KKU Journal for Public Health Research
Vol.13 No.3 July – September 2020

วารสารวิจัยสาธารณสุขศาสตร์ มหาวิทยาลัยขอนแก่น
ปีที่ 13 ฉบับที่ 3 เดือน กรกฎาคม – กันยายน 2563

Original Article

Risk Assessment of Chlorination Disinfection Byproducts in Tap Water after Boiling and in Swimming Pool Water

Kannikar Chatsantiprapa[(1)*], *Pinyapat Kongngern*[(2)], *Suthasinee Thappasarasart*[(3)]

Received Date: June 27, 2019
Accepted Date: January 6, 2020

** Corresponding author*
(1) Associate Professor, Faculty of Pharmaceutical Sciences, Khon Kaen University
(2) Master of Science Student in Toxicology, Faculty of Pharmaceutical Sciences, Khon Kaen University
(3) Assistant Professor, Faculty of Pharmaceutical Sciences, Khon Kaen University

Abstract

Introduction This study was aimed at assessing for human health risk from exposure to chlorination disinfection by-products (DPBs) of water from 2 sources, tap water and swimming pool water, by different routes of exposure since there have been reports of health risks. Methods Water samples in Khon Kaen Province from municipal tapwater after boiling in open and closed boilers, and swimming pool water from the middle and the border of the swimming pool, were investigated for THMs (Trihalomethanes) by Purge and Trap, GC-ECD, for HAAs (Haloacetic acids) by LCMSMS. Risk assessments of health effects from different routes of exposure to these DBPs were performed. Results Study proved that the open boiling was the most efficient method in reducing volatile THMs, the closed boiling with pump dispenser the second efficient and the closed boiler without pump dispenser was the least efficient. Repeated boiling increased evaporation of volatile chemicals and water, so involatile chemicals increased their concentrations. THMs in swimming pool water were found higher at the border than the middle of the pool. HAAs were found insignificant amount in tap water and swimming pool water. Lifetime excess cancer rates calculation of non-threshold toxicity from exposure to THMs in municipal tap water from various exposure routes were found too high, 258-378 fold the acceptable risk, most of them from ingestion route. The excess cancer rates from exposure during swimming was 1.24-1.93 fold the acceptable risk, most of them from inhalation route. However, the threshold toxicities of water of these 2 sources were in acceptable range. Conclusion We concluded that to reduce the cancer risk when boiling water, people should open the boiler to let volatile compounds to evaporate to reduce THMs, and should avoid repeated boilings since this will increase concentrations of involatile chemicals. When swim people should avoid to swim at the border of the pool for lesser cancer risk. Our study confirmed that there were unacceptable cancer risks from water resources disinfected by current chlorination disinfection methods in both tap water and swimming pool water.

***Keywords*:** *Trihalomethanes (THMs), Haloacetic Acids (HAAs), Closed Boiler, Open Boiler, Inhalation, Ingestion, Skin Contact*

KKU Journal for Public Health Research
Vol.13 No.3 July – September 2020

วารสารวิจัยสาธารณสุขศาสตร์ มหาวิทยาลัยขอนแก่น
ปีที่ 13 ฉบับที่ 3 เดือน กรกฎาคม – กันยายน 2563

นิพนธ์ต้นฉบับ

การประเมินความเสี่ยงสารที่เกิดจากการฆ่าเชื้อโรคในน้ำด้วยคลอรีนจากน้ำประปาที่ผ่านการต้มและน้ำจากสระว่ายน้ำ

กรรนิการ์ ฉัตรสันติประภา[(1)], ภิญญาพัชญ์ กองเงิน[(2)], สุธาสินี ทัพพสารพงศ์[(3)]*

วันที่ได้รับต้นฉบับ: 27 มิถุนายน 2562
วันที่ตอบรับการตีพิมพ์: 6 มกราคม 2563

ผู้รับผิดชอบบทความ
(1) รองศาสตราจารย์ คณะเภสัชศาสตร์ มหาวิทยาลัยขอนแก่น
(2) นักศึกษาหลักสูตรวิทยาศาสตรมหาบัณฑิต สาขาวิชาพิษวิทยา คณะเภสัชศาสตร์ มหาวิทยาลัยขอนแก่น
(3) ผู้ช่วยศาสตราจารย์ คณะเภสัชศาสตร์ มหาวิทยาลัยขอนแก่น

บทคัดย่อ

บทนำ งานวิจัยนี้มุ่งประเมินความเสี่ยงทางสุขภาพจากสารที่เกิดจากการฆ่าเชื้อโรคในน้ำด้วยคลอรีน (Chlorination Disinfection by-products, DBPs) จาก 2 แหล่งน้ำ(น้ำประปาที่ผ่านการต้ม และน้ำจากสระว่ายน้ำ)โดยช่องทางรับสัมผัสแตกต่างกันเนื่องจากมีรายงานถึงอันตรายต่อสุขภาพมาอย่างต่อเนื่องจากสาร DBPs วิธีวิจัย เก็บตัวอย่างน้ำประปาหลังต้มให้เดือดด้วยวิธีแตกต่างกันคือการต้มแบบเปิดฝาและการต้มแบบปิดฝาและเก็บตัวอย่างน้ำจากสระว่ายน้ำที่จุดเก็บตัวอย่างน้ำกลางสระและริมสระมาตรวจวิเคราะห์ โดย THMs (Trihalomethanes) ใช้ Purge and Trap, GC-ECD, ส่วน HAAs (Haloacetic acids) ใช้ LCMSMS แล้วทำการประเมินความเสี่ยง ผลการวิจัย งานวิจัยพบว่าการต้มโดยวิธีเปิดฝาจะลด THMs โดยการระเหยของสารได้ดีที่สุด การต้มแบบปิดฝาแล้วใช้วิธีการกดจ่ายน้ำออกจากหม้อต้มด้วยปั๊มลดสาร THMs ออกได้ดีรองลงมา และการต้มแบบปิดฝาแต่ไม่ได้ใช้วิธีการกดจ่ายน้ำออกจากหม้อต้มด้วยปั๊มจะลดสาร THMs ได้น้อยที่สุด การต้มน้ำซ้ำๆจะทำให้สารเคมีที่ระเหยได้และน้ำระเหยออกไปจนสารเคมีที่ระเหยได้น้อยมีความเข้มข้นเพิ่มขึ้นในน้ำ กรณีน้ำในสระว่ายน้ำงานวิจัยพบว่ามี THMs บริเวณขอบสระสูงกว่าบริเวณกลางสระ แต่กรณีสาร HAAs พบในน้ำประปาและน้ำสระว่ายน้ำในปริมาณที่ไม่มีนัยสำคัญ เมื่อประเมินอัตราเสี่ยงในการก่อมะเร็งตลอดชีวิต (Lifetime excess cancer rates) สำหรับกรณีความเสี่ยงด้านความเป็นพิษแบบไม่มีระดับกั้น (non-threshold toxicity) จากการใช้น้ำประปารวมจากหลายช่องทางรับสัมผัสพบว่าสูงเป็น 258-378 เท่าของอัตราเสี่ยงที่ยอมรับได้ซึ่งส่วนใหญ่เกิดจากช่องทางการกิน ส่วนอัตราเสี่ยงในการก่อมะเร็งตลอดชีวิตจากการรับสัมผัสน้ำในสระระหว่างว่ายน้ำสูงเป็น 1.24-1.93 เท่าของอัตราเสี่ยงที่ยอมรับได้ซึ่งส่วนใหญ่เกิดจากช่องทางการหายใจระหว่างว่ายน้ำ แต่กรณีความเสี่ยงด้านความเป็นพิษแบบมีระดับกั้น (threshold toxicity) ของน้ำจาก2แหล่งนี้อยู่ในระดับยอมรับได้ (acceptable range) สรุป ในการต้มน้ำควรปล่อยให้สารเคมีมีโอกาสระเหยออกไปได้เพื่อลดปริมาณ THMs ในน้ำ และควรหลีกเลี่ยงการต้มน้ำซ้ำๆ เนื่องจากเป็นการทำให้สารเคมีซึ่งระเหยยากกว่าน้ำหรือสารเคมีไม่ระเหยมีความเข้มข้นมากขึ้น เมื่อว่ายน้ำควรหลีกเลี่ยงการว่ายน้ำบริเวณขอบสระ เพื่อลดความเสี่ยงด้านการก่อมะเร็ง การศึกษานี้ยืนยันว่ามีความเสี่ยงต่อการเกิดมะเร็งในระดับยอมรับไม่ได้จากการฆ่าเชื้อโรคในน้ำด้วยคลอรีนด้วยวิธีการที่ใช้อยู่ในปัจจุบันทั้งน้ำประปาและน้ำในสระว่ายน้ำ

