Journal of Hazardous Materials 280 (2014) 288–294

Contents lists available at ScienceDirect

Journal of Hazardous Materials

journal homepage: www.elsevier.com/locate/jhazmat

Cancer risk assessment on trihalomethanes and haloacetic acids in drinking water of China using disability-adjusted life years

Shenling Pan[a], Wei An[a,*], Hongyan Li[a], Ming Su[a], Jinliang Zhang[b], Min Yang[a]

[a] State Key Laboratory of Environmental Aquatic Chemistry, Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, Beijing, 100085, China
[b] Department of Environmental Pollution and Health, Chinese Research Academy of Environmental Sciences, Beijing, 100012, China

HIGHLIGHTS

- The median total cancer risk of THMs and HAAs in drinking water of China was calculated as 7.34×10^{-7} DALYs ppy.
- The risk of TCAA was highest among the DBPs considered.
- Ingestion exposure was the most important pathway for the total risk.
- The risk in northeast China and Tianjin was highest.

ARTICLE INFO

Article history:
Received 12 May 2014
Received in revised form 23 July 2014
Accepted 28 July 2014
Available online 13 August 2014

Keywords:
Disinfection by-products
Trihalomethanes
Haloacetic acids
Cancer risk assessment
Disability-adjusted life years

ABSTRACT

The cancer risks from exposure to trihalomethanes (THMs) and haloacetic acids (HAAs) through multiple pathways were assessed based on the result of a water quality survey in 35 major cities of China. To express the risks in disability-adjusted life years (DALYs), the excess cancer incidence estimates were combined with a two-stage disease model for calculation. The median total cancer risk of THMs and HAAs was calculated as 7.34×10^{-7} DALYs per person-year (ppy), lower than the reference level of risk (10^{-6} DALYs ppy) set by WHO. The risk from ingestion and inhalation exposures contributed 93.6% and 6.3% of the total risk respectively, while dermal contact made a negligible contribution. The median risk of trichloroacetic acid (TCAA) (2.12×10^{-7} DALYs ppy) was highest among the disinfection by-products (DBPs) considered. The risk ratio of total HAAs (THAA) to total THMs (TTHM) was 1.12. The risk was highest in northeast China while lowest in northwest China. As for the 35 cities, Tianjin had the highest risk while Yinchuan had the lowest. This study attempted to use DALYs for the risk assessment of DBPs, which will provide useful information for risk comparison and prioritization of hazards in drinking water.

1. Introduction

Disinfection is a critical step in drinking water treatment to protect public health from pathogenic microbes. Chlorine is the most widely used disinfectant due to its low cost, ease of operation and high efficiency. However, chlorine reacts with natural organic matter to generate disinfection by-products (DBPs) during chlorination. So far, more than one thousand chlorinated DBPs have been reported [1], among which trihalomethanes (THMs) and haloacetic acids (HAAs) are the two most abundant classes on a weight basis [2], thus gaining particular attention and being regulated globally [3]. DBPs could introduce potential health risks of cancers as well as adverse developmental and reproductive effects [4]. An increased incidence of bladder cancer has been most consistently associated with chlorinated drinking water by epidemiologic studies [5].

Risk assessment has now become the most important basis for regulating and prioritizing pollutants in drinking water [6]. However, risks of different pollutants, usually expressed in terms of specific disease endpoints (e.g. cancer, diarrheal disease), cannot be compared directly [7]. To set a common unit for risk, the World Health Organization (WHO) recommends the use of disability-adjusted life years (DALYs) to assess the disease burden caused by environmental risk factors. DALYs is a time-based measure, combining the healthy life lost due to premature mortality and morbidity [8]. Many cancer risk assessments have been conducted on DBPs, but most of them conveyed the risk as the excess cancer

* Corresponding author. Tel.: +86 10 62923475; fax: +86 10 62923541.
E-mail address: anwei@rcees.ac.cn (W. An).

http://dx.doi.org/10.1016/j.jhazmat.2014.07.080
0304-3894/

incidence through lifetime exposure [9–16]. Havelarr et al. [17] calculated DALYs for renal cancer due to bromate, the major DBP in the ozone disinfection process. He eliminated morbidity burden, since it was very small compared with mortality burden for renal cancer. However, for some other cancer types (e.g. bladder cancer), morbidity burden usually accounts for a non-ignorable part of the DALY estimate [18]. To completely calculate the cancer risks of DBPs in DALYs, this study introduced the disease model that was designed by WHO for estimating the morbidity burden of cancers [19].

In China, approximately 99.5% of urban water supply systems use chlorine for disinfection [20]. Thus a significant number of people are exposed to DBPs through their lifetimes. Though some regional cancer risk assessments have been conducted for DBPs [11,14], nationwide risk assessment has never been conducted due to the limitation of information regarding the occurrences of DBPs. In this paper, the cancer risks of THMs and HAAs through multiple pathways were estimated and compared using DALYs, based on the nationwide DBP survey in China. This work will be useful in risk comparison and prioritization of hazards in drinking water.

2. Materials and methods

2.1. Data source

Between December 2009 and May 2012, two large-scale water quality survey activities were carried out across China. Finished water samples were collected in the distribution systems of 127 large drinking water treatment plants (DWTPs) in 35 major cities, as shown in Appendix Fig. A1. The name, location and scale of the cities is provided in Table A1.

