Cancer Risk Assessment from Trihalomethanes in Community Water Supply at Northeastern Thailand

Prapat Pentamwa, Benchamaporn Sukton, Tanisa Wongklom, and Sathaporn Pentamwa

Abstract—This study aims to investigate the concentration, lifetime cancer risk, and hazard index of trihalomethanes (THMs) through oral ingestion, dermal absorption and inhalation exposure from tap water of 17 community water treatment plants in northeastern Thailand. Chloroform (CHCl_3) was found at highest level compared to dichlorobromomethane (CHCl_2Br), chlorodibromomethane (CHClBr_2) and bromoform (CHBr_3) species. Results revealed that the Chongsammoe water treatment plant in Chaiyaphum province was found in the highest levels of 48.46 $\mu\text{g/L}$ for total THMs whereas the levels were below the water quality guideline of WHO. Among the three pathways studies, the highest lifetime cancer risk comes from oral ingestion followed by dermal absorption and inhalation exposure route, mainly because of the exposure to CHCl_3 . Overall 6 of 17 plants, the lifetime cancer risk for CHCl_2Br and CHCl_3 through oral ingestion route were higher than risk level of 10^{-6} , the negligible defined by the USEPA. The average hazard index of total THMs in all multi-pathway exposure routes was lower than 1 indicating to acceptable non-carcinogenic risk level.

Index Terms—Cancer risk assessment, trihalomethanes, Thailand, water supply.

I. INTRODUCTION

Water supply sector is play a major role of economy growth and social well being. The inadequate access to clean water is directly combined with the lack of basic sanitation. The Millennium Development Goal aims at by 2015; the proportion of the world population would sustainable access to safe drinking water. In Thailand, the surface water resource is the core importance of water supply for community that the total volume of water from the rainfall in all river basin of about 800,000 million m^3 . The estimated for the use of improve drinking water sources was 97% of the country which both of 48% on the proved piped water system and other improved water sources [1]. The water treatment systems in Thailand are organized by four organizations: 1) the metropolitan waterworks authority responsible for the Metropolitan Bangkok Region, and the provincial waterworks authority responsible to the major city of the country, the rural water supply is operated by the local authority and the private water treatment plant. The water

sources of water treatment systems were commonly taken from surface water and underground water. The surface water supply was typically consisted of the coagulation-flocculation, filtration and disinfection systems. Chlorine has been recognized of the most effective agent to disinfect for deactivated microorganism and also to ensure the residual concentration for protected microorganism regrowth i.e. bacterial, virus, protozoa, in water distribution system. The effectively chlorination can protect human health risk from water born diseases such as cholera, typhoid fever, and dysentery. Chlorine has been preferred as disinfecting agents in community water supply systems due to their effectiveness and inexpensive. As a result of chlorination of natural water, the trihalomethanes (THMs) formation was reported from the reaction of chlorine with naturally occurring organic matter, mainly humic and fulvic acid. The THMs formation consists of chloroform (CHCl_3), dichlorobromomethane (CHCl_2Br), chlorodibromomethane (CHClBr_2) and bromoform (CHBr_3). They are considered to be possible carcinogenic compounds (B2 class). There are various organizations to set the maximum contaminant level of total THMs standard and guideline of 100 $\mu\text{g/L}$ for WHO and EU guideline whereas USEPA phase I standard have set to 80 $\mu\text{g/L}$. The maximum concentration levels of THMs are shown in Table I. Several epidemiology studies have been reported the correlation of the disinfection byproduct such as THMs contamination and carcinogenic diseases. In 1976, the US National Cancer Institute was first published that chloroform of THMs from drinking water was carcinogenic in rodent. The later research studies suggested that drinking chlorinated drinking water may be associated with increased incidence of bladder, rectal, and colon cancer and adverse reproductive effects [2].

TABLE I: THE GUIDELINE AND STANDARD LEVELS OF THMS

THMsSpecies	Cancer group	WHO Guideline ($\mu\text{g/L}$)	EU 2007	Japan Standards ($\mu\text{g/L}$)	USEPA Phase I ($\mu\text{g/L}$)
CHCl_3	B2	300	-	60	-
CHCl_2Br	B2	60	-	30	-
CHClBr_2	B2	100	-	10	-
CHBr_3	B2	100	-	90	-
Total THMs	-	Ratio of 1*	100	100	80

Remark: B2 Probable human carcinogen, *The sum of the ratio of each of the four levels to their individual guideline value should not exceed 1

Water from water treatment plant and tap water is generally used not only for drinking but also for washing, cleaning, cooking, showering, and bathing. The water constituted of contaminants i.e. THMs was potential to expose through ingestion during drinking or bathing, contact

