.

Table 6 | *E. coli* and coliform bacteria in water samples

Source	Total number of samples	Number of samples contaminated with *E. coli*	Number of samples contaminated with coliforms	Number (percentages) of samples with no coliform or *E. coli* contamination
Tap water	19	13	18	1 (5)
Tap water with household treatment for drinking	8	1	5	3 (38)
Tap water with household treatment for other purposes	7	7	7	0 (0)
Bottled water	7	5	6	1 (14)

Our finding regarding the DOC removal efficacy of CPs is similar to that of a study conducted in South Africa (39% DOC reduction) (Mahlangu *et al.* 2012). Our results indicate that RO devices removed DOC more effectively than did CPs.

The *E. coli* reduction efficacies of the CP and RO treatments were very high (mean, 100% and 99.99%, respectively). According to a study conducted in Cambodia, CPs can reduce the concentrations of key microbes, with a mean *E. coli* reduction efficacy of approximately 99% and mean bacteriophage reduction efficacy of 90–99% (Brown & Sobsey 2010). The average heterotrophic bacteria reduction efficacy of RO treatment was 73% and that of CP treatment was 99% in this study. Similarly, CPs had a better microbial reduction efficacy than did RO devices.

Compliance with the MNDWQS

Four types of water sample were analyzed in this study: tap water arriving at consumers' homes, tap water treated for drinking with point-of-use devices, tap water treated again for purposes other than drinking, and bottled water. Aside from microbial quality, all water quality parameters examined met the requirements of the MNDWQS. Overall, 38% of tap water treated for drinking met all of the MNDWQS requirements, including those for microbial quality, followed by bottled water (14%) and tap water (5%; Table 6).

CONCLUSIONS

In the study area, bottled water was frequently contaminated with *E. coli* and coliform bacteria. Immediate actions are required to strengthen the regulation of bottled water by various authorities (the regional government, YCDC, health department, and food and drug administration), thereby ensuring compliance with the MNDWQS. These actions should include regular monitoring of the quality of bottled water available in markets and prevention of the sale of water produced by unlicensed bottled-water manufacturers.

The free chlorine concentration should be monitored regularly along with other quality parameters to ensure that sufficient free chlorine residuals are present in tap water to protect against bacterial contamination. Otherwise, people may assume that disinfected tap water is safe to drink despite the lack of free chlorine. Household RO and CP treatments were very effective for *E. coli* elimination, with efficacies exceeding 99%. These methods could be used as supplementary treatments to achieve compliance with the MNDWQS. According to our findings, the quality of Yangon tap water delivered to the homes studied is not sufficient for drinking. Unfortunately, the reliability of bottled water is also poor. Consumers should consider the use of household treatment devices to produce drinking water until the YCDC tap water system is upgraded fully.

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CONFLICT OF INTEREST STATEMENT

All authors declare that they have no conflict of interest associated with this manuscript.

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DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information. Datasets for the parameters examined are embedded in the Results and discussion section (Tables 1 and 4) and appendices (Tables A1 and A2).

REFERENCES

AOAC International. 2016 *Official Methods of Analysis*, 20th edn. Rockville, USA.

Brown, J. & Sobsey, M. D. 2010 Microbiological effectiveness of locally produced ceramic filters for drinking water treatment in Cambodia. *Journal of Water and Health* **8** (1), 1.

Department of Population (DOP) 2015 *The 2014 Myanmar Population and Housing Census. Yangon Region Report. Census Report Volume 3*. Nay Pyi Taw, Myanmar.

Do, A. T., Kuroda, K., Hayashi, T., Nga, T. T. V., Oguma, K. & Takizawa, S. 2014 Household survey of installation and treatment efficiency of point-of-use water treatment systems in Hanoi, Vietnam. *Journal of Water Supply: Research and Technology – AQUA* **63** (2), 154–161.

Fawell, J. & Nieuwenhuijsen, M. J. 2003 Contaminants in drinking water: environmental pollution and health. *British Medical Bulletin* **68** (1), 199–208.

Government of the Republic of the Union of Myanmar (GRUM) 2016 *National Strategy for Rural Water Supply, Sanitation and Hygiene (WASH)*. Nay Pyi Taw. Myanmar.

ISO 2007 *Microbiology of Food and Animal Feeding Stuffs. General Requirements and Guidance for Microbiological Examinations*. International Organization for Standardization, Geneva, Switzerland.

JICA 2017 *Final Report on Preparatory Survey for Greater Yangon Water Supply Improvement Project (Phase 2)*. Japan International Cooperation Agency, Tokyo, Japan.

Kordach, A., Chardwattananon, C., Wongin, K., Chayaput, B. & Wongpat, N. 2018 Evaluation on the quality of Bangkok tap water with other drinking purpose. In: *Water, Water, Wastewater and Energy in Smart Cities E3S Web of Conferences*, Vol. 30.

