EXPOSURE ASSESSMENT AND THE RISK ASSOCIATED WITH TRIHALOMETHANES COMPOUNDS IN DRINKING WATER

Avaliação da exposição e o risco associado com compostos trihalometanos na água potável

Artigo Original

ABSTRACT

Objective: *To measure the concentrations of trihalomethanes (THMs) in marshland of Jacarepaguá drinking water, Rio de Janeiro-RJ, Brazil, and their associated risks.* **Methods:** *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.* **Results***: The THMs (dibromochloromethane, bromoform, chloroform, and bromodichloromethane) ranged from 3.08 µg/l to 129.31 µg/l. Non-carcinogenic risks induced by ingestion of THMs were below the tolerable level (10^{-6}).* **Conclusion***: Data obtained in this research demonstrate that exposure to drinking water contaminants and associated risks were higher than the acceptable level.*

Descriptors: *Drinking Water; Risk; Trihalomethanes.*

RESUMO

Objetivo: Medir as concentrações de Trihalometanos (THM) na rede de distribuição de água potável da Baixada de Jacarepaguá, Rio de Janeiro-RJ, Brasil, e seus riscos associados. **Métodos**: Duzentas casas foram visitadas e coletaram-se amostras de água das torneiras dos consumidores. Estimativas de riscos baseadas em exposições foram projetadas, empregando abordagens determinísticas e probabilísticas. **Resultados**: Os THMs (dibromoclorometano, bromofórmio, clorofórmio e bromodiclorometano) variaram de 3,08 µg/l a 129,31 µg/l. Riscos não cancerígenos induzidos por ingestão de THMs foram abaixo do nível tolerável (10^{-6}). **Conclusão**: Os dados obtidos nesta pesquisa demonstram que a exposição aos contaminantes da água potável e os riscos associados foram superiores ao nível aceitável.

Descritores: Água Potável; Risco; Trialometanos.

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INTRODUCTION

Water supply is probably one of the most important public services in a city, mainly because if distributed in a safe mode, it protects the population from illness-producing microorganism such as bacteria and viruses, but unfortunately, may also be the source of many illnesses[1]. Particularly with regard to water supply, most watersheds are used for multiple purposes, among them: public water supply, electric power production, recreation and irrigation, also considering the disordered occupation of the soil, especially on the margin coastal of river basins[2].

Economic development in recent decades has contributed effectively to an urban and industrial growth, primarily in metropolitan areas. In Brazil, this growth has been the target of many concerns and has taken place without adequate planning[2]. This fact has been regarded as a major cause of environmental degradation due to intensive use of water and waste, mainly produced by industries and the public in general[3,4].

The treatment process of water supply used in Brazil is based on a comprehensive study of the quality of raw water, so that thus can be used with appropriate technologies to make it drinkable. The most common treatment, the Water Treatment Plants (WTP) is a complete treatment or conventional, which consists of five steps: coagulation, flocculation, sedimentation or flotation, filtration and disinfection[5].

In Brazil, Ministry of Health Decree nº 518/2004[6], which regulates the drinking water standards for human consumption, specifies that, after disinfection, the water must contain a minimum content of free residual chlorine (FRC) 0.5 mg/l, with mandatory maintenance of at least 0.2 mg/l at any point in the distribution network, recommending that the chlorination is performed at pH <8.0 and contact time of at least 30 minutes. However, this decree does not establish the maximum allowable value (MAV) for FRC, above which water is considered potable.

The principal disinfecting agents are: chlorine, ozone, hydrogen peroxide, bromine, iodine, potassium permanganate, heat and ultraviolet radiation[7]. Chlorine is one of the principal disinfecting agents. The risks related to the process of water chlorination are more associated to their sub-products than the agents used. Although several studies suggest benefits for human health in the use of chlorine during the disinfection process[8], when there is some organic material in water supply, some reactions can occur between these substances generating as a sub-product the THMs[9-11].

Among the organochlorines produced as by-products of chlorine disinfection, the highlights are the THMs[4]. The THMs are chlorinated organic compounds derived from methane (CH_4). In their molecules, three of its four hydrogen atoms have been replaced by an equal number of atoms of the halogen elements chlorine, bromine or iodine. The compounds of the most common group of THM in drinking water are: Chloroform ($CHCl_3$), bromodichloromethane ($CHBrCl_2$), dibromochloromethane ($CHBr_2Cl$), and Bromoform ($CHBr_3$)[4,12,13].

