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Seasonal and spatial variations of source and drinking water quality in small municipal systems of two Canadian regions

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HIGHLIGHTS

- Factors affecting seasonal variations of drinking water quality are similar in small and in large systems.
- In small systems, highest levels of DBPs were observed in summer and in fall.
- Taste and odor indicators are higher in summer and in fall.
- The beginning of the distribution system represents the overall water quality.
- Chlorine demand was a good indicator of residence time and was strongly associated with HPC levels.

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ABSTRACT

A one-year sampling program covering twenty-five small municipal systems was carried out in two Canadian regions to improve our understanding of the variability of water quality in small systems from water source to the end of the distribution system (DS). The database obtained was used to develop a global portrait of physical, chemical and microbiological water quality parameters. More precisely, the temporal and the spatial variability of these parameters were investigated. We observed that the levels of natural organic matter (NOM) were variable during different seasons, with maxima in the fall for both provinces. In the regions under study, the highest trihalomethane (THM) and haloacetic acid (HAA) levels were achieved in warmer seasons (summer, fall), as observed in previous studies involving large systems. Observed THM and HAA levels were three times higher in systems in the province of Newfoundland & Labrador than in the province of Quebec. Taste and odor indicators were detected during the summer and fall, and higher heterotrophic plate count (HPC) levels were associated with lower free chlorine levels. To determine spatial variations, stepwise statistical analysis was used to identify parameters and locations in the DS that act as indicators of drinking water quality. As observed for medium and large systems, free chlorine consumption, THM and HAA levels were dependant on their location in the DS. We also observed that the degradation of HAAs is more important in small systems than in medium or large DS reported in the literature, and this degradation can occur from the beginning of the DS. The results of this research may contribute to providing precious information on drinking water quality to small system operators and pave the way for several opportunities to improve water quality management.

1. Introduction

Drinking water is obtained from ground or surface water sources for which quality is variable according to seasons and geographical location (Giannoulis et al., 2004; Ouyang et al., 2006). Water quality is more variable in surface waters because they are influenced by environmental changes such as precipitation or human activities (Fokmare and Mussadiq, 2001). In order to produce drinking water from surface sources, treatment technologies including filtration and disinfection are usually applied. Typically, large municipalities have enough financial and human resources to ensure safe drinking water (Conestoga-Rovers and Associates, 2010). Small municipalities are often far removed from political and industrial interests, and their populations are more vulnerable to waterborne related illnesses (Hrudey and Hrudey, 2004; NCCPH, 2011). In fact, small municipalities cannot afford complex multi-stepped treatment systems (CWWA, 1998; MDDEFP, 2004). In addition, available information on drinking water quality is limited for these systems. As a result, small systems are more vulnerable to drinking water quality failures.

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Disinfection serves to inactivate microorganisms and maintain stable microbiological quality in the distribution system (DS) (Propato, 2003). In 1974, Rook discovered that the reaction of chlorine with natural organic matter (NOM) can result in the formation of chlorinated disinfection by-products (DBPs) (Rook, 1974; Hua and Reckhow, 2008). These compounds have been under study for several years, and epidemiological and toxicological studies have suggested potential negative effects on human health (Boorman et al., 1999; Nieuwenhuijsen, 2005; Richardson et al., 2007). Consequently, to protect the population from these and other chemical or microbiological contaminants, government has implemented regulations and guidelines concerning drinking water quality (USEPA, 2004; Health Canada, 2010; Gouvernement du Québec, 2012; CCME, 2004).

Despite the efforts of government to provide funding for water-related infrastructures, small systems experience problems complying with regulations and guidelines concerning drinking water quality (Health Canada, 2010). Moreover, drinking water quality can vary seasonally and location-wise within the DS (Al Khatib, 2005; Giannoulis et al., 2004). Given their limited human resources, it is difficult for small systems to control and maintain drinking water quality from source to tap. In addition, there is limited information available about the spatial and the temporal variability of drinking water quality in small systems: basically, they are subject to fewer monitoring exigencies than medium and large systems and their quality control resources are limited (Gouvernement du Québec, 2012).

The objective of this study is to improve our understanding of the variability of water quality in small drinking water systems, from the water source to the extremity of a DS. The study is based on a time-space structured sampling campaign conducted in 25 small municipal systems of two Canadian provinces. According to our knowledge, no structured campaign that includes several water quality parameters has been carried out for small systems in Canada.

