WATER RESEARCH 42 (2008) 3263–3274

Available at www.sciencedirect.com

ScienceDirect

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

Human health risk assessment of chlorinated disinfection by-products in drinking water using a probabilistic approach

Nasrul Hamidin[a], Qiming Jimmy Yu[a,*], Des W. Connell[b]

[a]Griffith School of Engineering, Nathan Campus, Griffith University, Brisbane, Queensland 4111, Australia
[b]Griffith School of Environment, Griffith University, Brisbane, Queensland 4111, Australia

ARTICLE INFO

Article history:
Received 4 September 2007
Received in revised form
22 February 2008
Accepted 28 February 2008
Available online 6 March 2008

Keywords:
Drinking water
Disinfection by-products (DBPs)
Health risk assessment
Probabilistic technique

ABSTRACT

The presence of chlorinated disinfection by-products (DBPs) in drinking water is a public health issue, due to their possible adverse health effects on humans. To gauge the risk of chlorinated DBPs on human health, a risk assessment of chloroform (trichloromethane (TCM)), bromodichloromethane (BDCM), dibromochloromethane (DBCM), bromoform (tribromomethane (TBM)), dichloroacetic acid (DCAA) and trichloroacetic acid (TCAA) in drinking water was carried out using probabilistic techniques. Literature data on exposure concentrations from more than 15 different countries and adverse health effects on test animals as well as human epidemiological studies were used. The risk assessment showed no overlap between the highest human exposure dose (EXP_D) and the lowest human equivalent dose (HED) from animal test data, for TCM, BDCM, DBCM, TBM, DCAA and TCAA. All the HED values were approximately 10^4–10^5 times higher than the 95th percentiles of EXP_D. However, from the human epidemiology data, there was a positive overlap between the highest EXP_D and the lifetime average daily doses ($LADD_H$) for TCM, BDCM, DCAA and TCAA. This suggests that there are possible adverse health risks such as a small increased incidence of cancers in males and developmental effects on infants. However, the epidemiological data comprised several risk factors and exposure classification levels which may affect the overall results.

1. Introduction

Chlorine is widely used in the disinfection of drinking water because it is relatively cheap and effective in eliminating pathogenic microorganisms, and it provides residual protection in water distribution systems. Waterborne diseases such as cholera, typhoid and dysentery have decreased dramatically due to chlorine disinfection, thus reducing human mortality and morbidity (Calderon, 2000; Golfinopoulos and Nikolaou, 2005). However, chlorine and its related species react with organic matter in water to produce chemical compounds known as disinfection by-products (DBPs). Of these, trihalomethanes (THMs) and haloacetic acids (HAAs) are found in the highest concentrations in treated drinking water (Richardson, 2003).

Several epidemiological studies have revealed that there is an association between health effects and exposure to DBPs. King et al. (2000a) and Wright et al. (2003, 2004) noted a

*Corresponding author. Tel.: +61 737 355 289; fax: +61 737 357 459.
E-mail address: Jimmy.Yu@griffith.edu.au (Q.J. Yu).

Abbreviation: TCM, trichloromethane; BDCM, bromodichloromethane; DBCM, dibromochloromethane; TBM, tribromomethane; DCAA, dichloroacetic acid; TCAA, trichloroacetic acid; EXP_D, exposure doses; HED, human equivalent doses; $LADD_H$, lifetime average daily doses.

0043-1354/$ - see front matter
doi:10.1016/j.watres.2008.02.029

relationship between THMs and adverse birth outcomes. King and Marrett (1996) and King et al. (2000b) identified an association between THMs and the risk of bladder and colon cancer, respectively. Also, Hinckley et al. (2005) and Wright et al. (2004) found that exposure to dichloroacetic acid (DCAA) and trichloroacetic acid (TCAA) was linked to a risk of growth reduction in infants.

Animals exposed to THMs and HAAs in laboratory experiments were also found to have adverse health effects. THM exposure resulted in tumor formation in the liver (George et al., 2002) and kidney of these animals (Hard et al., 2000). It also resulted in pregnancy loss (Narotsky et al., 1997; Bielmeier et al., 2001), decreased sperm motility (Klinefelter et al., 1995) and fetotoxicity (Ruddick et al., 1983). HAA exposure resulted in liver tumors (DeAngelo et al., 1996; Pereira, 1996), affected male reproductive capacity (Toth et al., 1992; Linder et al., 1997) and had adverse effects on infants and pregnant mice (Smith et al., 1989; Epstein et al., 1992; Johnson et al., 1998).

