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ORIGINAL PAPER

Han-Keng Lee · Yir-Yarn Yeh · Wei-Ming Chen

Cancer risk analysis and assessment of trihalomethanes in drinking water

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Abstract This study conducts risk assessment for an array of health effects that may result from exposure to disinfection by-products (DBPs). An analysis of the relationship between exposure and health-related outcomes is conducted. The trihalomethanes (THMs) species have been verified as the principal DBPs in the drinking water disinfection process. The data used in this study was collected from the Taiwan Water Corporation (TWC) from 1998 to 2002. Statistical analysis, multistage of Benchmark model, Monte Carlo simulation (MCS) and sensitive analysis were used to estimate the cancer risk analysis and assessment. This study included the statistical data analysis, epidemiology investigation and cancer risk assessment of THMs species in drinking water in Taiwan. It is more significant to establish an assessment procedure for the decision making in policy of drinking water safety predominantly.

Keywords DBPs · Monte Carlo simulation · Multistage of benchmark model · Sensitive analysis

1 Introduction

Chlorination has been the major, economical and effective drinking water disinfection strategy from microorganisms. This disinfection process may induce serious waterborne infectious diseases dangerous to public health. Research consequence of Rook (1974) and Bellar et al. (1974) exhibited that disinfection by-products (DBPs) were produced in the disinfection process. Nowadays, such disinfection process is most adopted in drinking water treatment commonly (Houston 1913; Yang et al. 1998; Hsu et al. 2001).

Disinfection by-products are defined as hazardous materials with carcinogenic risk by Taiwan USEPA. Animal and epidemiology study evaluations have shown that developmental toxicity and adverse effects are the main potential risks to humans. The result from animal studies demonstrated evidence of liver, kidney, intestinal tumor genesis, urinary bladder, rectum and colon cancer (Morris et al. 1992; Doyle et al. 1997; Cantor et al. 1998) and some associated effects of intrauterine growth and retardation (Kramer et al. 1992). Low birth weight, small for gestational age, central nervous system defects, oral cleft defects and cardiac defects (Bove et al. 1995), retarded fetal growth (Gallagher et al. 1998) and spontaneous abortion (Waller et al. 1998) that are caused by disinfected water. Epidemiologic studies were conducted that examined the possible associations between consumption of chlorinated drinking water and cancer mortality, risk or incidence (Page et al. 1976; Cantor et al. 1978, 1987, 1998; Yang et al. 1998, 2000). The results suggest a positive association between consumption of chlorinating drinking water and cancer of the rectum, lung, bladder and kidney (Yang et al. 1996).

This study has been carried out from 1998–2002, in order to develop risk assessment and management for THMs species in drinking water for the purpose of preserving a safe environment and protecting human health in Taiwan. Risk assessment is a systematic, analytical method used to determine the probability of adverse effects. The purpose of this study conferred the risk assessment to process the derived THMs species in the drinking water of Taiwan. By following the estimation procedure of risk assessment, the outcomes will interpret the condition of the level of impact by THM species. The consequence may be a good decision-making process for risk management in the drinking water.

H.-K. Lee · W.-M. Chen
Department of Water Source Engineering,
100, Wnehwa Road, Seatwen, Taichung, 407, Taiwan, ROC

Y.-Y. Yeh (✉)
Graduate Institute of Civil and Hydraulic Engineering,
100, Wnehwa Road, Seatwen, Taichung,
407, Taiwan, ROC
E-mail: yyyeh@fcu.edu.tw
Tel.: +886-4-24517250
Fax: +886-4-24513797

2 Methods

The risk assessment paradigm was developed by the US NRC (National Research Council 1983) to evaluate the procedures of framework. It contained hazard identification, dose-response assessment, exposure assessment and risk characterization, mainly.

2.1 THMs species data in Taiwan since 1998–2002

This study assumed and divided the geographical distribution of Taiwan into five parts (northern, midland, southern, eastern and external islands). Official Data obtained from Taiwan Water Corporation (TWC) since 1998 to 2002. There are 35, 45 and 13 water treatment plants and 25, 52 and 54 supply systems in Northern, Midland and Eastern regions. 30 water treatment plants and 45 supply systems in Southern and External islands regions, respectively. The monitoring stations examined the temperature, pH per month and THMs species for three months. Four thousand nine hundred and forty water quality monitoring data are obtained from those monitoring stations that was published in the annual TWC subscriber drinking water reports.

2.2 Cancer risk analysis and assessment

2.2.1 Hazard identification of THMs species

Hazard identification involves a qualitative assessment of the presence of, and the degree of hazard that an agent could have on potential receptors. USEPA has developed a scheme that contains two broad categories of sufficient and insufficient evidence in Table 1. Hossein (1995) defined THM species as TCM, BDCM, DBCM and TBM, respectively. Animal and epidemiology studies exhibited THMs species by considered weight of evidence in EPA reports on cancer guideline descriptions about Group B2 as TCM, BDCM, DBCM and Group C is TBM (USEPA 1999), respectively.

2.2.2 Dose-response assessment

Dose-response relationships are then used to quantitatively evaluate the toxicity information, and to characterize the relationship between dose of the contaminant administered or received and the incidence of adverse effects on the exposed population. Specially, the purpose of the assessment developed for the risk management ensures the safety and offers procedures to control the quality of drinking water.

Table 1 Basic processes involved in USEPA carcinogenesis

Group A	Human carcinogen	Sufficient human evidence for causal association between exposure and cancer
Group B1	Probable human	Limited evidence in humans
Group B2	*Probable human*	Inadequate evidence in humans and sufficient evidence in animals
Group C	*Possible human carcinogen*	Limited evidence in animals
Group D	Not classifiable as to human carcinogenicity	Inadequate evidence in animals
Group E	No evidence of carcinogenicity in humans	At least two adequate animal tests or both negative epidemiology and animal studies

Table 2 Animal experimental carcinogenic data derived from THMs species

Chemicals	Data set	Data values			Reference
		Dose (mg/kg/day)	*N*	Incidence	
TCM	Moderate or marked fatty cysts in males plus females	0	27	1	Heywood et al. (1979)
		15	15	9	
		30	15	13	
		25	50	1	
		50	50	8	
BDCM	B6C3F1 mice, male	0	46	1	NTP (1987)
		25	49	2	
		50	50	9	
DBCM	Mouse/B6C3F1, female	0	50	6	NTP (1985)
		50	49	10	
		100	50	19	
TBM	F344/N rat, female	0	50	0	NTP (1988)
		25	50	1	
		50	50	8	

IRIS (2003)

In the dose-response assessment step, the goal determined the relationships between the route, dose, frequency and duration of exposure conditions and the health that effect chemical hazards. Additionally, apply the uncertainty or safety factors and mathematical model may an approach by USEPA.