In 1979, the Environmental Protection Agency (EPA) established the maximum concentration of 100 µg/l TTHM (total trihalomethanes) water for public supply in the United States. Currently, the maximum value in the U.S. is 80 µg/l[14]. Other industrialized countries have also established limits for TTHM. For example, in Canada, the limit is of 80 µg/l[15], the UK is 100 µg/l[16] and in Australia, is 250 µg/l[17]. In Brazil according the Ministry of Health by Decree No. 518, the maximum value is 100 µg/l[6].

Levels of chloroform, the most common THM, are commonly higher in chlorinated water originating from surface water than in groundwater, because of higher organic matter in the former[18]. The extent of formation of chloroform varies with different WTP. Concentrations of chloroform in chlorinated water in WTP and distribution systems are approximately twice as high during warmer months as during colder months. This is an outcome of the higher concentrations of precursor organic materials and especially of the higher rates of formation of disinfection by-products in the raw water during the warmer period[19].

THMs may possibly be present in water for public supply at levels high enough to cause adverse health effects. Ingestion of drinking water containing these contaminants may go ahead to liver and kidney damage, immune system, nervous system, and reproductive system disorders as well as numerous types of cancers[20]. Reported data suggest that an association exists primarily between bladder cancer, colon and rectum and the intake of these compounds. Various country governmental health protection agencies have focused on THMs and promulgated regulations for THMs as shown in table I.

The purpose of the evaluation developed for the risk management ensures the safety and offers procedures to control the quality of drinking water. The probabilistic approach provides a more comprehensive characterization of information and knowledge available, quantifying the intervals and the probability of exposure for groups of individuals, including evidence, which requires further study. It involves the use of mathematical models for the physical and chemical processes that provide a range of values and the probability distribution for the exposure, i.e., provides for the distribution of exposure values within the study population[21].

Table I - Guidelines for drinking water related to THMs (µg/l) in various jurisdictions of World.

Compounds	WHO (1996)	USEPA (2001)	Health Canada (2006)	Brazil (2004)	UK (2000)
$CHCl_3$	200	0.000*	-	-	-
$CHCl_2Br$	60	60*	-	-	-
$CHClBr_2$	100	0.000*	-	-	-
$CHBr_3$	100	0.000*	-	-	-
TTHMs	(THM/WHO)£100**	80	100	100	100

*Maximum Contaminant Level Goals (MCGL)
**the sum of the ratios of the THM levels to the guideline values should not exceed 100 µg/l

The objectives of this study are to measure the concentrations of THMs in marshland of Jacarepaguá drinking water, Rio de Janeiro-RJ, Brazil, determining demographic rates and drinking water consumption levels, and estimating both individual and population based exposure.

METHODS

The marshland of Jacarepaguá is located on the southern coast of the municipality of Rio de Janeiro. It is limited to the west by Pedra Branca massif, at the east by the Tijuca massif and the south by the Atlantic Ocean. It is a coastal area that is constantly changing, but still has a significant natural biodiversity and heterogeneity of environments such as remnants of mangroves, salt marshes and lagoons (Figure 1).

Throughout the THMs inspection, samples were collected monthly from different sampling point in marshland of Jacarepaguá drinking water, Rio de Janeiro, Brazil. The water sample was collected once a month starting in August, 2009 to September, 2010.

