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Age dependent adjustment factor (ADAF) for the estimation of cancer risk through trihalomethanes (THMs) for different age groups- A innovative approach

Minashree Kumari*, S.K. Gupta

Department of Environmental Science and Engineering, Indian Institute of Technology (ISM) Dhanbad, 826004 Jharkhand, India

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ABSTRACT

Lifetime cancer risk due to trihalomethanes (THMs) in drinking water supplies for different age groups were investigated for the first time using age dependent adjustment factor (ADAF) as per USEPA protocol. Five water treatment plants (WTPs) in Eastern part of India were monitored for establishing the baseline concentrations of THMs and their seasonal variations. The concentration of THMs (231–484 μg/L) in all WTPs exceeded the USEPA guidelines (80 μg/L). Risk analysis of THMs through different pathways revealed that major risk (> 97%) is caused through oral ingestion and is the most vulnerable pathway. Amongst different THMs, chloroform triggered the major risk through oral and dermal routes while BDCM for inhalation. The analysis of lifetime cancer risk for various age group dictated that it was highest (2.37×10^{-4}) for 60–80 yrs age group while it was lowest (4.89×10^{-5}) for 0–1 yr. The cancer slope factors for each THM species were combined with different exposure models and probability of cancer risks for different age groups. Monte Carlo simulations of cancer risk through different exposure routes dictated significant correlation between estimated and simulated risk. The average risk estimated through different exposure models lies well within ± 2.7% of the simulated average risk.

1. Introduction

The provision of safe and clean drinking water is one of the major concerns of developing countries like India. Chlorination is the most accepted disinfectant throughout the world because of its economical availability and effectiveness against the waterborne pathogens. Although chlorine disinfection reduces mortality and morbidity due to water-borne diseases (Calderon, 2000; Golfinopoulos and Nikolaou, 2005) however, it can react with natural organic matter (NOM) and form various types of trihalomethanes (THMs) such as chloroform, bromodichloromethane (BDCM), dibromochloromethane (DBCM) and bromoform, which are probable carcinogens (NCI, 1976; Hrudey, 2009. Based on the toxicological studies, National Cancer Institute (1976) emphasized the probable carcinogenic effect of various THM species. Over the years, a number of toxicological and epidemiological studies have been carried out which indicates a direct relationship between THMs and carcinogenic and non-carcinogenic risk (Boorman et al., 1999; Nieuwenhuijsen, 2005; Richardson et al., 2007; Villanueva et al., 2007). Literature studies have revealed that exposure to these THMs may lead to development of different type of cancers such as bladder, colon–rectum and brain. In addition to this, reproductive disorders, birth defects, cardiac anomalies, still-births, miscarriages, low birth weights, pre-term deliveries and neural tube defects have also been reported (Wright et al., 2004; Richardson, 2005; Ristoiu et al., 2009; Wu et al., 2010; Viana et al., 2009).

US EPA cancer risk paradigm is generally used to estimate the probable risk of THMs on the human population. Human health cancer risk index is the unit risk and represents the probability of an individual developing cancer as a result of contaminant exposure over his (her) lifetime (USEPA 1989, 2005a). The human health risk assessment for THMs in drinking water considers multiple routes of exposure including ingestion, inhalation and skin contact (i.e. dermal absorption). Water is not used only for drinking purposes but also for cooking, showering, bathing, washing, laundering, cleaning and so forth activities. Thus, the exposure and uptake of the contaminants not only occurs by ingestion but also through skin contact i.e. dermal absorption and inhalation. Hence, in all risk assessments studies inhalation and dermal absorption should also be considered along with oral ingestion (Jo et al., 1990; Weisel et al., 1999).

Previous studies on cancer risk assessment were mainly focused on estimating the risk considering explicit values of input parameters i.e. body weight, skin surface area, ingestion rate, exposure duration etc.

* Corresponding author.
E-mail address: minashreekumari2501@gmail.com (M. Kumari).

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(Pardakhti et al., 2011; Siddique et al., 2015; Amjad et al., 2013). However, these input parameters vary for different age groups and also differs for male and female. The exposure to these carcinogens and their mutagenic action increases especially after attainment of developmental maturity (USEPA, 2005b). This also recommends that when considering the childhood exposure, age dependent adjustment factor (ADAFs) should be applied to cancer slope factors (CSF) calculated from the studies (bioassay or epidemiological) that involve only adult exposures. To address these issues, efforts were made to evaluate the risk individually for male and female (Uyak, 2006; Lee et al., 2004; Abdullah, 2014; Kumari et al., 2015). However, these studies also did not consider ADAF, an adjustment to the CSF which is required for estimating the risk for different age group as per USEPA guidelines USEPA (2011). To avoid these uncertainty and errors in risk analysis, this study made an attempt to estimate the cancer risk for different age groups considering the ADAFs.

2. Material and methods

2.1. Study Area and Sampling Protocol

Five major drinking WTPs located in Eastern region of India were selected as model plants for collection of water samples. Out of the five WTPs, two are situated in West Bengal whereas the rest three are in Jharkhand (Fig. 1). Ganga, Damodar and its tributaries were the source of raw waters to these WTPs. The selected water treatment plants (WTPs) follows the conventional method of treatment for supplying drinking water in the areas as mentioned above. Drinking water supply samples were collected in triplicates on monthly basis from October 2014 to September 2015. Samples for THMs analysis were collected in 40-mL clean glass vials and were stored at < 4 °C till further analysis (Kumari et al., 2015).

