ASSESSMENT OF POTENTIAL CANCER RISKS FROM TRIHALOMETHANES IN WATER SUPPLY AT MEXICAN RURAL COMMUNITIES

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ABSTRACT

Chlorination is used worldwide to produce drinking water in rural communities of the developing world. Frequently in these places, a lack of proper sanitation and pollution control increases the organic content in water sources thereby increasing the potential for trihalomethanes (THMs) formation. This paper evaluated the lifetime cancer risk and the hazard index caused by THMs contained in drinking water from four rural communities of Mexico. Oral exposure and the health risk were estimated using a probabilistic approach. This was done by monitoring the free residual chlorine and the THMs content in drinking water and by obtaining the actual population characteristics. Population characteristics considered, among other variables, the water intake rate, the body weight and the exposure time, and were expressed as empirical frequency distribution curves. Results showed that the 95th percentile of the carcinogenic risk estimated for Bromodichloromethane and Dibromochloromethane were above the acceptable level of one in a million (10^{-6}) even though in 50% of the cases tap water did not meet the minimum free residual chlorine content required by the Mexican drinking water norm. Until proper sanitation is implemented and water is managed integrally (in quantity and quality), the Mexican government will need to consider alternate disinfection systems or will need to review integrally its water supply policy in rural areas.

Key words: Cancer risk, drinking water, risk assessment, rural communities, trihalomethanes

1. INTRODUCTION

A water service is currently supplied to 88% of the Mexican population; however, coverage for rural population is only 68% (CNA, 2004). It is estimated that 95% of the distributed water is chlorinated. In parallel, only 21% of the municipal wastewater is treated, mostly all in urban areas. Water government policy, in general, is reduced to providing water rather than to applying an integral water service. For rural communities, this means supplying underground-chlorinated water in networks operating for only several hours per day and at low pressure. Chlorination of water has certainly contributed to reducing the incidence of gastrointestinal diseases such as cholera, typhoid fever, hepatitis, etc. And, disinfection with chlorine has been recognized as one of the major public health achievements. However, appropriate levels of free residual chlorine in supply systems are needed to protect health and increasingly amount of chlorine is been added to sources that are becoming polluted. The addition of chlorine reduces microbial risk but poses chemical risks when disinfection by-products (DBPs) are formed. DBPs occur when chlorine reacts with natural (e.g., humic and fulvic) or anthropogenic organic matter contained in water (Gallard and Gunten, 2002). Organic matter, commonly measured as total organic carbon (TOC) is the organic precursor, while bromide ion is the inorganic one.

Among the DBPs that can be found in chlorinated water, trihalomethanes (THMs), which include chloroform ($CHCl_3$), Bromodichloromethane ($CHCl_2Br$), Dibromochloromethane ($CHClBr_2$) and Bromoform ($CHBr_3$), have been widely studied because they are considered potentially carcinogenic (McGeehin *et al.*, 1993). In addition, recent studies suggest that they also produce reproductive disorders (Graves *et al.*, 2002) if ingested during pregnancy (Bove *et al.*, 1995, King and Marret, 1996, Dodds *et al.*, 1999). Therefore, water utility managers try to reduce their formation while maintaining a free residual chlorine content that is enough to inactivate microorganisms and prevent their regrowth in the distribution system. To control health risks caused by THMs, several countries have established a maximum content in drinking water. In the USA, the US EPA (2006) has set a value of 0.08 mg/L, in the United Kingdom (2000) and Canada (Health Canada, 2001) the limit is 0.10 mg/l, and in Australia, New Zeeland (Aus-NZ, 2000) and México (SSA, 2000) it is 0.20 mg/L. However, in Mexico, evidence that water sources are becoming increasingly polluted due to a lack of sanitation (Jimenez and Torregrosa, in press) raises concerns about the possible presence of DBPs in drinking water, particularly in rural areas where the risks are bigger because most of the population consumes tap water instead of bottled water unlike in urban areas.

2. OBJECTIVES

The aim of this research was to evaluate the life cancer risk and the hazard index caused by THMs contained in drinking water from four rural communities of Mexico using field data to characterize the local population and the quality of the drinking water.