คำสำคัญ: *Trihalomethanes (THMs), Haloacetic Acids (HAAs), Closed Boiler, Open Boiler, Inhalation, Ingestion, Skin Contact*

Introduction

Chlorination disinfection in public water supply is the most popularly used method around the world due to the lowest cost and high efficacy despite several harmful disinfection byproducts (DBPs) are produced such as trihalomethanes (THMs), haloacetic acids (HAAs), haloacetonitriles (HANs) of which THMs and HAAs are used as indicators for DBPs since these 2 groups compose for about 80% of all DBPs (Health Canada, 2008). Studies showed that THMs (including chloroform or CF, bromodichloromethane or BDCM, chlorodibromomethane or CDBM, and bromoform or BF) could be carcinogens in animals and humans (WHO, 2004). For more detail please see Chatsantiprapa et al. (2020). In this article, DBPs of 2 different sources of water from chlorination-disinfection are presented, i.e., tap water after boiling and swimming pool water since boiling water has been reported to increase concentrations of DBPs in water (ATSDR, 2005; Rahman *et al.*, 2011), and swimming pool water is another important source of DBPs.

Methods

1. Water samples

Two sources of water are presented in this article. The first source of water samples was Khon Kaen municipal tap water as described in Chatsantiprapa et al. (2020). Since there are 2 common boiling methods used in households in Thailand, municipal tap water from a household at the last collection point (point 5, Chatsantiprapa et al., 2020) was used in the experiment to test for different disinfection byproducts (DBPs) occurrence between the 2 boiling methods, using an open boiler and a closed boiler (Figure1). In both boiling methods, 1 litre of water was boiled and collected for detection of DBPs (described in Chatsantiprapa et al. (2020) at 3 boiling intervals. The first interval, water was boiled for 5 min, then let cooling down before collection. The second interval was 10 h apart, re-boiling, let cooling down before collection. The third interval was another 14 h apart, re-boiling, let cooling down before collection. Water from the open boiler was collected by using a ladle up the boiler, whereas from the closed boiler water was pumped out through the self-contained-water-pump dispenser (as this is a common type of boiler used in households in Thailand). The second source of water samples was water from a swimming pool. This swimming pool is an active and open-air swimming pool with size Width x Length x Depth=25 x 50 x 1.2-2.2 m. The collection points were at the middle (eye sight estimation) and the border of the pool (within 50 cm from the swimming pool's border) (Figure 2). Collection time was at 7 am when the swimming pool was just open for swimming activities. Comparison between rainy and after-rainy periods of swimming pool water was also conducted. Analyses presented were from triplicate collections. Data shown were mean±S.D..



2. Water sample preparation and chemical analyses

Water was collected in rainy period (during September-October 2014) and after-rainy period (November-December 2014). Analysis for THMs (Trihalomethanes) was by Purge and Trap and GC- ECD, for HAAs (Haloacetic acids) by LCMSMS (see Chatsantiprapa et al. (1) for detail).

3. Risk assessment estimation (ATSDR, 2005; US.EPA., 1989; US.EPA., 1992a; US.EPA., 1992b)

3.1 Calculation for risk of threshold toxicity (non-carcinogenic effects)

Total hazard index (HI)=Hazard quotient from ingestion of water containing DBPs +Hazard quotient from inhalation of volatile DBPs from water during shower or swimming + Hazard quotient from dermal contact of water containing DBPs during shower or swimming.

Each hazard quotient from ingestion (HQ_{ing}), inhalation (HQ_{inh}), dermal contact (HQ_{der}) = ADD /RfD

ADD =average daily intake dose of DBPs from ingestion, inhalation, dermal contact (average over a year of exposure)

RfD = reference dose from ingestion, inhalation, dermal contact of DBPs

3.2 Calculation for risk of non-threshold toxicity (carcinogenic effects)

Total cancer risk = Cancer risk from ingestion of water containing DBPs + Cancer risk from inhalation of volatile DBPs from water during shower or swimming + Cancer risk from dermal contact of water containing DBPs during shower or swimming

Cancer risk for a lifetime from ingestion, inhalation, dermal contact from each DBPs = SF x LADD

Where SF = slope factor (carcinogenic potency factor) of DBPs

LADD = lifetime average daily intake dose of DBPs from ingestion, inhalation, dermal contact (average over a lifetime)

3.3 Calculation for intake dose

The intake doses from exposure via ingestion, inhalation and dermal contact routes were calculated for average daily intake dose (ADD) over a year of exposure to evaluate for threshold toxicity (non-carcinogenic effects), and for lifetime average daily intake dose (LADD) over a lifetime of exposure to evaluate for non-threshold toxicity (carcinogenic effects) for DBPs detected from municipal water supply and swimming pool water (2 sources) as follow.

ADD_{ing} = Average daily intake dose from ingestion = C_w x IR x EF / BW

ADD_{inh} = Average daily intake dose from inhalation = C_w x K x IR x EF / BW

ADD_{der} = Average daily intake dose from dermal contact = C_w x K_p x SA x EF / BW

$LADD_{ing}$ = lifetime average daily intake dose from ingestion = C_w x IR x EF x AT / BW x LT

$LADD_{inh}$ = Lifetime average daily intake dose from inhalation = C_w x Kx IR x EF x AT / BW x LT

$LADD_{der}$ = Lifetime average daily intake dose from dermal contact = C_w x K_p x SA x EF x AT / BW x LT

and EF = F x ED / d

ADD =average daily intake dose, LADD= lifetime average daily intake dose, C_w= chemical concentration in water, K =volatilization factor of the chemical from water to air = 0.5 L/m^3 (US. EPA} 1991), IR = intake rate from ingestion or inhalation, EF= exposure factor, F = frequency of exposure, ED = exposure duration, BW = body weight= 63 kg (male and female combined, Size Thailand, 2007-2008; U.N., 2015), AT= averaging time, LT = lifetime= 74 years (male and female combined, SizeThailand, 2007-2008; U.N., 2015),

K_p = permeability coefficient of the chemical via skin, SA = body surface area = 1.688m^2 (male and female combined, SizeThailand, 2007-2008; U.N., 2015). Conversion factors: 1 litre = 0.001 m^3=1000 cm^3.