2.2. Analysis of THMs

THMs were analyzed in accordance with USEPA method 551.1 (USEPA 1995). Certain modification in the method was carried out to get the accurate results since the injector and oven temperature varies with different gas chromatograph (GC) and needs to be adjusted. A Chemito CERES 800 Plus GC (Thermo Fischer) equipped with an electron capture detector (ECD) was used for the determination and quantification of THMs. Fused silica DB-5 column (30 m × 0.32 mm I.D. × 0.30 μm) was used for the quantification of THMs. Injector and detector temperatures were kept at 200 °C and 250 °C, respectively. The oven temperature was programmed to remain constant at 40 °C for 3 min and rise to 150 °C at a ramp rate of 8 °C/min. Nitrogen was used as a carrier gas at a flow rate of 60 mL/min. THMs calibration standards with a purity of 99.5% were procured from Sigma Aldrich (Germany).

2.3. Cancer risk analysis

The empirical models prescribed by USEPA guideline (USEPA, 1986, 1999, 2002a) and Lee et al. (2004)'s were used to estimate the probable cancer and non-cancer risk. In this study, the cancer risk for different age groups through three different exposure pathways i.e. oral, dermal and inhalation, were estimated using Eqs. (1)–(3), respectively.

$$\mathrm{RISK}_{Oral} = \left(\frac{C_w \times \mathrm{IR} \times \mathrm{EF} \times \mathrm{ED}}{\mathrm{BW} \times \mathrm{AT}}\right) \times \mathrm{CSF}_{Oral} \times \mathrm{ADAF}_i \quad (1)$$

$$\mathrm{RISK}_{Dermal} = \left(\frac{C_w \times \mathrm{SA} \times \mathrm{PC} \times \mathrm{ET} \times \mathrm{EF} \times \mathrm{ED}}{\mathrm{BW} \times \mathrm{AT}}\right) \times \mathrm{CSF}_{Dermal} \times \mathrm{ADAF}_i \quad (2)$$

$$\mathrm{RISK}_{Inhalation} = \left(\frac{C_{air} \times \mathrm{IR}' \times \mathrm{ET} \times \mathrm{EF} \times \mathrm{ED}}{\mathrm{BW} \times \mathrm{AT}}\right) \times \mathrm{CSF}_{Inhalation} \times \mathrm{ADAF}_i \quad (3)$$

Where, C_w is the concentration of THMs (μg/L); IR is the Ingestion rate in L/h; EF is the Exposure frequency in Days/year; ED is the Exposure duration in Year; BW is the Body weight in kg; AT is the Average lifetime in days; ET is the Exposure time in hour/event; CSF is the cancer slope factor $(\mathrm{mg/kg\text{-}day})^{-1}$; ADAF_i is the age dependent adjustment factor for i^{th} age group; SA is the Skin surface area in m^2; PC is the permeability constant in m/h; C_{air} is THM concentration in air; IR' is Inhalation rate in m^3/h.

In most of the studies, the cancer risk were evaluated for a particular age using chronic daily intake (CDI) and cancer slope factor (CSF) without considering ADAF. However, as per USEPA (2011) risk estimation protocol, if there is early-life exposure, ADAFs is an adjustment to the CSF and should be applied for age wise risk calculations. The study suggested that the exposure to chemical carcinogens with a mutagenic mode of action is likely to have increased incidence for cancer than the exposures which begin after attainment or development of maturity (USEPA, 2005b). Hence, ADAF_i was also considered for

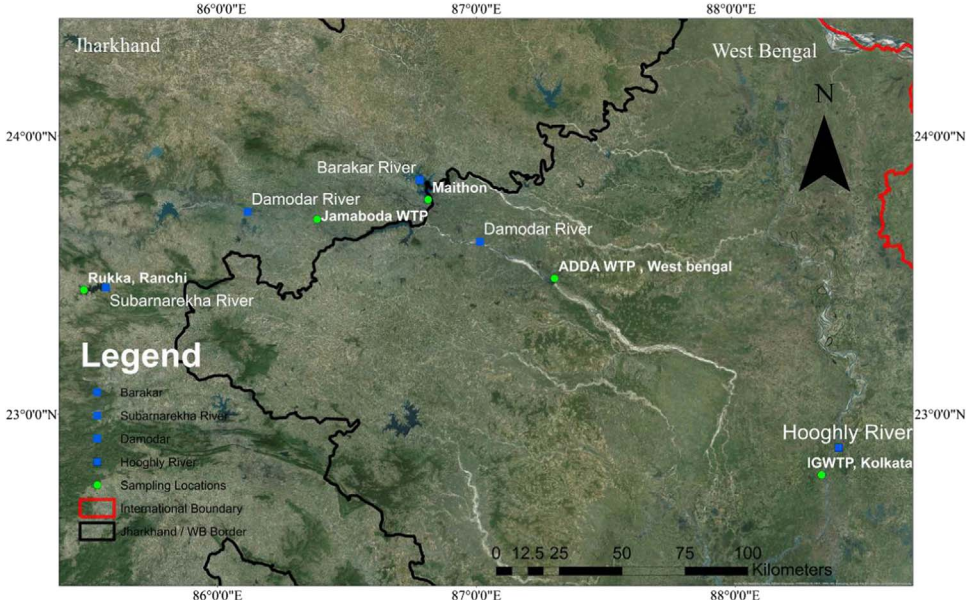

Fig. 1. Location map of study area.