ARSENIC IN CANADA

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ABSTRACT
In Canada, arsenic is listed in Group 1 of the Priority Substances by the Canadian Environmental Protection Act (CEPA). Both release from natural enrichments and anthropogenic activities attribute to the elevated arsenic levels reported in several regions. Most arsenic is of inorganic form. It is critical to recognize that such contaminations impose serious adverse effects on various aquatic and terrestrial organisms and human health. Serious incidences of chronic arsenic poisonings have occurred. This paper provides a summary of the currently available information on recognized problem areas. However, much still remains unclear. More extensive studies are necessary to build practical guidance on avoiding and reducing arsenic contamination.

RÉSUMÉ
Au Canada, l'arsenic est énuméré dans la Groupe 1 des substances d'intérêt prioritaire par la *Loi canadienne sur la protection de l'environnement (LCPE).* Les lessivages à partir des enrichissements naturels et les activités anthropogéniques rendent les niveaux d'arsenic élevés qu'ont été détectés dans plusieurs régions, dont la majeure partie se trouve sous forme inorganique. Il est critique pour identifier que ces contaminations imposent des effets nocifs sérieusement chez divers organismes aquatiques et terrestres et santé humaine. Des incidences sérieuses des intoxications chroniques d'arsenic ont été indiquées. Cet article fournit un sommaire d'information disponible actuellement sur des régions où problèmes qui ont été trouvés. Cependant, beaucoup reste toujours peu clair. Des études plus étendues sont nécessaires pour établir des conseils pratiques sur éviter et réduire les contaminations arsenicales.

1. INTRODUCTION

Arsenic ranks as the 20th most abundance element in the earth's crust and is widely distributed throughout the rocks and soils, natural waters. It is present in trace amounts in all-living matters. Naturally, arsenic exists essentially in four oxidation states (-III, 0, +III, and +V). The forms of arsenic present are dependent on the characteristics of ambient environment (e.g., pH, Eh) and microbial activity (Yong and Mulligan, 2004). Arsenic metal rarely occurs and the minus III oxidation state is found only in extremely reduced environments. Arsenate (+V) and arsenite (+III) are the primary forms. Under flooded conditions, arsenite is dominant, and aerobic conditions favor the oxidation of As (III) to As(V). Inorganic species can be converted to organoarsenic compounds by microorganisms through biomethylation under favorable conditions. Arsenic speciation has gained significance since it plays a vital role in determining the mobility and toxicity of arsenic in the environment. Generally, inorganic forms are more toxic and mobile than organoarsenic species (Xu et al., 1988; Lamble and Hill, 1996).

Recently there has been increasing attention concerning this notorious element due to the serious health risks associated with exposure to elevated levels. Environmental impacts have incurred from both anthropogenic and naturally occurring enrichments. Most arsenic compounds are odorless and tasteless and readily dissolve in water, which creates a high risk. It is established that ingesting food or water containing only 60 mg/L of inorganic arsenic can be fatal, while lower levels can damage nerves (WHO, 1993). Many cases of acute and chronic arsenic poisoning, including dermal lesions, peripheral neuropathy, skin cancer, peripheral vascular disease and other internal cancers, have now been documented in various parts of the world (Gray et al., 1989; WHO, 1993; Senesse et al., 1999; Saha, 2003). It is also demonstrated that arsenic can cause toxic effects to plants or may accumulate in plants and thereby enter the animal and human food chain. An average toxicity threshold of 40 mg/kg was established for crop plants (Sheppard, 1992).

In Canada, arsenic is produced mainly as arsenic trioxide through the roasting of arsenious gold ores. Canadian arsenic production from 1885 to 1990 is illustrated in Figure 1. Arsenic is used mainly in metallurgical applications and in the manufacture of wood preservatives. Release from naturally weathering and erosion processes of arsenic-bearing rocks and soils, doubled with anthropogenic activities such as historic and recent gold- and base-metal processing, the use of arsenical pesticides, thermal and power generation, and the disposal of domestic and industrial waste materials, attributes to the elevated arsenic concentrations in the Canadian environment. Levels of arsenic have been reported in air up to 6.5 μg/m^3, surface water and groundwater up to 1,570,000 μg/L, and soils and sediments up to 25,000 mg/kg, near sources in several regions such as Cobalt, Ontario, Quebec, New Brunswick, and Halifax, Nova Scotia, Northwest Territories (ENVIRDOQ, 1997; Coumans, 2003; Newhook et al., 2003). These elevated levels can cause severe adverse effects on the environment and human health.