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with skin as dermal absorption and even inhalation of the risk compounds. Several studies were estimated the lifetime cancer risk and non-carcinogenic risk for THMs through multi-pathway exposure routes [3]-[5]. The risk assessment for water was commonly calculated to ingestion exposure to toxic compound. Presently, the other routes of exposure in dermal and inhalation exposure may be more important than direct ingestion exposure [4]. In Hong Kong, the researcher reported that the cancer risk and hazard index of THMs from tap water that exposed through ingestion route higher than dermal and inhalation routes [3]. The another research study also reported that the THMs in Beijing and Canada drinking water were higher risk through oral ingestion than through other two pathway (dermal and inhalation) and female was more exposed of THMs than male [5]. The reported level of THMs in drinking water supply in Istanbul stated that oral ingestion was found at highest concentration and chloroform was mostly detected in water [6]. However, the study in Taiwan revealed that the Chloroform in water was highest risk from the inhalation exposure during shower and dominated to the total risk of THMs. This study also showed that exposure from THMs dermal absorption is not significant comparing to oral and inhalation exposure [4]. The importance of THMs inhalation exposure route was also reported in India that accounted of 80-90% of the total risk followed by oral exposure and dermal absorption. Chloroform was found to be major THMs [5]. One study in Thailand was investigated the THMs in tap water and swimming pool water in Nakorn Pathom. Results showed that the concentration of THMs in swimming pool water was higher than in tap water and cancer risk from skin exposure while swimming was 94.18% of the total risk [7]. The three exposure route of exposure may be attributed to different concentration and species of THMs present in water. However, THMs are generally well absorbed, metabolized and rapidly eliminated by mammals after oral or inhalation exposure [8].

In this study was first investigated the THMs exposure from tap water in community water supply plant from the northeastern Thailand. The lifetime cancer risks associated with THMs exposure from water treatment plant was estimated for each species and each route of exposure. Exposure to THMs species were considered through ingestion, dermal adsorption and inhalation routes for cancer risk, non-carcinogenic risk and a level of THMs was evaluated based on the drinking water standard.

II. MATERIALS AND METHODS

A. Study Area and Water Sampling

This study was carried out to collect water from communities water treatment plant in the lower northeastern of Thailand. The area covers of 4 cities namely Nakorn Ratchasima (Korat), Chaiyaphum, Buriram and Surin provinces. This region is covers more than one-third of the country which is called "Khorat Plateau" (Fig. 1). The water supply consumption in this area has been seriously concerned because of the low level of rainfall intensity and long dry period in this area. Total of 17 samples from surface water treatment plants were collected during March-June 2012 from 17 locations in the study area. This study was focused on the surface water treatment plant owned by community organization. The mostly water supply system was originally designed by Department of Health and commissionable operated by their community operation committee. The typically system consists of screening, coagulation-flocculation, sedimentation, filtration, chlorination and lastly distribution system to residential. The selected general water supply system was shown in Fig. 2. Water samples were collected from residential tap water which mainly connected from water supply distribution system.

Fig. 1. The map of study area

Fig. 2. Typical surface water treatment plant (Nongwang, Burirum)

B. Analytical Methods

Each sample was collected in 60 mL glass bottles with TFE silicone septa cap liner containing Na_2SO_3 (0.5% w/v) and H_3PO_4 (1+10) 0.2 mL solution for dechlorination and preservation. The sample was opened for about 3-5 min before sampling to ensure that the water was coming directly from the distribution system. The samples were then kept at 4°C until analysis. All samples were sent to the metropolitan waterworks authority of Thailand laboratory for analysis. Separations of the four forms-THMs were analyzed by gas chromatography with ECD detector of head-space technique (Hitachi model 263-50, Fig. 3), N_2 as carrier gas, injection and detector temperature were at 180 °C. The detection limit of chloroform, CHCl_2Br , CHClBr_2 , and bromoform were 0.17, 0.05, 0.15 and 1.50 $\mu\text{g/L}$, respectively. The glasswares used in the experiment were washed with detergent, tap water and then rinsed many times with distilled water. All glassware was dried at oven of 120 °C for 2-3 hours and then cooled in the room temperature.