Benchmark model (USEPA http://www.epa.gov/ncea, 2003b) supported the assessment tool focused on the low-dose in the animal experiment that may cause an observed adverse influence. Generally, the adverse effects included reproductive, developmental toxicity or mortality phenomenon etc.

In this study, we adopted the USEPA risk assessment guidance (1986) and the reference data (Table 2) of animal studies from Integrated Risk Information System (IRIS, 2003) to process the BMD/BMDL value of THM species mathematically. BMD/DMDL value can interpret the toxicity information of THM species in the low-dose level.

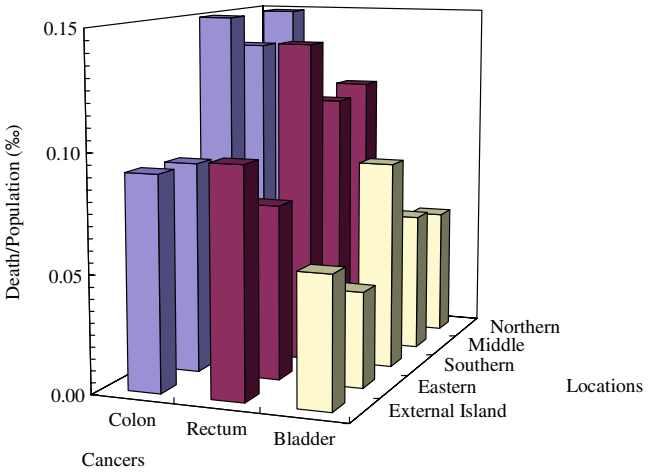


Fig. 1 Announced consequences in death of colon, rectum and bladder cancers by DOH of Taiwan

2.2.3 *Exposure assessment*

Exposure is defined as human contact with THM species through different pathways. Referring to the exposure factor data handbook (USEPA 1997), USEPA risk assessment guidance for superfund Volume-Human Health Evaluation Manual (USEPA 1989), and Risk Assessment Information System (RAIS 2003a) assumed the pathways to reasonable maximum exposure (RME) to THM species as ingestion, inhalation and dermal intake, evaluated based on chronic daily intake (CDI).

Table 3 References data and formula for exposure assessment

Parameters	Value	Reference
Weight of population, $C = \frac{C_i \times P_i}{P_{\text{total}}}$		
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		
Exposure pathway of ingestion, $\text{CDI} = \frac{(\text{CW} \times 0.8 \times \text{IR} \times \text{EF} \times \text{ED})}{(\text{AT} \times \text{BW})}$		
Chronic daily intake (CDI) [mg (kg day^{-1})]		
THMs concentration of drinking water (CW)		
Intake quantity (IR)	2.5 (L day^{-1})	Wu (1999)
Average exposure time (AT)	70 (year) × 365 (day/year)	USEPA (1989)
Exposure during (ED)	70 (year)	USEPA (1989)
Exposure frequency (EF)	365 (day year^{-1})	USEPA (1989)
Body weight (BW)	Male: 64.8 ± 10 (kg)	Taiwan DOH
	Female: 56.3 ± 9.09 (kg)	http://www.doh.gov.tw/statistic/index.htm
Absorptivity of body	100%	Assumption
Exposure pathway of inhalation, $\text{CDI} = \frac{(C_{\text{air}} \times \text{VR} \times \text{EF} \times \text{ET} \times \text{ED})}{(\text{AT} \times \text{BW})}$		
THMs vapor concentration in the bathroom (C_{air})		
Mean vapor quantity of daily inhalation (adult) (VR)	12.3 (m^3 day^{-1})	Wu et al. (2003)
Flow velocity (Q_{L})	0.032 (L min^{-1})	Wu et al. (2003)
Air flow velocity (QGS)	50 (L min^{-1})	Little (1992)
Volume of bathroom (Vs)	6.6 (m^3)	Wu et al. (2003)
Henry constant (H)	TCM: 0.150	RAIS (2003a)
	BDCM: 0.087	
	DBCM: 0.032	
	TBM: 0.022	
Transferred coefficient of liquid mass × valid air/surface area, K_{OL} A	0.019	Little (1992)
Exposure pathway of dermal intake, $\text{CDI} = \frac{(\text{CW} \times \text{PC} \times \text{SA} \times \text{EF} \times \text{ET} \times \text{ED})}{(\text{AT} \times \text{BW})}$		
Dermal intake permeable coefficient (PC)	TCM: 8.9×10^{-3} (cm h^{-1})	USEPA (1997)
	BDCM: 5.8×10^{-3} (cm h^{-1})	
	DBCM: 3.9×10^{-3} (cm h^{-1})	
	TBM: 2.6×10^{-3} (cm h^{-1})	
Surface area dermal intake contact (SA)	$(4\text{BW}+7)\ (\text{BW}+90)^{-1}$	USEPA (1997)
Exposure time (ET)	20 (min day^{-1})	MCKone (1989)

Table 4 The ranges of variables, means, maximum, minimum and standard deviations of subscriber