The purpose of this paper is to give a critical overview of the situation of arsenic contamination in Canada. Through examining available literature, screening and selecting existing data, site-specific problems are discussed. It is demonstrated that arsenic contamination in Canada is quite serious. Further efforts are necessary to obtain profound insights into this particular problem, and to clean past contamination and to avoid further ones.

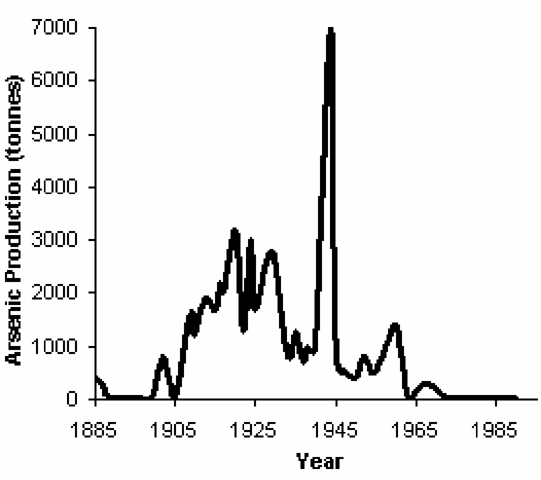

Figure 1. Canadian Arsenic Production, 1885-1990 (modified from Cranstone, 2001)

2. ARSENIC SOURCES

The ubiquity of arsenic in the environment originates from natural enrichments and is intensified by anthropogenic activities. The most common sources of arsenic in the natural environment are volcanic rocks, specifically their weathering products and ash, marine sedimentary rocks, hydrothermal ore deposits and associated geothermal waters, and fossil fuels, including coals and petroleum (Korte and Fernando, 1991; Smedley and Kinniburgh, 2002). The main anthropogenic activities that may impose arsenic in the environment include nonferrous metal mining and smelting, fossil fuels processing and combustion, and applications of arsenical pesticides and pigments, and disposal and incineration of municipal and industrial wastes (Popovic et al., 2001; Prosun et al., 2002). The anthropogenic influence on the level of arsenic depends on the intensity of human activity, the distance from the pollution sources, and the pollutant dispersion pattern. Most anthropogenic releases of arsenic are to land or soil, primarily in the form of pesticides or solid wastes. However, substantial amounts are also released to air and water. Soluble forms of arsenic are known to leach into groundwater and may enter surface waters from runoff.

Arsenic occurs naturally in a wide range of minerals in soils in forms of inorganic compounds. The most common arsenic-containing minerals are arsenopyrite or mispickel (FeAsS), realgar (AsS), and orpiment (As_2S_3). These minerals are usually associated with sulfide ores or other metal ores and work as a major starting point for introduction of arsenic into the environment. The average arsenic concentrations in the earth's crust and shales are 2-5 mg/kg (USDHHS, 2000) and 13 mg/kg (Iimura, 1981), respectively. The global average concentration of arsenic in uncontaminated soil is 5-6 mg/kg (Peterson et al., 1981). However, it varies among geographic regions. Amounts of arsenic in natural uncontaminated soils up to 11 mg/kg were reported in Canada (MacLean and Langille, 1981). The arsenic levels in soil derived from arsenic-enriched sedimentary rocks may attain a value of 20-30 mg/kg (Zou, 1986). Bennett and Dudas (2003) reported an acid sulfate soil that contained up to 37.9 mg/kg arsenic in northwestern Alberta. Extremely high arsenic concentrations of 4600 mg/kg were detected in the A_2 horizon of soils near mineralized veins in British Columbia (Warren et al., 1964).

Arsenic is known to be concentrated in coals. Arsenic is released during coal processing and combustion. Arsenic exceeding 6000 mg/kg (ash basis) was reported in separate lithotypes of Kimberly coals in Westphalian A Joggins Formation, Cumberland Basin, Nova Scotia (Hower et al., 2000). Goodarzi and Huggins (2001) investigated the concentration of arsenic in milled coal, bottom ash and fly ash from a coal fire-power plant in western Canada. The average arsenic concentrations were 1.6, 1.6, and 17.5 mg/kg, respectively. Arsenic occurs in forms of both arsenite and arsenate in the milled coal, while virtually all (>90%) of the bottom ash and fly ash appears to be arsenate.

