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Arsenic in Well Water Supplies in Saskatchewan

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Arsenic is the twentieth most abundant element found in the earth's crust and is usually present in the form of various sulphides and oxides. It is found in numerous ores and minerals. Arsenic may also be found in trace levels in virtually all living matter. Industrial uses of arsenic compounds include the manufacturing of transistors and semi-conductors, wood preservatives, pesticides, and veterinary drugs.

Arsenic is introduced into water supplies from the leaching of minerals and soil. Bedrock containing arsenic is an important source of this element in groundwater. Wells in Oregon (Stoner et al. 1977) and Nevada (Warner et al. 1994) have been reported to contain arsenic levels over 1000 µg/L. Drilled wells in Finland were found to have arsenic concentrations up to 980 µg/L (Kurttio et al. 1998). Arsenic levels up to 4781 µg/L have been reported in well water samples collected in Alaska (Kreiss et al. 1983). Drinking water samples collected from private wells in Nova Scotia were found to contain up to 740 µg/L (Meranger et al. 1984). Of the 94 samples analyzed, 67 were found to have arsenic levels in excess of 25 µg/L.

The use of arsenical pesticides may also contribute to the level found in surface waters and shallow wells, however the use of such compounds has been restricted in recent years. Atmospheric deposition contributes to the content of surface waters and shallow groundwater. The principal sources of atmospheric arsenic are the burning of fossil fuels, in particular coal, as well as smelters and waste incinerators.

The major concern associated with arsenic in drinking water arises from the fact that the majority of it is present in inorganic forms, either arsenate [As(V)] or arsenite [As(III)]. Inorganic forms of arsenic are much more highly toxic to humans than organic forms. Byrd (1996) recently reviewed the risks of cancer in humans that are associated with exposure to inorganic forms of arsenic.

Arsenic has been classified by the International Agency for Research in Cancer (IARC) as a Group I carcinogen; that is to say it is a documented human

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carcinogen. Much of the information gathered linking arsenic to cancer has been obtained through studies of human exposure via drinking water. Internal cancers that have been linked to the consumption of drinking water containing elevated levels of arsenic include cancers of the bladder, liver, lung and kidneys (Chen et al. 1985 and 1992; Smith et al. 1992). Increased bladder and lung cancer mortality rates have been linked to the presence of elevated levels of arsenic in drinking water in part of Chile (Smith et al. 1998). Similarly, increased bladder cancer mortalities have been attributed to arsenic in drinking water in Argentina (Hopenhayn-Rich et al. 1996). Other symptoms of chronic arsenic poisoning include skin cancer, dermal lesions, peripheral vascular disease (e.g., blackfoot disease) and peripheral neuropathy (Health Canada, 1992). High levels of certain elements, including arsenic, in drinking water supplies have been associated with an increased frequency of spontaneous abortion in women (Achengrau et al. 1989). Exposure to arsenic from drinking water has also been identified as a risk factor for diabetes mellitus (Rahman et al. 1998).

In a rare case of fatal arsenic poisoning involving the consumption of contaminated water, two members of a family of nine died as a result of drinking groundwater containing 108 ppm of arsenic (Armstrong et al. 1984). It was believed that arsenic had leached from soil contaminated with pesticide through cracks in the casing of the farm's well. Arsenic poisoning from the mishandling of chemical waste materials resulted in the contamination of drinking water supplies near a factory in Calcutta that manufactured copper acetoarsenate (Mazumder et al. 1992).

While other toxic effects have been observed in populations ingesting water with elevated arsenic concentrations, drinking water quality guidelines for arsenic are established primarily based on calculated risk assessments for cancer. The United States Environmental Protection Agency (EPA) and the World Health Organization (WHO) have recommended a drinking water quality guideline of 50 µg/L. Health Canada has recommended an interim maximum acceptable concentration (IMAC) of 25 µg/L for arsenic. The IMAC is subject to period review as dictated by additional data on health risks associated with the consumption of water containing elevated levels of arsenic.

MATERIALS AND METHODS

In order to carry out the survey of arsenic levels in private and rural municipality wells throughout Saskatchewan, public health inspectors were contacted and asked to collect well water samples from several sites within their respective health districts. The laboratory provided 0.5-L plastic bottles and a survey questionnaire requesting information regarding the location of the well, its depth, height of water, etc.

All water samples were preserved with 2.5 mL of concentrated nitric acid (Ultrex II, ultrapure reagent grade, J.T. Baker, Phillipsburg, NJ). Reduction of arsenate to arsenite was accomplished by mixing 50 mL of sample with 50 mL of concentrated hydrochloric acid and 5 mL of a 20% (w/v) solution of potassium iodide. The analysis of arsenic was performed using hydride generation atomic absorption spectrometry (HGAAS). The fully automated HGAAS system (Varian Australia Pty Ltd, Mulgrave, Victoria, Australia) consisted of a model SpectrAA-100 spectrometer equipped with SPS-5 autosampler, VGA-76 vapour generator assembly, and an ETC-60 electrothermal heating chamber with a quartz flowcell. The current for the arsenic hollow cathode lamp was set to 10mA and an absorbance wavelength of 193.7 nm was utilized for all measurements. All sample solutions were automatically mixed with 12M hydrochloric acid and a solution containing 0.6% (w/v) sodium borohydride and 0.5% (w/v) sodium hydroxide to yield arsenic hydride (arsine). Ultrahigh purity argon gas (Praxair Products Inc., Mississauga, ON) was used as the flowcell carrier gas. All standards were prepared by serial dilution of a stock AA standard consisting of 1000 mg/L of arsenic (Caledon Laboratories Ltd., Georgetown, ON).

