

## Risk assessment of trihalomethanes from tap water in Fortaleza, Brazil

Rommel B. Viana · Rivelino M. Cavalcante ·  
Fuad M. G. Braga · Anderson B. Viana ·  
José C. de Araujo · Ronaldo F. Nascimento ·  
André S. Pimentel

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**Abstract** The cancer risks (CR) by oral ingestion, dermal absorption, and inhalation exposure of trihalomethanes (THM) from tap water of ten districts in Fortaleza, Brazil were estimated. The mean levels of

THM compounds were obtained in Fortaleza tap water as follow:  $63.9 \mu\text{g L}^{-1}$  for chloroform ( $\text{CHCl}_3$ ),  $40.0 \mu\text{g L}^{-1}$  for bromodichloromethane ( $\text{CHBrCl}_2$ ), and  $15.6 \mu\text{g L}^{-1}$  for dibromochloromethane ( $\text{CHBr}_2\text{Cl}$ ). Bromoform ( $\text{CHBr}_3$ ) was not detected. The mean CR for THMs in tap water is  $3.96 \times 10^{-4}$ . The results indicate that Fortaleza residents have a higher CR by inhalation than dermal absorption and oral ingestion. The CR for  $\text{CHCl}_3$  contributes with 68% as compared with the total CR, followed by  $\text{CHBrCl}_2$  (21%), and  $\text{CHBr}_2\text{Cl}$  (11%). The hazard index (HI) is about ten times lower than unity, not indicating non-cancer effects.

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R. B. Viana (✉)  
Departamento de Química e Física Molecular,  
Instituto de Química de São Carlos,  
Universidade de São Paulo,  
Av. Trabalhador São Carlense, 400 Cx. Postal 780,  
13560-970 São Carlos, SP, Brazil  
e-mail: rommel@iqsc.usp.br

R. M. Cavalcante · F. M. G. Braga · R. F. Nascimento  
Departamento de Química Analítica e Físico Química,  
Universidade Federal do Ceará,  
Centro de Ciências, Bloco 940, Campus do Pici,  
60451-970 Fortaleza, CE, Brazil

F. M. G. Braga · J. C. de Araujo  
Departamento de Engenharia Hidráulica e Saneamento,  
Universidade Federal do Ceará,  
Centro de Tecnologia, Bloco 713, Campus do Pici,  
60451-970 Fortaleza, CE, Brazil

A. B. Viana  
Companhia Vale do Rio Doce,  
rua Sapucaí 383, Floresta,  
30150-904 Belo Horizonte, MG, Brazil

A. S. Pimentel  
Departamento de Química,  
Pontifícia Universidade Católica do Rio de Janeiro,  
Rua Marquês de São Vicente 225, Gávea,  
22453-900 Rio de Janeiro, RJ, Brazil

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### Introduction

Chlorination, the most commonly used method to disinfect tap water, has led to a sharp decrease in both mortality and morbidity from many diseases known to be waterborne (Boorman et al. 1999). However, the presence of chlorinated disinfection by-products (DBP) in tap water is of concern from a public health aspect because they are suspected to be carcinogenic (Attias et al. 1995; Moudgal et al. 2000; Tokmak et al. 2004; Komulainen 2004). The most significant group of DBP formed during chlorination is the THM such

as  $\text{CHCl}_3$ ,  $\text{CHBrCl}_2$ ,  $\text{CHBr}_2\text{Cl}$ , and  $\text{CHBr}_3$ .  $\text{CHCl}_3$  is classified in Group 2B as a possibly carcinogenic to humans, based on limited evidence of carcinogenicity in humans but sufficient evidence of carcinogenicity in experimental animals (IARC 1999).  $\text{CHBrCl}_2$  is a weakly mutagenic and it has been classified as probably carcinogenic to humans, with sufficient evidence in animals and inadequate evidence in humans (IARC 1991). Between the four THMs found in drinking water,  $\text{CHBrCl}_2$  appears to be the most potent rodent carcinogen.  $\text{CHBr}_2\text{Cl}$  and  $\text{CHBr}_3$  are classified in group 3 due to the inconclusive genotoxicity (IARC 1991). The second prevalent DBP group is haloacetic acids (HAAs). Aside from THMs and HAAs, many other compounds that comprising the DBP group have been found in treated waters, which include haloacetonitriles, halo ketones, haloaldehydes, halopicrin, cyanogen chloride, halophenols and chloral hydrate and many others (Lee et al. 2004; Chow et al. 2005). The main THM effects are cancer and adverse reproduction problems such as abortion, miscarriage, and retarded fetal development (Nieuwenhuijsen et al. 2000; Graves et al. 2001).