Fig. 3. GC-ECD (Hitachi, model 263-50)

C. Human Health Risk Assessment

This study, the deterministic exposure approach to human health risk assessment was estimated according to USEPA guidelines [9], [10] and recently adopted by [3]-[5]. The estimation of life time cancer risk of THMs was calculated through oral ingestion, dermal absorption, and inhalation

exposure route. The cumulative risk over multiple routes of exposures and chemicals were assessed by used of concern RfD/C or slope factor approach [9]. The total life time cancer risk of THMs through multiple pathways was expressed as (1) and (2).

$$R_T = \sum_m (SF_i * d_i) \\ = \sum_{m=1}^n \left\{ \frac{C_m * EF * ED}{BW * AT} \left[(SF_{oral} * IR_w) + (SF_{dermal} * SA * K_p) \right] \right\} \quad (1)$$

where; R_T , Total lifetime cancer risk (unitless); d_i , The dose of stressor from the specified exposure route i (mg/kg*day); m the number of different chemical (unitless); SF_i , Slope factor from the specified exposure route i (mg/kg*day)⁻¹; i = oral, dermal and inhalation expressed as the exposure route is oral, dermal and inhalation exposure, respectively; C_m The concentration of chemical m in water (mg/L); EF , Exposure frequency (days/year); ED , Exposure duration (year); ET the exposure time (h/day); IR_a Daily indoor inhalation rate (m^3/day); IR_w Daily water ingestion rate (L/day); K , Volatilization factor (unitless); SA , Skin-surface area available for contact (cm^2); K_p The chemical-specific dermal permeability constant (cm/h); BW , Body weight (kg); AT The average time (days).

$$\text{Total cancer risk} = \text{Risk}_{oral\ ingestion} + \text{Risk}_{inhalation} + \text{Risk}_{dermal\ absorption} \quad (2)$$

The total life time hazard index of THMs through multiple pathways were illustrated in (3) and (4).

$$HI_T = \sum_m (d_i / RfD_i) = \sum_{m=1}^n \left\{ \frac{C_m * EF * ED}{BW * AT} * \left[\left(\frac{IR_w}{RfD_{oral}} \right) + \left(\frac{SA * K_p * ET}{RfD_{dermal}} \right) + \left(\frac{K * IR_a * ET}{RfD_{inhalation}} \right) \right] \right\} \quad (3)$$

where; HI_T Total lifetime hazard index (unitless); RfD_i Chronic reference dose from the specified exposure route i (mg/kg*day); i =oral, dermal and inhalation expressed as the exposure route is oral, dermal and inhalation exposure, respectively.

$$\text{Total hazard index (HI)} = HI_{oral\ ingestion} + HI_{inhalation} + HI_{dermal\ absorption} \quad (4)$$

The reference dose (RfD) was used to calculated hazard index for evaluated noncarcinogenic and developmental effect in humans. The slope factor was used to define a potential cancer risk with assumption of higher slope factor with higher potential of cancer risk. The slope factor value and reference dose (RfD) of THMs were presented in Table II.

TABLE II: SLOPE FACTOR (SF) OF THMS AND RfD FOR RISK CALCULATION

Species	SF oral (mg/kg/day) ⁻¹	SF dermal (mg/kg/day) ⁻¹	SF inhalation (mg/kg/day) ⁻¹	RfD (mg/kg/day) ⁻¹
CHCl_3	6.10×10^{-3}	3.05×10^{-2}	8.05×10^{-2}	1.00×10^{-2}
CHCl_2Br	6.20×10^{-2}	6.33×10^{-2}	6.20×10^{-2}	2.00×10^{-2}
CHClBr_2	8.40×10^{-2}	1.40×10^{-1}	8.40×10^{-2}	2.00×10^{-2}
CHBr_3	7.90×10^{-2}	1.32×10^{-2}	3.85×10^{-3}	2.00×10^{-2}

Source: IRIS (2005) [11]; RAIS, (2005) [12]; (Wang et al, 2007) [4]

In this study the estimations of body weight in Thailand was taken as 68.83 and 57.40 kg for males and females, respectively [13]. The average life time expectancy for males is 66, whereas for females is 74. The average water ingestion rate for adults was assumed for oral cancer risk calculations was 2.0 L/day [10]. The inhalation rate for daily dose was calculated by assuming 20 m³/day [3]. The concentration of THMs in air used for the estimation of risk through inhalation was calculated using a volatilization factor of 0.0005×1000 L/m³ as suggested by USEPA [14].