In calculating for municipal water supply, ADDs was assumed equal to LADDs as water was assumed to be used (exposed) regularly at the same rate every day all through a lifetime. For inhalation and dermal contact of municipal water it was assumed to occur during the shower. In the worst case: daily intake dose was calculated from the highest concentration of DBPs detected (see Chatsantiprapa et al., 2020). In the best case: daily intake dose was calculated from the concentration of DBPs detected in finished water at Kotha water treatment plant (the start point of tap water supply route) (see Chatsantiprapa et al., 2020).

In calculating for intake doses of swimming pool water, ingestion, inhalation, and dermal exposure were assumed to occur during swimming. In the worst case: daily intake dose was calculated from the highest concentration of DBPs detected. In the best case: daily intake dose was calculated from the lowest concentration of DBPs detected.

4. Statistical analysis

Differences between groups were tested by one–way ANOVA, then Tukey HSD for post-hoc multiple comparisons, using statistix10 (Analytical Software, USA).

Results

1. Validation of methods for chemical analyses

All analyses were proved to be within acceptable range both for THMs and HAAs (see Chatsantiprapa et al. (2020) for detail).

2. Water from different boiling methods

Baseline values were from Chatsantiprapa et al. (2020). Boiling significantly reduced free chlorine from baseline even after the first boiling in both boiling methods. From the open boiling, free chlorine was further reduced significantly after the second boiling but remained unchanged after the third boiling. While from the closed boiling, free chlorine did not change further in repeated boilings. Dissolved organic carbons (DOCs) were found significantly higher in the closed boiling than the open boiling. However, after the third boiling, DOCs increased its concentration significantly in both boiling methods with the open boiling significantly higher than the closed boiling (Table 4).

For trihalomethanes (THMs) detection, it was found that after the first boiling, THMs were significantly reduced in both boiling methods and every repeated boiling in both methods further reduced THMs significantly. Closed boiling was found to significantly reduce THMs more efficiently than the open boiling after the second and third boiling (Table 5).

Comparison of THMs after mixing the boiling methods and the water collection methods - an open boiler collecting water by ladling up the boiler, a closed boiler collecting through a self- contained- water- pump dispenser, and a closed boiler collecting by ladling up the boiler - to test for the effects of boilers and collection methods. It was found that the open boiler gave the lowest each THM compound and TTHMs of all boiling methods since after the first boiling. Comparing between 2 different collection methods of the closed boilers found that the pump dispenser significantly reduced more THMs than using a ladle up the boiler (Table 6). These results meant that the open boiling was the most efficient method in reducing volatile chemicals, the

closed boiling with pump dispenser the second efficient and the closed boiler using a ladle was the least efficient.

For haloacetic acids (HAAs) detection, it seemed that boiling did not significantly change HAAs. Dichloroacetic acid (DCAA) was found the highest concentration of all HAAs in both boiling methods (Table 7).

3. Water from a swimming pool

After-rainy period, free chlorine in water was found significantly higher than water in rainy period. And water at the border of the swimming pool was found significantly higher free chlorine than water in the middle of the pool (Table 8).

For THMs detection, TTHMs and chloroform (CF) were found higher in the water at the border of the pool than in the middle of the pool in both rainy and after-rainy periods, with CF the highest concentration of all THMs. After-rainy period water was found higher TTHMs and CF than in the rainy period (Table 9).

For HAAs detection, there were no statistical difference in concentrations between rainy and after-rainy periods and between the border and the middle of the pool in each HAA and THAAs. However, DCAA the highest concentration of all HAAs was found significantly higher in the middle of the pool in rainy period (Table 10).

4. Risk assessment estimation

4.1 Risk of threshold and non-threshold toxicities from municipal tap water

In calculating from all routes of exposure (ingestion, inhalation, dermal) to municipal tap water for the worst case scenario, the risk of threshold toxicity was within acceptable range with grand total HI=0.5169. However, the risk of non-threshold toxicity was unacceptable with the grand total lifetime excess cancer rate = 3.78x10-4. It was 378 fold of acceptable lifetime excess cancer rate (10-6, US EPA). For the best case scenario calculation, the risk was a little better with the grand total HI=0.3701, the grand total lifetime excess cancer rate =2.58x10-4. The major source of the risks both for threshold and non-threshold toxicity were from the ingestion route (Table 11).

4.2 Risk of threshold and non-threshold toxicity from swimming pool water

In calculating for the worst case for the risk of threshold toxicity from swimming pool water (from the border of the pool at after-rainy period), it was found very safe with grand total HI= 0.0075, and the best case (from the middle of the pool at rainy period) grand total HI=0.0044 (Table 12). The hazards came mainly from dermal exposure and inhalation. However, the risk from non-threshold toxicity was unacceptable with the grand total lifetime excess cancer rate = 1.93x10-6 in the worst case, and = 1.24x10-6 in the best case. The cancer risks came mainly from inhalation (Table 13).

Discussion and conclusion

The lower free chlorine and higher DOCs after boiling of tap water compared to baselines reflected the evaporation of free chlorine and water but not DOCs. But for DBPs (THMs, HAAs), our boiling experiments had 2 major factors involved, the temperature activation factor, and the chemical evaporation factor.

To prove temperature as an activation factor building up DBPs (both THMs and HAAs) (ATSDR, 2005; Rahman *et al.,* 2011), we expected that after boiling the levels of DBPs should increase and more boilings more DBPs. For chemical evaporation factor, at boiling temperature we expected that the volatile compounds should reduce their concentrations, the involatile compounds should not reduce, but increase their

concentrations due to the evaporation of water. The temperature activation effect and evaporation of voltatile chemicals produced from temperature activation effect could be counteracted in our experiments. Hence, the results were difficult to observed. However, in our experiments situations were more complicated. The closed boiling method could have intervened the results since a closed boiler might have prevented the evaporation of chemicals and water. The different methods of water collection in our study could also be another factor intervening the results as water was collected from the open boiler by using a ladle collecting up the open boiler, whereas from a closed boiler, water was collected by pumping out through a self- contained- water-pump dispenser. The dispelling force of the dispensing pump of the closed boiler may have added to evaporation of the volatile compounds when running out of the closed boiler, thus, resulted in a lesser volatile compounds left in water.