Kyaw, T. S., Han, M., Chit, K., Nwe, Z. Z., Win, N., Khin, A. A., Htike, W. W. & Win, K. K. 2015 Detection of bacteriological contamination of bottled drinking water in Yangon city. *Myanmar Health Sciences Research Journal* **27** (2), 118–124.

Li, X., Li, C., Yang, Y. & Mao, X. 2014 Performance evaluation of common household water filters in China. *Fresenius Environmental Bulletin* **23** (10), 2460–2465.

Lothrop, N., Wilkinson, S. T., Verhougstraete, M., Sugeng, A., Loh, M. M., Klimecki, W. & Beamer, P. I. 2015 Home water treatment habits and effectiveness in a rural Arizona community. *Water* **7**, 1217–1231.

Mahlangu, T. O., Mamba, B. B. & Momba, M. N. B. 2012 A comparative assessment of chemical contaminant removal by three household water treatment filters. *Water SA* **38** (1). doi:10.4314/wsa.v38i1.6.

Ministry of Health (MOH) 2014 Myanmar National Drinking Water Quality Standard. The Republic of the Union of Myanmar. Nay Pyi Taw, Myanmar.

Ministry of Information (MOI) 2018 *FDA to Inspect Drinking Water Plants in Yangon*. Available from: https://www.moi.gov.mm/moi:eng/?q = news/15/11/2018/id-15599.

Phyo, S. S. M., Yu, S. S. & Saing, K. M. 2019 Bacteriological examination of bottled drinking water by MPN method. *Haya: The Saudi Journal of Life Sciences* **4** (**7**), 227–232.

Sakai, H., Kataoka, Y. & Fukushi, K. 2013 Quality of source water and drinking water in urban areas of Myanmar. *The Scientific World Journal* **2013**, 1–5. doi.10.1155/2013/854261.

Senda, M., Hlaing, K. T., Miyaoka, K., Haruyama, S. & Kuzuha, Y. 2014 Water environments in the southern delta of Myanmar during the rainy season. *Journal of JSCE* **2**, 299–309.

Shane, H. K. & Sakai, H. 2021 Perception on water quality, current and future water consumption of residents from central business district of Yangon city. *Water Supply*. doi:10.2166/ws.2021.212.

Shrestha, K. B., Thapa, B. R., Aihara, Y., Shrestha, S., Bhattarai, A. P., Bista, N., Kazama, F. & Shindo, J. 2018 Hidden cost of drinking water treatment and its relation with socioeconomic status in Nepalese urban context. *Water* **10**, 607. doi:10.3390/w10050607.

Sorlini, S., Palazzini, D., Sieliechi, J. M. & Ngassoum, M. B. 2013 Assessment of physical-chemical drinking water quality in the Logone Valley (Chad-Cameroon). *Sustainability* **5**, 3060–3076.

SuLatt, T. M., Myint, T., Aung, W. W. & Wai, K. T. 2015 Prevalence of household drinking-water contamination and of acute diarrhoeal illness in a periurban community in Myanmar. *WHO South-East Asia Journal of Public Health* **4** (1), 62–68.

UNICEF, Ministry of National Planning and Economic Development, Ministry of Health (MoH) 2011 *Myanmar Multiple Indicator Cluster Survey 2009–2010*. Nay Pyi Taw, Myanmar.

WHO 2009a *Diarrhoea: Why Children Are Still Dying and What Can Be Done*. World Health Organization, Geneva, Switzerland.

WHO 2009b *Calcium and Magnesium in Drinking Water: Public Health Significance*, 1st edn. World Health Organization, Geneva, Switzerland.

WHO 2011a *Technical Notes on Drinking-Water, Sanitation and Hygiene in Emergencies*. Available from: https://www.who.int/water_sanitation_health/publications/2011/tn11_chlorine_levels_en.pdf?ua = 1.

WHO 2011b *Water Sanitation and Health: Hardness in Drinking Water*. Available from: https://www.who.int/water_sanitation_health/dwq/chemicals/hardness.pdf.

WHO 2015 *Sanitation, Drinking Water and Hygiene Status Overview*. Available from: https://www.who.int/water_sanitation_health/monitoring/investments/myanmar-10-nov.pdf?ua = 1.

WHO 2017 *Guidelines for Drinking-Water Quality*. First addendum to the Fourth Edition. World Health Organization, Geneva, Switzerland.

Zaw, L., Shwe, T. & Hlaing, M. 2014 Studies of the status of central business district area (CBD) in Yangon, Myanmar. *International Journal of Emerging Technology and Advanced Engineering* **4** (5), 2250–2459.

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