Chloroform concentrations measured in breath or blood after swimming and showering have been correlated with the activity time, and the concentration of this compound found in water and air (Aggazzotti et al. 1990; Jo et al. 1990; Levesque et al. 1994; Nieuwenhuijsen et al. 2000). Backer et al. (2000) have reported that the THM concentration increases in blood as compared with their pre-activity blood levels in individuals after water-consuming. They have found that increases of THM concentrations in blood after showering or bathing were significantly greater than the increases related to regular water-consuming. On the other hand, Miles et al. (2002) have found that showering activity increases the THM concentration in blood, but there was no significant correlation between THM concentration in blood and tap water.

Mostly epidemiological studies of THM only involve the ingestion of contaminated tap water (Nieuwenhuijsen et al. 2000). Nevertheless, THM may also be inhaled during water-use activities (Fantuzzi et al. 2001; Egorov et al. 2003; Erdinger et al. 2004), and absorbed by skin (Levesque et al. 1994; Gordon et al. 1998; Miles et al. 2002; Xu et al. 2002). It has been suggested that the dermal THM uptake during bathing and washing can produce up to

70% of the dose received by ingestion (Xu et al. 2002). The quantity of a chemical absorbed through skin is proportional to the area covered and the concentration of the substance on the skin surface during showering, bathing or swimming (Cherrie and Robertson 1995; Weisel and Jo 1996). However, the THM dermal absorption from vapors and aerosols in a shower stall is predicted to be much lower than that resulting from direct contact with water (Jo et al. 1990). Other activities such as dishes and cloth washing, handling wet clothing or cleaning the house may also be a source of contamination (Xu et al. 2002).

The focus of this work is not directed to quantify the DBP precursors in the water treatment plant. Instead, the main motivation of this study is the multi-pathway analysis of CR by oral ingestion, dermal absorption, and inhalation routes. In response to the increasing public concern on the pollution of the water supply, this study aims to estimate the THM exposure, lifetime CR caused by these different routes due to the use of tap water in the city of Fortaleza, Brazil. Fortaleza is located in Northeastern Brazil (latitude: 3.45 S and longitude: 38.35 W) and has a small variation of temperature and a small atmospheric precipitation during the whole year. The temperature ranges from 22°C in winter to 31°C in summer. It is the sixth most important city in the country, with over 2.8 million people attended by the same local distribution system. The water plant source of Fortaleza is drawn directly from dams.

## Materials and methods

The analyses were performed in ten metropolitan districts in Fortaleza, Brazil. In each district was selected ten different representative points, i.e., residential buildings, which use the same water distribution system (ETA Gavião) with a water treatment capacity of  $10.42 \text{ m}^3 \text{ s}^{-1}$ . The extension of the water distribution system in the city is nearly 5,000 km. Three samples were collected in each residential buildings with a total of 900 samples during the period from October to December, 2004. The mean ambient temperature during these 3 months ranged from 28°C to 31°C, and the mean atmospheric precipitation was less than 26 mm for the entire city only, indicating that there is not need for sampling in different seasons. Water samples at the specified

locations were collected in 100 ml glass bottles, which were filled without passing air bubbles through the sample. Before sampling, a solution of ammonium chloride (NH<sub>4</sub>Cl, 40 g L<sup>-1</sup>) was added to the amber bottles to eliminate any remaining residual chlorine and to stop further THM formation. Each glassware used was previously washed with phosphate-free detergent, rinsed with ultrapure water (Milli-Q) and acetone (HPLC grade). Then, it was placed in an oven at 150°C for 2 h and cooled at room temperature.