2. Materials and methods

2.1. Small systems under study

The 25 municipal systems under study are located in two Canadian provinces, Quebec (QC) and Newfoundland and Labrador (NL). Systems were selected according to their type of water source, population size, type of water treatment, geographical location (for logistical purposes) and the degree of interest in collaborating with our university in this research project. All the systems provide drinking water from surface water facilities (rivers, lakes, ponds) to a population of 500 to 6000 inhabitants. Treatment plants are different from one system to the next, but all the systems in this study use chlorination for primary and secondary disinfection, with one exception (one system with chloramination as secondary disinfection). It is important to note that there is a basic difference between the two provinces regarding treatment (Table 1). While QC municipalities generally apply a physico-chemical treatment to raw water, none of the systems in NL use treatment other than chlorination (directly applied to raw water).

Table 1
Served population, type of source water and applied treatment for each studied system.

System	Province	Population served (Statistics Canada, 2011)	Source	Applied treatment	
				Primary treatment	Secondary treatment
BV	QC	6354	River	X	X
BP	QC	3439	River	X	X
BC	QC	6465	River	X	X
DV	QC	966	River	X	X
DC	QC	6283	River	X	X
LAS	QC	1373	Lake	X	X
LE	QC	4061	Lake	X	X
SA	QC	3458	River	X	X
SC	QC	1500	River	X	X
SF	QC	1596	Lake	X	X
SJ	QC	3304	River	X	X
SP	QC	1223	Lake	X	X
ST	QC	3880	Lake	X	X
SCJC	QC	6319	River	X	X
CV	NL	737	Pond	–	X
GM	NL	1984	Lake	–	X
GB	NL	335	Brook	–	X
GT	NL	2122	Pond	–	X
HB	NL	1031	Pond	–	X
HAS	NL	1681	Brook	–	X
KP	NL	675	Pond	–	X
RA	NL	807	Pond	–	X
SV	NL	317	Pond	–	X
SS	NL	452	River	–	X
TT	NL	998	Pond	–	X

2.2. Sampling program

Samples were collected at each system monthly from September 2010 to October 2011. At each system, sampling points were located at the source (RW), before chlorination (when different from the source — TW), and at three points in the DS. Points in the DS were chosen on the basis of residence time, even if this information was not precisely available in the small systems that were investigated. However, all the systems under study had a linear main line, and sampling points were chosen in order to consider the largest variety of residence times possible. Consequently, three points were selected: at the beginning (R1), in the middle (R2) and at the extremity (R3). The beginning and the extremity of the DS refer to the first and last accessible point of residency or public place where sampling was possible. The middle of the DS was determined by taking a middle point at almost equal distance from the first and the last sampling point. Samples were taken on Monday or Tuesday, in order to ensure analyses within an adequate timeframe. In total, more than 1400 samples were collected to characterize the spatio-temporal variations of the physical, chemical and microbiological quality of source and drinking water. Total organic carbon (TOC), ultraviolet absorbance at 254 nm (UV_{254}) and chlorophyll A were analyzed in order to characterize NOM. Two families of DBPs (trihalomethanes — THMs, and haloacetic acids — HAAs), free residual and total chlorine (free Cl and total Cl) were measured at all three sampling locations in the DS to evaluate their spatial variations. Bromide was also measured at RW as it is a precursor of brominated DBPs. Microbiological quality indicators (fecal coliforms and heterotrophic plate count — HPC) were carried out in raw water and in the middle of the DS to obtain a general overview of water salubrity. Organoleptic parameters (Geosmin, 2-methylisoborneol, 2-isobutyl-3-methoxypyrazine, 2-isopropyl-3-methoxypyrazine, 2,4,6-trichloroanisole) representing taste and odor were also considered. Supplementary information (SI) SI1 presents the parameters considered and the location of their measurement. All sampling points in the DS were located in public institutions or private residences. Samples were taken from cold tap water, at the nearest point possible to the main pipeline. Taps were disinfected for the microbiological samples. Tap water ran for 5 min before each sampling. For the analysis of physical parameters, a 500 ml polypropylene bottle was used. For microbiological analysis, water was sampled in two (one duplicate) 250 ml sterilized polypropylene bottles. Two amber plastic bottles were used for chlorophyll A and bromide sampling in RW. For THMs and HAAs, a dechlorinating agent (166 μl of ammonium chloride at 30 g/l) was added to four glass vials (40 ml) (one vial for THMs and HAAs individually, and two extra replicates) to neutralize the free chlorine residual and to avoid further DBP formation between sampling and analysis (USEPA, 2006). The number of samples was the same for all systems and seasons. Each parameter was analyzed monthly at each given sampling point. Consequently, at the same sampling point the same parameter was analyzed three times per season.