3. METHODS

For this research, four communities located in the central area of Mexico were considered: Tepetitla, San Mateo Ayecac, Michac and San Rafael with less than 16,000 total inhabitants. Each community has its own well to supply water where chlorine is automatically added before water enters the distribution network. The field study was divided into three parts. In the first one, an environmental study was performed to determine the quality of drinking water. The second one involved a community participation study that had the goal of training local people to measure the free residual chlorine content in their drinking water to complement the data required for this research. In the third part, data to characterize the population of each community was gathered to use it for the human health risk assessment. Field data was gathered during a 2-week sampling program in May 2005.

Water samples were taken in each community from household water intake points and from tap water inside the houses, after passage through individual storage tanks. Sampling sites were selected considering: (a) the population size; (b) the direct supply from the municipal network and (c) the household's agreement to participate in the monitoring of their water and in the survey to gather information for the risk assessment analysis.

The environmental study consisted of 23 sampling points in different households (water intake and tap water). The parameters measured were free-residual chlorine (Cl^-) and THMs. The THM extraction and analysis were carried out according to 8260 EPA method (Keith, 1996). Free residual chlorine was analyzed using a friendly colorimetric kit developed at the Institute of Engineering, UNAM (Jiménez *et al.*, 2004), based on the hydrochloride orthotolidine method (APHA, AWWA and WPCF, 1995). The kit was used in 13 households where participants monitored residual chlorine in water, both in the morning and in the afternoon, at the household's water intake point and tap water.

To characterize population exposure scenarios questionnaires were applied to 75 adults from the four communities to determine their: tap water ingestion habits, time of residence at the site and body weight, and were expressed as empiric distribution functions (EDFs) to describe the variability of those parameters. To evaluate the lifetime cancer risk (R_{ci}) caused by the exposure to halogen compounds in drinking water, a risk assessment model was applied (equation [1]) based on United States Environmental Protection Agency guidelines (US EPA, 1989). The non-cancer hazard quotient (HI_i) was used (equation [2]) to estimate the risk caused by chloroform as a secondary carcinogen.

$$R_{ci} \equiv \frac{EF \times ED}{BW \times AT} \times C_{ai} \times IR_a \times Sf_i \qquad [1]$$

$$HI_i \equiv \frac{EF \times ED}{BW \times AT} \times \frac{C_{ai} \times IR_a}{RfD_i} \qquad [2]$$

Where C_{ai} is the concentration of the trihalomethanes measured (mg/L) in drinking water for each community, IR_a is the water ingestion rate (L/d), Sf_i is the specific cancer slope factor $(mg/kg\text{-}d)^{-1}$ for bromide compounds and RfD_i is the reference dose for chloroform (mg/kg-d). The other exposure variables are EF, exposure frequency (d/y); ED, exposure duration (y); BW, body weight (kg) and AT, average exposure time (d).

4. RESULTS AND DISCUSSION

4.1 Free residual chlorine

A total of 840 measurements were done at households' water intake points and in tap water after passing through the individual storing tanks. Only 59% and 49% of the measurements (Table 1) made at the intake and in the tap water fulfilled the free residual chlorine content established by the Mexican drinking water standard of 0.2 and 1.5 mg/L (SSA, 2000). This is a serious concern about the safeness of water, particularly from a microbial point of view. Additionally, the decrease in the number of samples meeting the standard from the intake to the tap water showed the impact of storing water in plastic containers at home. These plastic containers are used because the network system has not enough pressure and water is distributed only for several hours per day, constraining people to store water and pump it into their homes.

According to table 1, Tepetitla has the worse water quality supply and the major impact on water quality due to storage followed by San Mateo, where all the values were less than or equal to the minimum permissible level of 0.2 mg/L (detail not shown on table 1). Less adverse conditions were observed in San Rafael and Michac. Results also indicate that even in the best-case scenario, the free residual chlorine content was usually near to the minimum acceptable level, and in fact, 35% and 48% of the household intake and tap water samples had no free residual chlorine.