Samples were prepared by extracting 10 ml of water with 2 ml of pentane by shaking for 2 min in a separation funnel of 25 ml. Phase separation occurred within 3 min and the upper phase was collected into 2 ml vials having screw caps with PTFE septa. THM measurements were made using a gas chromatograph equipped with a mass detector (GC–MS, Shimadzu, Model QP 5050). Chromatographic separation was accomplished with a capillary column DB-5 (J&W Scientific Inc/Agilent Technologies, 30 m×0.25 mm×0.25 μm). The GC–MS oven temperature program was as follow: initial temperature in 40°C for 2 min and then ramped 10°C per min until 150°C. Carrier gas (H<sub>2</sub>) at a flow rate of 1.8 ml min<sup>-1</sup> and split ratio of 1:10 were used in each experiment. It was injected 2 μl of each sample in the capillary column. For the calibration curve, standard solutions of CHCl<sub>3</sub> (Supelco Inc., 98.8%), CHBrCl<sub>2</sub> (Supelco Inc., 99.9%), CHBr<sub>2</sub>Cl (Supelco Inc., 99.0%), and CHBr<sub>3</sub> (Supelco Inc., 99.9%) in concentrations ranging from 0.05 to 150 μg L<sup>-1</sup> in ultrapure water. The lower value is the limit of quantification for THM measurements. The limit of detection was 0.03 μg L<sup>-1</sup> for each THM. Correlation coefficients were greater than 0.9909, demonstrating high correlation. Precision of the method was evaluated using relative standard deviation, which ranged between 10% and 16%. The mean recovery of THM species ranged between 88.9% and 105.3% for this method. Each analysis was performed in duplicate. The retention times to achieve complete separation of CHCl<sub>3</sub>, CHBrCl<sub>2</sub>, CHBr<sub>2</sub>Cl, and CHBr<sub>3</sub> were 1.75, 2.48, 3.50, and 4.78 min, respectively. The molecular ions (M<sup>+</sup>) for CHCl<sub>3</sub>, CHBrCl<sub>2</sub>, CHBr<sub>2</sub>Cl, and CHBr<sub>3</sub> were respectively detected at *m/z*=83, 83, 129, and 173 following high-energy ionization at 70 eV. Then, the M<sup>+</sup> signals were used in the calibration curves to obtain the THM concentration in water samples.

The CHCl<sub>3</sub> concentration in air (CA, mg m<sup>-3</sup>) inside the shower room is estimated using the model of Little (1992), which is represented by:

$$CA = \left(\frac{a}{b}\right) (1 - e^{-bt}) \tag{1}$$

$$a = \frac{CWxQ_Lx(1 - e^{-K/Q_L})}{V_s}$$

$$b = \frac{\left[\frac{Q_L}{H'}(1 - e^{-K/Q_L})\right] + Q_{GS}}{V_s}$$

where CW is the chemical concentration in water (mg L<sup>-1</sup>), and *a* and *b* are parameters based on Little (1992). Q<sub>L</sub> is the volumetric water flow rate (5 L min<sup>-1</sup>), Q<sub>GS</sub> is the volumetric flow rate (50 L min<sup>-1</sup>), V<sub>s</sub> is the volume of air in the shower (1.2 m<sup>3</sup>), *K* is the mass transfer coefficient of a liquid phase basis (7.4 L by each shower), and *H'* is the dimensionless Henry's law coefficient (Little 1992; Staudinger and Roberts 2001).

The estimate of the lifetime CR associated to THM is based on United States Environment Protection Agency (USEPA) guidelines. The detailed description is presented in the literature (US EPA 1990, 1999), and it is not reproduced here. Three kinds of THM exposure were considered to estimate the lifetime CR: inhalation, dermal absorption and ingestion. The CR of THM is estimated by multiplying the chronic daily exposures (CDE) and a potency factor (upper-bound lifetime cancer risk per mg kg<sup>-1</sup> day<sup>-1</sup>). The CDE for oral ingestion, dermal absorption and inhalation from volatilized water are respectively:

$$CDE_{ingestion} = \frac{(CW \times IR \times EF \times ED)}{(BW \times ATL \times NY)} \tag{2}$$

$$CDE_{dermal} = \frac{(CW \times SA \times PC \times ET \times EF \times ED)}{(BW \times ATL \times NY)} \tag{3}$$