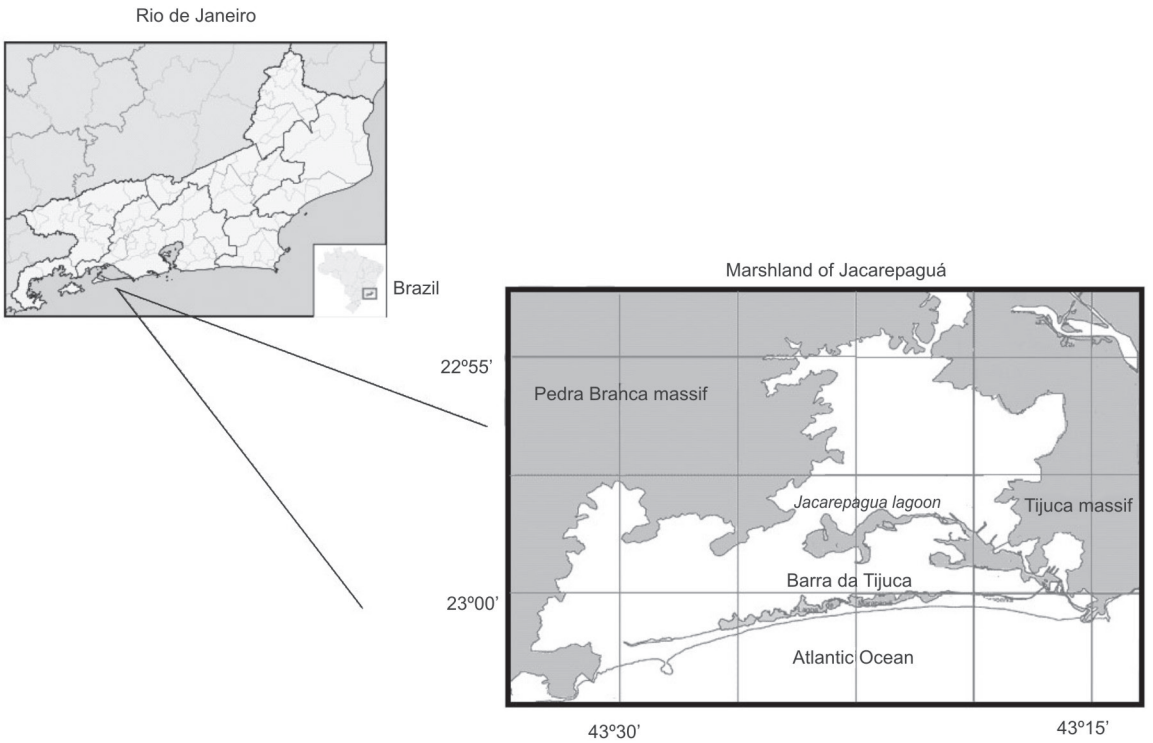

Figure 1: Study site: Marshland of Jacarepaguá, Rio de Janeiro, Brazil.

The appropriate sample size for a population-based survey is determined largely by three factors: (i) the estimated prevalence of the variable of interest, (ii) the desired level of confidence and (iii) the acceptable margin of error. Thus, 200 houses were randomly identified and

drinking water samples were collected from consumer taps in order to estimate the exposure and risk levels for this population associated with intake of THMs in drinking water.

Tap water samples were collected after allowing the system to flush for 3 minutes. Then the flow rate was reduced to avoid introducing bubbles and 10 ml of water was collected in the sampling vial. Duplicate samples were collected from each sampling unit in 40 ml vials and closed with Teflon lined screw cap, preserved with ascorbic acid as a reducing agent, in order to inhibit the initial formation of THMs and other chlorinated compounds in the period between collection and analysis. The samples were refrigerated at 4^0C immediately after collection to minimize the power of the volatilization of volatile compounds. All samples were measured 24 and 48 hours after sampling.

Detection was performed by gas chromatography (GC) coupled to either mass spectrometry (MS) using a Hewlett Packard 5890 Series II GC instrument coupled to a Hewlett Packard 5971 MSD, by a Varian Star 3400 GC with an electron capture detector (ECD)[22]. EPA Method 551.1 was followed[23]. This method is a reference method for chlorination by-products and is capable of generating THM into individual compounds.

The analysis was made using headspace technique. 10 ml of sample was filled into 20 ml headspace vials and closed with Teflon lined screw cap. After that the samples were equilibrated in an oven at 60°C for 45 minutes, 1 ml of the headspace was then injected into the GC

(Cyanopropylphenyl Polysiloxane column, 30 m x 53 mm, 3 mm film thickness, Thermo Finnigan, USA). The column program was 35°C (hold time 3 minutes), 15 °C/ minutes to 200°C (hold time 3 minutes). The inlet was set at 200°C. The calibration standards were prepared using the THM test mixture produced by Restek. The calibration standards were prepared for the range 0 – 100 mg/l in pure water. In the analysis of THMs samples, 1 ml volume of headspace were injected into the GC column with TriPlus HS auto sampler and four peaks were detected belonging to the four THM compounds.