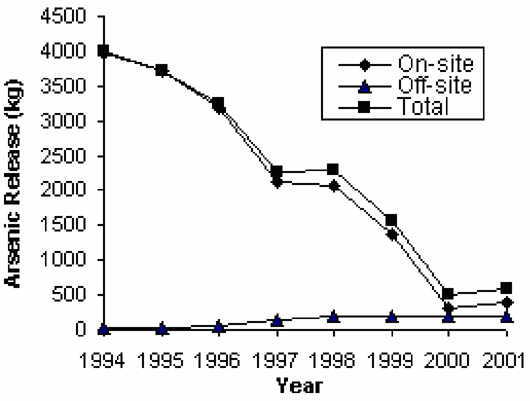

Figure 2. Arsenic Release from NPRI Reporting Facilities, 1994-2001 (Data Sources: NPRI online database)

Base-metal and gold-production facilities as well as thermal and power generating stations are the principal anthropogenic sources of arsenic in Canada. It was estimated that Canadian base-metal smelters and refineries released arsenic about 15 tonnes/year in liquid effluent, 310 tonnes/year into the atmosphere, and 770 tonnes/year as solid waste (MacLatchy, 1992). The on-site, off-site and total releases of arsenic from 1994 to 2001 based on the Environment Canada's National Pollutant Release Inventory (NPRI) are illustrated in Figure 2. The decrease in 2000 is largely due to the closure of a large gold mine in 2000 (Environment Canada, 2002). However, the total release in 2002 was dramatically increased to 501.2 tonnes (310 tonnes on-site, 191.2 tonnes off-site). Most of the release (> 90%) was from power or thermal generating stations and smelter and metallurgical facilities. It was reported that the annual total fluvial input of arsenic to the Moira Lake in Ontario was approximately 3.5 tonnes (Azcue and Nriagu 1995). Couman (2003) estimated that about 220 million tonnes of highly poisonous arsenic trioxide was buried underground and threatens ground and surface water for kilometers around the Giant Mine in Yellowknife, NWT. Elevated arsenic concentrations have been detected near the vicinity of these sources. Near a copper-zinc smelter in Manitoba, Zoltai (1988) reported arsenic concentrations in surface peats were up to 280 mg/kg, compared to a reported average background concentration of 4 mg/kg.

Another important anthropogenic source of arsenic is the extensive application of arsenical pesticides in agriculture and wood preservation. For the period 1984 to 1988, annual Canadian sales of arsenic (as arsenic pentoxide, As_2O_5) for use in wood preservation oscillated between about 650 and 1,300 tonnes (CEPA, 1993). Especially, chromated copper arsenate (CCA), a wood preservative containing (w/w) 47.5% CrO_3, 18.5% CuO, and 34% As_2O_5 (Cooper, 1994), is the overwhelmingly dominant preservative used in Canada. Stephens et al. (1994) estimated 59 million kg CCA were used in 1992, and the used amount of ammoniacal copper arsenate (ACA) is 88,000 kg. The sale volume of CCA/ ACA/ACZA (ammoniacal copper zinc arsenate) treated wood products was 2,078,694 m^3 in 1992, but in 1999 the amount jumped to 3,117,328 m^3 with an increase of about 50% (Stephens et al., 2001). CCA concentrations in treated wood range from 7,800 to 78,000 mg/kg (Fields, 2001). The widespread arsenic contamination around the wood preservation sites is due to raw material handling, spills, deposition of sludge and dripping from freshly impregnated wood or due to leaching from the piles of impregnated wood at these sites by rain water especially under low pH conditions (Lund and Fobian, 1991). Zagury et al. (2003) reported high arsenic concentrations of 410 ± 150 mg/kg on the ground and immediately adjacent to CCA/polyethylene glycol (PEG)-treated utility poles in Montreal, Quebec.

