ORIGINAL PAPER

Nagoya J. Med. Sci. **80**. 165–174, 2018
doi:10.18999/nagjms.80.2.165

Inadequate water treatment quality as assessed by protozoa removal in Sarawak, Malaysia

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ABSTRACT

Providing safe drinking-water to human civilization is indispensable; it is one of the most cost-effective means of reducing the disease burden of diarrhea. Unfortunately, water supply quality monitoring from public water treatment plants (WTPs) is often neglected or taken for granted. To determine the produced water quality, WTPs in Sarawak, Malaysia were assessed for their protozoa removal ability. A self-administered questionnaire based on the regulations in the Drinking-water Standards for New Zealand (DWSNZ) was developed. Optional 10-liter raw water samples were collected from willing WTPs for the detection of protozoan cysts. Routine physical and microbial testing of WTP parameters were also requested for raw water quality overview. Two of the nine assessed WTPs achieved three log credits in the treatment component, one of which belonged to Peninsular Malaysia. No log credits were obtained in the other tested components for any samples. Most of the WTPs employed “Coagulation, Sedimentation, and Filtration” using rapid gravity filters without enhancement ($P < 0.05$). *Giardia* cysts were detected in raw water sources used for treatment, and the geographical location was identified as an influencing factor for raw water quality. There is an urgent requirement for active collaboration and holistic approaches to review existing water management policies and interventions. WTPs in Sarawak did not achieve the log credits required to safeguard the microbial quality of the water supplied; however, only *Giardia* cysts were detected in 10-liter raw water samples despite routine microbial parameter monitoring showing disturbing contamination levels.

Keywords: water treatment, protozoa, log removal, Water Safety Plan, risk assessment

INTRODUCTION

Maslow’s hierarchy of needs describes water as a vital, basic, and human physical need[1]. Based on this, in 2010, the United Nations General Assembly declared access to safe and clean drinking-water as a human right[2]. To date, several international working groups that cater to water issues have been established. For instance, by 2015, Target 7.C of the Millennium Develop-

Received: July 14, 2017; accepted: November 15, 2017
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ment Goals (MDGs) has been determined to halve the proportion of the population not having sustainable access to safe drinking-water by 2015[3)]. This target is deemed to underpin several other MDGs, particularly, MDG 4 to reduce child mortality, because this is mainly associated with diarrheal diseases where access to safe water is limited[4)]. Although Malaysia reported that it had achieved clean piped water delivery to approximately 98% urban population and 87% rural population in 2000, diarrheal outbreaks still persist[3)].

In the 19th century, Robert Koch hypothesized that water supplies could be an etiological agent for the spread of diseases, and various interventions have been studied since then[5)]. Water treatment intervention has been noted as the most cost-effective method for globally reducing water-borne diseases[5-8)]. Contaminated water could be an etiological agent for communicable diseases, such as rotavirus infection[9)] and cryptosporidiosis[10-12)], as well as non-communicable diseases, such as bladder cancer[13)] and cognitive disorders[14)]. Cryptosporidiosis, for instance, was not considered as a human health risk until 1976[15)]. Therefore, the establishment of assessment methods concerning emerging water-borne diseases is considered important.

Intervention in water, sanitation, and hygiene (WSH) could approximately reduce 10% of the total global disease burden[6-8)]. It is noteworthy that even developed countries carry disease burdens similar to developing countries[7,8,15)]. The World Health Organization (WHO) introduced disability-adjusted life years (DALY) to measure the disease burden related to WSH diseases and set the ideal limit at 10^{-6} DALY/person/year[16,17)]. In 2002, the total WSH-related disease burden in Malaysia was 123 DALY (5×10^{-6} DALY/person/year) and accounted for 3.5% of the country's total DALY[8)]. Several previous studies have used DALY as an indicator[16)].

