ARSENIC IN CANADIAN DRINKING WATER

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CANADIAN WATER NETWORK
RÉSEAU CANADIEN DE L'EAU

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WHY DID WE DO THE RESEARCH?

The events in North Battleford, Saskatchewan and Walkerton, Ontario have increased awareness of water quality issues in Canada. Knowing what is in our drinking water is important for health and environmental reasons. Canadians need pertinent water quality information that is easily accessible, of high quality, and available in a timely manner.

Tap water undergoes a wide range of tests to ensure that it is safe to consume. However, three in ten Canadians use groundwater as their main source of drinking water. This is the case for 23% of Albertans and the entire population of Prince Edward Island. Water from private wells does not undergo the routine testing that municipal tap water undergoes.

Chemical elements can be present in different chemical forms with varying toxicities. The total concentration of an element in a water sample provides neither a complete picture of the toxicity level nor the potential impact on human health. Speciation involves the determination of the chemical form in which the element of interest is present, with the oxidation state and the form of the chemical as the main factors used by scientists for speciation. A water sample could contain high levels of a non-toxic species and therefore not present a health risk. Alternatively, high levels of an extremely toxic species could be present, causing harmful effects after a single exposure. Knowing the species to which exposure is occurring permits proper risk assessment for both human health and the environment as well as the ability to determine suitable water treatment processes.

Excess arsenic is known to cause several types of cancer, such as bladder, liver, kidney and lung. Chronic exposure to high concentrations of arsenic is known to cause skin lesions, hyperpigmentation and hyperkeratosis on the hands and feet. Over 50 different species of arsenic exist, either naturally or as metabolites. Their toxicities are dramatically different (Table 1). Arsenobetaine is the arsenic species more prevalent in seafood and is essentially non-toxic. Arsenite (+3 oxidation state)and arsenate (+5 oxidation state) are highly toxic inorganic forms of arsenic and are found in groundwater. Arsenic species with a +5 oxidation are less toxic than their equivalent form with a +3 oxidation state.

The Canadian guideline for arsenic in drinking water is 10 µg/L, which is in line with the World Health Organization and the US Environmental Protection Agency. These guidelines are only for total arsenic. They do not take into account the different toxicities of arsenic species.

NAME OF ARSENIC COMPOUND	TOXICITY IN MICE (LD50, mg/kg)	TOXICITY TO HUMAN (1T1) UROTHELIAL CELLS (LC50, µM)
Dimethylarsinous acid	N.D.	0.8
Monomethylarsonous acid	N.D.	1.0
Arsenite	11.2	4.8
Arsenate	112	31.3
Dimethylarsinic acid	1200	500
Monomethylarsonic acid	1800	1700
Arsenobetaine	>10 000	N.D.

N.D. not determined

Since a significant number of people still obtain their drinking water from groundwater, the effectiveness of home water treatment systems in removing contaminants and pathogens from the water must be determined.

WHAT DID WE DO?

To determine what information was available on arsenic in drinking water in Canada, we searched government websites and major scientific databases. A map of arsenic "hot spots" in Canada was generated with this information, as shown in Figure 1. A hot spot is an area with an arsenic concentration in the water greater than 10 µg/L. The location of hot spots could help predict arsenic concentrations in untested areas.

Water from domestic wells in the Beaver River Basin, Alberta, was collected to test the ability of treatment systems to remove arsenic from well water. Samples were collected before and after using the home treatment device. The treatments ranged from distillers, softeners, filters (carbon or iron) or reverse osmosis, to a combination of different methods, to no treatment at all. Speciation and total analysis were performed on the samples to determine the identity of arsenic species and total concentration present.

In distillers, the water is boiled and then the water vapour condenses in liquid form. Water softeners remove certain ions, such as calcium, and replace them with other ions, such as sodium. Carbon filters trap the toxic compounds through adsorption to produce cleaner water. Iron filters use an ion exchange mechanism to remove contaminant ions. This mechanism causes arsenic ion to bind with iron hydroxides. Reverse osmosis operates by pushing water through a semipermeable membrane. Water passes through the membrane while contaminant ions and molecules are removed.

The chemical species present in the samples were identified using high performance liquid chromatography (HPLC) which separates the sample into individual components. The total concentration of an element was determined using inductively coupled plasma mass spectrometry (ICP-MS) which breaks down a sample into elements and measures the concentration of each element. In combination, HPLC-ICP-MS can be used to identify the species present and determine the concentration of the individual species.

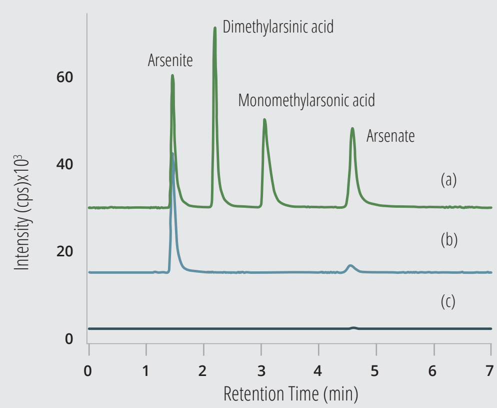

Figure 1. Typical chromatograms from the HPLC-ICP-MS analyses of arsenic in (a) a standard solution, (b) a well water sample before any treatment, and (c) a well water sample after reverse osmosis treatment.