$$CDE_{inhalation} = \frac{(CA \times IR \times ET \times EF \times ED)}{(BW \times ATL \times NY)} \tag{4}$$

where IR the ingestion rate (L day<sup>-1</sup>), EF the exposure frequency (days year<sup>-1</sup>), ED the exposure duration (years), BW the body weight (kg), and ATL the average time of a lifetime (years), NY the number of days per year (365 days year<sup>-1</sup>), SA the skin-surface

area available for contact ( $\text{cm}^2$ ), PC the chemical-specific dermal permeability constant ( $0.0020 \text{ m h}^{-1}$ ), ET the exposure time, hour per day or hour per event ( $0.2 \text{ h day}^{-1}$ ), and IR the inhalation rate ( $0.83 \text{ m}^3 \text{ h}^{-1}$ ). The standard values of average body weight, volume of air breathed by adults per day, skin-surface area, and potency factor for oral ingestion and inhalation of THM are taken from the literature (US EPA 1990). For adults, the exposures were converted to a daily dose by assuming  $20 \text{ m}^3$  aspirated air per day, and average body weights of 70 kg for male and 65 kg for female. The lifetime of residents was assumed to be the standard 70 years for both male and female. Finally, the skin-surface areas are 1.94 and  $1.69 \text{ m}^2$  for males and females, respectively.

In addition, the hazard index (HI) associated to THM exposure is calculated for oral ingestion and dermal absorption by using the ratio of the CDE to the chronic reference dose (RfD) for a individual chemical. The standard values of the potency factor of oral ingestion ( $\text{PF}_{\text{oral}}$ ) and inhalation ( $\text{PF}_{\text{inhalation}}$ ), and the reference dose (RfD) for THM are taken from the literature (US EPA 2006).

## Results and discussions

### THM concentrations in tap water samples

The mean values of THM concentrations found in ten Fortaleza districts are presented in Table 1. The

current national water quality standard (NWQS) for the total THM concentration is  $100 \mu\text{g L}^{-1}$  (Ministério da Saúde 2004). It can be observed in Table 1 that Fortaleza districts show higher total THM concentration than that for NWQS. The Downtown district is the one that presented the highest total THM mean concentration,  $141 \mu\text{g L}^{-1}$ , i.e., 41% higher than that allowed by the NWQS. Maracanaú district shows the lower one,  $105 \mu\text{g L}^{-1}$ , exceeding in 5% the NWQS.

THM concentrations in chlorinated tap water in Fortaleza districts have the following ranges:  $\text{CHCl}_3$ ,  $55.9\text{--}72.5 \mu\text{g L}^{-1}$ ;  $\text{CHBrCl}_2$ ,  $28.7\text{--}47.2 \mu\text{g L}^{-1}$ ; and  $\text{CHBr}_2\text{Cl}$ ,  $13.3\text{--}21.7 \mu\text{g L}^{-1}$ .  $\text{CHBr}_3$  was not detected in any district. The data variability is considerable, ranging up to 50%. Tokmak et al. (2004) found similar data variability associated with sampling locations. It suggested that this variability was correlated with travel time for the water within the distribution system, and the intermediate chlorination carried out within the water distribution system. We try to correlate the measured THM concentrations with distances of districts to the water treatment plant; however we find no correlation ( $R^2 < 0.10$ ). Nevertheless, this parameter does not completely reflect the length of pipes carrying water from the plant to the residential buildings where the sampling was performed. Our data variability may come from the variations of natural organic carbon in the reservoir, but officials from the water treatment plant unfortunately refused to give this information.

