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Variability of chlorination by-product occurrence in water of indoor and outdoor swimming pools

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ABSTRACT

Swimming is one of the most popular aquatic activities. Just like natural water, public pool water may contain microbiological and chemical contaminants. The purpose of this study was to study the presence of chemical contaminants in swimming pools, in particular the presence of disinfection by-products (DBPs) such as trihalomethanes (THMs), haloacetic acids (HAAs) and inorganic chloramines (CAMi). Fifty-four outdoor and indoor swimming pools were investigated over a period of one year (monthly or bi-weekly sampling, according to the type of pool) for the occurrence of DBPs. The results showed that DBP levels in swimming pools were greater than DBP levels found in drinking water, especially for HAAs. Measured concentrations of THMs (97.9 vs 63.7 μg/L in average) and HAAs (807.6 vs 412.9 μg/L in average) were higher in outdoor pools, whereas measured concentrations of CAMi (0.1 vs 0.8 mg/L in average) were higher in indoor pools. Moreover, outdoor pools with heated water contained more DBPs than unheated pools. Finally, there was significant variability in tTHM, HAA9 and CAMi levels in pools supplied by the same municipal drinking water network, suggesting that individual pool characteristics (number of swimmers) and management strategies play a major role in DBP formation.

1. Introduction

Swimming is one of the most popular aquatic activities in industrialized countries. During busy periods, the quality of pool water may be compromised. Indeed, swimmers bring microorganisms and organic substances (saliva, sweat, cosmetics, sunscreen and urine) with them into the water, which strongly contributes to water contamination (Sakkas et al., 2003; Kanan and Karenfil, 2011; Keuten et al., 2012). Chlorine is the most common agent used to disinfect pool water. However, using disinfectants in the presence of organic matter (OM) in water may lead to the formation of disinfection by-products (DBPs). More than 600 DBPs have been identified in drinking water (Richarson et al., 2007). Trihalomethanes (THMs) and haloacetic acids (HAAs) are the two main groups of DBPs in drinking water and are monitored in many countries. Total THMs (in this paper denoted tTHM) include four compounds: chloroform, bromodichloromethane (BDCM), dibromochloromethane (DBCM) and bromoform. HAAs comprise the following nine compounds (HAA9): bromochloroacetic acid (BCAA), chlorodibromoacetic acid (CDBAA), bromodichloroacetic acid (BDCAA), tribromoacetic acid

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(TBAA), monochloroacetic acid (MCAA), dichloroacetic acid (DCAA), trichloroacetic acid (TCAA), monobromoacetic acid (MBAA) and dibromoacetic acid (DBAA).

There are no regulations for THMs and HAAs in recreational water in Canada. However, there are guidelines in some countries in the world. According to the study of the Agence Française de Sécurité Sanitaire de l'Environnement et du Travail (AFSSET, 2010), the United Kingdom, Finland and the World Health Organization (WHO) recommend a maximum concentration of 100 μg/L of tTHMs for all types of pools. In Belgium, the maximum value for chloroform (instead of total THMs) is also 100 μg/l. In Germany, the recommended maximum concentration is 20 μg/L for tTHMs for any type of pool, while in Switzerland the recommended level for tTHMs is 30 μg/L for indoor pools only. In Denmark, the maximums levels for tTHMs are 25 or 50 μg/L depending on the type of pool (www.retsinformation.dk/Forms/R0710.aspx?id=142195). With regard to swimming pools in France, the AFFSET (2010) recommends not exceeding a level of 100 μg/L of tTHMs. A guideline was determined by the WHO to control the presence of chloramines in pool water (WHO, 2006). In its guideline, the WHO proposes a concentration below 0.2 mg/L of combined chlorine (the difference between total residual chlorine and free available residual chlorine) corresponding to total chloramines in pool water (indoor) (MDDEP, 2006). Using the WHO guideline as a benchmark, several countries have regulated this group of by-products. Indeed, the standard for chloramines in indoor pools is 0.6 mg/L in France and 1 mg/L in Australia (MDDEP, 2006). In Canada, the standard is 0.1 mg/L in Alberta, whereas in Quebec, it is 0.5 mg/L for indoor pools and 1 mg/L for outdoor pools (MDDEP, 2006; MDDEP, 2012a). In the Province of Quebec (Canada), in addition to chloramines, the Regulation Respecting Water Quality in Swimming Pools and Other Artificial Pools (MDDEP, 2012a) establishes standards for free residual chlorine (between 0.8 and 2 mg/L for indoor pools and between 0.8 and 3 mg/L for outdoor pools), pH, alkalinity, turbidity and microbiological parameters (faecal coliforms, *E. coli*, *Pseudomonas aeruginosa* and *Staphylococcus aureus*). However, no standards for THMs and HAAs exist yet for pool water in Quebec.

