Ecotoxicology and Environmental Safety 113 (2015) 433–438

Contents lists available at ScienceDirect

Ecotoxicology and Environmental Safety

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

Multi-exposure cancer and non-cancer risk assessment of trihalomethanes in drinking water supplies – A case study of Eastern region of India

Minashree Kumari, S.K. Gupta*, B.K. Mishra

Department of Environmental Science and Engineering, ISM Dhanbad, 826004 Jharkhand, India

ARTICLE INFO

Article history:
Received 8 September 2014
Received in revised form
15 December 2014
Accepted 16 December 2014
Available online 26 December 2014

Keywords:
Trihalomethanes
Oral ingestion
Dermal absorption
Cancer risk
Hazard index

ABSTRACT

The lifetime cancer risk and the hazard index of trihalomethanes (THMs) through oral ingestion, dermal absorption, and inhalation exposure from supply water of five WTPs were analysed. THMs concentration varied from plant to plant and was found to be in the range of 274–511 μg/l, which is much higher than the prescribed USEPA standards of 80 μg/l. Chloroform was the most dominant THM followed by bromodichloromethane (BDCM), and dibromochloromethane (DBCM). Cancer risk analysis through multi-pathways exposure reveals that residents had a higher cancer risk through oral ingestion than other two routes of exposure. The lifetime cancer risks of THMs from supply water were 100 times higher than prescribed USEPA guidelines. The higher cancer risk found for Indian context than those reported for other countries like USA, UK, Japan, Australia, is mainly due to the higher concentration level of THMs, water intake and average body weight. The study also revealed that amongst different THMs, chloroform is the major THMs causing cancer risk through both oral and dermal route of exposure whereas in case of inhalation it was mainly because of BDCM. Average lifetime cancer risk analysis indicated that females are more prone to cancer risk than males. Oral ingestion is a major route indicating the potential impact of non-cancer risk while it was insignificant through dermal exposure. Sensitivity analysis of THMs revealed that chloroform is the predominant parameter followed by body weight and exposure duration influencing cancer risk.

1. Introduction

Disinfection is the last step in the water treatment processes for the protection of public health. In India, chlorine is used as the primary disinfectant because of its low cost and its convenience for application in water purification. However, the presence of trihalomethanes (THMs) in chlorinated drinking water can pose severe health threat due to its potential carcinogenicity. In recent decades, various epidemiological studies have been conducted to determine the relationship between disinfection by-products (DBPs) and different health outcomes e.g., cancers and reproductive outcomes (Nieuwenhuijsen, 2005; Tardiff et al., 2006; Hrudey, 2009). Many studies suggested that exposure to DBPs increase the risk of bladder, colon, rectum, leukaemia, stomach and rectal cancers (Llopis-González et al., 2011; McGeehin et al., 1993). The results of animal studies have demonstrated that liver, kidney, and intestinal tumorigenesis are associated with chronic ingestion of THMs (Dodds et al., 1999; Yang et al., 2000). In addition, some experimental studies have also demonstrated that exposure to DBPs in water is related to spontaneous abortion, and other adverse reproductive outcomes (Waller et al., 1998). Since THMs are the most prevalent and well documented DBP compounds in drinking water, they are generally considered as indicators of DBP exposure in epidemiological investigations.

Recent studies have attempted to improve exposure assessment by using individual exposure measures combining routinely collected water system THM measurements with a measure of ingestion, such as number of glasses or water drank per day. However, only a few studies accounted for spatial and temporal fluctuations in THM levels across the distribution system. Furthermore, seeking to improve the exposure assessment, studies have begun to incorporate behavioural determinants of different routes of exposure to DBPs such as dermal absorption and inhalation during bathing and showering, and ingestion of drinking water but the contribution of these was unclear (Hoffman et al., 2008; MacLehose et al., 2008). Lee et al. (2004) calculated cancer risks and hazard index of THMs through different exposure routes

* Corresponding author. Fax: +91 3262296624.
E-mail address: skgsunil@gmail.com (S.K. Gupta).

http://dx.doi.org/10.1016/j.ecoenv.2014.12.028
0147-6513/

for tap water in Hong Kong, and reported that exposure through oral ingestion had higher risk than through dermal absorption and inhalation. A similar result was reported by Tokmak et al. (2004) and Amjad et al. (2013) which concluded that the highest risk was from the exposure to chloroform through oral ingestion. It has also been reported that THMs are generally well absorbed, metabolized, and rapidly eliminated by mammals after oral or inhalation exposure (IPCS, 2000). The discrepancy that the importance of the three exposure pathways ranked differently in the studies may be attributed to different concentration and speciation of THMs present in the waters.

Traditional risk assessments of water often consider only ingestion exposure to toxic chemicals, but scientists proposed that inhalation and dermal absorption be considered in the risk assessment of drinking water since 1990 (Jo et al., 1990; Weisel et al., 1999). Therefore, the purpose of this study is to conduct multipathway exposure assessment of the drinking water of five water treatment plants (WTPs) based on the concentrations of THMs within distribution systems in Jharkhand and West Bengal. In this study, the cancer risks associated with THMs exposure from drinking water in Eastern region of India was estimated for each species and each exposure pathway. The THM data in drinking water were first collected from WTPs. Furthermore, cancer and non-cancer risk assessment of THMs for both males and females, respectively were also carried out using different models as no such study has been carried out for them in this region.