In this study, the closed boiler was found with a little (insignificant) higher THMs after the first boiling than the open boiler. This may have reflected the prevention of evaporation effect in a closed boiler of THMs. However, after the second and third boiling, the closed boiler showed a much significantly lower THMs than the open boiler. This may have proved the more efficient effect of pump dispensing methods of the closed boiler in reducing the volatile THMs than the mere evaporation of chemicals from an open boiler. As THMs are volatile at high temperature, even if compounds may have been produced from heat activation during boiling (ATSDR, 2005; Rahman *et al.,* 2011) and escaping of compounds may have been prevented in a closed boiler, the high pumping force while dispensing through the self- contained- water-pump dispenser should have overcome these factors and dispelled most of the volatiles, resulted in much lesser levels found in the second and third boilings. Moreover, when comparing between the 2 closed boilings with different collection methods, using a ladle collecting water up the container vs. pumping out through the dispenser, the pumping collection still resulted in lesser amount of THMs in water. Therefore, we confirmed that the closed system of boiling with self- contained- water-pump dispenser although THMs produced may have been prevented from evaporating during boiling, it posed a lesser health risk due to the high dispelling force during pump- dispensing comparing to without pump dispensing. Our experiments proved that the open boiling was the most efficient method in reducing volatile chemicals, the closed boiling with a pump dispenser the second efficient and the closed boiler without pump dispenser was the least efficient methods.

Therefore, in households where people boil chlorination disinfected water (thus containing chlorine residues and DOCs – precursors of DBPs, Rodriguez et al., 2004; Yee et al., 2006; Gough et al., 2014) in a tightly closed container and do not use a pump dispenser but other collection methods without dispelling force, or if the boiled water is left in the boiler until cool before use, in particular repeated boilings, the health risks from THMs produced could be higher than expected.

The finding with HAAs, another DBPs, was different from THMs. HAAs are not volatile compounds at water boiling temperature. Therefore, boiling had no effect in decreasing the chemicals, but evaporation of water from boiling temperature should result in increasing the concentrations. After boiling, only DCAA and

DBAA were detectable in our study but MCAA and other chemicals were not detectable, thus, resulting in lesser THAAs than baselines. However, as HAAs occurred in only a small amount in our municipal tap water, the significance before or after boiling did not change. Overall, HAAs in municipal tap water in this study should have had only little health effects.

In the swimming pool, free chlorine and THMs were found higher at the border of the pool than the middle of the pool. This may be due to the usually higher movement of water in the middle of the pool from swimming activities than in the border. This factor resulted in more escaping of volatile compounds in the middle of the pool. Hence, the health risk was higher to people who tended to swim around or near the border of the pool than in the middle of the pool. THMs were also found higher in after-rainy period than the rainy period. This may be due to less water dilution from rain in after-rainy period.

In this study, the estimations of risk were based on many assumptions. The discussion on assumptions of risk from ingestion of municipal tap water was described in Chatsantiprapa *et al*. (1) in which ADD was assumed equal to LADD since water should be consumed regularly in every day through out the lifetime. However, ADDs and LADDs when calculated for risk from swimming water were different since the exposure did not occur daily and the averaging time was not equal to the lifetime. We assumed ADD as the average dose of exposure for a yearly basis while LADD as a lifetime basis with 50 years exposure duration (averaging time for swimming). The risk from inhalation route of exposure was calculated with more uncertainties than ingestion route since the reference doses of THMs via inhalation were not specified by US EPA. Therefore, we assumed the inhalation reference doses the same as the ingestion reference doses although the uptake of these chemicals via these two different routes should be different. Moreover, the volatilization factors of THMs were used 0.5 L/m^3 for all THMs as suggested by Andelman (1990) in US EPA (1991) due to simplicity although many other studies proposed many different methods in estimating these factors such as Smith et al. (1980), Moya et al. (1999), Marti et al. (2014) and others. Gordon et al. (cited in Nuckols et al., 2005) reported that much higher levels of THMs were measured in exhaled breath if the water temperature was raised from 30 or 35°C to 40 °C and study of Nuckols et al. (2005) confirmed that showering and bathing activities are important sources of THMs exposure. Nevertheless, we expected that the result of the inhalation risk in our study may have been overestimated for situations in Thailand. The intake dose via inhalation in Thailand could be somehow lower than that occured in the settings of the temperate countries from both during shower and swimming since our shower room and swimming pool are usually better ventilated (swimming pool in open-air) due to a natural warmer weather in Thailand, and therefore, the shower and swimming water are usually not heated. These factors might have produced lesser volatilization of THMs while taking shower or swimming. Therefore, intake of these volatiles via inhalation and thus the risk for people in Thailand might be somehow lower than the situations in temperate countries due to unheated water and better ventilation in the shower room or swimming pool area.

Previous studies had reported different significance of the exposure routes to DBPs. Some studies reported inhalation exposure the highest risk during showers (Wang et al., 2007) or

that inhalation contributed to 80-90% of the total risk (Basu et al., 2011) or inhalation was higher risk compared to ingestion or dermal exposure (Siddigue et al., 2015). Panyakapo et al. (2008), a study in Thailand, reported THMs in swimming pool higher than that in tap water and skin exposure while swimming was the highest risk to people. Our study and Pentamwa et al. (2013) were also in Thailand, studies' results were similar in that ingestion gave the highest risk of all routes of exposure to public water supply containing DBPs. However, in our study of exposure to swimming pool water, the inhalation route gave the highest risk of all routes of exposure for nonthreshold toxicity. The total excess cancer risk from swimming water exceeded the acceptable rate. The differences among studies may have been due to different study locations and settings, methods of chemical analyses, assumptions in the calculation, and reference values used in the calculation. However, all studies pointed to the unacceptable cancer risk from THMs in water resources disinfected with chlorination. Therefore, for safety, we recommend urgent measures should be pursued. More safety measures were described in Chatsantiprapa et al. (2020)

Acknowledgement

This study was supported by Khon Kaen University general research grant, fiscal year 2013. We are grateful to Kotha Water Treatment Plant for allowing us to collect water samples for this study.

References

Agency for Toxic Substances and Disease Registry [ATSDR]. (2005). **Public health assessment guidance manual (2005 update): Appendix G, calculating exposure doses.** Retrieved June 30, 2016, from https://www.atsdr.cdc.gov/hac/phamanual/appg.html

Basu, M., Gupta, S. K., Singh, G., & Mukhopadhyay, U. (2011). Multi-route risk assessment from trihalomethanes in drinking water supplies. **Environmental Monitoring and Assessment, 178**(1-4), 121-134.

Chatsantiprapa, K, Kongngern, P, Thappasarasart, S. (2020). Risk Assessment of Disinfection Byproducts from Ingestion of Municipal Tap Water Supply in Khon Kaen, Thailand. **KKU Journal for Public Health Research, 13**(2), 77-92.

Dufour, A. P., Evans, O., Behymer, T. D., & Cantú, R. (2006). Water ingestion during swimming activities in a pool: A pilot study. **Journal of Water and Health, 4**(4), 425-430.

Gough, R., Holliman, P. J., Willis, N., & Freeman, C. (2014). Dissolved organic carbon and trihalomethane precursor removal at a UK upland water treatment works. **Science of the Total Environment, 468-469**, 228-239.

Martí, V., De Pablo, J., Jubany, I., Rovira, M., & Orejudo, E. (2014). Water-Air Volatilization Factors to Determine Volatile Organic Compound (VOC) Reference Levels in Water. **Toxics, 2**(2), 276–290.

Moya, J., Howard-Reed, C., & Corsi, R. L. (1999). Volatilization of Chemicals from Tap Water to Indoor Air from Contaminated Water Used for Showering. **Environmental Science & Technology, 33**(14), 2321–2327.