The risk assessment paradigm was developed by the US National Research Council[24]. Based on the THMs data collected in this survey; an exposure assessment was conducted to evaluate the potential THMs uptake via oral ingestion. Conventionally, risk assessments for toxic chemical exposure from water often consider ingestion exclusively although showering has been shown to also increase the body burden of certain chemicals by inhalation and dermal absorption; thus this needs to be token into account in the analysis of total human exposure to volatile contaminants in tap water[1]. As a general rule, a risk assessment process includes the following four components: data collection and evaluation, exposure assessment, toxicity assessment, and risk characterization. Results are then integrated and compared to estimates of intake with appropriate toxicological values to determine the likelihood of adverse effects in potentially exposed populations[25]. In this research, two approved risk assessment models are adopted (a) the World Health Organization (WHO) index for additive toxicity, and (b) the United States Environmental Protection Agency (USEPA) - approved Risk Assistant model.

The WHO index for additive toxicity for THMs estimates the toxic risk associated with chlorinated drinking water. The I_{WHO} value should be ≤ 1 for compliance with WHO guidelines and is calculated as follows:

$$I_{WHO} = \frac{C_{TCM}}{GV_{TCM}} + \frac{C_{BDCM}}{GV_{BDCM}} + \frac{C_{DBCM}}{GV_{DBCM}} + \frac{C_{TBM}}{GV_{TBM}} \leq 1 \quad \textbf{eq. 1}$$

Where C is the surveyed concentration of each THM, and GV is the WHO guideline value. WHO guidelines values have been established separately at 200 μg/l for chloroform, 100 μg/l for each of bromoform and dibromochloromethane, and 60 μg/l for bromodichloromethane[26].

The USEPA Risk Assistant model estimates both toxic and carcinogenic risks. The toxicological risks are expressed as the hazard quotient (HQ), and calculated based on the comparison of actual exposure to a chemical to the reference dose (RfD) of that substance as follows:

HQ = [total amount ingested / body weight x exposure time x reference dose] **eq.2**

Reference doses are extrapolated from toxicological studies of exposure which demonstrate a critical effect, are expressed in units of mg/kg/day, and are available in the Integrated Risk Information System (IRIS) database maintained by USEPA[27]. The total amount of chemical ingested depends on several typical or population-specific exposure factors such as the chemical concentration in local waters, water consumption rate, the frequency and the duration of exposure. Body weight and exposure time estimates are also needed to calculate HQ.

In addition to toxic risks, carcinogenic risks of exposure to surveyed THM levels were calculated using the USEPA methodology. Carcinogenic compounds differ from toxic compounds in that there is no lower limit for the existence of risk. Thus, carcinogen risk assessment models are generally based on the premise that risk is proportional to total lifetime dose, and the exposure metric used for carcinogenic risk assessment is the Lifetime Average Daily Dose (LADD). The LADD is typically used in conjunction with the Cancer

Slope Factor (CSF) to calculate individual excess cancer risk. It is an estimate of the daily intake of a carcinogenic agent throughout the entire life of an individual. The CSF is the gradient of the line of the dose-response curve derived from laboratory toxicological studies, and values for each substance are available in the USEPA IRIS databases[27]. For THM species, the USEPA range of concern is for an increased carcinogenic risk of 10^{-6} (1:1,000,000)[21].

In this survey was calculated the cancer risk by THM ingestion. The following relationship was used:

THM carcinogenic risk of oral route = $LADD_{oral}$ x CSF_{oral} **eq.3**

Where $LADD_{oral}$ = [total amount ingested/body weight x life time] **eq.4**

= (THM concentration in water x IR x EF x ED) / (BW x AT)

and,

IR – ingestion rate (l/h)

ER - exposure rate = Based on a typical water consumption rate of 2 litres/day

EF – exposure frequency = Equivalent to events per year, i.e. 365 days per year for water consumption

ED – exposure duration = Equivalent to life expectancy of 71.2 years.

BW – body weight = A typical adult weight of 70 kg is considered

AT – average exposure time = Based on life expectancy. Expressed in days; calculated as 71.2 years x 365 days/year = 25,988 days

The probabilistic risk assessment was used to subsidize the management of environmental exposures to carcinogenic THMs. A probability sample, is defined as samples in which every member of the target population has a known probability of being included in the survey[28]. A sampling design was used in this study, and the number of samples collected from each district was calculated according to geographical population distribution. So, the households to be visited in each area were selected randomly on the day of the sampling.

RESULTS

THMs species data

The THMs concentration of the water samples analyzed in each sampling area are given in table II. The total THM concentrations were calculated using an additive model, i.e., the concentrations for the four individual THM species were summed up. Fourteen of the drinking water samples exceeded the TTHM of 100 µg/l established by the Decree No. 518 of Ministry of Health, Brazil[6]. TTHMs concentrations ranged from 3.08 µg/l to 129.31 µg/l.