III. RESULTS AND DISCUSSION

A. THMs Concentration in Home Tap Water

In total, 17 samples from surface water treatment plants in 4 provinces of northeastern Thailand were analyzed for the 4 target species of THMs. The results of THMs concentrations are shown in Table III and are compared with the WHO guideline, Japan standards, EU and USEPA phase I as shown in Table I. Most of analyzed THMs, Chloroform (CHCl₃) was most detected in water samples. Only one compound, that is CHBr₃, was not detected in any samples by the analytical method. The highest total THMs concentration were found in the Chongsammoe (Chaiyaphum province) (48.46 µg/L), followed by the Donyai (Nakorn Ratchasima province) (20.55 µg/L) and then the Chumsang (Buriram province) (17.24 µg/L), as seen in Table III. Among the highest THMs levels investigated in 17 samples, the total THMs concentration were lower than the reported of Japan standards and USEPA phase I THMs standard values of 100 and 80 µg/L, respectively. Chloroform was found at the highest levels among all analyzed THMs in the 4 provinces. In Chongsammoe water treatment plant of Chaiyaphum province, the water sample was found at highest levels for 3 THMs species (CHCl₃, CHCl₂Br, and CHClBr₂) in the following of 30.53, 12.77, 3.66 µg/L, respectively. This is consistent with other studies. All the results were lower the

THMs levels reported in many countries [3], [5], [6].

B. Life Time Cancer Risk for THMs in Multi-Pathway Exposure Route

The results of multi-pathway cancer risk assessment in tap water for male and female residents in 4 provinces were presented in Fig 3. The cancer risk through oral ingestion was found at highest levels, followed by dermal absorption, and inhalation exposure. The lifetime cancer risk for THMs in multi-pathway exposure route of female was higher than male. Among the four THMs, the highest lifetime cancer risk was found at Chongsammoe water treatment plant in Chaiyaphum province of 4.11×10^{-5} for CHCl₂Br through ingestion route of exposure. For CHCl₃, the highest lifetime cancer risk through ingestion route of 7.13×10^{-6} was in tap water from Chongsammoe, Chaiyaphum province, followed by Donyai plant in Nakorn Ratchasima of about 2.72×10^{-6} . For CHCl₂Br, the highest lifetime cancer risk of 4.11×10^{-5} was in water from Chongsammoe, Chaiyaphum province, followed by Donyai plant in Nakorn Ratchasima of about 1.38×10^{-5} . Among the lifetime cancer risk estimation, only two plants as mentioned above for CHCl₂Br and CHCl₃ species were higher than USEPA acceptable risk of 10^{-6} through multi-pathway exposure routes. This is indicated that residents in Chongsammoe and Donyai area have the potential to cancer risk through ingestion water of CHCl₂Br and CHCl₃ compounds. For CHClBr₂ and CHBr₃ in all sampling water plants, the lifetime cancer risk was below the USEPA acceptable level of 10^{-6} . For the dermal absorption and inhalation exposure pathway, the lifetime cancer risk among 4 THMs was also below the USEPA acceptable level. The average lifetime cancer risk for THMs was from high to low in order of CHCl₂Br, CHCl₃, CHClBr₂ and CHBr₃ compounds.

TABLE III: SUMMARY OF THMS LEVELS IN 17 SUB-DISTRICTS

No.	Province	Sub-district	CHCl ₃ (µg/L)	CHCl ₂ Br (µg/L)	CHBr ₂ Cl (µg/L)	CHBr ₃ (µg/L)	Total THMs (µg/L)	THMs (sum of ratio)
1	Nakorn Ratchasima (Korat)	Srisuk	0.84	0.06	<0.15	<1.50	2.55	0
2		Donyai	11.64	4.30	3.11	<1.50	20.55	0.14
3		Khoksang	8.26	<0.05	<0.15	<1.50	9.96	0.03
4		Mapaung	0.39	<0.05	<0.15	<1.50	2.09	0
5		Chak	<0.17	<0.05	<0.15	<1.50	1.87	0
6	Chaiyaphum	Huangyae	0.58	<0.05	<0.15	<1.50	2.28	0
7		Chongsammoe	30.53	12.77	3.66	<1.50	48.46	0.35
8		Nongbuekhok	<0.17	<0.05	<0.15	<1.50	1.87	0
9	Surin	Takok	0.33	<0.05	<0.15	<1.50	2.03	0
10		Banpue	<0.17	<0.05	<0.15	<1.50	1.87	0
11		Kaeyai	<0.17	<0.05	<0.15	<1.50	1.87	0
12		Meangsri	<0.17	<0.05	<0.15	<1.50	1.87	0
13	Buriram	Chumsang	8.25	4.64	2.85	<1.50	17.24	0.13
14		Nongwang	<0.17	0.36	0.76	<1.50	2.79	0.01
15		Chorpakha	<0.17	<0.05	<0.15	<1.50	1.87	0
16		Nongwang Municipal	1.6	0.51	0.33	<1.50	3.94	0.02
17		Krokkeaw	<0.17	<0.05	<0.15	<1.50	1.87	0