Nuckols, J. R., Ashley, D. L., Lyu, C., Gordon, S. M., Hinckley, A. F., & Singer, P. (2005). Influence of Tap Water Quality and Household Water Use Activities on Indoor Air and Internal Dose Levels of Trihalomethanes. **Environmental Health Perspectives, 113**(7), 863–870.

Panyakapo, M., Soonthornchai, S., & Paopuree, P. (2008). Cancer risk assessment from exposure to trihalomethanes in tap water and swimming pool water**. Journal of Environmental Sciences, 20**, 372-378.

Pentamwa, P., Sukton, B., Wongklom, T., & Pentamwa, S. (2013). Cancer Risk Assessment from Trihalomethanes in Community Water Supply at Northeastern Thailand. **International Journal of Environmental Science and Development, 4**(5), 538–544.

Rahman, M. B., Driscoll, T., Clements, M., Armstrong, B. K., & Cowie, C. T. (2011). Effects of tap water processing on the concentration of disinfection by-products. **Journal of Water and Health, 9**(3), 507–514.

Risk Assessment Information System [RAIS]. (n.d). **Risk assessment information system: Chemical data profiles.** Retrieved Sep 17, 2018, from https://rais.ornl.gov/tools/profile.php

Rodriguez, M. J., Sérodes, J. B., & Levallois, P. (2004). Behavior of trihalomethanes and haloacetic acids in a drinking water distribution system. **Water Research, 38**(20), 4367–4382.

Siddique, A., Saied, S., Mumtaz, M., Hussain, M. M., & Khwaja, H. A. (2015). Multipathways human health risk assessment of trihalomethane exposure through drinking water. **Ecotoxicology and Environmental Safety, 116**, 129–136.

SizeThailand. (2007-2008). **Survey of morphology whole country Thailand (2550-2551).** Retrieved July 11, 2016, from http://www.sizethailand.org

Smith, J. H., Bomberger, D. C., & Haynes, D. L. (1980). Prediction of the volatilization rates of high-volatility chemicals from natural water bodies. **Environmental Science & Technology, 14**(11), 1332–1337.

Strenge, D. L., & Chamberlain, P.J. (1995). **Multimedia Environmental Pollutant Assessment System (MEPAS): Exposure pathway and human health impact assessment models.** Retrieved July 11, 2016, from https://mepas.pnnl.gov/mepas/formulations/exposure/vol5expo.pdf

United Nations. (2015). **World population prospects: The 2015 revision, Key findings and advance tables.** Retrieved July 11, 2016, from https://population.un.org/wpp/Publications/Files/Key_Findings_WPP_2015.pdf

United States Environmental Protection Agency [US. EPA]. (1987). **Integrated Risk Information System (IRIS): Chemical assessment summary.** Washington, DC: U.S. Environmental Protection Agency.

United States Environmental Protection Agency [US. EPA]. (1989). **Risk assessment guidance for superfund.** Washington DC: Human health evaluation manual.

United States Environmental Protection Agency [US. EPA]. (1991). **Risk Assessment Guidance for Superfund (RAGS): Part B. RAGS part B guidance documents, Chapter 3 calculation of risk-based preliminary remediation goals.** Retrieved June 13, 2016, from https://www.epa.gov/sites/production/files/2015-09/documents/chapt3.pdf

United States Environmental Protection Agency [US. EPA]. (1992a). **Dermal exposure assessment: Principles and applications. Office of health and environmental assessment.** Washington, DC: U.S. Environmental Protection Agency.

United States Environmental Protection Agency [US. EPA]. (1992b). **Guidelines for exposure assessment. Risk assessment forum.** Washington DC: U.S. Environmental Protection Agency,

United States Environmental Protection Agency [US. EPA]. (2005). **EPA Guidelines for Accurately Determining Volatile Organic Compound Concentration in Soil and Solid Matrices.** Washington DC: U.S. Environmental Protection Agency,

United States Environmental Protection Agency [US. EPA]. [n.d.]. **Integrated Risk Information System, US Environmental Protection Agency: IRIS Advanced Search.** Retrieved Jul 21, 2016, from https://www.epa.gov/iris

Wang, G. S., Deng, Y. C., & Lin, T. F. (2007). Cancer risk assessment from trihalomethanes in drinking water. **Science of The Total Environment, 387**(1–3), 86–95.

Yee, L. F., Abdullah, P., Ata, S., Ishak, B., & Ehsan, S. D. (2006). Dissolved organic matter and its impact on the chlorine demand of treated water. **The Malaysian Journal of Analytical Sciences, 10**(2), 243-250.

Table 1 Standard values used in calculation for ingestion

Term	Meaning	Value	Unit	Reference source
SF	Slope factor, ingestion			
	CF (chloroform)	0.061	$(mg/kg/d)^{-1}$	US EPA (n.d.)
	BDCM (bromodichloromethane)	0.062	$(mg/kg/d)^{-1}$	US EPA (n.d.)
	CDBM (chlorodibromomethane)	0.084	$(mg/kg/d)^{-1}$	US EPA (n.d.)
	BF (bromoform)	0.0079	$(mg/kg/d)^{-1}$	US EPA (n.d.)
RfD	Reference dose, ingestion			
	CF (chloroform)	0.01	mg/kg/d	U.S. EPA (1987)
	BDCM (bromodichloromethane)	0.02	mg/kg/d	U.S. EPA (1987)
	CDBM (chlorodibromomethane)	0.02	mg/kg/d	U.S. EPA (1987)
	BF (bromoform)	0.02	mg/kg/d	U.S. EPA (1987)
IR	Ingestion rate of water			
	- Municipal water	2.5	L/d	RAIS (n.d.)
	- Swimming pool water	0.016	L/event	Dufour, *et al.* (2006)
EF	Exposure factor for ingestion			
	- Municipal water	1		United Nations (2015)
	- Swimming pool: 24 events per year	24	events/y	Assumed for ADD calculation
	Averaging time for swimming	50	y	Assumed for LADD calculation

Table 2 Standard values used in calculation for inhalation

Term	Meaning	Value	Unit	Reference source [2-14]
SF	Slope factor,inhalation			
	CF (chloroform)	0.081	$(mg/kg/d)^{-1}$	US. EPA. IRIS (2005)
	BDCM (bromodichloromethane)	0.062	$(mg/kg/d)^{-1}$	US. EPA. IRIS (2005)
	CDBM (chlorodibromomethane)	0.084	$(mg/kg/d)^{-1}$	US. EPA. (n.d.)IRIS (2005)
	BF (bromoform)	0.0039	$(mg/kg/d)^{-1}$	US. EPA. (n.d.)IRIS (2005)
K	Volatilization factor	0.5	L/m^3	US. EPA. 1991, Strenge and Chamberlain, 1995
IR	Inhalation rate (Male and Female combined)			
	- Light intensity -shower	9.268E-3	m^3/min	Calculated from US.EPA (2011) and
	- Moderate intensity -swim	2.06E-2	m^3/min	United Nations (2015)
EF	Exposure factor for inhalation			
	- Municipal water supply:shower time 10 min/	20	min/d	Assumed ADD= LADD
	event, 2 event/d	74	y	United Nations (2015)
	Averaging time=Lifetime			
	- Swimming pool: 1 h per event, 24 events	24	h/y	Assumed for ADD calculation
	per year Averaging time for swimming	50	y	Assumed for LADD calculation

Table 3 Standard values used in calculation for chronic dermal contact

Term	Meaning	Value	Unit	Reference source
K_p	Chemical-specific dermal permeability constant			
	CF (chloroform)	0.0089	$cm.h^{-1}$	EPA (1992a)
	BDCM (bromodichloromethane)	0.0058	$cm.h^{-1}$	EPA (1992a)
	CDBM (chlorodibromomethane)	0.0039	$cm.h^{-1}$	EPA (1992a)
	BF (bromoform)	0.0026	$cm.h^{-1}$	EPA (1992a)

Table 3 Standard values used in calculation for chronic dermal contact (cont.)