Table 1 Free residual chlorine at household water intake and in tap water samples, in percentage

Free residual Chlorine (mg/L)	Total		Tepetitla		San Rafael		Michac		San Mateo	
	Water intake	Tap water	Water intak	Tap water	Water intak	Tap water	Water intak	Tap water	Water intak	Tap water
< 0.20	39	50	54	71	27	41	15	28	47	43
0.2 – 0.6	48	42	35	21	48	43	69	67	53	57
0.8 – 1.5	11	7	9	7	25	16	7	5	0	0
> 1.5	2	1	2	1	0	0	9	0	0	0

4.2 THMs Exposure levels

While, 50% of the samples did not fulfil the minimum free residual chlorine content, 100% of the samples did present THMs. The total THMs concentration varied from 5 to 22 μg/L, always meeting the Mexican drinking water standard of 200 μg/L (SSA, 2000). THMs concentration ranges for the different chemical species were as follows: $CHCl_3$, 1.3 - 12 μg/L; $CHCl_2Br$, 1.7 – 8.2 μg/L; $CHClBr_2$, 0.7 – 4.3 μg/L; mg/L; and $CHBr_3$, 0.25 – 0.75 μg/L. Chloroform ($CHCl_3$) was then the major specie, and was notably present in San Rafael and Michac (Fig. 1). $CHCl_2Br$ was the most important brominates compound, $CHBr_3$ being the least one. This is consistent with other studies (Chang *et al.*, 1996; Hsu *et al.*, 2001; WHO, 2004). It should be pointed out that the higher concentrations of $CHCl_2Br$ and $CHClBr_2$ were found in water samples taken in Tepetitla where the lower level of free residual chlorine was recorded. This once again raises the concern that while microbial risks are not being properly addressed, other health risks are increasing.

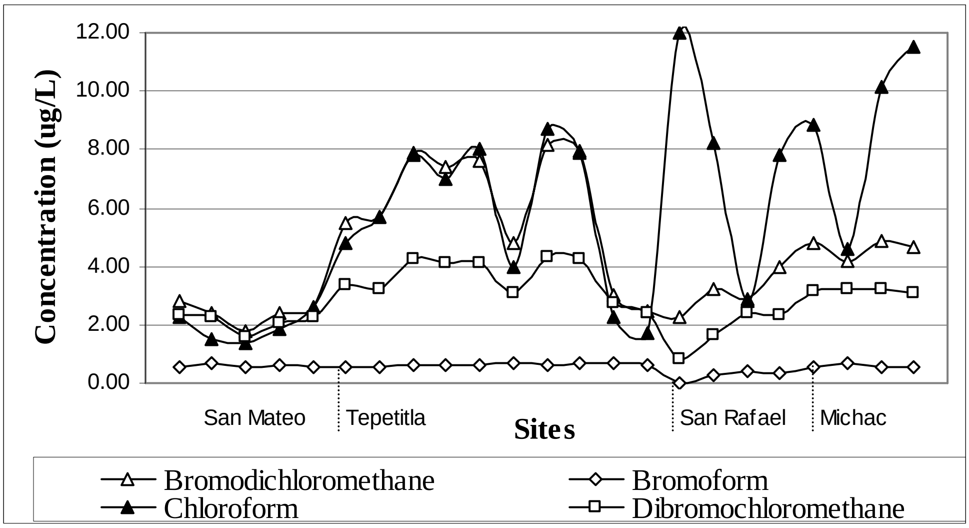

Figure 1 THMs Concentration in tap water samples

4.3 Population characteristics and water habits

Drinking water intake rate (IR_a). Most of the people in the sample (84%) consume drinking water directly from the tap while 16% drink bottled water only. Daily water ingestion varied from less than 0.5 L to 3.4 L, as seen in the empirical distribution functions (EDFs) showed in figure 2, but about 70% of the population reported daily water ingestion between 1 L and 2.5 liters. The typical water intake rate recommended of 2L/d (US EPA, 1997) is within the 95% confidence range for the daily reported mean.