**Table 1** The mean concentration (CW,  $\bar{X} \pm \sigma$ ,  $\mu\text{g L}^{-1}$ ) of each THM, total THM (TTHM), and residual chlorine (in  $\text{mg L}^{-1}$ ) in tap water in Fortaleza districts

| n  | District    | Distance (km) | CA ( $\mu\text{g m}^{-3}$ ) |                   |                      |                      |                   |            | TTHM    | Cl <sub>2</sub> |
|----|-------------|---------------|-----------------------------|-------------------|----------------------|----------------------|-------------------|------------|---------|-----------------|
|    |             |               | CHCl <sub>3</sub>           | CHCl <sub>3</sub> | CHCl <sub>2</sub> Br | CHBr <sub>2</sub> Cl | CHBr <sub>3</sub> |            |         |                 |
| 1  | Messejana   | 7.71          | 325.8                       | 61.4±8.9          | 43.1±15.3            | 18.7±5.8             | N.D.              | 123.2±27.0 | 2.5±0.3 |                 |
| 2  | Downtown    | 20.77         | 382.5                       | 72.1±9.0          | 47.2±5.0             | 21.7±2.6             | N.D.              | 141.1±31.2 | 1.3±1.0 |                 |
| 3  | Aldeota     | 20.64         | 351.2                       | 66.2±3.7          | 44.1±22.2            | 13.3±0.8             | N.D.              | 123.5±29.9 | 1.7±0.4 |                 |
| 4  | Mucuripe    | 25.26         | 384.7                       | 72.5±6.3          | 37.0±10.5            | 13.3±0.7             | N.D.              | 122.9±31.8 | 1.0±0.3 |                 |
| 5  | Floresta    | 24.79         | 333.2                       | 62.8±10.5         | 28.7±12.3            | 14.0±4.7             | N.D.              | 105.5±26.9 | 1.3±0.4 |                 |
| 6  | Barra Ceará | 27.81         | 308.8                       | 58.2±3.2          | 38.7±17.9            | 16.1±2.9             | N.D.              | 113.0±25.5 | 1.9±0.3 |                 |
| 7  | Montese     | 18.49         | 360.3                       | 67.9±14.4         | 35.1±11.6            | 16.0±1.2             | N.D.              | 119.0±29.2 | 1.9±0.5 |                 |
| 8  | Cocorote    | 18.02         | 322.6                       | 60.8±10.9         | 46.1±2.5             | 13.6±2.1             | N.D.              | 120.5±28.1 | 1.0±0.3 |                 |
| 9  | Caucaia     | 30.95         | 327.4                       | 61.7±12.9         | 41.5±13.4            | 14.3±2.2             | N.D.              | 117.5±27.6 | 0.9±0.1 |                 |
| 10 | Maracanaú   | 11.06         | 295.0                       | 55.6±11.2         | 35.1±14.3            | 14.6±2.8             | N.D.              | 105.3±24.2 | 2.3±0.4 |                 |

The  $\text{CHCl}_3$  concentration (CA,  $\mu\text{g m}^{-3}$ ) in air inside the shower room estimated using the model of Little (1992). The district numbers *n* are presented here to help the reader in the following figures. The district distances from the water treatment plant (ETA Gavião) are showed to refer in Fig. 1