Term	Meaning	Value	Unit	Reference source
SF	Slope factor (Cancer potency)			
	CF (chloroform)	0.0305	$(mg/kg/d)^{-1}$	RAIS (2005)
	BDCM (bromodichloromethane)	0.0633	$(mg/kg/d)^{-1}$	RAIS (2005)
	CDBM (chlorodibromomethane)	0.0140	$(mg/kg/d)^{-1}$	RAIS (2005)
	BF (bromoform)	0.0132	$(mg/kg/d)^{-1}$	RAIS (2005)
RfD	Reference dose, dermal			
	CF (chloroform)	0.002	mg/kg/day	U.S. EPA
	BDCM (bromodichloromethane)	0.02	mg/kg/day	U.S. EPA
	CDBM (chlorodibromomethane)	0.02	mg/kg/day	U.S. EPA
	BF (bromoform)	0.012	mg/kg/day	U.S. EPA
EF	Exposure factor for dermal contact			
	-Municipal water supply: shower time 10 min /event, 2events/d	20	min/d	Assumed ADD=LADD
	-Swimming pool: 1 h/event,			
	24 events per year	24	h/y	
	Averaging time for swimming	50	y	Assumed for LADD calculation

Table 4 Characteristics of municipal tap water after 2 different boiling methods, closed boiling and open boiling, at 3 boiling intervals. Collection of water samples of the open boiling was by ladling up the boiler, of the closed boiling was by pumping out through a self-contained-water-pump dispenser

Boiling methods	pH	Free chlorine (mg/l)	Dissolved organic carbon (mg/l)
Baseline values	6.87±0.01	0.50±0.00	4.95±0.59
Open, 1st boiling	7.16±0.00	0.025±0.20	4.68±0.00
Open, 2nd boiling	7.36±0.00	0.015±0.00[1]	4.62±0.00
Open, 3rd boiling	7.16±0.01	0.015±0.01[1]	6.94±0.00[1]
Closed, 1st boiling	7.20±0.00	0.025±0.00	5.40±0.00[#]
Closed, 2nd boiling	7.28±0.00	0.025±0.00[#]	5.52±0.00[#]
Closed, 3rd boiling	7.20±0.00	0.025±0.00[#]	6.16±0.00[1,#]

[1] = significantly different at $p<0.05$ when compared to the first boiling

[#]= significantly different at $p<0.05$ when compared between different boiling methods

Table 5 Trihalomethanes (THMs) detected in municipal tap water after 2 different boiling methods, an open boiling and a closed boiling, from 3 boiling intervals. Collection of water samples of an open boiling was by ladling up the boiler, of a closed boiling was by pumping out through a self-contained-water-pump dispenser

Boiling methods	THMs µg/l (mean ±SD)				
	CF	BDCM	CDBM	BF	TTHMs
Baseline values	92.39±5.9	33.94±1.53	17.77±0.81	0.17±0.50	144.27±8.8
Open, 1st boiling	63.43±2.35	26.79±0.54	3.36±0.31	0.09±0.01	93.67±3.21
Open, 2nd boiling	42.99±1.45[1]	13.87±1.48[1]	0.94±0.03[1]	ND	57.80±2.96[1]
Open, 3rd boiling	3.92±0.53[1,2]	0.37±0.05[1,2]	0.34±0.01[1,2]	ND	4.63±0.59[1,2]
Closed, 1st boiling	65.68±2.39	28.48±0.82	4.23±0.36	0.09±0.01	98.48± 3.58
Closed, 2nd boiling	2.92±2.07[1,#]	0.42±0.04[1,#]	0.35±0.01[1,#]	ND	3.69±2.12[1,#]
Closed, 3rd boiling	1.64±0.12[1,2,#]	0.33±0.02[1,2,#]	0.34±0.00[1]	ND	2.31±0.14[1,2,#]

CF-chloroform, BDCM=bromodichloromethane, CDBM=chlorodibromomethane, BF=bromoform, TTHMs=total THMs, ND=not detectable

1 = significantly different at p<0.05 when compared to the 1st boiling of the same method

2 = significantly different at p<0.05 when compared to the 2nd boiling of the same method

#= significantly different at p<0.05 when compared between different boiling methods

Table 6 Comparison of Trihalomethanes (THMs) between 3 different methods, an open boiler using a ladle up the boiler, a closed boiler using a self-contained-water-pump dispenser, and a closed boiler using a ladle up the boiler. All methods had 2 boiling intervals with 10 hours apart

Boiling methods	THMs µg/l (mean ±SD)				
	CF	BDCM	CDBM	BF	THMs
Open, 1st, ladle	52.12± 1.48	10.18 ± 0.64	0.91 ± 0.04	ND	63.21±2.16
Open, 2nd, ladle	19.71 ± 0.93[1]	0.38 ± 0.01[1]	0.34± 0.00[1]	ND	20.43±0.94[1]
Closed, 1st, pump	54.66 ± 1.41	18.85 ± 1.09	3.77 ± 1.06	0.08 ± 0.00	77.36±3.29
Closed, 2nd, pump	24.61 ±1.41[1,a]	0.31 ± 0.04[1]	0.34 ± 0.00[1]	ND	25.26±1.45[1,a]
Closed, 1st, ladle	60.39± 0.30	15.82 ± 1.31	3.20 ± 0.35	0.09 ± 0.00	79.50± 1.96
Closed, 2nd, ladle	30.82±1.71[1,a,b]	0.45 ± 0.00[1,a,b]	0.33±0.00[1]	ND	31.6±1.71[1,a,b]

CF-chloroform, BDCM= bromodichloromethane, CDBM= chlorodibromomethane, BF=bromoform, TTHMs=total THMs, ND = not detectable

1= significantly different at p<0.05 when compared to the 1st boiling of the same method

a= significantly different at p<0.05 when compared to the open boiling using a ladle up the boiler

b= significantly different at p<0.05 when compared to the closed boiling using a pump dispenser

Table 7 Haloacetic acids (HAAs) detected in municipal tap water after 2 different boiling methods, an open boiling and a closed boiling, from 3 boiling intervals

Boiling methods	HAAs µg/l (mean ±SD)					
	MCAA	DCAA	TCAA	MBAA	DBAA	THAAs
Baseline values	2.35±0.00	6.55±0.07	ND	ND	5.47±0.52	14.37±0.59
Open, 1st boiling	ND	6.65±0.05	ND	ND	5.77±0.58	12.42±0.63
Open, 2nd boiling	ND	6.58±0.05	ND	ND	5.25±0.46	11.83±0.51[1]
Open, 3rd boiling	ND	6.76±0.02	ND	ND	6.05±0.18[1]	12.81±0.2
Closed, 1st boiling	ND	6.94±0.07	ND	ND	5.64±0.79	12.58±0.86
Closed, 2nd boiling	ND	6.94±0.07	ND	ND	5.57±0.70	12.51±0.77
Closed, 3rd boiling	ND	6.88±0.02	ND	ND	5.46±0.62	12.34±0.64

