Science of the Total Environment 651 (2019) 1735–1741

Contents lists available at ScienceDirect

Science of the Total Environment

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

Chlorination by-product levels in hot tap water: Significance and variability

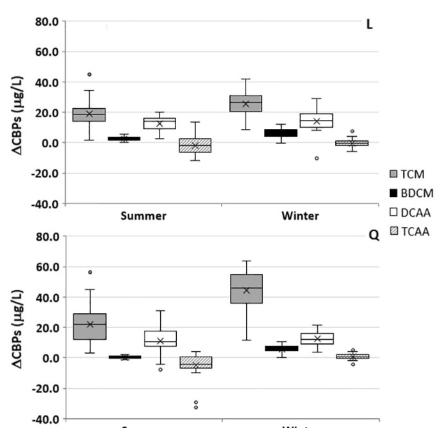
Christelle Legay [a], Sylvie Leduc [b], Jean Dubé [c], Patrick Levallois [d], Manuel J. Rodriguez [a,*]

[a] NSERC Industrial Research Chair on Drinking Water Quality, Université Laval, QC, Canada
[b] Canada Research Chair on Water Quality Modeling, Université Laval, QC, Canada
[c] School of Urban and Regional Planning, Université Laval, QC, Canada
[d] Institut National de Santé Publique du Québec, QC, Canada

HIGHLIGHTS

- The impact of residential water heating on DBPs was studied.
- The increase of THMs from water heating varied between residences and seasons.
- The impacts of water heating on HAAs were different between DBP species.
- Models partially explain the variability of the impacts of water heating on DBPs.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 14 August 2018
Received in revised form 4 October 2018
Accepted 6 October 2018
Available online 09 October 2018

Editor: Damia Barcelo

Keywords:
Drinking water
Chlorination by-products
Water heating
Tap water

ABSTRACT

People are exposed to chlorinated by-products (CBPs) through the consumption of cold tap water (CTW) (ingestion, inhalation, dermal contact) but also through the use of hot tap water (HTW) in such activities as showering and bathing (inhalation, dermal contact). This study focuses on the impact of residential water heating on CBP levels in tap water. Trihalomethane (THM) and haloacetic acid (HAA) levels were measured in the CTW and HTW of 50 residences located in two distribution systems supplied by chlorinated surface water during summer and winter. Results show important differences between CBP levels measured in cold and hot tap water. However, the magnitude of changes differs according to the specific species of THMs and HAAs, the season, the distribution system and the location within the same distribution system. Residential water heating led to an increase in average THM levels for the two distribution systems studied, which tended to be greater in winter. Residential water heating affected the two main HAA species found in the area studied (dichloroacetic (DCAA) and trichloroacetic (TCAA) acids) differently. In fact, the average DCAA levels increased due to water residential heating while a small change in average levels was observed for TCAA. However, the water heating impact on HAAs (in terms of importance and sometimes of tendency (increase vs. decrease)) may also differed between residences. The influence of seasons on the change in the average DCAA and TCAA levels (in μg/L) from residential water heating was not statistically significant except for TCAA levels in one distribution system. Results show the importance of considering site-specific characteristics of CTW (CBP level, temperature, residual chlorine, etc.) to estimate the levels of CBPs in HTW in CBP exposure

* Corresponding author at: Pavillon Félix-Antoine-Savard, 2325 rue des Bibliothèques, Office 1616, Université Laval, Québec, QC G1V 0A6, Canada.
E-mail address: manuel.rodriguez@esad.ulaval.ca (M.J. Rodriguez).

https://doi.org/10.1016/j.scitotenv.2018.10.075

assessment studies (and not to generalize for an entire population). The reported data can thus be useful in assessing for exposure to DBPs in epidemiological studies.

1. Introduction

During the last few decades, the impact of chlorination by-products (CBPs) from drinking water on human health has been investigated in many studies (Hrudey, 2009; Nieuwenhuijsen et al., 2009; Villanueva et al., 2015). Trihalomethanes (THMs) and haloacetic acids (HAAs) represent the most abundant classes of CBPs and are regulated in many countries (Government of Quebec, 2014; US EPA, 2006). THM regulation is based on the sum of four species (trichloromethane – TCM, bromodichloromethane – BDCM, dibromochloromethane – DBCM, tribromomethane – TBM), noted as THM4 in this paper. For HAAs, regulation is based on the sum of the five following species: monochloroacetic – MCAA, monobromoacetic – MBAA, dichloroacetic – DCAA, trichloroacetic – TCAA, and dibromoacetic – DBAA acids, noted as HAA5 in this paper. Given THMs and HAAs are usually routinely measured, these two CBP classes are often used as indicators of CBP exposure in epidemiological studies focusing on the link between CBP exposure and adverse health outcomes (Legay et al., 2010; Nieuwenhuijsen et al., 2009).