Many studies have been conducted on the presence of DBPs in swimming pools. Some studies conducted on swimming pool water have served to document tTHM, especially chloroform. Beech et al. (1980) measured an average concentration of 125 μg/L for tTHM (primarily chloroform) in the water of 101 pools in Miami (United States). Fantuzzi et al. (2001), on the other hand, observed a lower average chloroform concentration (33.2 μg/L) in the water of five indoor pools in Italy. Chloroform was also the subject of studies by Jackson and Rule (2002), who observed average values for this compound between 11.4 μg/L and 236 μg/L in indoor pool water in several regions in Europe. Other studies have focused on chloroform to study its effects on the health of swimmers and target the main routes of exposure by using plasma, blood, urine or alveolar air as exposure biomarkers (Aggazzotti et al., 1990, 1993; Lévesque et al., 1994; Aiking et al., 1994; Aggazzotti et al., 1995; Cammann and Hübner, 1995; Lindstrom et al., 1997; Aggazzotti et al., 1998; Erdinger et al., 2004; Caro and Gallego, 2007, 2008).

Some of these studies have limitations, such as the investigation of a single group of DBPs including THMs (chloroform) or chloramines (Aggazzotti et al., 1990; Aiking et al., 1994; Cammann and Hübner, 1995; Carbonnelle, 2003; Lévesque et al., 2006; Aprea et al., 2010; Schmalz et al., 2011), measurements carried out on pool water on a reduced scale or with samples generated in laboratory-scale simulations (Judd and Jeffrey, 1995; Judd and Black, 2000; Kim et al., 2002; Hansen et al., 2012), the study of a single type of pool, usually indoor (Jackson and Rule, 2002; Lévesque et al., 1994, 2000, 2006; Kanan and Karenfil, 2011), and small numbers of pools studied (Lahl et al., 1981; Fantuzzi et al., 2001; Thacker and Nitnaware, 2003; Cardador and Gallego, 2011). In addition, very little attention has been paid to investigating the seasonal occurrence of DBPs in pool water.

The purpose of this study is to provide a better understanding of the variability of THMs, HAAs and inorganic chloramines (CAMi) in pool water. In particular, the study identifies differences in DBP levels between drinking water and pool water, compares the levels between indoor and outdoor pools and identifies the factors responsible for this variability. The study is based on a large sample of indoor and outdoor pools investigated during a full year.

2. Methodology

2.1. Study cases

The study conducted over a period of one year involved 54 municipal public pools in Québec City (Canada). The pools under investigation included 15 indoor and 39 outdoor pools. These pools are located in eight boroughs of the city. The boroughs are served by five drinking water distribution systems (Québec, Des îlets, Ste-Foy, Val-Bélair and Lac des Érables) all supplied by water chlorinated during the treatment process. The pools under study were selected according to the water disinfection method. In fact, the water of all the pools is disinfected with chlorine (using online chlorine control). In every case, a hypochlorite-based disinfectant is used. Residual chlorine monitoring is carried out periodically by the swimming pool operator. In most cases, in particular in outdoor pools, water renewal is carried out during the night (with filtration) in order to reduce accumulated contaminants.

2.2. Sampling strategy

The pools under study were sampled once a month over one year for indoor pools and every two weeks during the summer (June, July and August) for outdoor pools. All indoor and outdoor pools were sampled during weekdays in the morning or in the afternoon in the presence of swimmers. Sampling consisted of collecting water in the less frequented area of each pool 30 cm under the surface of the water and between the outlet of the filtration system and the backflow. During each visit, two 250 ml water samples per pool were collected in Nalgene bottles and refrigerated at 4 °C in order to carry out the following physical-chemical analyses in the laboratory: UV absorbance at 254 nm, conductivity, turbidity, ammonia, total organic carbon (TOC) and CAMi. For each pool, four water