For example, Figure1a shows how HPLC-ICP-MS can separate, identify, and quantify different arsenic species in a standard solution (laboratory prepared). Additionally, in Figure 1b and 1c, the difference in arsenic levels in well water samples before and after water treatment can be clearly seen using this measurement technique. This method was used to determine the concentration of arsenic species in well water before and after applying a home water treatment device.

WHAT DID WE FIND?

Information on arsenic in drinking water was available online, mainly on government websites. A large variation exists in the quality and accessibility of the data between jurisdictions as several areas have easily accessible and complete information while others have incomplete data that is not readily available. Using the collected data, a map of arsenic hotspots was developed for Canada (Figure 2). Not all provinces and territories have documented hot spots; however each province and territory likely has areas with high arsenic concentrations. The hotspots are generally due to natural, non-anthropogenic sources. Water supplies for most municipalities are under the 10 µg/L limit.

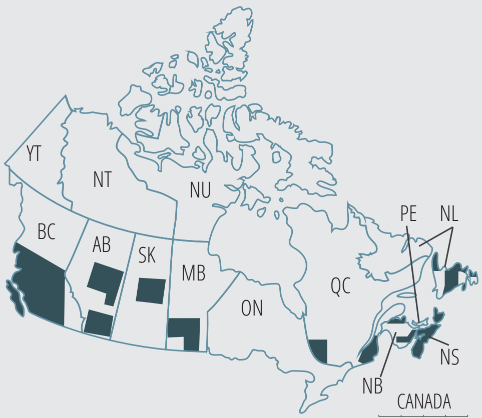

Figure 2. Map of provinces and territories of Canada, with known arsenic hotspots (shaded areas). Please note that the shaded areas are approximations only; not all water sources within a shaded area will contain high arsenic concentrations. AB, Alberta; BC, British Columbia; MB, Manitoba; NB, New Brunswick; NL, Newfoundland and Labrador; NS, Nova Scotia; ON, Ontario; PE, Prince Edward Island; QC, Quebec; SK, Saskatchewan; NT, Northwest Territories; NU, Nunavut; YT, Yukon. Map adapted from The Atlas of Canada http://atlas.gc.ca (adapted from McGuigan et al. 2010).

The concentration and species of arsenic in the well water samples before and after treatment were compared (Figure 3). Home treatment systems such as distillers, carbon filters, and softeners had no effect on the overall arsenic concentration in the water (Figure 3a). These treatments were not effective in removing any species of arsenic.

Iron filters were not consistent in removing arsenic species from the well water. The concentration of arsenate decreased after treatment while the concentration of arsenite, the more toxic of the two species, did not (Figure 3b). This is because under normal pH conditions, arsenate is a negatively charged ion and can therefore be removed by the ion exchange mechanism used in iron filters. On the other hand, arsenite is a neutral species that is unaffected by the ion exchange mechanism and is not removed by iron filters.