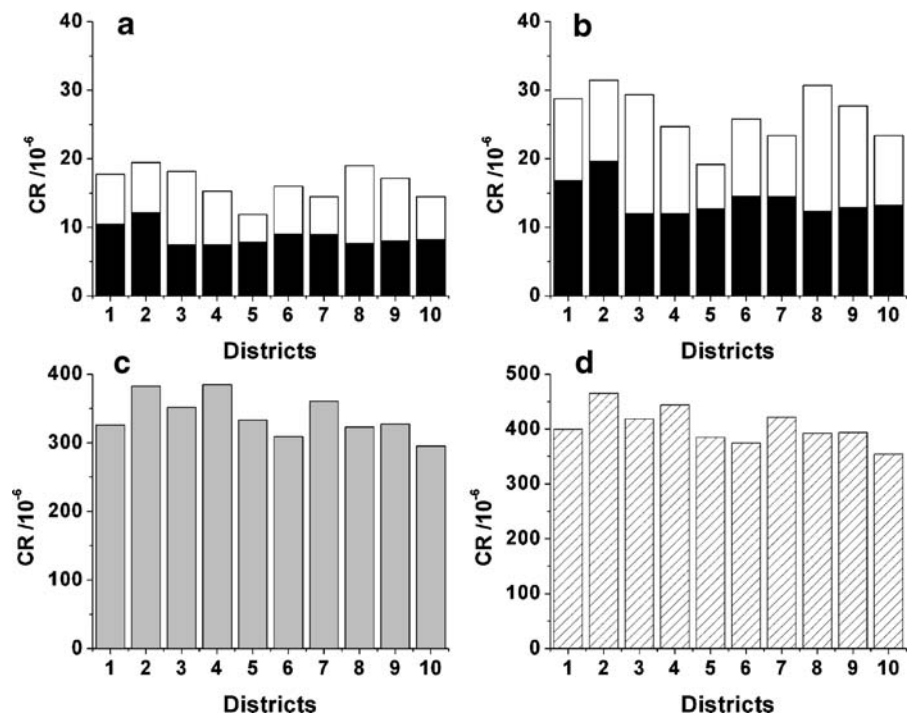
CHCl<sub>3</sub> is the major THM species and CHBr<sub>2</sub>Cl the minor one within the studied districts. From our knowledge, there are only two studies of THM levels in the Brazilian tap water up to this date. One was performed in the state of São Paulo (Valente et al. 1998) and the other one in Santa Catarina (Budziak and Carasek 2007). While, Valente et al. (1998) observed a similar THM level in the state of São Paulo from that found in Fortaleza city, Budziak and Carasek (2007) lower levels. This probably means that Fortaleza and São Paulo water sources in each water treatment plant may have comparable amounts of DBP precursors. In fact, CHCl<sub>3</sub> levels are generally higher in chlorinated water from surface distribution systems than from groundwater ones (LeBel et al. 1997). The explanation for that is the high precursor organic matter in the former (LeBel et al. 1997). It also depends on the water treatment process and temperature (LeBel et al. 1997). Sadiq et al. (2002) measured the CHCl<sub>3</sub> concentration in the Newfoundland province, Canada. They observed that it is five times higher than that found in Fortaleza city. The CHCl<sub>3</sub> level in Fortaleza is reasonably higher than other levels found in literature (Kuo et al. 1998; Lin and Hoang 2000; Williams et al. 2002; Lee et al. 2004; Tokmak et al. 2004; Uyak 2006). The concen-

trations of CHBrCl<sub>2</sub> and CHBr<sub>2</sub>Cl measured in our work are also higher than those concentrations found in studies cited above. CHBr<sub>3</sub> level may be below the limit of detection of the method. Nevertheless, CHBr<sub>3</sub> has been detected in Kuwait and Florianopolis what it may be due to bromide sources and the use of a different water treatment (Ali and Ripley 1990).

Cancer risks and hazard indexes

The CR by oral ingestion, dermal absorption, and inhalation of THM for males and females were slightly different. Thus, this study only takes in account the average CR between males and females. The CR by oral ingestion for Fortaleza districts are showed in Fig. 1a. Assessing the mean values for ten districts in Fortaleza, the CR by oral ingestion of total THM is  $2.50 \times 10^{-5}$ , which is above the allowable limit,  $10^{-6}$ , by a factor of about 25. THM contribute individually to the CR by oral ingestion in the decreasing order: CHBrCl<sub>2</sub> and CHBr<sub>2</sub>Cl. The percentage contribution of each THM collected in Fortaleza districts indicates that the lifetime CR by oral ingestion of CHBrCl<sub>2</sub> contributes with the highest percentage (67%) compared with the total risk, followed by CHBr<sub>2</sub>Cl (33%). Lee et al. (2004) have

**Fig. 1** CR by **a** oral ingestion, **b** dermal absorption, **c** inhalation, and **d** total CR of THM from tap water in Fortaleza districts (see Table 1 for district numbering). CHCl<sub>3</sub> is presented in gray color, CHBrCl<sub>2</sub> in white, CHBr<sub>2</sub>Cl in black, and the total THM is hatched