Fig. 3. Life time cancer risk of THMs through multi-pathway in 17 locations of 4 cities

C. Non Carcinogenic Risk for THMs in Multi-Pathway Exposure Route

The hazard indexes of THMs in oral ingestion, dermal absorption and inhalation exposure route for male and female in 4 provinces are shown in Fig. 4. The hazard index for oral ingestion route of exposure was higher levels than other two exposure routes. The highest hazard index was found at CHCl₃ compound (0.11), followed by CHClBr₂ (0.007) for both of oral ingestion in Chongsammoe plant, Chaiyaphum province. The hazard index of CHCl₃ through ingestion route ranges from 0.0006 to 0.11. Female was found to be higher hazard index than male in all THMs and exposure routes. In this study, the hazard index was found to be lower than 1 for all THMs species through multi-pathway route of exposure, which the hazard index less than 1 is complied with acceptable toxicity.

Fig. 4. Life time hazard index of THMs through multi-pathway in 17 locations of 4 cities

TABLE IV: TOTAL CANCER RISK AND HAZARD INDEX (HI) FOR RESIDENT

No.	Province	Sub-district	Total Cancer risk		Total HI	
			Male	Female	Male	Female
1	Nakorn Ratchasima (Korat)	Srisuk	8.80E-07	3.14E-06	7.11E-03	7.60E-03
2		Donyai	1.78E-05	3.99E-05	6.75E-02	7.22E-02
3		Khoksang	2.58E-06	1.46E-05	3.82E-02	4.09E-02
4		Mapaung	7.42E-07	2.40E-06	5.20E-03	5.56E-03
5		Chak	6.91E-07	2.06E-06	4.28E-03	4.57E-03
6	Chaiyaphum	Huangyae	7.87E-07	2.70E-06	6.00E-03	6.41E-03
7		Chongsammoe	4.96E-05	1.04E-04	1.66E-01	1.77E-01
8		Nongbuekhok	6.91E-07	2.06E-06	4.28E-03	4.57E-03
9	Surin	Takok	7.28E-07	2.31E-06	4.95E-03	5.29E-03
10		Banpue	6.91E-07	2.06E-06	4.28E-03	4.57E-03
11		Kaeyai	6.91E-07	2.06E-06	4.28E-03	4.57E-03
12		Meangsri	6.91E-07	2.06E-06	4.28E-03	4.57E-03
13	Buriram	Chumsang	1.80E-05	3.58E-05	5.35E-02	5.72E-02
14		Nongwang	1.83E-06	3.88E-06	6.21E-03	6.64E-03
15		Chorpakha	6.91E-07	2.06E-06	4.28E-03	4.57E-03
16		Nongwang Municiple	2.55E-06	6.32E-06	1.16E-02	1.24E-02
17		Krokkeaw	6.91E-07	2.06E-06	4.28E-03	4.57E-03

IV. CONCLUSION

This study shows the possible carcinogenic and non-carcinogenic risk assessment for THMs compound in community water treatment plants in northeastern Thailand. Results revealed that chloroform (CHCl_3) was found at highest level compared to other three species. The Chongsammoe water treatment plant in Chaiyaphum province was found in the highest levels for THMs and the levels were below the general water quality guideline of

D. Total Cancer Risk and Hazard Index for THMs in Multi-Pathway Exposure Route

The total cancer risk and total hazard index for THMs in tap water through oral ingestion, dermal absorption and inhalation are summarized in Table IV. The oral ingestion is the major route of hazardous exposure to human health. This study results indicated that resident living in Donyai, Khoksang, Chongsammoe, Chumsang, Nongwang, and Nongwang municipal have the high cancer risk due to the THMs exposure through multi-pathway exposure routes, mainly because of chloroform and CHCl_2Br compounds. Chloroform and CHCl_2Br are both classified as group B2 of probable human carcinogen.

WHO. The highest lifetime cancer risk comes from oral ingestion followed by dermal absorption and inhalation exposure, respectively. The non carcinogenic risk analysis found that the average hazard index of total THMs in three multi-pathway exposure routes was lower than 1 which indicated to acceptable level. However, overall 6t of 17 plants, the lifetime cancer risk for CHCl_2Br and CHCl_3 through oral ingestion route were exceeded than acceptable cancer risk level of 10^{-6} . Safe drinking water is a critical for considering to water treatment and disinfection methods. The

coagulation-flocculation process, membrane and other disinfection methods i.e. ozone and ultraviolet should be determined to remove natural organic matter and microorganism. Therefore, the optimized use and practice of chlorination should be controlled in order to reduce THMs formation at acceptable risk for providing the safe water to people.

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