MCAA=monochloroacetic acid, DCAA=dichloroacetic acid, TCAA=trichloroacetic acid, MBAA=monobromoacetic acid, DBAA=dibromoacetic acid, THAAs= total HAAs, ND = not detectable

1= significantly different at p<0.05 when compared to the 1st boiling of the same method

Table 8 Characteristics of a swimming pool water in rainy period and after-rainy period

Locations	pH	Free chlorine (mg/l)	Dissolved organic carbons (mg/l)
Rainy period			
Border	3.32±0.28	3.25±0.36	41.83±5.77
Middle	3.63±0.72	3.05±0.07	40.38±15.71
After-rainy period			
Border	3.47±0.14	4.65±0.21[#]	39.31±0.35
Middle	3.36±0.21	4.05±0.08[1,#]	39.94±0.52

Border=water was collected within 50 cm from the swimming pools border

Middle=water was collected from the middle point of the swimming pools (eye sight estimation)

1= significantly different at p<0.05 when compared with border

= significantly different at p<0.05 when compared with rainy period

Table 9 Trihalomethanes (THMs) detected in a swimming pool water in rainy period and after-rainy period from 2 locations

Location	THMs (µg/l) (mean ±SD)				
	CF	BDCM	CDBM	BF	TTHMs
Rainy					
Border	38.02 ± 0.06	3.14 ± 0.23	0.47 ± 0.05	0.01 ± 0.25	41.64± 0.59
Middle	29.08 ± 0.38[1]	3.34 ± 0.16[1]	0.46 ± 0.01	0.34 ± 0.04[1]	33.22± 0.59[1]
After-rainy					
Border	51.40 ± 4.09	1.32 ± 0.06	0.35 ± 0.00	ND	53.07± 4.15[#]
Middle	48.69 ± 7.43[1,#]	2.11 ± 0.05[1,#]	0.54±0.03[1,#]	ND	51.34± 7.51[1,#]

CF-chloroform, BDCM= bromodichloromethane, CDBM= chlorodibromomethane, BF=bromoform, TTHMs=total THMs, ND = not detectable

Border=water was collected within 50 cm from the border of the swimming pools Middle=water was collected from the middle point of the swimming pools (eye sight estimation)

1= significantly different at $p<0.05$ when compared with border

= significantly different at $p<0.05$ when compared that point between after-rainy period with rainy period

Table 10 Haloacetic acids (HAAs) detected in a swimming pool water in rainy period and after-rainy period from 2 locations and 2 periods

Location	HAAs µg/l (mean ±SD)					
	MCAA	DCAA	TCAA	MBAA	DBAA	THAAs
Rainy						
Border	2.41±0.03	6.25±0.00	ND	ND	5.00±0.01	13.66±0.04
Middle	2.42±0.03	7.25±0.00[1]	ND	ND	5.00±0.01	13.68±0.04
After-rainy						
Border	2.35±0.00	6.24±0.00	ND	ND	5.00±0.00	13.64±0.00
Middle	2.40±0.02	6.24±0.00[#]	ND	ND	4.99±0.01	13.63±0.03

MCAA=monochloroacetic acid, DCAA=dichloroacetic acid, TCAA=trichloroacetic acid, MBAA=monobromoacetic acid, DBAA=dibromoacetic acid, THAAs= total HAAs, ND = not detectable

Border=water was collected within 50 cm from the border of the swimming poolsMiddle=water was collected from the middle point of the swimming pools (eye sight estimation)

1= significantly different at $p<0.05$ when compared with border

= significantly different at $p<0.05$ when compared that point between after-rainy period with rainy period

Table 11 Risk assessment of THMs from Khon Kaen municipal tap water supply as for threshold toxicity by Hazard Index (HI) and Hazard Quotients(HQ) and for non-threshold toxicity by lifetime excess cancer risk from the daily intake dose[1] (DD) from ingestion, inhalation, and dermal contact routes

THMs	Conc (µg/l)	$^{1}DD_{ing}$ (µg/kg.d)	HQ_{ing}	$^{4}Cancer\ risk_{ing}$	$^{1,2}DD_{inh}$ (µg/kg.d)	$^{3}HQ_{inh}$	$^{4}Cancer\ risk_{inh}$	$^{1}DD_{der}$ (µg/kg.d)	HQ_{der}	$^{4}Cancer\ risk_{der}$	Total HI	Total cancer risk[4]
Calculation for the worst case scenario												
CF	92.39	3.5869	0.3587	2.2E-4	0.1359	0.0136	1.1E-5	0.0734	0.0367	6.5E-7	0.4090	2.3E-4
BDCM	33.94	1.3468	0.0673	8.4E-5	0.0499	0.0025	3.1E-6	0.0176	0.0009	1.0E-7	0.0707	8.7E-5
CDBM	17.77	0.7052	0.0353	5.9E-5	0.0260	0.0013	2.2E-6	0.0062	0.0003	2.4E-8	0.0369	6.1E-5
BF	0.17	0.0067	0.0003	5.3E-8	0.5E-3	1.3E-5	2.0E-11	3.9E-5	3.3E-6	1.0E-10	0.0003	5.3E-8
sum			0.4616	3.63E-4		0.0174	1.63E-5		0.0379	7.7E-7	0.5169	3.78E-4
	Grand total HI = 0.5169, Grand total cancer risk = 3.78E-4											

Table 11 Risk assessment of THMs from Khon Kaen municipal tap water supply as for threshold toxicity by Hazard Index (HI) and Hazard Quotients(HQ) and for non-threshold toxicity by lifetime excess cancer risk from the daily intake dose[1] (DD) from ingestion, inhalation, and dermal contact routes (cont.)

THMs	Conc (µg/l)	$^{1}DD_{ing}$ (µg/kg.d)	HQ_{ing}	$^{4}Cancer\ risk_{ing}$	$^{1,2}DD_{inh}$ (µg/kg.d)	$^{3}HQ_{inh}$	$^{4}Cancer\ risk_{inh}$	$^{1}DD_{der}$ (µg/kg.d)	HQ_{der}	$^{4}Cancer\ risk_{der}$	Total HI	Total cancer risk[4]
Calculation for the best case scenario												
CF	67.11	2.6631	0.2663	1.6E-4	0.0987	0.0099	8.0E-6	0.05334	0.0267	4.7E-7	0.3029	1.68E-4
BDCM	28.43	1.1282	0.0564	7.0E-5	0.0418	0.0021	2.6E-6	0.01473	0.0007	8.5E-8	0.0592	7.27E-5
CDBM	3.82	0.1516	0.0076	1.3E-5	0.0562	0.0003	4.7E-6	0.00133	0.0001	5.2E-9	0.008	1.77E-5
BF	ND	-	-	-	-	-	-	-	-			
			0.3303	2.43E-4		0.0123	1.5E-5		0.0275	5.6E-7	0.3701	2.58E-4
	Grand total HI = 0.3701, Grand total cancer risk = 2.58E-4											

1 average daily intake dose (ADD) and lifetime average daily intake dose (LADD) were assumed equally as daily intake dose (DD) in assessing the hazard quotients and index (HQ and HI) and cancer risk from municipal water supply for threshold toxicity and non-threshold toxicity assessment

2 volatilization factor was assumed equally for all THMs = 0.5 L/m^3 (US.EPA, 1991)

3 reference doses for all individual THMs via inhalation were assumed the reference doses via ingestion, as the reference doses from inhalation were not specified by US EPA.