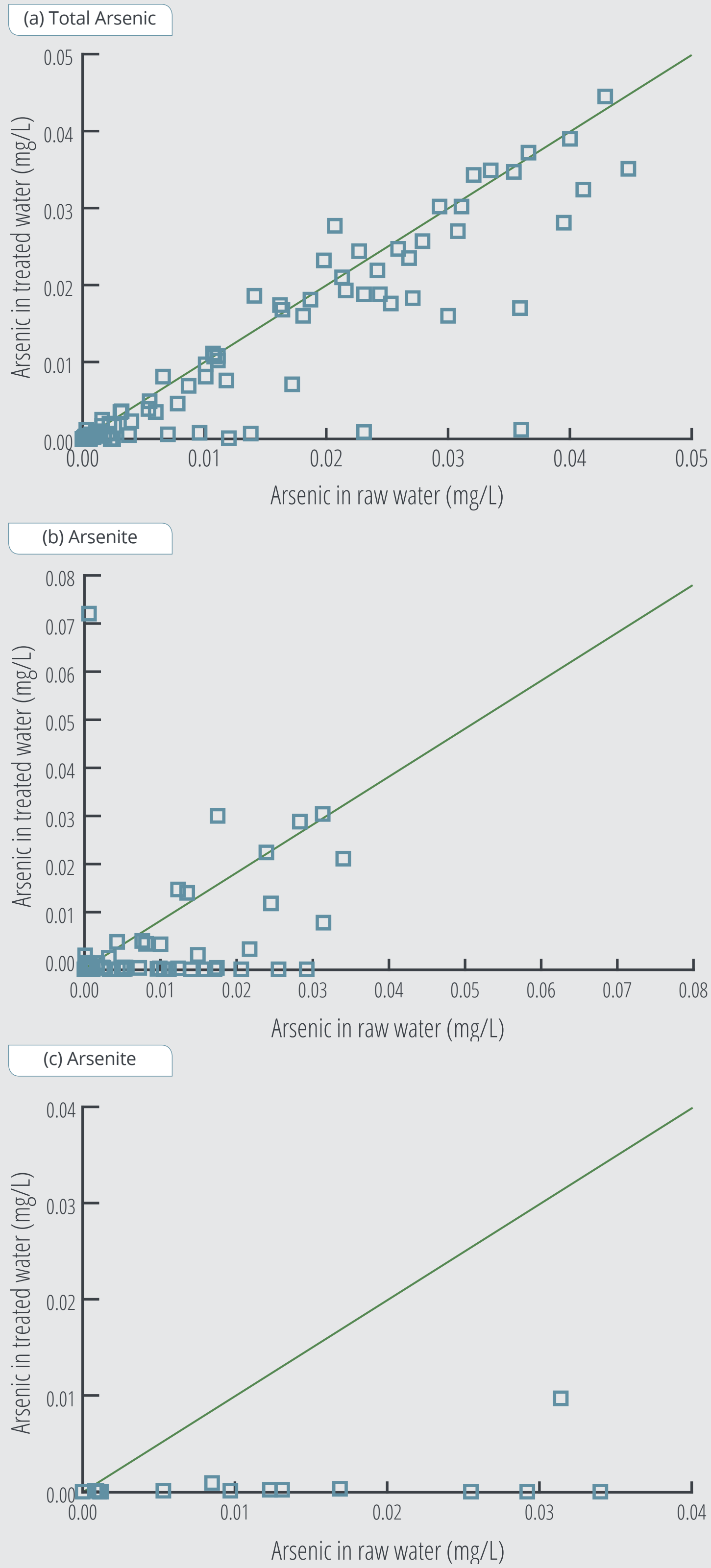

Figure 3. Comparison of arsenic concentrations in well water samples in raw water and water treated by a home treatment device. (a) Total arsenic for home treatment systems excluding reverse osmosis and iron filter treatments. (b) Arsenite concentrations in water treated with an iron filter system. No other treatment was used. (c) Arsenite concentrations in water treated with a reverse osmosis system. No other treatment was used. The data points close to or on the green line indicate that the treatment had no effect on the concentration of arsenic in the water.

The most effective home treatment device was found to be reverse osmosis. Before treatment, 9 out of 15 wells had total arsenic concentrations above the WHO guideline. After treatment, only one home still had a total arsenic concentration above the guideline. Therefore, reverse osmosis was very effective at reducing total arsenic levels in well water samples. Most importantly, the reverse osmosis treatment successfully reduced the concentration of the toxic species arsenite in the well water samples (Figure 3c).

The type of water treatment device used to reduce arsenic in drinking water is very important. One method may reduce the overall concentration of arsenic in the water, but have no effect on the more toxic species present. It is important to know the effectiveness of each technique individually. A better combination of devices can be chosen to minimize risk and potential exposure to toxic species. Knowing what species are in the water creates the opportunity to pick the best available treatment.

WHAT DO THESE FINDINGS MEAN FOR MUNICIPALITIES?

There is no standardized way to determine areas with a high arsenic concentration in the drinking water. The arsenic hot spot map of Canada provides some information about areas of potential concern; however, there is still a knowledge gap for certain provinces and territories regarding their arsenic hot spots. Improving the availability of the information on drinking water should be a priority for governments at all levels. The authority responsible for providing the information to the public varies, depending on the province or territory, from the individual water supplier to the health region to the provincial ministry of the environment.

The sampling methods, sampling dates, and test methods used for water testing are not always provided. An arsenic concentration that was reported as "undetectable" in a previous decade may actually have a detectable concentration if tested using more current methods. Including such important information in the reports available to the public would allow for an understanding of the implications of the results and a better comparison of the data. Creating a standard way of reporting the data, having the information in one centralized system, preferably online for greater ease of access, would improve the dissemination of drinking water information.

When testing is performed to determine the identity of arsenic species present in drinking water, whether it be a private well or a municipal water source, then proper measures can be taken in order to reduce harm. The appropriate treatment system can be chosen and proper implementation can occur when the effectiveness of the different treatments systems available to both home owners and municipalities is known. For example, iron filters would be appropriate if the high arsenic concentration is due to arsenate, but would be a poor choice in the presence of high arsenite concentrations. In those cases, reverse osmosis would then be the best option.

Since speciation directly affects the toxicity of a compound, knowing the species to which people are being exposed is important when assessing the potential risks. By performing speciation testing, one can determine if people are being exposed to the less harmful species or a more harmful species.

The effect of low levels of arsenic on human health is not well understood. Therefore, the available science cannot tell us with certainty what level of arsenic in drinking water is acceptable. Water utilities and regulatory agencies should be prepared for continued research and new findings which will help to inform the refinement of new regulatory standards.

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