

Exposure Assessment and the Risk Associated with Trihalomethane Compounds in Drinking Water, Cairo – Egypt

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Abstract

The main objectives of the study to measure the concentrations of trihalomethanes (THMs) in drinking water of Cairo, Egypt, and their associated risks. Two hundred houses were visited and samples were collected from consumer taps water. Risks estimates based on exposures were projected by employing deterministic and probabilistic approaches. The THMs species (dibromochloromethane, bromoform, chloroform, and bromodichloromethane) ranged from not detected to 76.8 µg/lit. Non-carcinogenic risks induced by ingestion of THMs were exceed the tolerable level (10^{-6}). Data obtained in this research demonstrate that exposure to drinking water contaminants and associated risks were higher than the acceptable level.

Keywords: Drinking water; Risk; Trihalomethanes; Cairo

Introduction

Chlorination, the most commonly used method to disinfect tap water, has led to a sharp decrease in both mortality and morbidity from many diseases known to be waterborne [1]. However, the presence of chlorinated disinfection by-products (DBP) in tap water is of concern from a public health aspect because they are suspected to be carcinogenic [2-4]. The most significant group of DBP formed during chlorination is the THM such as CHCl_3 , CHBrCl_2 , CHBr_2Cl , and CHBr_3 . CHCl_3 is classified in Group 2B as a possibly carcinogenic to humans, based on limited evidence of carcinogenicity in humans but sufficient evidence of carcinogenicity in experimental animals [1]. CHBrCl_2 is a weekly mutagenic and it has been classified as probably carcinogenic to humans, with sufficient evidence in animals and inadequate evidence in humans. Between the four THMs found in drinking water, CHBrCl_2 appears to be the most potent rodent carcinogen. CHBr_2Cl and CHBr_3 are classified in group 3 due to the inconclusive genotoxicity [1]. The second prevalent DBP group is haloacetic acids (HAAs). Aside from THMs and HAAs, many other compounds that comprising the DBP group have been found in treated waters, which include haloacetonitriles, halo ketones, haloaldehydes, halopicrin, cyanogen chloride, halophenols and chloral hydrate and many others. The main THM effects are cancer and adverse reproduction problems such as abortion, miscarriage, and retarded fetal development [5].

Chloroform concentrations measured in breath or blood after swimming and showering have been correlated with the activity time, and the concentration of this compound found in water and air [6]. Rafael et al. have reported that the THM concentration increases in blood as compared with their pre-activity blood levels in individuals after water-consuming [7].

They have found that increases of THM concentrations in blood after showering or bathing were significantly greater than the increases related to regular water-consuming. On the other hand, Chowdhury et al. have found that showering activity increases the THM concentration in blood, but there was no significant correlation between THM concentration in blood and tap water. The focus of this work is not directed to quantify the DBP precursors in the water treatment plant. Instead, the main motivation of this study is the multipath way analysis of cancer risk (CR) by oral ingestion, dermal absorption, and inhalation

routes. In response to the increasing public concern on the pollution of the water supply, this study aims to estimate the THM exposure, lifetime CR caused by these different routes due to the use of tap water in the Cairo, Egypt. Cairo is located in middle of Egypt and has a variation of temperature during the whole of the year. The temperature ranges from 15°C in winter to 40°C in summer.

Material and Methods

Water samples analyzed according to (USEPA, 2005). The water samples were collected from five water treatment plants and its distribution systems, Water samples at the specified locations were collected in 40 ml glass bottles (amber glass), which were filled without passing air bubbles through the sample. Before sampling, a solution of sodium thiosulfate was added to the amber bottles to eliminate any remaining residual chlorine and to stop further THM formation. Each glassware used was previously washed with phosphate-free detergent, rinsed with ultrapure water (Milli-Q) and acetone (HPLC grade). Then, it was placed in an oven at 150°C for 2 h and cooled at room temperature.

Samples were prepared by extracting 10 ml of water with 2 ml of pentane by shaking for 2 min in a separation funnel of 25 ml. Phase separation occurred within 3 min and the upper phase was collected into 2 ml vials having screw caps with PTFE (Teflon septum) septa. THM measurements were made using a gas chromatograph equipped with a mass detector (GC-ECD, Varian, Model CP-3800). Chromatographic separation was accomplished with a capillary column DB-5 (J&W Scientific Inc/Agilent Technologies, 30 m×0.25 mm×0.25 µm). The GC oven temperature program was as follow: initial temperature in 40°C

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for 2 min and then ramped 10°C per min until 150°C. Carrier gas (N₂) at a flow rate of 0.8 ml min⁻¹ and split ratio of 1:10 was used in each experiment. It was injected 2 µl of each sample in the capillary column. For the calibration curve, standard solutions of CHCl₃ (Supelco Inc., 98.8%), CHBrCl₂ (Supelco Inc., 99.9%), CHBr₂Cl (Supelco Inc., 99.0%), and CHBr₃ (Supelco Inc., 99.9%) in concentrations ranging from 0.05 to 100 µg/L⁻¹ in ultrapure water.