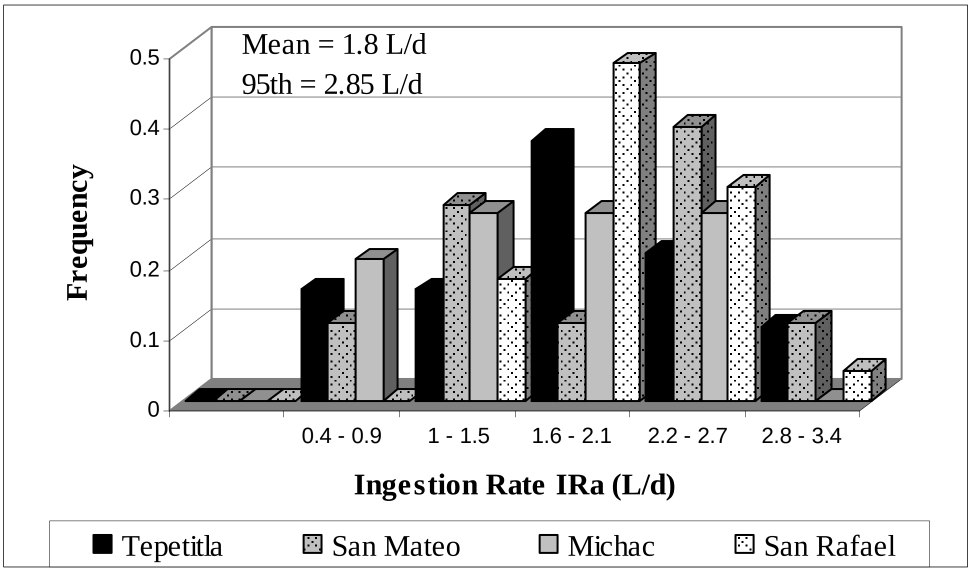

Figure 2 Adults' drinking water intake rate (IR_a) frequency distributions

Exposure duration (ED). The mean residence time (ED) of the population varied from 22 to 30 years, the mean value being closer to 30 years. Different behaviour among the communities is represented by the diverse EDF patterns obtained for ED (Fig. 3). In comparison, mobility reported for the USA is 9 years, according to US EPA (1997).

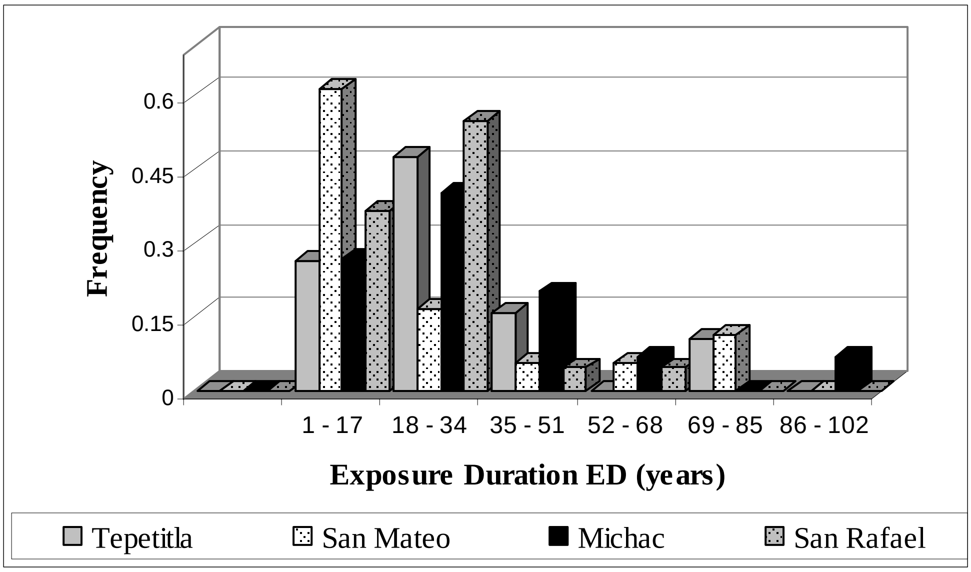

Figure 3 Exposure duration (ED) frequency distributions

Body weight (BW). Average body weight (BW) among the adult population varied from 62 to 67 kg, values that are lower than the 70 kg recommended by US EPA (1997), for health risk assessments. Moreover, the global 90th percentile of the community's distributions was 79 kg (Fig. 4).