In addition to the four THMs (chloroform, bromodichloromethane, dibromochloromethane, and bromoform), the numbers of samples in which these THMs were detected are shown in table III**.**

Table II - Descriptive statistics for THM concentrations in marshland of Jacarepaguá drinking water.

THMs	X	Sd(yEr±)	Se(yEr±)	P_{25}	P_{75}	P_{95}	X_{Min}	X_{Max}	R	Median	Var	Coef Var
Chloroform	58,06	22,71	1,72	42,45	72,43	102,9	23,62	115,32	91,7	51,40	515,60	0,39
Bromodichloromethane	19,98	5,02	0,64	17,63	20,85	29,85	12,25	37,11	24,86	19,61	25,23	0,25
Dibromochloromethane	11,53	2,77	0,40	9,74	12,95	17,28	5,73	17,58	11,85	11,70	7,67	0,24
Bromoform	5,87	1,66	0,34	4,55	6,68	8,58	2,84	8,70	5,86	6,20	2,76	0,28

N = 200

All values are in µg/l.

X-arithmetic mean; Sd- standard deviation; Se- standard error; P_{25} – percentile 25; P_{75} – percentile 75; P_{95} – percentile 95; Xmin- minimum; Xmax-maximum; R – range; Var – variance; CoefVar- coefficient of variation (%)

Table III - Detection Frequencies of the THMs of Concern.

THM	Frequency (%)
Chloroform	87
Bromodichloromethane	31
Dibromochloromethane	24
Bromoform	12

The WHO index for additive toxicity approach

Applying the WHO index for additive toxicity approach to network THM levels in marshland of Jacarepaguá resulted in I_{WHO} values of 0.79738 for all samples collected from the various distribution networks, during the period studied. Therefore, it can be concluded that the additive toxicity of recorded THM levels in the distribution networks of investigated sources is compliant with the WHO guideline value, and consequently such concentrations do not pose any adverse toxic health impacts.

The USEPA risk assistant model approach

According to this USEPA model, toxicological risks are estimated and expressed as the HQ. Mean lifetime excess cancer risks using the USEPA 70-year life expectancy were: HQ_{TCM} = 0.01181 (i.e., a 1.18 in 100 chance of developing cancer over a lifetime); HQ_{DBCM} = 0.0011729 (i.e., a 1.17 in 1000); HQ_{BDCM} = 0.0012195 (i.e., 1.12 in 1000), and HQ_{TBM} = 0.000597 (i.e., 5.97 in 10,000). In conclusion, THM concentrations found in local networks do not pose adverse developmental and non-carcinogenic risks.

Ingestion route: Evaluations of lifetime cancer risks for THM

Considering a water ingestion of 2 litres/day, computed cancer risks via oral exposure revealed that the investigated network exceeded the set USEPA range of concern for an increased carcinogenic risk of 10^{-6} for all THM species. Increased oral cancer risks presented 3.8467 folds, 2.8547 folds, 2.8928 folds and 1.1675 folds for TCM, BDCM, DBCM, and TBM, respectively. The highest cancer risk increases were recorded for TCM, followed by DBCM, BDCM, and TCM.

DISCUSSION

Epidemiological studies regarding adverse effects on health, associated with exposure to chlorinated water demonstrated the production of organohalogens from the combination of chlorine with organic compounds in drinking water[9]. In another study was observed in a retrospective cohort study in Guastala, Italy, which, among 5,144 residents consuming water with trihalomethanes, particularly chloroform, men had higher rates of mortality from stomach cancer in liver, lung, prostate and bladder, with an OR of 1.2 [95% CI: 1.1 to 1.4], and women had a higher incidence of stomach cancer, pancreatic, breast, ovary and leukaemia[29]. However, no significant association was demonstrated for both sexes, which was attributed to the difficulty of controlling confounding factors such as smoking and other aspects of lifestyle.

Data from Canadian provinces demonstrated that the mean THM level was about 66 µg/l in drinking-water samples from all systems. Some systems had average values in the 400 µg/l range, and some systems had maximum or peak values in the 800 µg/l range. From the eight provinces, 282 water systems (23% of sampled systems), representing a sampled population of 523 186 (3.4% of the sampled population served), reported having mean THM levels greater than 100 µg/l, whereas 506 water systems (41%), serving a sampled population of 2 509 000 (16%), reported at least one instance of THM levels being greater than 100 µg/l[30].