The estimate of the lifetime CR associated to THM is based on United States Environment Protection Agency (USEPA) guidelines. The detailed description is presented in the literature (US EPA 1999), and it is not reproduced here. Three kinds of THM exposure were considered to estimate the lifetime CR: inhalation, dermal absorption and ingestion. The CR of THM is estimated by multiplying the chronic daily exposures (CDE) and a potency factor (upper-bound lifetime cancer risk per mg kg⁻¹ day⁻¹). The CDE for oral ingestion, dermal absorption and inhalation from volatilized water are respectively:

$$CDE_{ingestion} = \frac{(CW \times IR \times EF \times ED)}{(BW \times ATL \times NY)}$$

$$CDE_{dermal} = \frac{(CW \times SA \times PC \times ET \times EF \times ED)}{(BW \times ATL \times NY)}$$

$$CDE_{inhalation} = \frac{(CA \times IR \times ET \times EF \times ED)}{(BW \times ATL \times NY)}$$

Where IR the ingestion rate (L day⁻¹), EF the exposure frequency (days year⁻¹), ED the exposure duration (years), BW the body weight (kg), and ATL the average time of a lifetime (years), NY the number of days per year (365 days year⁻¹), SA the skin-surface area available for contact (cm²), PC the chemical specific dermal permeability constant (0.0020 mh⁻¹), ET the exposure time, hour per day or hour per event (0.2 h day⁻¹), and IR the inhalation rate (0.83 m³h⁻¹).

The standard values of average body weight, volume of air breathed by adults per day, skin-surface area, and potency factor for oral ingestion and inhalation of THM are taken from the literature (US EPA 1999). For adults, the exposures were converted to a daily dose by assuming 20 m³ aspirated air per day, and average body weights of 70 kg for male and 65 kg for female. The lifetime of residents was assumed to be the standard 70 years for both male and female. Finally, the skin-surface areas are 1.94 and 1.69 m² for males and females, respectively.

$$\text{Weight of Population, } C = \frac{C_i \times P_i}{P_{total}}$$

$$\text{Exposure pathway of Ingestion, } CDI = \frac{(CW \times 0.8 \times IR \times EF \times ED)}{(AT \times BW)}$$

(Table 1)

Results and Discussion

Chloroform (CHCl₃)

The data presented in Table 2 and Figure 1, showed that, the concentration of chloroform (Cai) ranged from 18.9 to 76.24 µg/L with average value 24.28 µg/L in Tebeen WTP, and the risk assessment of chloroform (HIi) ranged from 24.50E-6 to 95.60E-6 with average value 44.70E-6.

The concentration of chloroform (Cai) in Manial el roda WTP, ranged from 18.6 to 38.84 µg/L with average value 25.5 µg/L, and the

risk assessment of chloroform (HIi) ranged from 23.30E-6 to 48.70E-6 with average value 32.00E-6.

The concentration of chloroform (Cai) in Ameria WTP, ranged from 22.9 to 74.28 µg/L with average value 33.4 µg/L, and the risk assessment of chloroform (HIi) ranged from 28.70E-6 to 93.10E-6 with average value 41.90E-6

The concentration of chloroform (Cai) in Shubra el kheima WTP, ranged from 12.8 to 54.5µg/L with average value 34.42 µg/L, and the risk assessment of chloroform (HIi) ranged from 16.10E-6 to 68.30E-6 with average value 43.20E-6

The concentration of chloroform (Cai) in Embaba WTP, ranged from 21.4 to 53.4 µg/L with average value 39.69 µg/L, and the risk assessment of chloroform (HIi) ranged from 26.8E-6 to 67.00E-6 with average value 49.80E-6

Bromodichloromethane (CHBrCl₂)

The data presented in Table 3 and Figure 2, showed that, the concentration of bromodichloromethane (Cai) ranged from 11.7 to 23.9 µg/L with average value 17.0 µg/L in Tebeen WTP, and the risk assessment of bromodichloromethane (HIi) ranged from 1.94×10⁻⁵ to 3.96×10⁻⁵ with average value 2.81×10⁻⁵.