Besides anthropogenic inputs, arsenic in waters has been attributed to several naturally geochemical processes, including oxidation of arsenic-bearing sulfides, desorption of arsenic from (hydro)oxides, reductive dissolution of arsenic-bearing (hydro)oxides, release of arsenic from geothermal waters, and evaporative concentration, as well as leaching of arsenic from sulfides by carbonate (Kim et al., 2000; Bennett and Dudas, 2003). It is a complex function of the site geology characteristics, pH, redox potential, climate changes and human activities as well. Brooks et al. (1982) reported high background arsenic levels of 37 μg/L in the water of Mitchell Brook near Halifax, Nova Scotia.

3. ARSENIC DISTRIBUTION

3.1 Arsenic in Air

Arsenic in air is present mainly in inorganic particulate forms with a minor portion of methylated arsenic. Human impacts are largely health-related and generally associated with inhalation of particulate matter of < 10 μm in diameter. Respirable particles (< 2.5 μm in diameter) can reach the lung alveoli (Brewer and Belzer, 2001).There is no national quality guideline for arsenic in air. Ontario developed a standard of 0.3 μg/m^3 over 24-hours for total arsenic based on general toxicity.

Levels of arsenic in inhalable particulates (<10 μm in diameter) in ambient air in 11 Canadian cities and one rural site monitored from 1985 to 1990 ranged from < 0.0005 to 0.017 μg/m^3 (24-hour average), and the mean level in most cities was 0.001 μg/m^3 (Environment Canada, 1990). In northwest Edmonton, from September 2001 to March 2002, the maximum 24-hour concentration of arsenic in total suspended particulate (TSP) varied from 0.0021 to 0.0048 μg/m^3, and the median concentration was 0.0006-0.0015 μg/m^3 (Alberta Environment, 2003). Brewer and Belzer (2001) measured the mean arsenic concentration in atmospheric particulates of 0.023 μg/m^3 at Burnaby Lake, British Columbia, with a range from 0.0012 to 0.28 μg/m^3. In Windsor, Ontario, the levels of arsenic were observed to be rather constant at about 0.001-0.002 μg/m^3. The maximum 24-hour values ranged from 0.003 to 0.016 μg/m^3 (IAQAB, 2004). Most of this arsenic is probably inorganic.

Newhook et al. (2003) investigated the arsenic release from copper smelters and refineries and zinc plants in Canada. Annual average concentration of arsenic in ambient air nearby oscillated between 0.007 and 0.589 μg/m^3, while the several-years-averaged background concentration is 0.00062 ± 0.00028 μg/m^3. The annual average for total arsenic in air was 0.002 μg/m^3 in Yellowknife in 2001, but the highest 24-hour level reached 0.033 μg/m^3 (RWED, 2003). Due to copper smelting, 24-hour maximum concentrations up to 1.0 and 6.5 μg/m^3 were measured in Murdochville and Rouyn-Noranda, Quebec, while the background concentrations were 0.001 and 0.002 μg/m^3, respectively (ENVIRDOQ, 1997). Atmospheric arsenic near such industrial sources is typically As_2O_3 in particulate form.

Some air-borne arsenic particles can condense onto dust particles which can be either inhaled or ingested. The total arsenic concentrations in housedust of Ottawa residences varied from 1.7 to 79.5 mg/kg with an average of 7.3 mg/kg, while the average total arsenic concentration in street dust adjacent was 1.3 mg/kg with a maximum value of 2.9 mg/kg (Rasmussen et al., 2001).

Arsenic is removed from the atmosphere either by dry deposition or by rainfall, with the rate of deposition typically being highest in the immediate vicinity sources (CEPA, 1993). Walsh et al. (1979) estimated that the average residence time of arsenic in the atmosphere was about 9 days. However, depending on the meteorological situations and size distribution, these particles may be easily transported large distances and may stay in the air in a prolonged manner.

3.2 Arsenic in Waters

The ambient concentration of arsenic in surface and ground waters in Canada usually ranges from 1 to 2 μg/L (BCMWLAP, 2002). The levels of arsenic in drinking water are generally less than 5 μg/L (Health Canada, 2003). Concentrations in groundwater are often higher than those measured in surface waters. Some creeks that are recharged by groundwater with high levels of arsenic may also have high levels. At the town of Virden in Manitoba, arsenic levels range from 65 to 70 µg/L in its untreated source water, which originates as groundwater fed from an aquifer (OSMONICS, 2002). Inorganic arsenic species were measured in the porewaters collected from eighteen piezometers installed in a thick till and clay-rich aquitard sequence located in southern Saskatchewan. The aqueous concentrations of arsenate, arsenite and total arsenic are in the range of 0.31-97, 0.71-21 and 3.2-98 µg/L, respectively (Yan et al., 2000).