The Water Safety Plan (WSP), multidisciplinary approach managing safe water from catchment to the point-of-use, driven by health-based targets, was introduced by the WHO in 2004 to prevent adverse water-associated effects[16)]. Microbial quality risk assessments in the WSP emphasize protozoa monitoring because although *Escherichia coli* and other fecal coliforms indicate presence of certain microbial pathogens, this does not include all species, such as chlorine-resistant *Cryptosporidium*[11,15-17)]. Several developed countries, such as Japan and New Zealand[18,19)], require compulsory WSP implementation by water purveyors. Influenced by this international drive, the local government of Sarawak took proactive steps to develop a WSP framework for all water purveyors in 2011. Unfortunately, the plan was more of a formality rather than a call to continual action.

Cryptosporidiosis outbreaks can occur globally[10-12,15)], the most well-known being the 1993 Milwaukee outbreak, which originated from substandard water supplies and resulted in illness affecting >400,000 people[12)]. Although no outbreaks have been recorded, several Malaysian studies have reported the presence of *Cryptosporidium* and *Giardia* in water bodies[11,20-22)]. Previous studies have revealed that outbreaks are usually under-reported, and that robust protozoa may remain undetected during routine quality control procedures[5,16,23)]. To date, protozoal water contamination is not a notifiable disease, and protozoan testing is not mandatory for water quality monitoring in Malaysia. There has been no study that yet addresses susceptibility levels of these pathogens to the methods employed in water treatment plants (WTPs) in Sarawak.

Hence, this study aims at assessing the efficacy of WTPs in the elimination of *Cryptosporidium* risk using the log credit approach, regulated by the Drinking-water Standards for New Zealand (DWSNZ)[18)]. Apart from log credit assessment, descriptive comparisons based on physical (pH, color, and turbidity) and microbial (total and fecal coliforms, *Cryptosporidium* oocysts, and *Giardia* cysts) parameters for willing WTPs were made. This study was anticipated to add value from the water treatment processes and technology perspective to ensure safe water supply.

METHODS

Samples

Public WTPs in Sarawak, Malaysia with population ≥10,000 and that source raw water for treatment from surface water were targeted. Twenty-five eligible WTPs across eleven administrative divisions were identified (Figure 1) and managed by four main players: Kuching Water Board, Sibu Water Board, LAKU Management Sdn. Bhd., and Sarawak Public Works Department. This study was approved by the Medical Ethics Committee of University Malaya Medical Center (Ethics Committee Reference Number 890.11).

Questionnaire

The log credit approach, developed by DWSNZ[18], was used as the performance target. According to this standard, a default four log credit applies where the raw water protozoa risk was never determined. For the purpose of this study, the standard requirements were transformed into a self-administered questionnaire under the log credit assessment components. Except for demographic information, a bipolar survey scale with forced "Yes" or "No" choices was used in the questionnaire for three main treatment components: Pre-treatment, Treatment, and Inactivation. The log credit score ranges from minimum 0 to maximum 8, as summarized in Table 1. The questionnaire was reviewed by a Sarawak Water Supply Consultative Committee member and by university professors, who are experts in protozoa and water engineering. A log credit is defined as follows: Log credit = $\log_{10}$ (1/{1-(percentage removal/100)}).

Raw Water Sampling

In addition to log credit assessment, the participants were encouraged to send a 10-liter raw water sample to the University of Malaya Laboratory, Department of Parasitology for standard analysis in accordance with the United States Environmental Protection Agency (US EPA), Method 1623: *Cryptosporidium* and *Giardia* in water by filtration/ immunomagnetic separation/