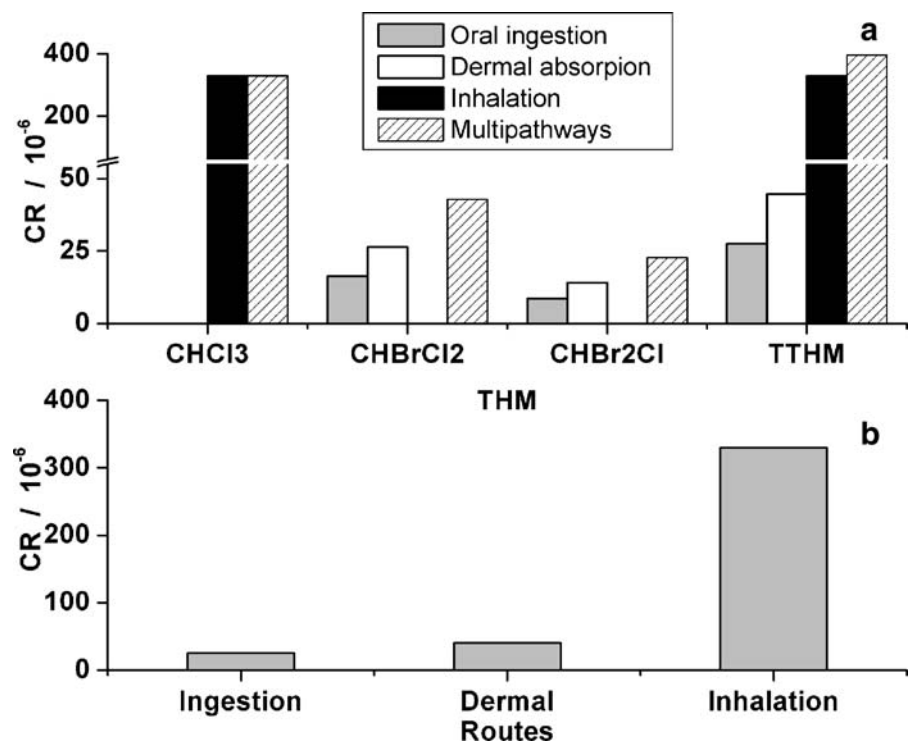
found the same contribution for  $\text{CHBrCl}_2$  but different percentages for  $\text{CHBr}_2\text{Cl}$  (24%). Nevertheless, Uyak (2006) has observed a higher contribution of  $\text{CHBr}_2\text{Cl}$  (43%), while Hsu et al. (2001) have obtained 2%. For  $\text{CHBrCl}_2$ , the Downtown district presents the highest CR by oral ingestion,  $1.95 \times 10^{-5}$ , while the lowest one is observed in Floresta district,  $1.18 \times 10^{-5}$ . Assessing the CR by oral ingestion of  $\text{CHBr}_2\text{Cl}$ , the district that presents the highest CR is Downtown with  $1.22 \times 10^{-5}$ . Aldeota and Mucuripe districts show the lowest CR by oral ingestion,  $7.43 \times 10^{-6}$ .

Figure 1b shows the CR by dermal absorption of THM in Fortaleza districts. The CR by dermal absorption of total THM are also higher than the allowable limit,  $10^{-6}$ . The values found for  $\text{CHBrCl}_2$  and  $\text{CHBr}_2\text{Cl}$  are higher than  $10^{-5}$ . The Downtown district is the most affected by total THM through dermal absorption, and Floresta is the less affected. The CR by dermal absorption of total THM for Downtown and Floresta districts are  $5.10 \times 10^{-5}$  and  $3.18 \times 10^{-5}$ , respectively. Dermal absorptions  $\text{CHBrCl}_2$  and  $\text{CHBr}_2\text{Cl}$  are higher in Downtown district. The CR by dermal absorption of  $\text{CHBrCl}_2$

and  $\text{CHBr}_2\text{Cl}$  in this district are  $3.15 \times 10^{-5}$  and  $1.96 \times 10^{-5}$ , respectively. The mean CR by dermal absorption of  $\text{CHBrCl}_2$  and  $\text{CHBr}_2\text{Cl}$  found in Fortaleza districts are  $2.64 \times 10^{-5}$ ,  $1.41 \times 10^{-5}$ , respectively. Thus, the contribution of each THM in the CR by dermal absorption is almost equal that found in oral ingestion.