Location	Northern					Midland				Southern					Eastern		External island
	Yi-Lan[a]	Ji-Long	Tai-Pei	Tao-Yuan	Shin-Chu	Miao-Li	Tai-Chung	Nan-Tou	Chang Hua	Yun-Lin	Chia-Yi	Tai-Nan	Kao-Chiong	Ping-Dong	Hua-Lian[a]	Tai-Dong	Peng-Hu
Temperature (°C)																	
Mean	21.1	20.4	22.1	21.7	21.5	22.6	23.9	23.2	26.2	26.9	21.6	27.1	25.5	23.1	23.6	23.8	25.0
Max	24.0	28.5	30.5	27.5	28.0	27.0	31.5	30.5	29.0	31.8	30.0	31.0	31.0	29.0	31.0	29.0	29.5
Min	15.5	15.0	15.5	16.0	14.5	19.0	16.0	16.0	23.5	22.3	6.0	20.0	15.0	14.0	17.0	19.0	17.0
Stdev	2.2	3.5	3.6	3.5	3.5	2.2	2.2	2.7	1.2	2.2	6.5	3.3	2.6	3.5	3.2	2.6	4.0
PH																	
Mean	7.5	7.1	7.2	7.5	7.6	6.7	6.8	8.0	7.4	7.6	7.9	8.3	7.6	7.2	7.8	7.8	8.2
Max	8.1	7.7	8.9	8.2	8.4	8.3	8.2	6.7	7.8	8.2	8.7	8.8	8.2	8.1	8.4	8.4	8.9
Min	6.5	6.4	6.3	6.3	7.0	5.2	5.6	6.0	6.3	6.4	6.7	8.0	6.9	5.3	7.1	7.1	7.4
Stdev	0.5	0.3	0.5	0.5	0.3	1.0	0.6	5.6	0.4	0.4	0.5	0.3	0.3	0.7	0.4	0.4	0.4
Number	39	45	88	30	50	54	123	170	52	116	59	11	169	78	56	62	45
Trichloromethane [(TCM) μg/L]																	
Mean	–	9.3	4.4	7.6	5.2	7.1	4.8	3.5	3.8	5.7	7.9	18.5	11.4	3.6	–	2.5	1.3
Max	–	38.1	18.8	67.5	24.9	24.6	24.5	32.5	14.4	26.4	35.0	47.4	57.3	32.8	–	34.8	21.0
Min	–	0.2	0.1	0.2	0.3	0.3	0.3	0.3	0.3	0.2	0.2	1.8	0.2	0.2	–	0.1	0.2
Stdev	–	10.0	5.2	8.1	5.7	5.8	6.9	5.1	3.5	6.9	10.5	12.5	14.1	6.4	–	19.4	2.9
Dichlorobromomethane [(DCBM) μg/L]																	
Mean	–	6.9	2.6	2.1	0.3	0.5	0.5	0.2	0.2	2.2	1.5	6.2	4.2	1.3	–	1.9	3.4
Max	–	27.1	13.6	17.4	1.0	4.2	9.1	1.1	1.1	12.7	5.8	17.5	26.5	9.6	–	29.3	21.0
Min	–	0.8	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.1	1.0	0.2	0.2	–	0.1	0.2
Stdev	–	6.6	2.6	2.3	0.3	1.0	1.3	0.2	0.3	2.7	1.7	3.9	5.2	2.4	–	16.4	5.1
Number	0	20	73	189	37	28	57	54	19	89	59	31	144	66	0	61	61
Dibromochloromethane [(DBCM) μg/L]																	
Mean	–	4.3	1.6	0.6	0.2	0.2	0.4	0.1	0.3	1.3	0.7	5.6	1.6	0.9	–	2.2	11.2
Max	–	13.1	10.2	6.4	1.1	0.4	6.4	0.7	2.5	13.1	5.6	35.3	11.0	6.3	–	20.0	37.3
Min	–	0.8	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	–	0.1	0.2
Stdev	–	3.0	1.7	0.9	0.3	0.1	0.9	0.1	0.6	2.5	1.2	9.8	2.2	1.6	–	10.9	12.4
Tribromomethane [(TBM) μg/L]																	
Mean	–	0.7	0.3	0.4	0.2	0.1	0.1	0.1	0.4	2.6	0.4	3.4	0.4	0.7	–	1.0	24.8
Max	–	2.6	1.6	8.2	2.1	0.4	0.7	0.4	5.5	37.4	2.5	26.8	1.5	24.5	–	41.3	65.1
Min	–	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	–	0.0	0.4
Stdev	–	0.8	0.3	1.1	0.4	0.1	0.1	0.1	1.2	6.5	0.5	7.0	0.3	3.0	–	23.6	17.7
Total Trichloromethane [(TTHM) μg/L]																	
Mean	–	21.2	8.9	10.8	5.8	7.9	5.8	3.9	4.7	11.9	10.5	33.7	17.5	6.5	–	7.6	40.6
Max	–	80.5	32.1	86.0	25.5	28.7	28.2	33.1	17.7	71.9	41.3	84.0	96.2	49.0	–	66.7	107.2
Min	–	2.0	0.2	0.8	0.4	0.6	0.4	0.4	0.8	0.7	0.7	6.8	0.7	0.7	–	0.2	0.9
Stdev	–	19.1	7.9	10.3	5.7	6.7	7.9	5.1	4.0	14.5	11.7	17.9	20.4	10.5	–	36.4	29.9
Number	0	20	73	189	37	28	57	54	19	89	59	31	144	66	0	61	61

Mean average value, *Max* maximum value, *Min* minimum value, *Stdev* standard deviation, *Number* sampling number
[a]Yi-Lan and Hua-Lian lacked TTHMs data

Table 5 Physical–chemical properties of total THMs species

Chemicals	CAS No.[a]	Physical–chemical property[a]								Harmfulness		Slope factor [mg (kg day^{-1})]			Benchmark Model[d]		
		MW	SG	*D*	BP	CP	VP	VPD	Diss.	*R*	CI[b]	R_fD[c]	Ingestion	Inhalation	Dermal	BMD	BMDL	Stage
TCM	067-66-3	119.4	1.485	1.484	61.2	−63.5	159.6	4.12	0.80	1.4422	B2	0.01	6.10×10^{-3} (IRIS)	3.05×10^{-2} (IRIS)	8.05×10^{-2} 0.41–3.58 (IRIS)	0.49–3.58 0.28–2.44	0.28–2.44	First second
BDCM	075-27-4	163.8	–	1.971	90.1	−57.1	–	–	0.67	1.4953	B2	0.02	6.20×10^{-2} (IRIS)	6.33×10^{-2} (RAIS)	6.20×10^{-2} (Dan)	1.17–3.48 0.55–4.84	0.38–2.67 0.32–2.86	First second
DBCM	124-48-1	208.3	–	2.451	120	−22	–	–	0.40	1.5465	C	0.02	8.40×10^{-2} (IRIS)	1.40×10^{-1} (RAIS)	8.40×10^{-2} (Dan)	1.23–4.43 0.45–3.99	0.30–2.65 0.29–2.54	First second
TBM	075-25-2	252.8	2.089	–	151.2	9	–	–	–	1.6005	B2	0.02	7.90×10^{-2} (RAIS)	1.32×10^{-2} (IRIS)	6.10×10^{-3} (IRIS)	8.36–24.8 3.21–36.4	3.21–19.3 2.50–22.0	First second

[a]MSDS, [b]USEPA, [c]USEPA 2003a, [d]BMR (Benchmark response, set BMR = 2.5, 5, 10 and 20% in the confidence 95% at one or two stage degree)

MW Molecular weight, *SG* Specific gravity (25/4°C), *D* Density (20°C), *BP* Boiling point (1 atm, °C), *CP* Congeal point (1 atm, °C), *VP* Vapor pressure (20°C, mmHg), *VPD* Vapor pressure density, *Diss* Dissolution (20°C, g/100 mL H_2O), *R* Refraction (25°C), *CI* Carcinogenetic identification, R_fD Reference dose (mg/kg/day), *BMD* Benchmark dose (mg/kg/day), *BMDL* Lower-bound confidence limit on BMD (mg/kg/day)

For many drinking water DBPs, the potential for exposure and uptake occurs by ingestion but also through dermal absorption or inhalation (Lee et al. 2004). Since 1990, scientists proposed that inhalation and dermal absorption were considered in the risk assessment of drinking water (Jo et al. 1990; Maxwell et al. 1991; Weisel and Jo 1996; Weisel et al. 1999; Lin and Hoang 2000).