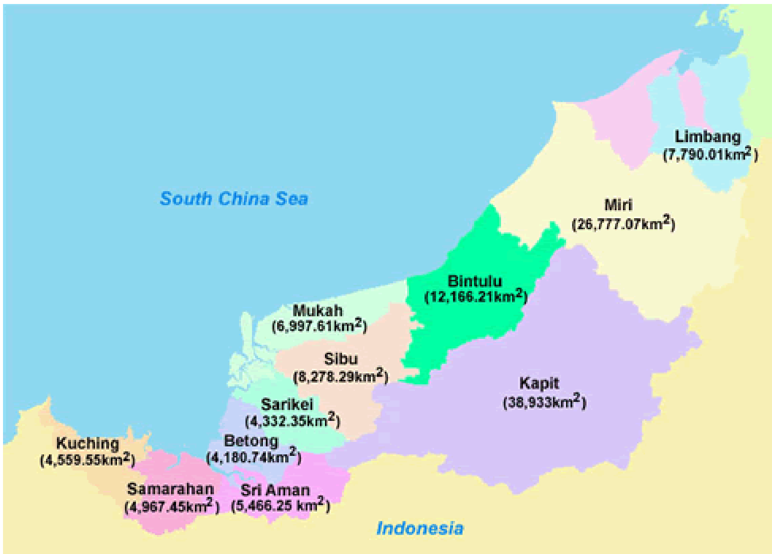

Fig. 1 Geographical and administrative divisions of Sarawak

Table 1 Log credits condition for different treatment options

Section	Sub-sections (treatment options)	Log credit can be obtained
Pre-treatment	Bank filtration	0.5–1.0
Treatment	Coagulation or sedimentation without filtration	0.5
	Coagulation, sedimentation and filtration	3.0–4.0
	Coagulation, direct filtration	2.5–3.0
	Filtration without coagulation	1.0–2.5
Inactivation	Chlorine dioxide	up to 3.0
	Ozone	up to 3.0
	Ultraviolet light	up to 3.0

immunofluorescence assay[24]. The sampling was voluntary because of financial constraints, as the participating WTPs had to bear the cost of analysis.

Data Collection

In January 2012, the prepared questionnaire was sent as an attachment via e-mail to the person in charge of the water quality at each water purveyor. The participants were provided three months to respond and were followed up via periodic e-mail reminders; however, because of a low response rate, a second survey was conducted from May 15 to 30, 2012 using a Google questionnaire. This round also involved extended e-mail invitations to participants from Peninsular Malaysia. Besides the questionnaire, WTPs in Sarawak were requested to provide routine raw water treatment details (i.e., pH, turbidity, color, and total and fecal coliform counts).

Statistical Analyses

The data was entered into a Microsoft Excel file via a personal computer. The names of the participating WTPs were denoted with letters to maintain confidentiality. IBM SPSS Statistics, version 19.0 for Windows, was used for descriptive statistics, Cronbach's Alpha value, the Chi-squared test, and Fisher's exact test. $P < 0.05$ was considered statistically significant.

RESULTS

Demographic Characteristics

At the end of the survey period, the questionnaires were returned from eight of the 25 WTPs in Sarawak and one WTP in Peninsular Malaysia (Table 2). An open-ended question requesting the respondents' opinion regarding public health experiences of raw water quality was included in the questionnaire. WTP "X" from Peninsular Malaysia, aware of *Cryptosporidium* and *Giardia* presence in raw water, suggested that it resulted from upstream human or animal fecal contamination. WTP "X" was the only WTP that had an existing protozoa monitoring program. WTP "G" expressed concern over rotavirus, which recently caused an outbreak in certain parts of Sarawak. The knowledge of other WTPs on microbial risks to public health was limited to coliform groups (i.e., *E. coli*). They suggested the expectation that the Ministry of Health would instruct them on the next course of action, should violations or water-borne disease outbreaks occur.

Table 2 Demographic characteristic of WTPs

Administrative Region	Code of WTP	Population[a], ('000)	Age of WTP (years)	Log Credit
Southern	A	683.6	≥ 11	0.0
	B	227.5	≥ 11	0.0
Central	C	257.8	≥ 11	3.0
	D	257.8	≥ 11	0.0
	E	32.7	≥ 11	0.0
Northern	F	231.2	≥ 11	0.0
	G	371.4	≥ 11	0.0
	H	92.2	≥ 11	0.0
Reference WTP in Peninsular Malaysia	X	251.8	≥ 11	3.0

WTP, Water Treatment Plant
[a]Information from Department of Statistics Malaysia, *Basic Population Characteristics by Administrative District*, 2010

WTP "F" did not respond to this question.