In the USA, monitoring data were collected over an 18-month period between July 1997 and December 1998 from approximately 300 water systems operating 501 plants and serving at least 100,000 people. The mean, median, and 90th-percentile values for surface water distribution system average concentrations in the US survey are 8.6, 70.2, and 20.3 µg/l, respectively, for BDCM (range of individual values 0–65.8 µg/l); 2.4, 4.72, and 13.2 µg/l, respectively, for DBCM (range 0–67.3 µg/l); and 0, 1.18, and 3.10, respectively, for bromoform (range 0–3.43 µg/l)[31].

Even though not complete, available epidemiological data are consistent with the hypothesis that ingestion of chlorinated drinking-water, if not THMs specifically, may be associated with cancers of the bladder and colon[32]. Additionally, epidemiological data available since 1993 have associated adverse reproductive outcomes with exposure to THMs, particularly the brominated THMs, although neither clear evidence of a threshold nor a dose–response pattern of increasing risk with increasing concentration of total THMs has been found[33]. Nevertheless, in view of the potential link between such adverse health effects and THMs, particularly brominated THMs, it is recommended that THM levels in drinking-water be kept as low as practicable.

In Brazil, the use of risk assessment in decision-making processes by regulatory agencies are weak, with two different focuses: the first one in the prevention of chemical accidents which involve acute exposures, the other in the management of contaminated areas as a subsidy to the definition of remediation alternatives. There is a great lack for decision makers, which can result in intolerable economic or environmental costs, and worst, without perspectives of adequately drinking water treatment as alternative for reducing exposure.

Throughout the history of risk assessment, traditionally, are employed deterministic calculations, made on the basis of point estimates of the input parameters of the models for assessing exposure and risk. However, the limitations of this approach concern the actors involved, either by the degree and direction of bias or by conservatism.

CONCLUSION

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

The analysis conducted in the approach for carcinogenic risk showed results indicating that an expressive risk of cancer may exist by oral ingestion within the studied population. In fact, all of investigated THMs exceed the set USEPA range of concern for an increased carcinogenic risk of 10^{-6}.

Analysis conducted in the approach for non-carcinogenic risk assessment of THM was estimated by using the WHO index for additive toxicity approach as well as the USEPA Risk Assistant model approach. Both approaches indicated that network THM concentrations do not pose adverse developmental and non-carcinogenic risks in population from studied area.

A method for decision-makers in formulating a *modus operandi* 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.

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REFERENCES

1 Hsu CH, Jeng WL, Chang RM, Chien LC, Han BC. Estimation of potential lifetime cancer risks for trihalomethanes from consuming chlorinated drinking water in Taiwan. Environ Res. 2001; 85(2):77-82.

2 Borges JT. A utilização da técnica MIMS na determinação de trihalometanos em águas de abastecimento e a influência do íon brometo, da amônia e de algas na formação desses compostos [tese]. São Paulo: Unicamp/ Faculdade de Engenharia Civil; 2002.

3 Bellar TA, Lichtenberg JJ, Kroner RC. The occurrence of organohalides in chlorinated drinking waters. J Am Water Works Ass. 1974; 66(12):703-6.

4 Fawell J. Disinfection by-products in drinking water: current issues. Cambridge: Royal Society of Chemistry; 1999.

5 Von Sperling M. Introdução à qualidade das águas e ao tratamento de esgotos. Belo Horizonte: Universidade Federal de Minas Gerais/Departamento de Engenharia Sanitária e Ambiental; 2005.

6 Ministério da Saúde (BR). Portaria nº 518, de 25 de março de 2004. Brasília; 2004.

7 Marhaba TF, Washington MB. Drinking water protection and by-products: history and current practice. Adv Environ Res. 1998; 2:103–15.

8 World Health Organization. Disinfectants and disinfectant by-products. Environmental Health Criteria 216, Geneva, Switzerland; 2000.

9 Rook JJ. Formation of haloforms during chlorination of natural waters. Water Treatment and Examination. 1974; 23:234-43.

10 White G. The Handbook of Chlorination. 2nd ed. New York: Van Nostrand Reinhold Company; 1986.

11 Morris RD, Audet AM, Angelillo IF, Chalmers TC, Mosteller F. Chlorination, chlorination by-products, and cancer: a meta-analysis. Am J Public Health. 1992; 82(7):955–63.