Moreover, the study assumed the behaviors of "drinking water", "take a shower", and "skin contact in the shower" represent the exposure pathways of ingestion, inhalation and dermal intake simplistically (Dan 2003; Chen 2003). The mathematic model by Little (1992) exhibited THM species concentration within the air was influenced by many parameters adopted to evaluate the concentration in the bathroom. All exposure pathway formulas and parameters are displayed in Table 3. We adopted the weight of population pattern to calculate the concentration of THM species in the five regions of Taiwan. It is more reasonable to interpret the weight of population in the exposure concentration level. Utilized the concentration, it can obtain the CDI values from different exposure routes, respectively.

2.2.4 *Risk characterization*

In this step, the hazardous identification, dose-response and exposure assessment procedures are summarized and integrated into quantitative and qualitative expressions of the risk level. For carcinogenic effects, the risk is expressed as the probability that an individual will exhibit dose-response characteristics. Under the assumption that the slope factor is a constant, the risk related to the intake pathways in this study directly.

Linear low-dose cancer risk equation Risk
$= \text{CDI} \times \text{SF}$,

where

Risk a unitless of an individual developing cancer,
CDI chronic daily intake averaged over 70 years [mg (kg day^{-1})],
SF slope factor, expressed in milligram (kg day^{-1}).

Estimating the risk or hazard potential requires a combination of simultaneous exposures to more than one pathway and carcinogenic effect. In this paper we assumed THM species dose are additivity. And there are no synergistic or antagonistic interactions. Equally, the total cancer risk assumes that all carcinogens are equal, and the slope factors derived from the animal data are given the same weights as factors derived from the human data. It can express into below:

Total exposure cancer risk =
Risk (exposure pathway 1)
+ Risk (exposure pathway 2)
+ ... + Risk (exposure pathway *i*)

2.2.5 *Uncertainty and sensitivity analysis*

There are several types of uncertainty parameters. An important task in risk analysis is to determine what kinds of uncertainty are likely to affect the MCS finding suggested by USEPA (1997) in processing the uncertainty and sensitivity analysis. Essentially, MCS involves conducting and comparing repeated inputs that sample the system parameter distributions. This study utilized *@ Risk view (version 4.5)* software to execute the data probability distribution and simulate the sensitivity using MCS.

3 Results and discussion

3.1 Investigated result of epidemiologic studies

The consequence of epidemiologic studies that inhibited several cancers caused by THM species are colon, rectum and bladder cancers, respectively. Annual reports from the Department of Health, Taiwan (DOH http://www.doh.gov.tw/statistic/index.htm) announced the mean numbers for these cancers, which were discriminated by location from 1996 to 2000. Fig. 1 exhibited the ratio of death count versus water supply population (TWC http://www.water.gov.tw/sample1/about/data1.asp#3). The investigation results exhibited Northern region has a higher death count (colon (1,535), rectum (1,188) and bladder (566)), but Southern region displays higher ratio (colon (0.15‰), rectum (0.14‰) and bladder (0.09‰)) in these cancers evidently.

3.2 Statistic analysis of THMs species data

Statistical results in Table 4 exhibit the means, maximum, minimum and standard deviations values in sub-

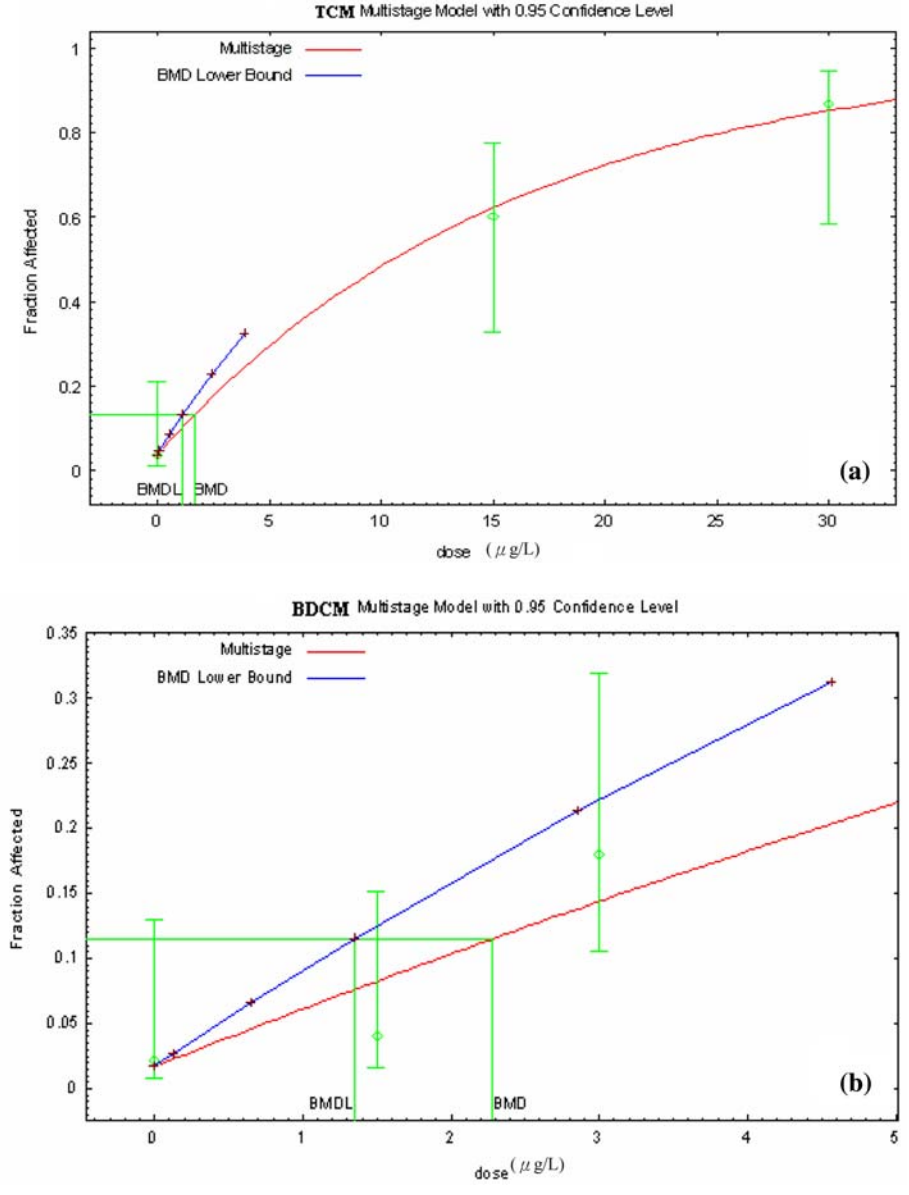
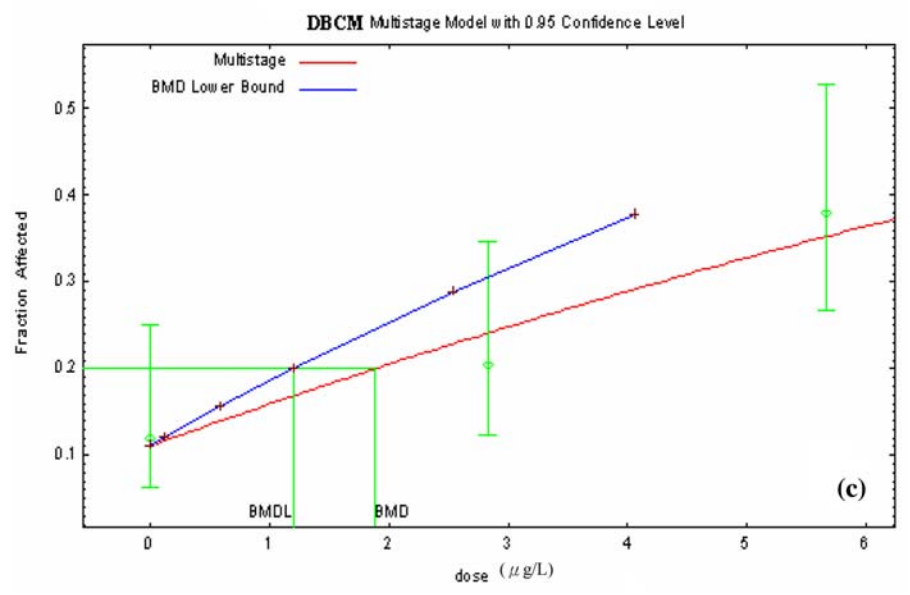
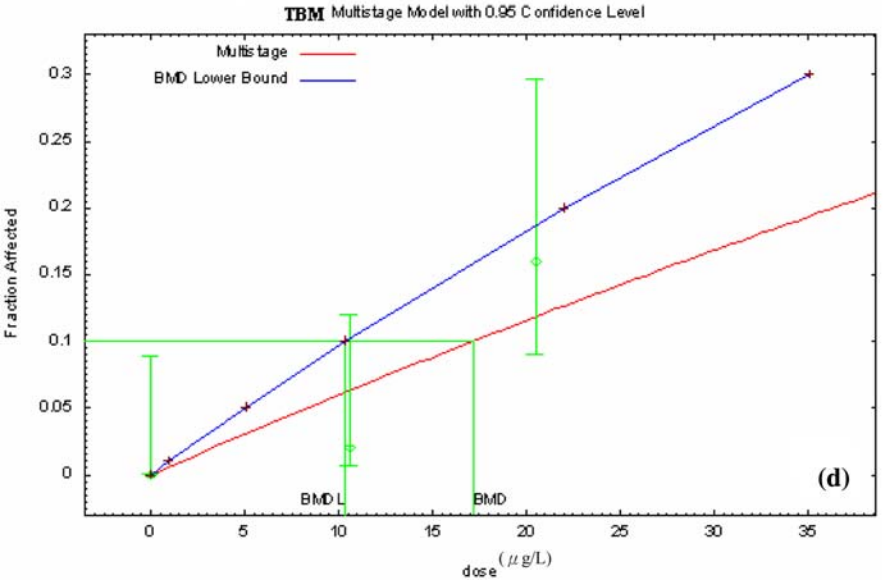