Log Credit Assessment

All participating WTPs are conventional water treatment plants and apply "Coagulation, Sedimentation, and Filtration" for treatment. WTP "C" and "D" claimed to have bank filtration, but failed to fulfill the requirements for log credit gain. WTP "X" and "C" obtained three log credits for answering "Yes" to all eight questions indicated in Table 3, whereas the other WTPs did not obtain any log credits. Although WTP "X" had enhanced filtration, they failed to obtain an additional log credit. For the Inactivation component, it was observed that all WTPs used chlorine-based disinfection and thus, none of them obtained any log credits.

The populations of each WTP were weighed based on the lowest estimated proportion, and were used for statistical analysis (Table 2). The Cronbach's Alpha for this Treatment component was 0.798 (Table 3).

Protozoan Cyst Detection in Raw Water

Raw water samples for protozoan cyst detection were collected from the intake points of three of the four water purveyors in Sarawak. Totally, eleven raw water samples were tested for both *Cryptosporidium* oocysts and *Giardia* cysts (Table 4). Four samples were received from WTP "Y," one from WTP "C," two from WTP "F," one from WTP "G," and three from WTP "H"; however, the samples submitted did not cover all available intake points.

Physical and Microbial Parameters

Three WTPs situated in the northern Sarawak submitted complete routine monitoring data for the year 2011 (Table 5). WTP "F" sourced the raw water from a reservoir (dam), whereas WTPs "G" and "H" sourced raw water from rivers. WTP "F" showed relatively lower physical

Table 3 Log credit characteristics for Treatment component (N=488,433)

Criteria for Coagulation, Sedimentation, and Filtration	Yes N (%)	No N (%)	*P*-value[a]
Q1. Is the filtration a rapid gravity granular media design (or pressure equivalent)?	478,296 (97.9)	10,137 (2.1)	0.035
Q2. Does all water pass through the full coagulation, flocculation, sedimentation, and filtration process; where all parts of which are continuous, excluding any periods when the filtered water is not going to supply?	377,843 (77.4)	110,590 (22.6)	0.141
Q3. Was turbidity from each filter being measured continuously for the past one month period? (one turbidimeter to each filter or housing)	251,312 (51.5)	237,121 (48.5)	0.328
Q4. Is turbidity for each filter being sampled sequentially (no blending) for five minutes?	261,449 (53.5)	226,984 (46.5)	0.492
Q5. Was the turbidity ≤0.30 NTU for more than 95% of the time when filter is online for the past one month?	201,262 (41.2)	287,171 (58.8)	0.141
Q6. Was the turbidity ≤0.50 NTU for more than 99% of the time when filter is online for the past one month?	201,262 (41.2)	287,171 (58.8)	0.141
Q7. Was the turbidity does not exceed 1.00 NTU for the duration of any three-minute period?	332,131 (68.0)	156,302 (32.0)	0.328
Q8. Is there any enhancement done to the filter performance?	100,720 (20.6)	387,713 (79.4)	0.035

NTU, Nephelometric Turbidity Unit
[a]Fisher's Exact Test

Table 4 Laboratory analysis (N=11)