Temperature shows significant effects on arsenic concentrations in waters. Geothermal fluid arsenic concentrations are usually two or three orders of magnitude greater than those in uncontaminated surface and ground waters (Webster and Nordstrom, 2003). Levels of arsenic in water from Meager Creek hot springs, British Columbia, were found to be naturally elevated (Koch et al., 1999). The average concentration in the hot springs water was 280 µg/L, ranging from 237 to 303 µg/L. It was two orders of magnitude higher than that in the cold Meager Creek water (5.4 µg/L), reflecting the action of hot water on arsenic-containing minerals. Moreover, Azcue and Nriagu (1995) found that the dissolved arsenic concentrations in the water of Moira Lake in Ontario showed seasonal differences, with an average concentration of 62 µg/L in summer and 22 µg/L in winter.

Elevated arsenic concentrations have been reported in waters near the vicinity of gold-mining or ore-roasting operations and wood preservative facilities as well. Contaminated from historic gold mine operations, both Moira River and Moira Lake, Ontario, contained elevated levels of arsenic in the surface water up to 75 µg/L in and 50 µg/L, respectively. 98% of them were present as arsenate. High concentrations of arsenic (> 300 µg/L), mainly present as arsenite, were detected in the sediment porewaters (Zheng et al., 2003). The arsenic content of the suspended particulates from Gegogan Lake, Nova Scotia near an abandoned gold mine, ranged from 1,500 to 5,000 mg/kg, and the arsenic content in filtered stream water varied from 30 to 230 µg/L (Wong et al., 1999). Coumans (2003) estimated that the surface water in the Kam Lake, Yellowknife, contained up to 1,570,000 µg/L of arsenic. The dominant species was found to be arsenate ions (Ollson, 1999). Donahue and Hendry (2003) reported that dissolved arsenic concentrations in 5 monitoring wells installed within the tailings body from the Rabbit Lake in-pit tailings management facility (RLITMF) in northern Saskatchewan ranged from 9,600 to 71,000 µg/L. High arsenic concentrations up to 11,000 µg/L were reported in the groundwater in the vicinity of an abandoned arsenical wood preservative facility near Vancouver, British Columbia (Henning and Konasewich, 1984).

3.3 Arsenic in Soils and Sediments

Soils and sediments are ultimately derived from the weathering and erosion of rocks. They consist of inorganic and organic particles of various sizes, undergo various dynamic reactions, and serve as an important medium for the accumulation, transformation, and migration of toxicants. Arsenic in soils and sediments are usually found in association with mineral oxyanions such as sulfates, phosphates and carbonates. By virtue of their ubiquitous nature in subsurface, these phases may serve as significant repositories of arsenic even when bulk arsenic concentrations are at trace levels. Arsenic-enriched soils and sediments are often proposed to be the primary starting sources of arsenic in waters.

Across Canada, arsenic can be found naturally in soil at concentrations ranging from 4.8 to 13.6 mg/kg, and average urban and agricultural soil concentrations are mostly between 4 and 6 mg/kg (CCME, 1999/2002; CED, 2003). Dudas and Pawluk (1980) reported an average of 5 mg/kg arsenic in soils from Alberta, while high concentrations ranging from 8 to 40 mg/kg were found in acid sulfate soils (Dudas, 1987; Bennett and Dudas, 2003). Total arsenic concentrations in garden soil of Ottawa residences varied from 1.7 to 9.9 mg/kg, with an average of 3.0 mg/kg (Rasmussen et al., 2001).The background arsenic concentration of soil in Yellowknife was determined to be 4-150 mg/kg (ESG, 2000). In 2002, the Canadian Council of Ministers of the Environment (CCME) collected 58 sand samples from playgrounds of 7 cities. The arsenic contents varied from 0.5 to 147.0 mg/kg. 60% of the playgrounds tested had arsenic levels above the federal soil guideline (25 mg/kg) for the protection of human health. The use of wood preservative, chromated copper arsenate (CCA) was proposed as a main source for the contamination (CED, 2003).