Fig. 2 BMD/BMDL values from **a** TCM, **b** BDCM, **c** DBCM and **d** TBM data by first stage multistage model fit with 95% confidence limits

Fig. 2 (Contd.)





scriber levels. The TCM level is the predominant derivation of THMs in Taiwan. The Northern and Southern regions presented higher mean concentrations, shown by the epidemiology study investigation of Taiwan DOH.

In the BDCM, DBCM and TBM levels are predominant in external island. Previous research (Garcia-Villanova et al. 1997; Golfinopoulos et al. 1996) verified groundwater and seawater contain bromide compounds if the water sources are near the seacoast. It conformed to the situation of external island of Taiwan.

3.3 Hazard identification

A number of epidemiological studies were performed to investigate adverse effects in human exposed to TCM, BDCM, DBCM and TBM, respectively.

Table 5 collates the physical–chemical properties, harmfulness, slope factors and quantity of Benchmark dose (BMD) of THMs species completely. Obviously, evidences of animal study revealed THMs species may carcinogenic hazardous materials.

3.4 Dose-response assessment

This study adopted a multistage type of benchmark model approved by USEPA (2003b) to process the dose-response assessment. The chronic toxicity and carcinogenic potential of total THMs species at low dose situation were interpreted. Figure 2 shows the BMD/BMDL value for the total THMs species calculated from the Benchmark model from animal data (95% confidence limits and first stage model fit). Furthermore, the range

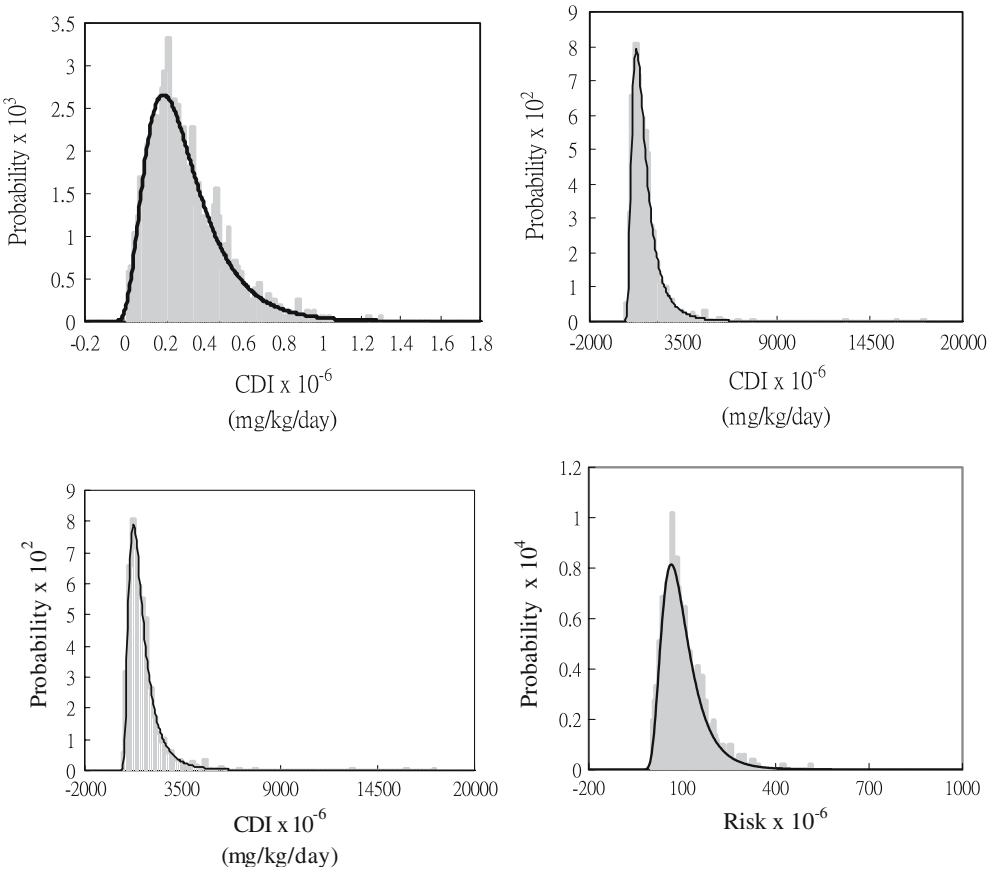


Fig. 3 MCS results of CDI values in the ingestion, inhalation, dermal intake exposure pathways and total risk probability distribution