The concentration of bromodichloromethane (Cai) in RodaWTP, ranged from 10.63 to 16.47 µg/L with average value 14.0 µg/L, and the risk assessment of bromodichloromethane (HIi) ranged from 1.76×10⁻⁵ to 2.72×10⁻⁵ with average value 2.3×10⁻⁵.

The concentration of bromodichloromethane (Cai) in Ameria WTP, ranged from 22.9 to 74.28 µg/L with average value 33.4 µg/L, and the risk assessment of bromodichloromethane (HIi) ranged from 1.3×10⁻⁵ to 4.2×10⁻⁵ with average value 1.9×10⁻⁵.

The concentration of bromodichloromethane (Cai) in Shubra el kheima WTP, ranged from 4.27 to 19.53 µg/L with average value 14.2 µg/L, and the risk assessment of bromodichloromethane (HIi) ranged from 7.1×10⁻⁷ to 3.23×10⁻⁵ with average value 2.35×10⁻⁵.

The concentration of bromodichloromethane (Cai) in Embaba WTP, ranged from 13.6 to 23.4 µg/L with average value 19.24 µg/L, and the risk assessment of bromodichloromethane (HIi) ranged from 2.25×10⁻⁵ to 3.87×10⁻⁵ with average value 3.18×10⁻⁵.

Chlorodibromomethane (CHBr₂Cl)

The data presented in Table 4 and Figure 3, showed that, the

Parameters	Value
C _i : Concentration of i region	
P _i : Population of water supply in the i region	
P _{Total} : Total population of water supply in the i region	
Chronic daily intake, CDI (mg (Kg-day) ⁻¹)	
THMS concentration of drinking water, CE	
Intake quantity, IR	2.5 (litres day ⁻¹)
Average exposure time, AT	70 (year) × 365 (day/year)
Exposure during, ED	70 (Year)
Exposure frequency, EF	365 (day/year)
Body weight, BW	Male : 64.8 ± 10 (Kg) Female : 56.3 ± 9.09 (Kg)
Absorptivity of body	100%

Table 1: References data and formula for exposure assessment (USEPA, 2003) [8].

Date	Tebeen		Roda		Ameria		Shubra el kheima		Embaba	
	Cai	Hli	Cai	Hli	Cai	Hli	Cai	Hli	Cai	Hli
Jan	0.015	25.5E-6	0.014	22.7E-6	0.017	28.0E-6	0.017	27.9E-6	0.015	24.8E-6
Feb	0.020	32.7E-6	0.015	24.9E-6	0.016	25.7E-6	0.015	24.9E-6	0.019	31.2E-6
Mar	0.018	30.1E-6	0.011	17.6E-6	0.015	24.1E-6	0.013	21.3E-6	0.016	27.0E-6
Apr	0.016	26.2E-6	0.011	18.2E-6	0.014	23.4E-6	0.014	23.9E-6	0.022	36.0E-6
May	0.017	27.4E-6	0.014	23.1E-6	0.016	25.9E-6	0.004	7.1E-6	0.023	38.2E-6
Jun	0.015	25.2E-6	0.015	24.2E-6	0.010	16.3E-6	0.009	14.2E-6	0.018	29.6E-6
Jul	0.016	26.6E-6	0.015	24.4E-6	0.016	26.2E-6	0.016	26.8E-6	0.019	31.7E-6
Aug	0.018	30.0E-6	0.016	25.7E-6	0.019	30.6E-6	0.017	27.8E-6	0.021	34.4E-6
Sep	0.024	39.6E-6	0.014	22.9E-6	0.021	34.7E-6	0.018	29.5E-6	0.023	37.4E-6
Oct	0.015	24.1E-6	0.016	27.2E-6	0.019	31.0E-6	0.020	32.3E-6	0.023	38.7E-6
Nov	0.019	30.7E-6	0.015	25.5E-6	0.017	28.4E-6	0.016	27.2E-6	0.018	30.3E-6
Dec	0.012	19.4E-6	0.013	21.3E-6	0.015	24.3E-6	0.011	19.0E-6	0.014	22.5E-6

Table 2: Risk assessment of Bromodichloromethane.