RESULTS AND DISCUSSION

Sixty-one groundwater samples, including 25 privately owned wells and 36 wells operated by rural municipalities, were sampled for arsenic testing. Virtually all of the rural municipal wells were not subject to any form of chemical or physical water treatment other than periodic chlorination. Conversely, approximately half of the private wells utilized some form of water treatment. The most commonly used forms of water treatment included water softening with an ion exchange device, filtration, and iron removal. In order to determine potential exposure to arsenic, all samples collected were taken after any treatment devices and were representative of the water typically being consumed by humans.

The results of the arsenic analyses are summarized in Table 1. Arsenic was not detected in 25 samples (10 private wells and 15 rural municipal wells) based on a method detection limit of 1 µg/L. Health Canada has established an interim maximum acceptable concentration for arsenic in drinking water at a level of 25 µg/L. Four of the 25 private well water supplies exceeded this guideline while only 1 of the 36 rural municipal supplies was above 25 µg/L.

Communities that produce over 5000 gallons of treated water per day are required under regulation by Saskatchewan Environment and Resource Management to have their supplies tested for various trace metals including arsenic. Of 121 communities tested between 1981 and 1985, approximately 88% had arsenic levels less than 10 µg/L and 42% had levels less than 2 µg/L (Health Canada 1992). The highest arsenic concentration detected was 34 µg/L. In this study, 77% (or 47 of 61) of the rural wells were found to have arsenic levels less than 10 µg/L with a maximum reported concentration of 117 µg/L.

In the early 1990’s, the United States Environmental Protection Agency (USEPA) reported that there were approximately 70,000 groundwater sources that supplied

Table 1. Distribution of arsenic concentrations in groundwater supplies.

Arsenic Concentration (µg/L)	No. of Private Wells	No. of Rural Municipal Wells
< 1	10	15
1 – 5	6	13
6 – 10	0	3
11 – 15	2	2
16 – 20	1	1
21 – 25	2	1
26 – 50	2	1
51 – 100	1	0
> 100	1	0

community and nontransient-noncommunity water systems (e.g., schools and office buildings) which in turn served over 76 million people in the U.S.A. (Reid 1994). Arsenic concentrations were estimated to be greater than 1 µg/L in 31% of supplies and greater than 20 µg/L in only about 1%. Approximately 36% of the samples tested in this study had arsenic concentrations greater than 1 µg/L while 13% had levels greater than 20 µg/L. It must be noted that the higher frequency of elevated arsenic levels in groundwater relative to the USEPA estimates may be the result of the relatively small number of samples that were analyzed. It does, however, indicate the need for expanded monitoring of private and rural municipal drinking water supplies that are derived from groundwater sources.

It was noted that the most significant levels of arsenic were typically found in groundwater samples collected within relatively near proximity to one another. In other words, there appeared to be at least one "hot spot" within the province, presumably where similar geological characteristics may result in elevated arsenic levels in the groundwater. The approximate location of wells containing greater than 10 µg/L are summarized in Table 2.

Table 2. Approximate location of wells with arsenic levels >10 µg/L.

Approximate Geographic Boundary	Arsenic Concentrations (µg/L)
53.0-54.0 °N; 103.5-104.5 °W	15, 15, 20, 24, 25, 26, 29, 60, 117
52.5-53.5 °N; 108.5-109.5 °W	16, 34
51.0-51.5 °N; 105.5-106.0 °W	21
50.0-50.5 °N; 105.3-105.8 °W	11
49.4-49.9 °N; 105.5-106.0 °W	12

Municipal drinking water treatment plants in Saskatchewan are required under government regulations to regularly monitor the levels of various constituents including arsenic in the finished product. Water supplies that are owned and utilized privately (e.g., rural families and cottage owners), small non-municipal public supplies and municipal wells that are not connected to a distribution (e.g. rural municipal wells) are not subject to such regulations. There are no requirements for owners of private water supplies to regularly test the water quality, although health agencies promote the need for regular testing. Since the cost of having the water quality tested is borne by the user, these supplies are generally tested for only a limited number of parameters on an infrequent basis. In the case of rural municipal wells and small non-municipal public supplies the sampling type and frequency is determined by the public health inspector. It is estimated that there are over 66,000 private wells in the province of Saskatchewan. Given that there are also numerous rural municipal wells with little or no water treatment, a significant portion of the one million residents in the province rely upon groundwater as a source of drinking. Unfortunately little data is available regarding the concentration of arsenic found in these wells.