of BMD/BMDL value in first/second multistage model had shown in Table 5. Generally, the BMD values of first are higher than second stage, but the BMDL values are similar between first and second stage model. USEPA proposed the standard BMD and BMDL values of TCM is 1.69, 1.15; BDCM is 2.28, 1.35; DBCM is 1.88, 1.20; and BMD is 17.6, 10.3 mg/kg day^{-1}, respectively.

3.5 Exposure assessment

THM species data processed the weighted average method via the regional population and specific year to acquire the statistical analysis. The MCS method was used to evaluate the CDI dose and obtain the probability distribution results by performing 1,000 frequency calculations.

Figure 3 shows the MCS consequence exhibited in the ingestion pathway, southern region exist the higher CDI values, in opposite to female examined higher CDI endured than male (CDI ranges are 1.07×10^{-4} to 1.63×10^{-3} and 9.22×10^{-5} to 1.42×10^{-3} mg (kg day^{-1}), respectively). The variance in body weight between females and males is the main reason for the CDI ingestion level. Moreover, in the respired estimated, consequence exhibited in ingestion pathway, external island exist higher CDI values. Similarly, females exhibited higher levels than males (CDI range is 7.28×10^{-6} to 1.42×10^{-3} mg (kg day^{-1}) and 4.29×10^{-5} to 4.96×10^{-3} mg (kg day^{-1}), respectively) because of their shower behavior. This included the difference between municipal and rural areas and gender. In the estimated skin contact, the dermal intake pathway was similar to the ingestion pathway. The Southern region exhibited higher CDI values and females were higher than males (CDI ranges are 2.55×10^{-7} to 2.95×10^{-5} and 2.42×10^{-7} to 2.81×10^{-5} mg (kg day^{-1}), respectively). In the contact time during showers, females took longer showers than males. The Taiwan DOH announced and suggested that showers not exceed 12 minutes, otherwise, the health risk will increase.

3.6 Risk characterization

The THM species slope factor from the dose-response curve showed a low dose situation from the linear model (Table 5). Assumption the cancer risk is CDI multiplication slope factor and total cancer risks include different exposure pathways. The total cancer risk assessment order was southern, northern, central over the external island segment. The average value for females was 4.04×10^{-6} to 4.67×10^{-4} and 9.25×10^{-6} to 4.07×10^{-4} for men, respectively. Figures 4 and 5 exhibited the THM species distribution via different exposure pathways to estimate the CDI value, risk assessment and contribution percentage simultaneously. The cancer risk

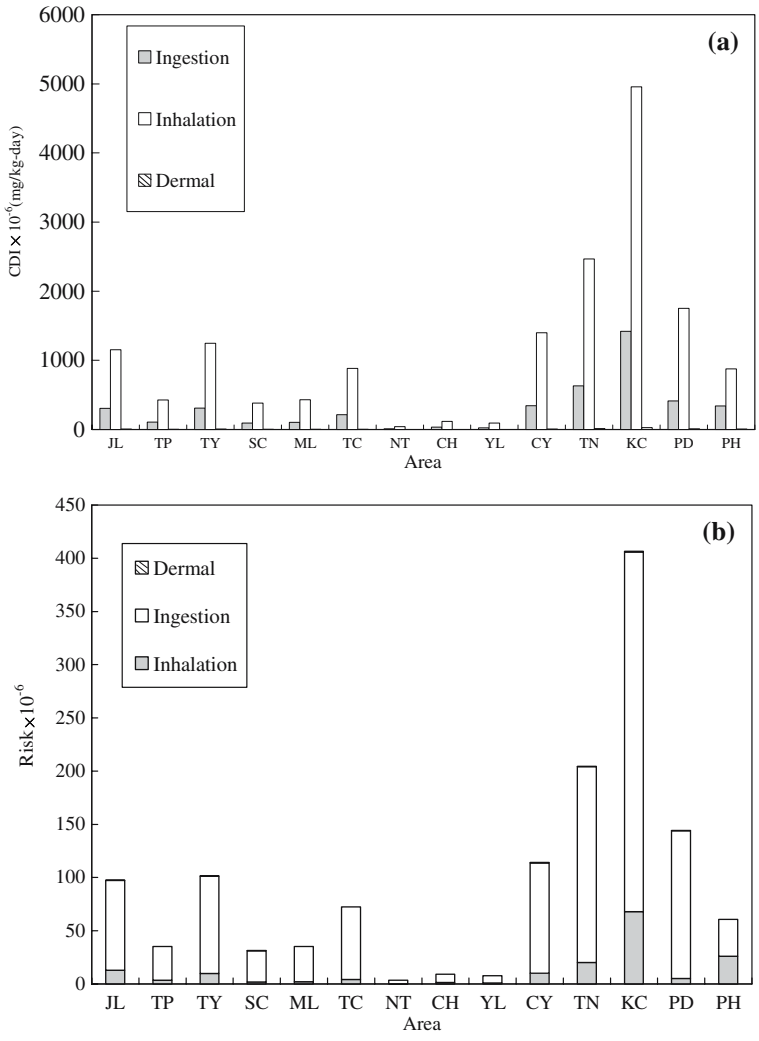


Fig. 4 Special distribution via different exposure pathways in CDI (**a**) and risk (**b**) assessment

quantitative analysis evaluation for Taiwan (*Arc View* plot) is shown in Fig. 6. It is shown that the Southern Taiwan region presents a higher risk.

In term of the inhalation pathway distinct revealed the magnificent in the risk assessment of THMs species, continuous is ingestion and dermal intake pathways, respectively. TCM is the main contribution to the risk assessment in Taiwan (50% approximately), and TBM is predominance in external island (50% approximately).

3.7 Sensitivity analysis

The sensitivity analysis processed the ±20% extra risk to interpret the effective THM species parameters, including body weight, intake quantity and exposure duration in formula of exposure assessment. Analysis was performed using the radar plots exhibited in Fig. 7. The research regions displayed a negative correlation consistent with the exposure duration and positive correlation in body weight dramatically. Furthermore, the TCM concentration is the predominant influence parameter in Taiwan, whereas the external islands are influenced by the DBCM concentration shown in Table 6.