$\text{CHCl}_3$  is assumed to be the major compound exposed to humans during showering and bathing due to its high Henry's law coefficient compared with those for  $\text{CHBrCl}_2$ ,  $\text{CHBr}_2\text{Cl}$ , and  $\text{CHBr}_3$  (Staudinger and Roberts 2001). Our calculation for the CR by inhalation only considers  $\text{CHCl}_3$ . Our estimate is within the range of  $\text{CHCl}_3$  concentration in air measured in a shower stall by Nuckols et al. (2005). Jo et al. (2005) measured a  $\text{CHCl}_3$  concentration in air inside household of about 0.15% less than in shower stalls, showing  $\text{CHCl}_3$  dispersion is very important. Thus, it is necessary to be careful comparing with other studies published in the literature (Williams et al. 2002; Lee et al. 2004; Tokmak et al. 2004; Uyak 2006). Kuo et al. (1998) and Lin and Hoang (2000) performed an estimate using the model proposed by Little (1992), which should be more reliable. Most

**Fig. 2 a** Individual and total contribution of each THM in CR by different pathways; and **b** total CR by different routes



published studies on inhalation exposures apply the THM concentration in water to estimate its concentration in air, which gives a very low CR by inhalation. Our results are presented in Fig. 1c. The mean CR by inhalation of  $\text{CHCl}_3$  is  $1.35 \times 10^{-4}$ , which is much higher than  $10^{-6}$ . The Mucuripe district population is the most affected with CR of  $1.53 \times 10^{-4}$ , while the Maracanaú district has the lowest CR,  $1.17 \times 10^{-4}$ . The inhaled chloroform is rapidly absorbed in the lung, and the total amount is directly proportional to the chloroform concentration in the inspired air, exposure time, blood/air Ostwald solubility coefficient, solubility in the lung tissues (mainly in fat tissue), and intensity of physical activity (Aggazzotti et al. 1990; Batterman et al. 2000).

It can be observed the total risk by different pathways in Fortaleza districts in Fig. 1d. The mean total CR is  $3.96 \times 10^{-4}$ . The Downtown district population shows the highest CR,  $4.65 \times 10^{-4}$ , while Maracanaú district the lowest one,  $3.54 \times 10^{-4}$ . The human exposure to multiple toxicants may result a synergistic or antagonistic effect (Hsu et al. 2001). Thus, due to these effects, the study presented here suggests a lower-bound CR. Nevertheless, this risk is extended to the infant in pregnant women. Furthermore, THM may provoke intrauterine growth retardation and spontaneous abortion, and cause anomalies in the central nervous system and skeletal defects in infants (Graves et al. 2001).

Figure 2a shows the THM and total THM contribution in different routes.  $\text{CHBrCl}_2$  and  $\text{CHBr}_2\text{Cl}$  are the most harmful THM by oral ingestion and dermal absorption, which is due to their high carcinogenic potential factor by both routes (US EPA 2006). However, chloroform is the only THM with carcinogenic action in its gaseous form. Figure 2b presents that the contribution of CR by dermal absorption is larger than that for oral ingestion, and the CR by inhalation has the smaller contribution.

Our high CR values found by multi-pathway routes do not necessarily represent the probability to the population developing cancer. The tumor may take a long time to manifest in residents due to carcinogenic substances. In addition, the calculation of HI is necessary for evaluating adverse effects by oral, ingestion and dermal absorption of THM through the contaminated water. It shows that the highest value found in this study is an order of magnitude lower than a unit. These values for HI in different

locations indicate that THM exposure would be unlikely to cause non-cancer effects such as jaundice, neurobehavioral effects, subjective central nervous system effect, and enlarged livers (US EPA 2006).

## Conclusions

The evaluation of THM exposures by oral ingestion, dermal absorption, and inhalation routes is presented in this paper to associate with lifetime cancer risks. Our results show that residents had higher cancer risks through inhalation due to the application of the model of Little into the USEPA risk assessment model. The mean cancer risk for THMs in tap water was  $3.96 \times 10^{-4}$ , about 400 times higher than the USEPA limit. Fortaleza residents had a higher CR by inhalation than dermal absorption and oral ingestion. The total CR for  $\text{CHCl}_3$  contributed with 68% of the total cancer risk. Nevertheless,  $\text{CHBrCl}_2$  was the prominent (59%) by both dermal and ingestion routes. The hazard index was about ten times lower than unity, which does not indicate non-cancer effects.

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