Raw water samples from WTP tested[a]	Date of sampling	*Cryptosporidium* oocyst, per liter	*Giardia* cyst, per liter
Intake No. 1 of "Y[b]"	21/03/2012	ND	0.67
Intake No. 2 of "Y[b]"	21/03/2012	ND	0.50
Intake No. 3 of "Y[b]"	21/03/2012	ND	0.33
Reservoir of "Y[b]"	21/03/2012	ND	0.17
River Intake of "C"	20/03/2012	ND	ND
River Intake of "F"	20/02/2012	ND	ND
Reservoir of "F"	20/02/2012	ND	ND
Intake of "G"	09/02/2012	ND	ND
River No. 1 of "H"	20/02/2012	ND	0.67
River No. 2 of "H"	20/02/2012	ND	0.33
Intake of "H"	09/02/2012	ND	0.30

WTP, Water Treatment Plant; ND, Not detected
[a]Grab sample of 10-L and tested by third-party laboratory using US Environmental Protection Agency Method 1623.
[b]A WTP located in Southern Region but did not participate in log credit assessment.

Table 5 Routine parameters of raw water in 2011 for Water Treatment Plant "F", "G," and "H"

Parameters	Water Treatment Plant					
	F (n=51)		G (n=52)		H (n=39, 13[a])	
	Range	Mean	Range	Mean	Range	Mean
Physical						
pH	6.0–6.9	6.6	3.8–6.3	4.9	5.7–7.6	6.4
Color, TCU	5–322	98.8	20–900	206.9	0–1,200	197.2
Turbidity, NTU	2–201	23.9	13–550	119.5	25–781	106.7
Microbial						
Total coliform, MPN/100 ml	2–16,090	781.8	23–16,090	2,668.9	110–16,090	5,510.0
Fecal coliform, MPN/100 ml	2–5,420	237.5	8–16,090	922.8	2–16,090	2,164.0

TCU, True Color Unit; NTU, Nephelometric Turbidity Unit; MPN, Most Probable Unit; ml, milliliter
[a]Total samples tested for microbial parameter in 2011 due to testing laboratory down for the rest of the time.

parameter ranges and microbial counts. This data was obtained from the same raw water samples collected for protozoan cyst detection.

DISCUSSION

This is the first microbial risk assessment study conducted among WTPs in Sarawak, Malaysia, despite the fact that *Cryptosporidium* oocysts had been detected in raw and backwashed water among WTPs in Peninsular Malaysia[11,20]. The low response rate (32%) to our study was expected and could be explained by the reluctance to assessment by water supply authorities, similar to previous studies[21]. Furthermore, cryptosporidiosis and giardiasis were still possibly considered jargon among public health practitioners in Malaysia, as previously described[23].

The major water purveyors in Sarawak are either companies or statutory bodies owned by the Sarawak Government, with water management skills being inherited from the British colonization. Thus, similar to the scenario in the United Kingdom, management decisions are frequently made based on local factors occurring within the company's jurisdictional area and regulatory factors that are imposed by either local or central governments[25]. Our results revealed that most water purveyors only checked the microbial parameters (i.e., total coliform and *E. coli*) required by the legislation, with no additional microbial tests performed. Emerging harmful water-borne diseases, including cryptosporidiosis, giardiasis, and rotavirus infection, are not notifiable under the Malaysian Prevention and Control of Infectious Diseases Act, 1988 (Act 432). From the experience of leptospirosis, a disease will only be gazetted as notifiable after the occurrence of severe cases. This contradicts the promotion of the WSP as focusing more on prevention rather than corrective action. In contrast, regional water companies in the United Kingdom may be prosecuted for supplying water unfit for human consumption[25]. Water authorities and policymakers should focus more on water quality, since proper interventions are proven to reduce the disease burden of a nation.

Most WTPs employed "Coagulation, Sedimentation, and Filtration" in treatment, using a rapid gravity granular media filter without enhancement ($P < 0.05$). This selected combination of treatment processes is best for the removal of protozoan risk in the treatment of surface water sources[5,15-17]. Most WTPs were able to achieve a filtered water turbidity of 0.5–1.0 Nephelometric Turbidity Units (NTU). Although this result falls within the acceptable limit (5 NTU) of the Malaysian National Standard for Drinking-Water Quality, a limit of 5 NTU cannot safeguard the water supplied against microbial risks such as *Cryptosporidium*[4,15]. For example, a massive *Cryptosporidium* outbreak in Milwaukee was undetected by the public health surveillance system until the situation became severe[6,12]. It is well understood that once an outbreak occurs, it will have a great impact on cost[4,7,8] and health[4-6,8,9,15].