4 Conclusions

In the mean concentration distribution of total THMs in Taiwan external islands (48.39 μg L^{-1}), southern (17.28 μg L^{-1}), northern (12.11 μg L^{-1}) and middle segments (9.59 μg L^{-1}). By investigation consequences, the TCM concentration is the major DBP species in the local regions of Taiwan, and the external islands is characterized by TBMs, respectively.

A multistage Benchmark model (USEPA 2004) was used to evaluate the dose-response assessment. Consequence exhibited at the 95% confidence level, the BMD and the quantity of lower-bound confidence limit for the BMD (BMDL) of TCM were 1.69 and 1.15 mg (kg day^{-1}), dibromochloromethane (DBCM) are 1.88 and 1.20 mg (kg day^{-1}), dichloromethane (DCBM) are 2.28 and 1.35 mg (kg day^{-1}) and TBM are 17.6 and 10.3 mg (kg day^{-1}), respectively. The exposure was compared with the reaction dose concentration of

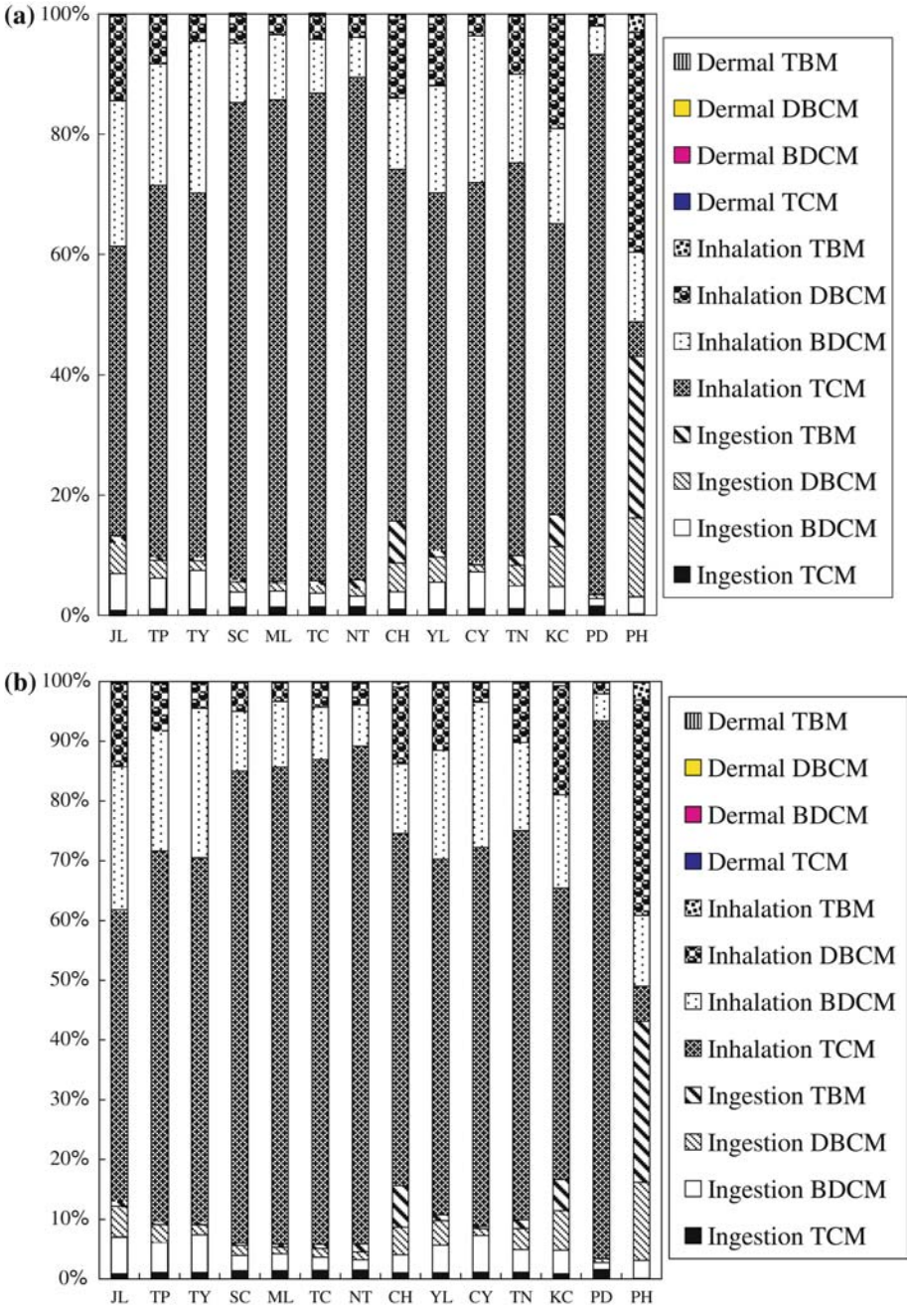


Fig. 5 Different contribution percentage of THMs species and exposure pathways in cancer risk assessment [(**a**) is male and (**b**) is female]

THMs species in drinking water. In terms of lower quantity of BMD/BMDL showed doses opposite to the cancer risk obviously.

In the exposure assessment calculated by MCS, inhalation was found as the principal pathway. The next pathway was ingestion followed by dermal intake. The quantity of average risk in male and female is 3.14×10^{-5} to 1.04×10^{-4} and 3.64×10^{-5} to 1.16×10^{-4} in northern, 9.25×10^{-6} to 7.25×10^{-5} and 4.04×10^{-6} to 8.40×10^{-5} in middle, 1.14×10^{-4} to 4.07×10^{-4} and 1.33×10^{-4} to 4.67×10^{-4} in southern, and 6.07×10^{-5} and 7.09×10^{-5} in external island, respectively. The Southern region presented a high cancer risk and corresponded with the result of epidemiology. Furthermore, females presented higher CDI values (intention risk level) than males in Taiwan.

Consequence of sensitivity analysis exhibited body weight and exposure duration are provided the influence in cancer risk analysis and assessment predominantly. Exposure time and body weight are the effective parameters used in the sensitivity analysis. The greater the exposure time, the greater the cancer risk endured. A negative correlation exists between body weight and the unit dose sustained risk probability.