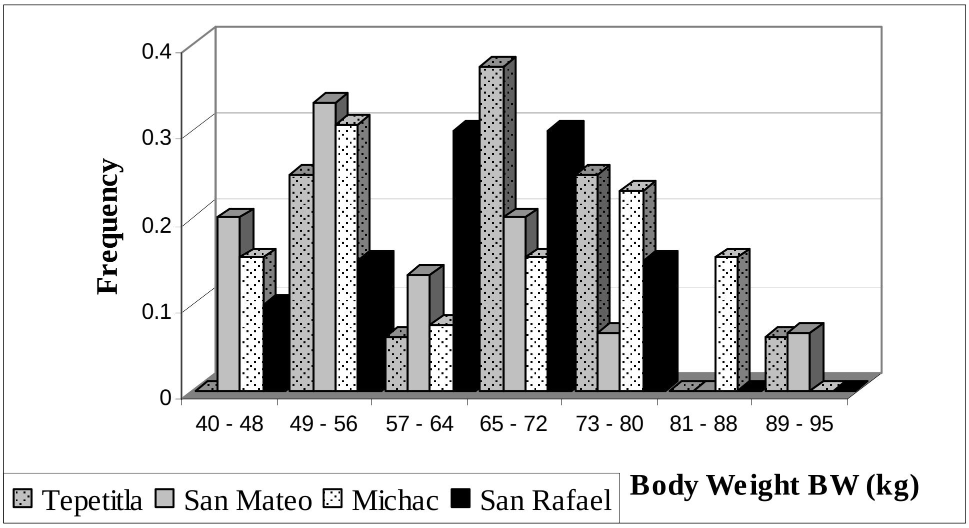

Figure 4 Adult body weight frequency distributions (BW)

4.4 Risk estimation

The probabilistic health risk estimation (US EPA, 2001) was estimated for drinking water ingestion. The cancer risk equation [1] was used for bromide compounds while the chloroform hazard quotient was estimated using equation [2]. The empirical distribution functions developed for the ED, BW, C_{ai} and IR_a variables were used as inputs to the risk equations in order to obtain the risks as probabilistic functions (not shown in text). For the other variables in equation [1] values recommended from literature were used (Table 2). The hazard quotient for chloroform was estimated using the reference dose value given by IRIS (2005), which is considered as protective to carcinogenic effects.

The 95th percentile of the probabilistic distribution functions (Table 3) calculated for the four rural communities showed in all cases that risk caused by chloroform and Bromoform are acceptable ($<$ than 1 for the first compound and $<$ than 10^{-6} for the second one). However, the 95th percentile for Bromodichloromethane and Dibromochloromethane for tap water was greater than 10^{-6} for all communities. These results show that oral exposure to these compounds is higher than international acceptable levels, although content in water fulfil the Mexican regulation. This occurs while microbial risks are not effectively controlled as described above.

Table 2 Exposure values used for the probabilistic risk estimation

Variables	Value (1)	Units	Reference
Cs	EDF	mg/L	Site specific survey data
IRa	EDF	L/d	Site specific survey data
EF	365	d/y	EPA (1997)
ED	EDF	y	Site specific survey data
BW	EDF	kg	Site specific survey data
AT	25550	d	EPA (1997)
Sfi (2)	specific	$(mg/kg\text{-}d)^{-1}$	IRIS (2005)
RfD (3)	1.00E-02	mg/kg-d	IRIS (2005)

(1) EDF = empirical distribution function for parameter indicated
(2) Specific cancer slope factor for Bromodichloromethane, Dibromochloromethane and Bromoform
(3) Reference dose for chloroform

Table 3 The 95th percentile from the risk distribution functions

Compound	Tepetitla	Michac	San Rafael	San Mateo
Chloroform	3.5E-02	4.6E-02	4.8E-02	1.4E-02
Bromodichloromethane	1.2E-05	1.1E-05	4.5E-06	3.3E-06
Dibromochloromethane	9.5E-06	1.0E-05	3.6E-06	3.8E-06
Bromoform	1.5E-07	1.8E-07	6.8E-08	1.0E-07

5. CONCLUSIONS

This research showed that risks produced by THMs in rural areas are not negligible and are present even though the free residual chlorine content is low or equal to zero and the drinking water limit in the norm is met. Based on these results, Mexican policy to provide water to rural communities should be reviewed integrally not only in terms of water supply but also to protect water sources, to enhance the operation of water distribution systems and, eventually, to consider alternative disinfection methods such as UV-light. Even though at the present time health risks caused by disinfection by-products remain small compared to those caused by microbes, they might become important in the future, hence the importance of planning future water supply for rural communities more carefully. This recommendation as well as the methodology approach used for the risk analysis might also be applied to other rural communities from developing countries in similar conditions where it is important to use actual data describing the specific local population characteristics and behaviour.

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