Samples were analyzed for THMs and HAAs. The detailed information on sample collection, sample preparation, sample analysis and quality assurance and quality control can be found elsewhere [21]. HAAs have nine species. However, the cancer potency information is only available for dichloroacetic acid (DCAA) and trichloroacetic acid (TCAA). So this study will focus on these two HAAs and four THMs.

2.2. Exposure assessment

Since the populations served by the DWTPs are different, the concentration data of DBPs were weighted by the daily water supply of DWTPs, and then characterized by best-fitted statistical distributions. Based on the DBP distributions, an exposure assessment was conducted to evaluate their potential intake through multiple pathways. THMs are kinds of volatile organic compounds, whose health risks from inhalation and dermal exposures during regular indoor activities cannot be ignored [22]. In this study, showering was assumed to be the major activity for inhalation and dermal contact [12]. In contrast, HAAs are non-volatile. Xu et al. [23] measured the inhalation dose of HAAs during showering to be less than 1% of the ingestion dose. Also, the dermal dose of HAAs is expected to be negligible because of their very low skin permeability ($1–3 \times 10^{-3}$ cm/h, pH 7) [24]. So, for THMs, ingestion, inhalation and dermal contact exposures were considered, while for HAAs, only ingestion exposure was considered. Chronic daily intake (CDI) estimates for different pathways were calculated by the following equations [10]:

$$\mathrm{CDI_{ing}} = \frac{C_w \times \mathrm{IR} \times \mathrm{EF} \times \mathrm{ED} \times \mathrm{CF}}{\mathrm{BW} \times \mathrm{AT}} \quad (1)$$

$$\mathrm{CDI_{inh}} = \frac{C_{air} \times R \times t \times F \times \mathrm{EF} \times \mathrm{ED}}{\mathrm{BW} \times \mathrm{AT}} \quad (2)$$

$$\mathrm{CDI_{der}} = \frac{C_w \times A_s \times \mathrm{PC} \times t \times F \times \mathrm{EF} \times \mathrm{ED}}{\mathrm{BW} \times \mathrm{AT}} \quad (3)$$

where $\mathrm{CDI_{ing}}$, $\mathrm{CDI_{inh}}$, $\mathrm{CDI_{der}}$ are CDI values for ingestion, inhalation and dermal pathways (mg/kg/day).

The descriptions and values of all the parameters are summarized in Table A2. The concentrations of THMs in the air (C_{air}) were estimated by two-resistance model proposed by Little [25], and the comprehensive formulas were summarized in Table A2. Shower frequency (F) and shower duration (t) were estimated from the shower-habit survey data in one northern city (Shijiazhuang) and two southern cities (Ningbo and Xiamen) to characterize the big difference of shower-habit between northern and southern China. To minimize the biases of possible outliers, 10th, 50th and 90th percentile values of the survey data were used to generate triangular distributions [13].

2.3. Calculating the lifetime cancer incidence rates

The lifetime incidence rates (IR) of developing cancer from exposure to different DBPs through different pathways were calculated as Eq. (4). Using an additive model, the total cancer incidence rate (TIR) was calculated as Eq. (5).

$$\mathrm{IR}_{i,j} = \mathrm{CDI}_{i,j} \times \mathrm{SF}_{i,j} \quad (4)$$

$$\mathrm{TIR} = \sum_{i,j} \mathrm{CDI}_{i,j} \times \mathrm{SF}_{i,j} \quad (5)$$

where i = exposure pathway, j = THM or HAA, SF = slope factor.

The summary of slope factors is shown in Table A3. Slope factors are estimated from animal toxicity data by various models, approximating 95% confidence limits. So, the calculated cancer incidence can be interpreted as the upper bound lifetime probability of an individual's developing cancer. Chloroform (TCM), generally regarded as a non-genotoxic carcinogen, is likely to be carcinogenic to humans by all routes of exposure under high-exposure conditions that lead to cytotoxicity and regenerative hyperplasia, otherwise, not likely to be carcinogenic to humans by any route of exposure [26–29]. After the year 2000, EPA proposed a mode of action (MOA) approach (a nonlinear approach) for the risk assessment on TCM, and set a threshold (0.01 mg/kg/day, equal to its RfD), considered protective against cancer risk [29]. However, most risk assessments on TCM still adopted its previous oral slope factor [9–16], which was developed by EPA under the default assumption of linearity and has been deleted. Currently, the majority of evidence and documents support a MOA based risk assessment for TCM [30–32]. In our case, the estimated maximum CDI for TCM was 0.0010 mg/kg/day, much smaller than its RfD. So, this paper excluded TCM as a possible human carcinogen through any route of exposure. For the other three THMs [bromodichloromethane (BDCM), dibromochloromethane (DBCM), bromoform (TBM)] and two HAAs (DCAA, TCAA), slope factors from the IRIS [29] and the Risk Assessment Information System (RAIS) [33] were used.

2.4. Disease model and DALY estimation

To assess the disease burden of cancer, the cancer incidence estimates were combined with a two-stage disease model (Fig. 1) [19] for DALY estimation. The disease model simplifies each disease phase in the disease history. There are two possible outcomes for cancer cases: (1) some will die from cancer ($1 - S_x$); (2) some will be cured from cancer (S_x), and a proportion of them ($S_x \times P_{seq}$) live with cancer sequelaes for the rest of their lives.

Different cancer types usually differ in severity, thus causing different disease burden. The selection of DBPs associated cancer was based on human epidemiology. Numerous epidemiologic studies have explored the possible cancer risk in relation to some measure of chlorinated DBPs. Bladder cancer, with the most consistent evidence, has the greatest likelihood of being causally associated