4 cancer risk = a lifetime additional cancer risk or a lifetime excess cancer rate from exposure

Table 12 Risk assessment of trihalomethanes (THMs) from a swimming pool as for threshold toxicity by Hazard Index (HI) and Hazard Quotients (HQ) from the average daily intake dose (ADD) from ingestion, inhalation, and dermal contact routes

THMs	Conc (µg/l)	$^{1}ADD_{ing}$ (µg/kg.d)	HQ_{ing}	$^{1,3}ADD_{inh}$ (µg/kg.d)	$^{4}HQ_{inh}$	$^{1}ADD_{der}$ (µg/kg.d)	HQ_{der}	Total HI
Calculation for the worst case scenario								
CF	51.40	8.6E-4	8.6E-5	3.32E-2	3.3E-3	8.1E-3	4.1E-3	7.5E-3
BDCM	1.32	2.2E-5	1.1E-6	8.5E-4	4.3E-5	1.4E-4	0.7E-5	5.1E-5
CDBM	0.35	5.8E-6	2.9E-7	2.3E-4	1.1E-5	2.4E-5	0.2E-6	1.1E-5
BF	ND	-	-	-	-	-	-	
sum			8.74E-5		3.4E-3		4.12E-3	7.5E-3
	Grand total HI = 0.0075							
Calculation for the best case scenario								
CF	29.08	4.9E-4	4.9E-5	1.9E-2	1.9E-3	4.6E-3	2.3E-3	4.25E-3
BDCM	3.34	5.6E-5	2.8E-6	2.2E-3	1.0E-4	3.4E-4	3.4E-5	1.37E-4
CDBM	0.46	7.7E-6	3.9E-7	3.0E-4	1.5E-5	3.2E-5	1.6E-6	1.66E-5
BF	0.34	5.7E-6	2.9E-7	2.2E-4	1.1E-5	1.6E-5	2.0E-6	1.3E-5
sum			5.2E-5		2.0E-3		2.3E-3	4.4E-3
	Grand total HI = 0.0044							

1 average daily intake doses (ADDs) were averaged from 24 swimmings over a year with 1 hour per swimming.

3 volatilization factor was assumed equally for all THMs = 0.5 L/m^3 (US.EPA, 1991)

4 reference doses for all individual THMs via inhalation were assumed the reference doses via ingestion, as the reference doses from inhalation were not specified by US EPA.

5 cancer risk means a lifetime additional cancer risk or a lifetime excess cancer rate from exposure

Table 13 Risk assessment of trihalomethanes (THMs) from a swimming pool water as for non-threshold toxicity (lifetime excess cancer risk) from the lifetime average daily intake dose (LADD) from ingestion, inhalation, and dermal contact routes

THMs	Conc (µg/l)	[2]$LADD_{ing}$ (µg/kg.d)	[5]Cancer $risk_{ing}$	[2,3]$LADD_{inh}$ (µg/kg.d)	[4,5]Cancer $risk_{inh}$	[2]$LADD_{der}$ (µg/kg.d)	[5]Cancer $risk_{der}$	Total cancer risk[5]
Calculation for the worst case scenario								
CF	51.40	5.8E-4	3.5E-8	2.2E-2	1.8E-6	5.4E-3	4.8E-8	1.88E-6
BDCM	1.32	1.5E-5	9.3E-10	5.7E-4	3.5E-8	0.9E-4	5.2E-10	3.65E-8
CDBM	0.35	3.9E-6	3.3E-10	1.6E-4	1.3E-8	1.6E-5	6.2E-11	1.3E-8
BF	ND	-	-	-	-	-	-	-
			3.5E-8		1.85E-6		4.9E-8	1.93E-6
	Grand total cancer risk = 1.93E-6							
Calculation for the best case scenario								
CF	29.08	3.3E-4	2.0E-8	1.3E-2	1.1E-4	3.1E-3	2.8E-8	1.1E-6
BDCM	3.34	3.8E-5	2.3E-9	1.5E-3	9.3E-8	2.3E-4	1.3E-9	1.2E-7
CDBM	0.46	5.2E-6	4.4E-10	2.0E-4	1.7E-8	2.2E-5	8.6E-11	1.7E-8
BF	0.34	3.9E-6	3.1E-11	1.5E-4	5.9E-10	1.1E-5	2.9E-11	7.9E-10
			2.27E-8		1.1E-6		2.93E-8	1.24E-6
	Grand total cancer risk = 1.24E-6							

2 lifetime average daily intake doses (LADDs) were averaged over a lifetime (74 years) with 50 years averaging time

3 volatilization factor was assumed equally for all THMs = 0.5 L/m^3 (US.EPA, 1991)

4 reference doses for all individual THMs via inhalation were assumed the reference doses via ingestion, as the reference doses from inhalation were not specified by US EPA.

5 cancer risk means a lifetime excess cancer risk from exposure



Figure 1 Comparison of water boiling in 2 different methods, in an open boiler (left) and a closed boiler (right)

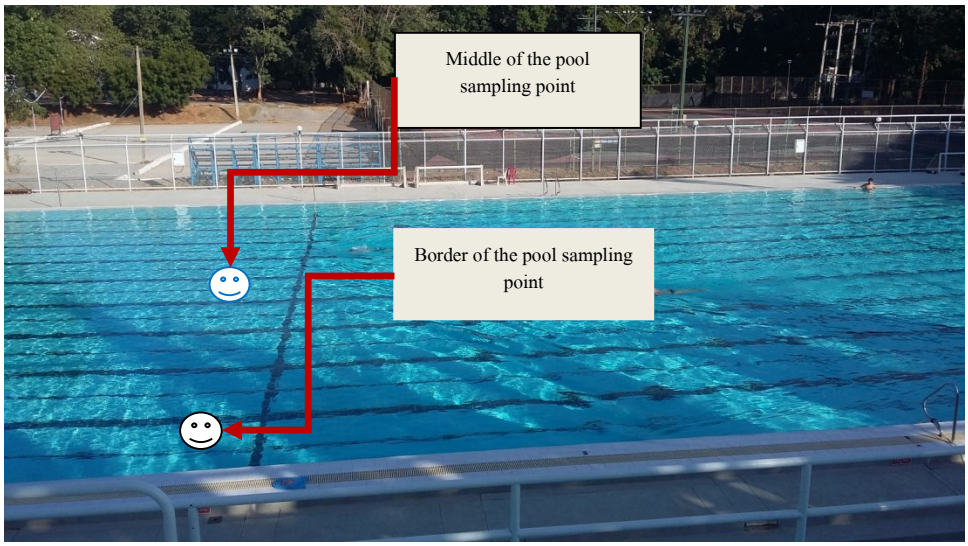


Figure 2 A swimming pool in Khon Kaen Province showing 2 water sampling points