Quantifying the risk factors is important for population and decision-making policy for drinking water

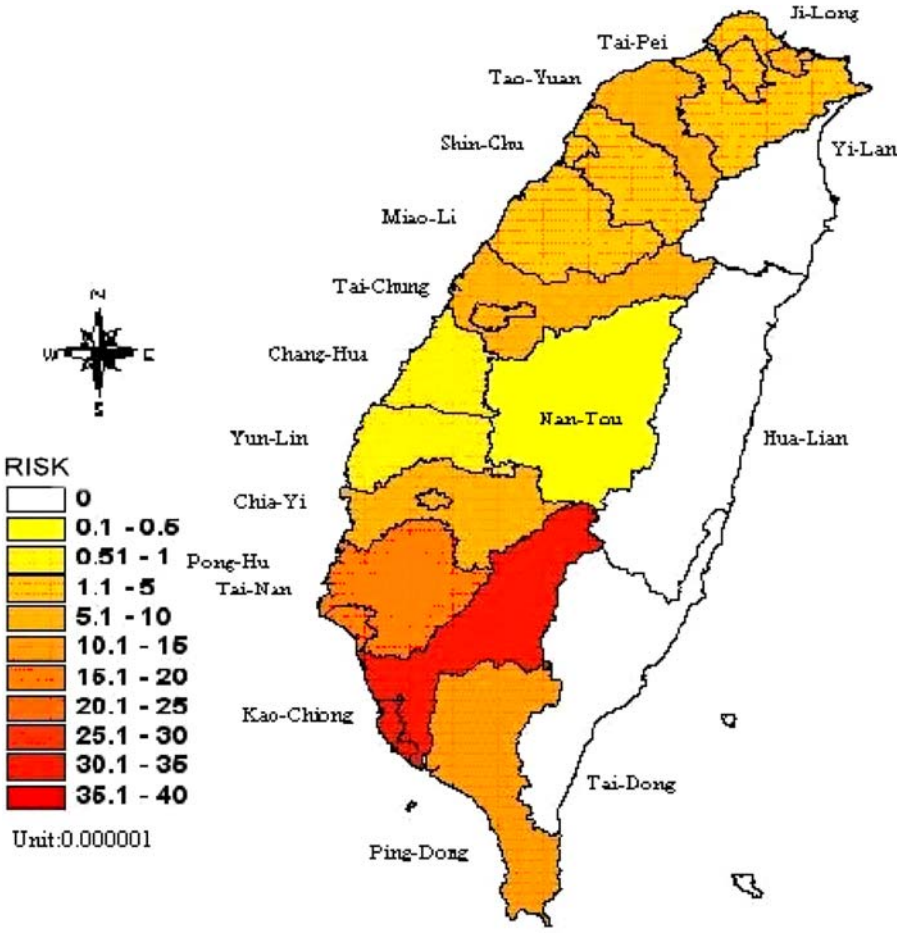


Fig. 6 Quantity of cancer risk assessment of Taiwan (*Arc View* plot)

Table 6 Cancer risk assessment sensitivity analysis

Regions	Parameters	TCM	BDCM	DBCM	TBM	BW	IR	ET
Northern	Ji-Long	3	4	5	7	1	6	2
	Tai-Pei	3	4	5	6	1	5	2
	Tao-Yuan	3	4	6	6	1	5	2
	Shin-Chu	3	4	5	6	1	5	2
Middle	Miao-Li	3	4	6	7	1	5	2
	Tai-Chung	3	4	5	6	1	5	2
	Nan-Tou	3	4	6	7	1	5	2
	Chang-Hua	3	6	4	7	1	5	2
	Yun-Lin	3	4	5	7	1	6	2
Southern	Chia-Yi	3	4	6	7	1	5	2
	Tai-Nan	3	4	5	7	1	6	2
	Kao-Chiong	3	5	4	7	1	6	2
	Ping-Dong	3	4	5	7	1	6	2
External island	Peng-Hu	7	6	3	5	1	4	2

Numbers exhibited are the extent of sensitivity, and 1 is the most sensitivity
BW Body weight, *IR* intake quantity, *ET* exposure time

Table 7 Legislation limit values for different counties in DBPs level

Chemicals	Taiwan	USA	WHO	Japan	Sweden	Australia
TCM	–	–	0.20	0.06	–	–
DBCM	–	–	0.10	0.03	–	–
DCBM	–	–	0.06	0.10	–	–
TBM	–	–	0.10	0.09	–	–
Total THMs species	0.10	Stage one: reduced to 0.08; Stage two: reduced to 0.04	1.0 (mg/L)[a]	0.10	0.05	0.25
Trichloroacetic acid	–	–	0.10	0.3	–	0.10
Dichloroacetic acid	–	–	0.05	0.04	–	0.10
HAAs	–	Stage one: reduced to 0.06; Stage two: reduced to 0.03	–	–	–	0.15

[a]Mean THMs ratio

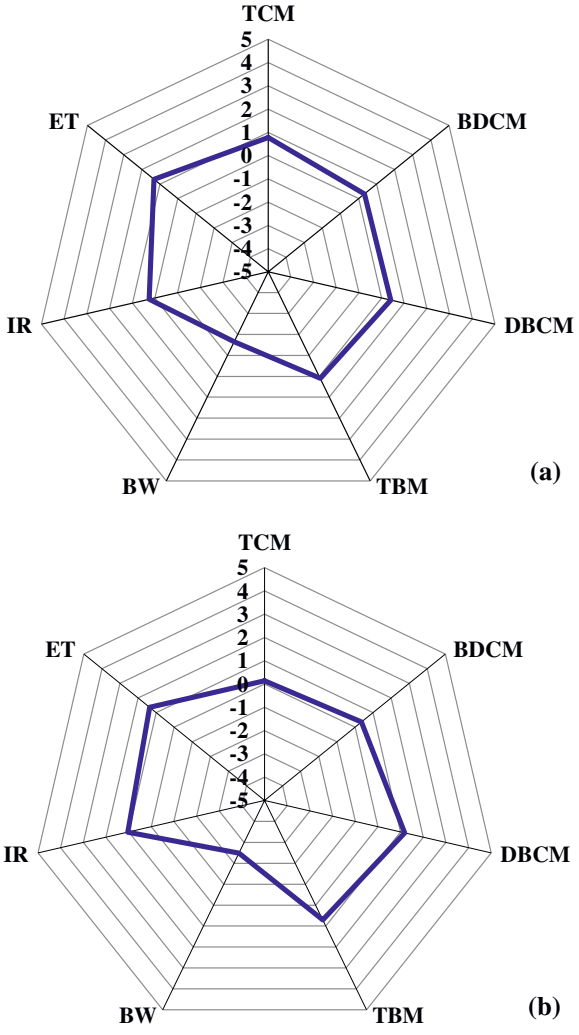


Fig. 7 Radar plots for sensitivity analysis in Taiwan area (**a**) and external island (**b**)

safety. Fortunately, the Benchmark model and MCS @Risk supply the methodology were used for risk calculation. The standard for the total THMs species in Taiwan was 100 ppb presently. Table 7 displays the legislation limit values for different countries for DBPs levels. We suggest that the standard be separated using separate TCM, BDCM, DBCM and TBM standards. This may establish a control management for individual material to reduce the harmful risk.

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