It was reported that the arsenic concentration in soil near a steel plant and coke ovens in Sydney, Nova Scotia, varied from 2 mg/kg to 157 mg/kg (Lambert and Lane, 2004). Ollson (1999) found that soils from the Con Mine property had a median concentration of 118 mg/kg while soil samples collected in the city of Yellowknife had a median arsenic concentration of 31 mg/kg. EBA (1998) reported that arsenic was present soils in the Giant Mine Townsite (Yellowknife) at a concentration between 754 and 9,580 mg/kg. At the same place, arsenic levels of 1,174 ± 519 mg/kg was found in samples of crushed rocks, and much lower levels of 87 ± 97 mg/kg were found in samples which were organic or clay in nature, well within the background concentrations of arsenic (36 ± 38 mg/kg) (ESG, 2000).

The natural sediment concentration range of arsenic is between 6 and 100 mg/kg, with a median of 68 mg/kg (Ollson, 1999). Azcue et al. (1994) detected that the surficial sediments of Moira Lake, Ontario, contained averagely 545 mg/kg of arsenic, and values close to 1,000 mg/kg at depths of 23-27cm below the sediment-water interface. The elevated arsenic concentrations in bottom sediments represent a continuous internal mining of arsenic towards the interface all year around. The sediment porewater is the link agent. The estimated annual upward diffusion flux was 0.8-3.8 µg/cm^2-year. Elevated values of arsenic up to 3,000 mg/kg were also associated with the mineralization at the Eagle–Telbel deposit (Legault et al., 2002). Bamwoya et al. (1991) measured 262 mg arsenic/kg in sediment downstream from an arsenical wood preservation facility near Elmsdale, Nova Scotia.

Mining tailings usually contain high residues of arsenic and are of concern as potential sources of environmental contaminations. Mulligan and Wang (2004) measured the arsenic contents of six mining tailing samples. ICP-MS analysis indicated that the highest arsenic concentrations reached to 2,200 mg/kg (Table 1). The detectable limit is 0.70 mg/kg.

Table 1. Arsenic Concentration in Mining Tailings

Type of Tailings	Location	Concentration (mg/kg)
Copper Mine	Murdochville, QC	500
Gold Mine	Musselwhite, ON	63
Copper-zinc Mine	Val d'Or, QC	270
Iron Mine	Mont-Wright, QC	<0.70
Lead-zinc Mine	Bathurst, NB	2200
Gold Mine	Marathon, ON	270

In Yellowknife, both historical and recently deposited tailings were found to contain high levels of arsenic, up to 25,000 mg/kg in Con Mine tailings, 4,800 mg/kg in Giant Mine tailings, and 12,500 mg/kg in the historical Negus tailings. Sediments from two popular recreational lakes, Rat Lake and Kam Lake, were found to contain arsenic up to 820 mg/kg and up to 1,570 mg/kg, respectively (Ollson, 1999). In northern Saskatchewan, total arsenic concentrations in the mine tailings and their associated pore fluids from the Rabbit Lake in-pit tailings management facility (RLITMF) ranged from 56 to 9,871 mg/kg and 0.24 to 140 µg/L, respectively (Moldovan et al., 2003). In the case of Jack of Clubs Lake (JCL), British Columbia, arsenic was transported from abandoned gold mine tailings to the lake, where it accumulated in bottom sediments in concentrations up to 1,104 mg/kg (Azcue et al., 1995).

3.4 Arsenic in Biota

Background arsenic concentrations in freshwater and terrestrial biota are usually less than 1 mg/kg (fresh weight) (Stoeppler and Nurnberg, 1979). But they can be much higher near anthropogenic sources or in areas with geothermal activity. Gamberg and Braune (1999) reported that arsenic residues in the kidney of male Yukon wolves were 0.51 (< 18 months) and 0.21 mg/kg dry wt (19-36 months). Values were slighter higher for females, 0.57 and 0.25 mg/kg, respectively. Arsenic residues in the liver of male wolves were 0.31 (< 18 months) and 0.21 mg/kg dry wt (19-36 months), whereas the values were 0.17 and 0.14 mg/kg for female wolves.