2. Materials and methods

2.1. Description of WTPs and sampling protocol

For this study, five major WTPs situated in the Eastern region of India namely Indira Gandhi WTP, Kolkata (IGWTP II), Asansol-Durgapur Development Authority WTP, Raniganj (ADDA), Swarnrekha WTP, Ranchi (SWTP), Maithon WTP, Maithon (MWTP) and Mineral Area Development Authority WTP, Dhanbad [MADA (N)] were selected. Two main rivers (i.e. Ganga and Damodar) were the source of raw waters to these WTPs. The WTPs selected under study ranged from 5MGD to 260MGD, which shows a wide variation in the water supply distribution network. All these water treatment plants (WTPs) follow the conventional method of treatment comprising of coagulation-flocculation, sedimentation, filtration, and chlorination or disinfection.

Drinking water samples were collected in triplicates from public water supplies between October 2012 and September 2013. A total of 25 samples were collected at each sampling location. The samples were collected in 40-mL clean glass vials with polypropylene cap and PTFE-faced rubber septa and it was added with sodium sulphite (0.010 g) as a dechlorination agent to eliminate any residual chlorine to stop further THM formation. The samples were stored in dark at temperature $<4\,^{\circ}C$ for further analysis.

2.2. Analysis of THMs

The samples were subjected to liquid–liquid extraction using pentane as a solvent. The vials were then shaken vigorously for 1 min and allowed to stand for 3 min to facilitate phase separation. The pentane phase was removed and placed in 2 ml auto-sampler vials. 1 μl extract was then analysed using nitrogen as the carrier gas at a flow rate of 1.2 ml/min. Trihalomethanes were analysed as per USEPA methods 551.1 (USEPA, 1995). A Chemito CERES 800 Plus gas chromatograph (Thermo Fischer) equipped with an electron capture detector (ECD) was used for the determination and quantification of THMs. The column used for analysis was fused silica DB-5, 30 m × 0.32 mm I.D. × 0.30 μm film thicknesses. Analytical grade calibration standards with a purity of $>99.5\%$ were procured from Sigma Aldrich (Germany). The mean recovery of four THM species ranged between 86.9% and 102.3% for this method.

2.3. Quality control/quality assurance procedure (QA/QC)

Laboratory requirements included, initial demonstration of laboratory capability, determination of method detection limit, analysis of laboratory reagent blanks, field reagent blank, field duplicates and calibration check standards (USEPA, 1995).

For the initial demonstration of the laboratory capability, the observed chromatographic peaks, obtained by running a standard solution of method analytes were identified by comparing the retention times with those given in the EPA method 551. Then, oven temperature programme was modified according to the retention time of the last peak of the method analyte. To obtain a smooth baseline, a non-polar organic solvent (hexane) was run before analysis of the each batch of the samples. Before each run, the GC syringe was rinsed three times with hexane.

The field reagent blanks were collected to determine if any interference was present in the field environment. Laboratory reagent blanks were analysed to determine if method analytes or other interferences were present in the laboratory environment, the reagents, or the apparatus. On the other hand, the precision of the measurements was estimated using field duplicates (FD). The relative difference (RPD) between two parallel samples was calculated. The method of detection limit was calculated for each compound by analysing replicates of standard solution at a concentration of 0.25 μg/L. Continuing calibration checks were performed every 20 samples. If the relative percent difference between the response of the initial calibration and the calibration check standard was $>20\%$, the instrument was considered as out of calibration, and recalibrated.

2.4. Cancer risk estimation

In this study, estimation of lifetime cancer risk of THMs in five WTPs is based on the United States Environmental Protection Agency (USEPA) guideline (USEPA, 1986, 1999, 2002) and Lee et al.'s (2004) study. However, the guideline values for the parameters such as water intake, average body weight, exposure duration and frequency were adopted as the Indian conditions (ICMR, 2009). In general, the process of risk assessment includes the following four components: data collection and evaluation, exposure assessment, toxicity assessment, and risk characterization (Lee et al., 2004). The exposure source pathways, potentially exposed populations, the magnitude, duration, and frequency of exposure to site contaminants were identified based on the lifestyle of residents and the behaviour of contaminated chemicals in drinking water. In this study, the cancer risks for exposure through oral ingestion, dermal absorption, and inhalation exposure were considered. Since, the values of the parameters like average body weight, the amount of air breathed, exposure frequency and ingestion rate of water varies from region to region due to change in climatic conditions, and standard of living. Therefore, the values of these parameters were adopted as per Indian conditions (ICMR, 2009). For adults, the exposure rates were converted to a daily dose by assuming 20 m^3 aspirated air per day, and average body weights of 70 kg for male and 60 kg for female. An entire lifetime of 70 and 60 years applies to males and females, respectively.

Moreover, the hazard indices of THMs in different exposure routes are also calculated for non-carcinogenic risk assessment. The calculation of hazard indices for ingestion route and dermal absorption is described elsewhere (Lee et al., 2004). On the other hand, calculation of cancer slope factors and unit risk estimates