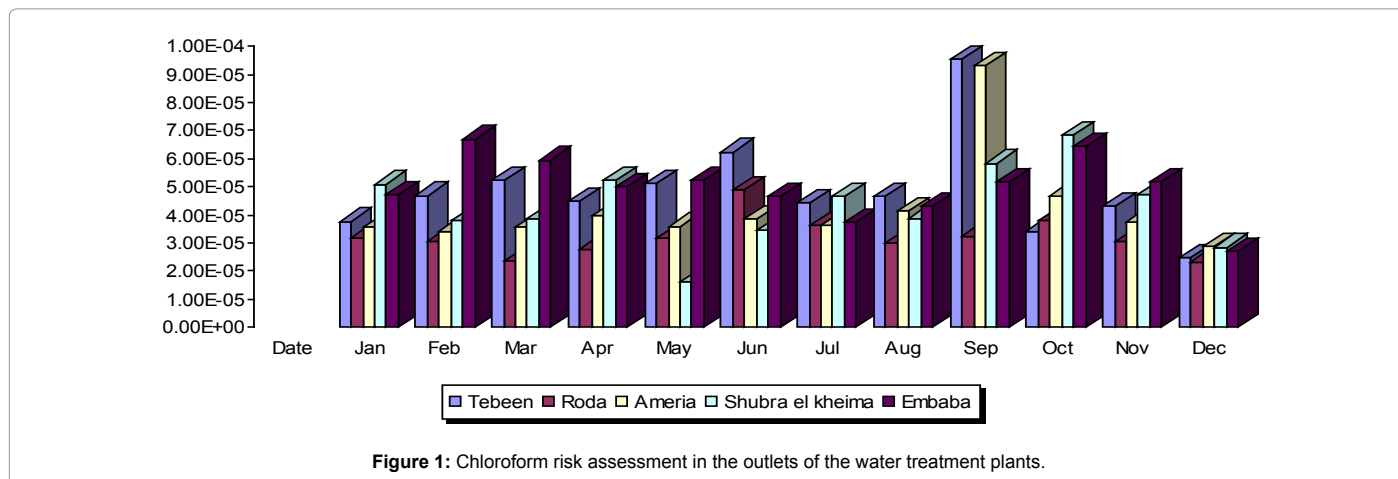


Figure 1: Chloroform risk assessment in the outlets of the water treatment plants.

Date	Tebeen		Roda		Ameria		Shubra el kheima		Embaba	
	Cai	Hli	Cai	Hli	Cai	Hli	Cai	Hli	Cai	Hli
Jan	15.41	25.5E-6	13.716	22.7E-6	16.939	28.0E-6	16.89	27.9E-6	14.999	24.8E-6
Feb	19.771	32.7E-6	15.089	24.9E-6	15.534	25.7E-6	15.08	24.9E-6	18.854	31.2E-6
Mar	18.188	30.1E-6	10.631	17.6E-6	14.552	24.1E-6	12.903	21.3E-6	16.344	27.0E-6
Apr	15.832	26.2E-6	11.033	18.2E-6	14.175	23.4E-6	14.433	23.9E-6	21.8	36.0E-6
May	16.6	27.4E-6	13.991	23.1E-6	15.684	25.9E-6	4.277	7.1E-6	23.1	38.2E-6
Jun	15.232	25.2E-6	14.655	24.2E-6	9.832	16.3E-6	8.566	14.2E-6	17.9	29.6E-6
Jul	16.115	26.6E-6	14.781	24.4E-6	15.824	26.2E-6	16.206	26.8E-6	19.2	31.7E-6
Aug	18.147	30.0E-6	15.516	25.7E-6	18.522	30.6E-6	16.832	27.8E-6	20.8	34.4E-6
Sep	23.962	39.6E-6	13.846	22.9E-6	20.978	34.7E-6	17.871	29.5E-6	22.6	37.4E-6
Oct	14.591	24.1E-6	16.475	27.2E-6	18.754	31.0E-6	19.532	32.3E-6	23.4	38.7E-6
Nov	18.559	30.7E-6	15.405	25.5E-6	17.173	28.4E-6	16.434	27.2E-6	18.3	30.3E-6
Dec	11.743	19.4E-6	12.872	21.3E-6	14.707	24.3E-6	11.487	19.0E-6	13.6	22.5E-6

Table 3: Risk assessment of bromodichloromethane.

concentration of Chlorodibromomethane (Cai) ranged from 4.32 to 8.58 µg/L with average value 6.52 µg/L in Tebeen WTP, and the risk assessment of Chlorodibromomethane (Hli) ranged from 0 to 1.92×10⁻⁵ with average value 8.5×10⁻⁶.