In the coastal area of British Columbia, an average arsenic concentration of 140 ± 12 µg/100g was found in the ooligan grease, a marine food fat rich with vitamin A and omega-3 fatty acids (Kuhnlein et al., 1996). Ebsuda et al. (2002) examined the total arsenic concentration in ringed seals from Pangnirtung. Arsenic concentrations ranged from 0.11 ± 0.04 mg/kg dry wt in the hair to 1.14 ± 0.37 mg/kg wet wt in the blubber. Arsenobetaine (>70%) was the predominant arsenic compound. Notable high accumulation of arsenic in the blubber was measured, accounting for about 90% of the total arsenic.

In Meager Creek hot springs, British Columbia, the highest levels of arsenic were found in microbial mats, algae and moss, ranging from 56 to 350 mg/kg dry wt. Plants contained arsenic in concentrations ranging from 0.96 to 14 mg/kg dry wt, which appeared to be elevated with respect to commonly observed concentrations in plants, ranging from 0.2 to 2.0 mg/kg dry wt. Low levels of arsenic were observed in lichens and fungi (<0.07 to 4.8 mg/kg dry wt). The oyster tissue (NIST 1566) concentration (14.0 ± 0.5 mg/kg, cf. 14.0 ± 0.2 mg/kg) and the fucus (IAEA-140/TM) concentration (41.4 ± 1.2 mg/kg, cf. 44.3 ± 2.1 mg/kg) were within the certified ranges at a 95% confidence level. The arsenic speciation in vascular plants was mostly inorganic arsenic in an amount of at least 13–67% of the total arsenic and significant amounts of arsenite were present in almost all plant samples (Koch et al., 1999).

Koch et al. (2000a) analyzed the arsenic levels in a variety of plants from Yellowknife. The arsenic levels varied between 3.6 and 1,220 mg/kg dry wt and mosses contained the highest levels of arsenic (490-1,220 mg/kg dry wt). The predominant arsenic species were in inorganic forms. Arsenic concentrations in terrestrial lichens and fungi from Yellowknife ranged from 6.4 to 2,300 mg/kg dry wt (Koch et al., 2000b). In Moria River and Moria Lake in Ontario, arsenic concentrations in plant samples ranged from 2.6 to 117 mg/kg dry wt. Accumulation of arsenic was observed in submerged plants, and most of this arsenic (70-93%) was inorganic arsenic (Zheng et al., 2003). These may give some indications of the hyperaccumulation technology for arsenic removal.

4. SUMMARY AND RECOMMENDATIONS

This investigation indicates that arsenic contamination in Canada is quite serious and cannot be neglected. In addition to the release from natural enrichments, human activities such as mining and metal smelting, and wood preservation as well as thermal and power generating, attribute to the elevated contamination levels. Most of the arsenic is present in highly toxic inorganic forms, which may cause severe adverse effects on the environment and human health, especially for people living in the vicinity near point sources.

Knowledge of the occurrence and speciation, origin and distribution of arsenic is necessary for reducing and avoiding arsenic related problems. Especially, speciation of arsenic is gaining increasing importance as the bioavailability and the physiological and toxicological effects of arsenic are connected to its oxidation state. However, in most cases the analysis is restricted to the determination of total arsenic. It is insufficient for environmental considerations. The quantitative determination of individual species rather than the total arsenic determination is therefore mandatory to obtain an appropriate measurement for accurate assessments of environmental impact and health risks.

Previous investigations of a number of contaminated sites have led to a better understanding of this problem. However, researches were focused only on seriously contaminated sites. Uncertainties still remain and much is unknown beyond these areas. National-scale investigation is preferred for gaining a full-scene picture of it, and for identifying areas of low-arsenic groundwater for future use. It is critical to assess arsenic exposure in people, especially in populations living near point sources and in rural areas. It may be helpful to increase in the public awareness of the toxicity and the environmental impact of arsenic contamination.

Furthermore, the implementation of new guidelines and regulations should be considered in order to protect the public health. For example, the Interim Maximum Concentration Level (IMCL) for drinking water (25 µg/L) should be reduced to the WHO standard of 10 µg/L or even lower to 5 µg/L as soon as possible. National quality guidelines for arsenic in air should be built since elevated levels have been detected. Sources reduction is of principle significance for preventing future contamination. The mining and smelting industries should be encouraged to develop new technologies for reducing arsenic release to reach the arsenic discharge limits set by the government.

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