This survey of arsenic levels in drinking water supplies derived from ground water was not intended to be an exhaustive study, but rather it was to be used as a general indicator of the potential significance of arsenic contamination. While the data set is not large enough to draw statistical conclusions regarding the extent of arsenic contamination in the estimated 66,000 wells in the province of Saskatchewan, it does however lead to two general conclusions. Firstly, it is not likely that elevated levels of arsenic in ground water pose a major concern for the majority of individuals relying upon such supplies for drinking water. Secondly, there is a need for expanded testing, particularly in areas where relatively elevated levels of arsenic were detected. Data should be collected in order to identify “hot spots” where ground water contains elevated arsenic concentrations. This is important for the protection of public health through the implementation of water treatment or use of alternative water supplies. In addition, this data could also be utilized for epidemiological and risk assessment studies based upon historical health data. Rural municipal supplies that are not connected to a distribution system and private wells often do not employ any form of treatment that would reduce the level of naturally occurring arsenic. Further testing is required to obtain more detailed information regarding the levels of arsenic in groundwater in Saskatchewan and the number of individuals whose health is potentially at risk from the consumption of water with elevated concentrations.

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REFERENCES

Armstrong CW, Stroube RB, Rubio T, Siudyla EA, Miller GB Jr. (1984) Outbreak of fatal arsenic poisoning caused by contaminated drinking water. Arch Environ Health 39:276-279

Aschengrau A, Zierler S, Cohen A (1989) Quality of community drinking water and the occurrence of spontaneous abortion. Arch Environ Health 44:283-290

Byrd DM, Roegner ML, Griffiths JC, Lamm SH, Grumski KS, Wilson R, Lai S (1996) Carcinogenic risks of inorganic arsenic in perspective. Int Arch Occup Environ Health 68:484-494

Chen CJ, Chuang YC, Lin TM, Wu HY (1985) Malignant neoplasms among residents of a blackfoot disease-endemic area in Taiwan: high-arsenic artesian well water and cancers. Cancer Res 45:5895-5899

Chen CJ, Chen CW, Wu MM, Kuo TL (1992) Cancer potential in liver, lung, bladder and kidney due to ingested inorganic arsenic in drinking water. Br J Cancer 66:888-892

Health Canada (1992) Guidelines for Canadian drinking water quality - supporting documentation for arsenic. Ottawa, ON (http://www.hc-sc.gc.ca/main/hc/web/ehp/ehd/catalogue/bch_pubs/dwgsup_doc/arsenic.pdf)

Hopenhayn-Rich C, Biggs ML, Fuchs A, Bergoglio R, Tello EE, Nicolli H, Smith AH (1996) Bladder cancer mortality associated with arsenic in drinking water in Argentina. Epidemiology 7:117-124

Kreiss K, Zack MM, Landrigan PJ, Feldman RG, Niles CA, Chirico-Post J, Sax DS, Boyd MH, Cox DH (1983) Neurologic evaluation of a population exposed to arsenic in Alaskan well water. Arch Environ Health 38: 116-l21

Kurttio P, Komulainen H, Hakala E, Kahelin H, Pekkanen J (1998) Urinary excretion of arsenic species after exposure to arsenic present in drinking water. Arch Environ Contam Toxicol 34:297-305

Mazumder DN, Das Gupta J, Chakraborty AK, Chatterjee A, Das D, Chakraborti D (1992) Environmental pollution and chronic arsenicosis in south Calcutta. Bull World Health Organ 70:48 l-485

Meranger JC, Subramanian KS, McCurdy RF (1984) Arsenic in Nova Scotian groundwater. Sci Total Environ 39:49-55

Rahman M, Tondel M, Ahmad SA, Axelson O (1998) Diabetes mellitus associated with arsenic exposure in Bangladesh. Am J Epidemiol 148:198-203

Reid J (1994) Arsenic occurrence: USEPA seeks clearer picture. J Amer Water Works Assoc 86:44-51

Smith AH, Hopenhayn-Rich C, Bates MN, Goeden HM, Hertz-Picciotto I, Duggan HM, Wood R, Kosnett MJ, Smith MT (1992) Cancer risks from arsenic in drinking water. Environ Health Perspect 97:259-267

Smith AH, Goycolea M, Haque R, Biggs ML (1998) Marked increase in bladder and lung cancer mortality in a region of Northern Chile due to arsenic in drinking water. Am J Epidemiol 147:660-669

Stoner JC, Whanger PD, Weswig PH (1977) Arsenic levels in Oregon waters. Environ Health Perspect 19: 139- 143

Warner ML, Moore LE, Smith MT, Kalman DA, Fanning E, Smith AH (1994) Increased micronuclei in exfoliated bladder cells of individuals who chronically ingest arsenic-contaminated water in Nevada. Cancer Epidemiol Biomarkers Prev 3:583-590