A human health risk assessment, using a probabilistic approach, was used to evaluate and quantify the adverse effects of these compounds on humans. This process evaluates the likelihood that the compounds will affect humans, and the magnitude of effects that may be experienced. The objectives of this paper are to review the exposure concentrations and adverse effects of trichloromethane (TCM), bromodichloromethane (BDCM), dibromochloromethane (DBCM), tribromomethane (TBM), DCAA and TCAA in chlorinated drinking water from an international perspective. These compounds were selected because they are the most widely regulated and have potentially adverse health effects on humans. A risk evaluation using probabilistic techniques, which identify the likelihood of adverse health effects associated with estimated human exposures, was considered appropriate for this study.

2. Methodology

2.1. Exposure assessment

The DBP study compounds were evaluated on the basis of published monitoring data for treated surface water, from more than 15 different countries around the globe (Table 1). The data consisted of minimum, mean and maximum concentrations and included concentrations in tap water and in the drinking water distribution systems. To maintain unit consistency, the published concentration values were all converted into mg/L for our analysis.

Table 1 – List of sources for exposure concentrations for development of EXP_D

DBPs	Country	Year	Source of water	References
TCM, BDCM, DBCM, TBM	Turkey	2004	Distribution system	Uyak (2006)
TCM, BDCM, DBCM, TBM, DCAA, TCAA	Greece	2001/02	Distribution system	Golfinopoulos and Nikolaou (2005)
DCAA, TCAA	UK	2003	Tap water	Malliarou et al. (2005)
TCM, BDCM, DBCM, TBM, DCAA, TCAA	Turkey & Italy	2004	After chlorination	Rizzo et al. (2005)
TCM, BDCM, DBCM, TBM	Turkey	2003	Distribution system	Toroz and Uyak (2005)
TCM, BDCM, DBCM, TBM	Hong Kong	1997	Tap water	Lee et al. (2004)
TCM, BDCM, DBCM, TBM, DCAA, TCAA	Canada	2000/01 and 2001/02	Distribution system	Rodriguez et al. (2004a, b)
TCM, BDCM, DBCM, TBM, DCAA, TCAA	Russia	1999–2001	Tap water	Egorov et al. (2003)
TCM, BDCM, DBCM, TBM	Spain	2000	After chlorination	Iriarte et al. (2003)
TCM, BDCM, DBCM, TBM, DCAA, TCAA	Spain	1990	Tap water	Villanueva et al. (2003)
TCM, BDCM, DBCM, TBM	UK	1992–1998	–	Whitaker et al. (2003)
TCM, BDCM, DBCM, TBM, DCAA, TCAA	Korea	–	After chlorination	Kim et al. (2002)
TCM, BDCM, DBCM, TBM, DCAA, TCAA	Finland	1994	After chlorination	Nissinen et al. (2002)
TCM, BDCM, DBCM, TBM, DCAA, TCAA	Korea	1996–1998	After chlorination	Lee et al. (2001)
TCM, BDCM, DBCM, TBM, DCAA, TCAA	European countries	1980–late 1990s	After chlorination	Palacios et al. (2000)
TCM, BDCM, DBCM, TBM, DCAA, TCAA	Spain	1997/98	After chlorination	Cancho et al. (1999)
TCM, BDCM, DBCM, TBM, DCAA, TCAA	US & Europe	1989–1993	–	Nikolaou et al. (1999)
TCM, BDCM, DBCM, TBM	Egypt	1991–1993	After chlorination	El-Shahat et al. (1998)
TCM, BDCM, DBCM, TBM, DCAA, TCAA	Canada	1993	After chlorination	Williams et al. (1997, 1998)
TCM, BDCM, DBCM	Greece	1995/96	Distribution system	Golfinopoulos et al. (1998)
TCM, BDCM, DBCM, TBM	Taiwan	–	Tap water	Kuo et al. (1997)
TCM, BDCM, DBCM, TBM	Egypt	–	–	Hassan et al. (1996)
TCM, BDCM, DBCM, TBM	Israel	–	–	Heller-Grossman et al. (1993)
TCM, BDCM, DBCM, TBM	Egypt	1989	Distribution system	El-Dib and Ali (1992)
TCM, BDCM, DBCM, TBM	Canada	1981	–	Morrison and Dionne (1982)

TCM, trichloromethane; BDCM, bromodichloromethane; DBCM, dibromochloromethane; TBM, tribromomethane; DCAA, dichloroacetic acid; TCAA, trichloroacetic acid.