Population exposure to THMs and HAAs is not only due to the occurrence of these compounds in drinking water provided by municipal distribution systems. In fact, THM and HAA levels at the residential point of use may be impacted by the water-flow indoors, such as water stagnation in residential pipes (Dion-Fortier et al., 2009; Weinberg et al., 2006). Levels of CBPs and other DBPs indoors may change depending on the initial characteristics of water quality and due to temperature increases during household treatment, water heating, etc. (Zhang et al., 2013; Zhang et al., 2015; Ma et al., 2017; Shi et al., 2017). Studies have shown that the heating of water in residential households may impact CBPs, including THM and HAA levels (Allen et al., 2017; Dion-Fortier et al., 2009; Eyring et al., 2008; Liu and Reckhow, 2015a, 2015b; Ma et al., 2017; Shi et al., 2017). In these field-scale studies, the THM levels in HTW (from showers in Allen et al., 2017) were higher than those measured in CTW except in residences with a tankless water-heating system (Liu and Reckhow, 2015a). In the case of HAAs, studies have shown that the impact of residential water heating differs between species (Allen et al., 2017; Dion-Fortier et al., 2009; Liu and Reckhow, 2015a, 2015b). For example, DCAA levels increase due to residential water heating while TCAA levels do not change significantly (Dion-Fortier et al., 2009; Liu and Reckhow, 2015a, 2015b) or decrease (Allen et al., 2017). For THMs, no significant differences in HAA levels were observed between CTW and HTW for tankless water-heating systems (Liu and Reckhow, 2015a). Some of these studies have also shown that the change in CBP levels from residential heating may differ between seasons (Dion-Fortier et al., 2009; Eyring et al., 2008). However, the studies mentioned above that focused on the impact of residential water heating on CBP levels were based on a relatively small number of study cases (one to six residences), except in Eyring et al. (2008) and Liu and Reckhow (2015a). In fact, Eyring et al. (2008) studied 15 to 22 residences, depending on the season. However, these residences were located in three distribution systems supplied by chloraminated drinking water. Changes from residential water heating have only been investigated for total THMs and HAAs (i.e., THM4 and HAA5) and not for the individual species. In Liu and Reckhow (2015a), CTW and HTW from 18 residences located in one chlorinated distribution system were sampled: ten residences with conventional tank heaters and eight residences with other types of heaters (e.g., tankless, gas water heater). The residences were sampled once and only in summer. In the studies mentioned previously, the variability of the impact of heating on regulated CBPs between residences within the same distribution system was not directly investigated. In addition, some of the reported studies on this subject have not investigated the relative contribution of factors that could explain such variability.

During activities such as showering, taking baths and washing dishes, people are exposed to CBPs present in HTW via multiple exposure routes (especially inhalation and dermal contact). However, regulatory compliance for THMs and HAAs is based only on the monitoring of CTW after a flow of several minutes to obtain sample water from the public distribution system (Government of Quebec, 2014; US EPA, 2016). As a result, the impact of residential water heating systems on CBP levels and exposure is not considered in the regulatory monitoring of drinking water.

The objective of this study was to investigate the significance and variability of the impact of residential tap water heating on THMs and HAAs (total and individual species) between residences and seasons. With this aim, CBP levels were measured in CTW and HTW from 50 residences located in two distribution systems during two seasonal sampling campaigns. The factors that may affect the changes in CBP levels from residential water heating were also studied through the development of explanatory multivariate models.

2. Material and methods

2.1. Case study

This investigation was carried out within two drinking water distribution systems located in the greater Québec City area (Province of Quebec, Canada), denoted in this paper as systems L and Q. These systems are supplied by different surface water sources. During the study period, the treatment process applied for system L consisted of screening, pre-chlorination, coagulation, flocculation, sedimentation, filtration and post-chlorination. For system Q, the water treatment included the following: screening, coagulation, flocculation, sedimentation, inter-ozonation, filtration and post-chlorination. Moreover, the two systems differed in their distribution system characteristics (e.g., size, hydraulic regime, pipe characteristics, presence of re-chlorination stations or reservoirs).

The region studied is subject to important climatic variations throughout the year, with average daily ambient air temperatures ranging from −12.8 to +19.3 °C (Government of Canada, 2016), and seasons of very different lengths (long winters and relatively short summers). These temporal fluctuations result in important temporal variations in the quality of raw water.

2.2. Sampling strategy

Two sampling campaigns were carried out in each of the distribution systems; one during summer and the other during winter. For both campaigns, 25 residences were sampled in system L and 29 residences in system Q. Cold tap water (CTW) and hot tap water (HTW) samples were collected at each residence (one time per campaign). The locations of the sampled residences in each system were selected in order to cover each system geographically and were the same during the two sampling campaigns.

For each residence, the water samples were collected from the restroom faucet. The CTW samples were collected after approximately 5 min of flow from the cold water tap, in order to obtain water from the public distribution system and not the stagnant water in the building pipes (meeting the requirements for regulatory sampling in the