12 Weisel CP, Kim H, Haltmeier P, Klotz JB. Exposure estimates to disinfection by-products of chlorinated drinking water. Environ Health Perspect.1999;107(2): 103-10.

13 Nikolaou AD, Golfinopoulos SK, Lekkas T, Kostopoulou MN. DBP levels in chlorinated drinking water: effect of humic substances. Environmental Monitoring and Assessment. 2004; 93(1):301-9.

14 United States Environmental Protection Agency - Usepa. Safe Drinking Water Act 30th Anniversary. Understanding the Safe Drinking Water Act. USA: Office of Water; 2004. (EPA 816-F-04-030)

15 Rodriguez MJ, Serodes JB, Levallois P. Behaviour of trihalomethanes and haloacetic acids in a drinking water distribution system. Water Research. 2004; 38:4367-4382.

16 Keegan T, Whitaker H, Nieuwenhuijsen MJ, Toledano MB, Elliott P, Fawell J. Use of routinely collected data on trihalomethane in drinking water for epidemiological purposes. Occupa Environ Med. 2001; 58(7):447–52.

17 Chisholm K, Cook A, Bower C, Weinstein P. Risk of birth defects in Australian communities with high levels of brominated disinfection by-products. Environ. Health Perspect. 2008; 116(9):1267-77.

18 Arora H, Lechevallier MW, Dixon KL. DBP occurrence survey. Journal of American Water Works Association. 1997; 89(6):60–8.

19 Hwang BF, Jaakkola J K. Water chlorination and birth defects: a systematic review and meta-analysis. Arch Environ Health. 2003; 58(2):83–89.

20 Calderon RL. The epidemiology of chemical contaminants of drinking water. Food and Chemical Toxicology. 2000; 38:S13-S20.

21 Vincenti AM, Fantuzzi G, Cassinadri M, Predieri G, Aggazzoti G. A retrospective cohort study of trihalomethane exposure through drinking water and cancer mortality in northern Italy. Sci Total Environ. 2004; 330(1-3):47-53.

22 Water Quality Issues Sub-Group. Water Quality Issues Sub-Group final report. Prepared for the Chlorinated Disinfection By-Product (CDBP) Task Force. Ontario; Health Canada; 2003.

23 United States Environmental Protection Agency - Usepa. National primary drinking water standards. USA: United States Environmental Protection Agency, EPA; 2001. (816-F-01-007).

24 United States Environmental Protection Agency - Usepa. draft final guidelines for carcinogen risk assessment: Risk Assessment Forum. Washington, DC; 2003. (EPA/630/P-03/001A, NCEA-F-0644A)

25 Cho DH, Kong SH, Oh SG. Analysis of trihalomethanes in drinking water using headspace-SPME technique with gas chromatography. Water Res. 2003; 37:402-408.

26 United States Environmental Protection Agency - Usepa. Determination of chlorination dbps, chlorinated solvents, and halogenated pesticides/herbicides in drinking water by liquid-liquid extraction and gas chromatography with electron capture detector. Method 551.1. Ohio: Office of Research and Development, National Exposure Research Laboratory, Cincinnati; 1995.

27 National Research Council - NRC. Risk Assessment in the Federal Government: Managing the Process. Committee on the Institutional Means for Assessment of Risks to Public Health, Commission on Life Sciences, NRC, Washington, DC, National Academy Press; 1983.

28 Lee SC, Guo H, Lam SMJ, Lau SLA. Multipathway risk assessment on disinfection by-products of drinking water in Hong Kong. Environmental Research. 2004; 94:47-56.

29 World Health Organization. Draft Third Edition of the WHO Guidelines for drinking-water quality. Geneva, Switzerland: WHO; 2004.

30 United States Environmental Protection Agency - Usepa. Integrated risk information system. Washington, DC: Office of Research and Development, National Center for Environmental Assessment; 2006.

31 Hattis D, Burmaster DE. Assessment of variability and uncertainty distributions for practical risk analyses. Risk Anal. 1994; 14(5):713-30.

32 Tokmak B, Capar G, Dilek FB, Yetis U. Trihalomethanes and associated potential cancer risks in the water supply in Ankara, Turkey. Environ Res. 2004; 96:345-52.

33 Duong HA, Berg M, Hoang MH, Pham HV, Gallard H, Giger W, Gunten U. Trihalomethane formation by chlorination of ammonium and bromide-containing groundwater in water supplies of Hanoi, Vietnam. Water Research. 2003; 37:3242–52.

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