The concentration of Chlorodibromomethane (Cai) in RodaWTP, ranged from 4.89 to 7.58 µg/L with average value 6.6 µg/L, and the risk assessment of Chlorodibromomethane (Hli) ranged from 0 to 1.7×10⁻⁵ with average value 7.4×10⁻⁶.

The concentration of Chlorodibromomethane (Cai) in Ameria WTP, ranged from 4.48 to 7.8 µg/L with average value 6.5 µg/L, and the risk assessment of Chlorodibromomethane (Hli) ranged from 0 to 1.76×10⁻⁵ with average value 8.5×10⁻⁶.

The concentration of Chlorodibromomethane (Cai) in Shubra el kheima WTP, ranged from 4.8 to 5.8 µg/L with average value 5.5 µg/L, and the risk assessment of Chlorodibromomethane (Hli) ranged from 0 to 1.3×10⁻⁵ with average value 6.1×10⁻⁶.

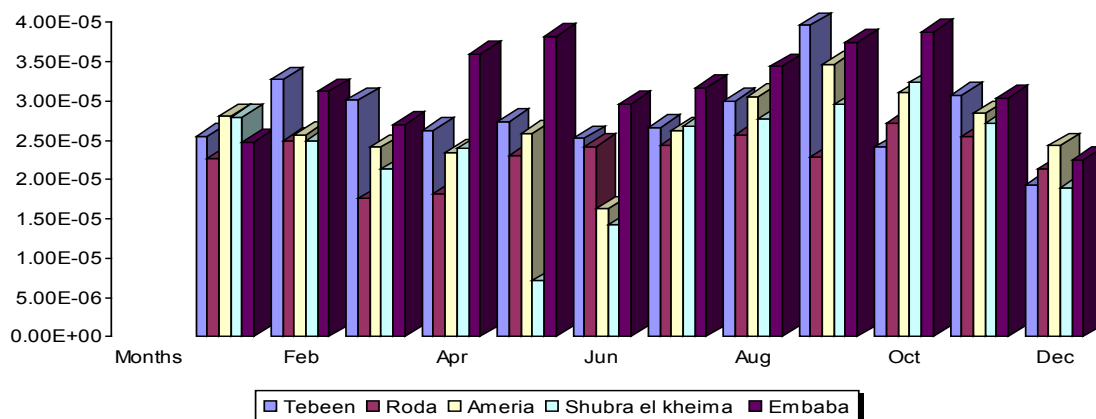


Figure 2: Bromodichloromethane risk assessment in the outlets of the water treatment plants.

Date	Tebeen		Roda		Ameria		Shubra el kheima		Embaba	
	Cai	Hli	Cai	Hli	Cai	Hli	Cai	Hli	Cai	Hli
Jan	7.321	16.4E-6	6.49	14.5E-6	7.861	17.6E-6	5.832	13.1E-6	4.222	9.5E-6
Feb	7.389	16.6E-6	7.347	16.5E-6	6.468	14.5E-6	5.565	12.5E-6	UDL	0
Mar	4.327	9.7E-6	UDL	0	UDL	0	UDL	0	UDL	0
Apr	UDL	0	UDL	0	UDL	0	UDL	0	UDL	0
May	UDL	0	UDL	0	4.483	10.0E-6	UDL	0	6.8	15.2E-6
Jun	UDL	0	UDL	0	UDL	0	UDL	0	5.2	11.6E-6
Jul	UDL	0	UDL	0	UDL	0	UDL	0	UDL	0
Aug	UDL	0	UDL	0	UDL	0	UDL	0	UDL	0
Sep	6.528	14.6E-6	4.897	11.0E-6	5.126	11.5E-6	4.881	10.9E-6	UDL	0
Oct	6.115	13.7E-6	6.683	15.0E-6	7.084	15.9E-6	5.696	12.8E-6	7.4	16.6E-6
Nov	8.585	19.2E-6	7.587	17.0E-6	7.855	17.6E-6	5.696	12.8E-6	7.4	16.6E-6
Dec	5.417	12.1E-6	6.638	14.9E-6	6.926	15.5E-6	5.221	11.7E-6	6.3	14.1E-6

Table 4: Risk assessment of chlorodibromomethane.