DWSNZ mandates a four log credit in cases of no prior protozoan risk determination for conventional WTPs serving >10,000 people[18]. None of the WTPs in our study achieved this target, mainly because turbidity (real-time turbidity) was not continuously measured and also because of the sole use of a chlorine-based disinfectant throughout the treatment processes. WTPs in Sarawak are inferior to those in Peninsular Malaysia, although both have been established for ≥11 years; however, WTP "X" from Peninsular Malaysia has the capacity to measure turbidity continuously during the treatment process. For this reason, the chances for misidentification of suboptimal treatment processes are elevated in Sarawak, hence decreasing the reliability of water supplied[11,16,17]. Thus, our study warrants attention from relevant planning and development authorities for imparity mitigation.

Differences in geography, climate, and community culture influence the raw water source quality and, therefore, influence the risk of microbial contamination[11,20]. This is demonstrated by the fluctuating data displayed for three WTPs in northern Sarawak, where results indicated that the coliform count in raw water was elevated (>16,000 counts/100 ml) on some occasions; however, no *Cryptosporidium* oocysts were detected in the 10-liter raw water sampled from the intake points, whereas less than one *Giardia* cyst/l was detected in seven of eleven raw water samples. Although these results improved compared with previous studies[11,20], their reliability was considered low because of the sampling frequency and sample size. In several previous studies, the raw water volumes sampled for protozoa detection was at least 50-liter[15,20]. Therefore, we assume that the protozoan cyst detection in our study was under-reported. With reference to the WHO Guidelines for drinking-water quality[17], the detectable concentration/l is 4–290 and 2–30 for *Cryptosporidium* and *Giardia*, respectively, from the bacterial fecal indicator results.

The present study has several limitations concerning sample size and financial aspects. Moreover, epidemiology profiles of water-borne diseases related to public water supply are limited in Malaysia. To date, laboratory protozoan cyst analysis is expensive and not feasible for routine analysis[11]. Thus, *Cryptosporidium* oocysts may be present in raw water, but remain undetected due to a single test method and small sample size of 10-liter. Although *Giardia* cysts were detected, their viability and endurance in water treatment processes should be questioned. Nonetheless, we strongly believe that our study provides an overview to the current situation in WTPs in Sarawak. We anticipate additional future research examining the emerging challenges of both chemical and microbial contaminants in drinking-water. This should be the ultimate goal of water treatment.

In conclusion, it is imperative that the existing water management policies and interventions be reviewed by all stakeholders, and that an all-inclusive approach toward water contamination is developed. WTPs in Sarawak did not achieve the log credits required to safeguard the microbial quality of water supplied, mainly because of lagging in the monitoring program. *Giardia* cysts were detected in 10-liter raw water samples, and indicator microbial parameters showed risky levels.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

AUTHOR CONTRIBUTIONS

NTL contributed to the study design, data collection, statistical analyses, and initial drafting of the manuscript. MABS carried out the final manuscript revision. YALL designed the study and revised the manuscript. MHOR was particularly involved in the statistical analyses and thorough revision of the initial draft. JS performed an extensive study design review, statistical analyses, and helped in manuscript finalization. All authors read and approved the final manuscript.

ACKNOWLEDGMENTS

The authors are grateful to Mr. Joshua A. Reyer, Assistant Professor, Department of Healthcare Administration, Nagoya University, for the technical support provided. They are also thankful to the staff of YLP for their eminent support. This study was partly supported by the nonprofit organization Epidemiological and Clinical Research Information Network (ECRIN), Kyoto, Japan.

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