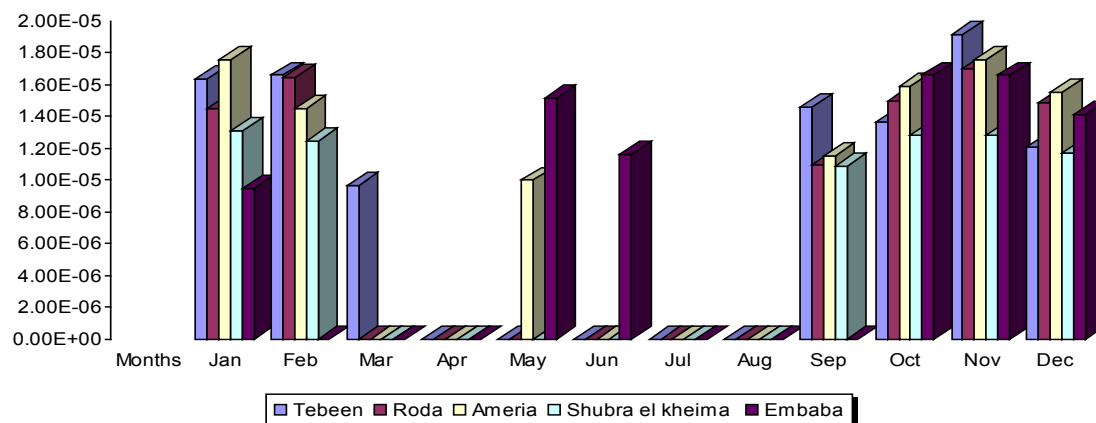


Figure 3: Bromodichloromethane risk assessment in the outlets of the water treatment plants.

The concentration of Chlorodibromomethane (Cai) in Embaba WTP, ranged from 4.2 to 7.4 µg/L with average value 6.2 µg/L, and the risk assessment of Chlorodibromomethane (Hli) ranged from 0 to 1.66×10^{-5} with average value 6.97×10^{-6} .

Bromoform (CHBr₃)

In the present study, the collected samples from the water treatment

plants (Tebeen, Roda, Ameria, Shoubra El Khema and Embaba WTPs) did not detect, so the risk assessment of bromoform were neglect.

For THM species, the USEPA range of concern is for an increased carcinogenic risk of 10^{-6} , that is, 1:1,000,000 [8-10].

Total carcinogenic risks for each of the oral and dermal routes were calculated as the sum of the risks values for four THMs specie, that is,

Total risk=risk for chloroform + risk for bromodichloromethane + risk for dibromochloromethane + risk for bromoform (RAIS).

Lifetime cancer risk value due to the oral ingestion of TTHMs in different districts of the Cairo city were exceeded from 1.0×10^{-6} , showing that residents of these districts were expected to be at higher cancer.

Risk hazard index for different districts was found to be lower than unity, indicating that no adverse health effects are expected as a result of exposure to THMs.

Conclusion

This investigation included statistical analysis, epidemiology data and cancer risk analysis and assessment of THMs species in drinking water in Cairo. It is more significant to establish an assessment procedure for the decision-making in policy of drinking water safety predominantly.

Specification the derive conclusions lie above from this study:

- The chloroform concentration is the major DBP species in the local regions of Cairo.
- The most dominant THMs are chloroform and bromodichloromethane and residents have a higher cancer risks through these two compounds in all results of studied five plants.
- Bromoform did not observed in most of collected samples.
- All lifetime cancer risks for CHCl_3 , CHBrCl_2 and CHBr_2Cl in water samples collected from tap water in the five water supply areas were higher than the negligible risk level of 10⁻⁶ by a factor of 10 or more in most districts.
- The Southern region presented a high cancer risk (Tebeen WTP).
- Residents of some districts were found to have a higher cancer risk through the oral ingestion of THMs. hazard indexes of TTHMs in different districts were found to be lower than unity, which did not indicate the noncancerous effects of THMs.
- Quantifying the risk factors is important for population and decision-making policy for drinking water safety. Fortunately, the Benchmark model and MCS and Risk supply the methodology were used for risk calculation. The standard for the total THMs species in Taiwan was 100 µg/L presently.

- We suggest that the standard be separated using separate dibromochloromethane, bromoform, chloroform, and bromodichloromethane standards. This may establish a control management for individual material to reduce the harmful risk. It displays the legislation limit values for different counties for DBPs levels.
- A methodology for decision-makers in formulating a procedure considering the economic, political, and feasible technology to reduce the standard value limits is necessary. An acceptable policy for safe drinking water and optimum social cost is the next objective of our study.
- The techniques can be used for removal of THM compounds are activated carbon, enhancement coagulation, alternatives of disinfectants such as ozone, chloramine and chlorine dioxide.

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