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Occurrence of arsenic contamination in Canada: Sources, behavior and distribution

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Abstract

Recently there has been increasing anxieties concerning arsenic related problems. Occurrence of arsenic contamination has been reported worldwide. In Canada, the main natural arsenic sources are weathering and erosion of arsenic-containing rocks and soil, while tailings from historic and recent gold mine operations and wood preservative facilities are the principal anthropogenic sources. Across Canada, the 24-h average concentration of arsenic in the atmosphere is generally less than 0.3 $\mu g/m^3$. Arsenic concentrations in natural uncontaminated soil and sediments range from 4 to 150 mg/kg. In uncontaminated surface and ground waters, the arsenic concentration ranges from 0.001 to 0.005 mg/L. As a result of anthropogenic inputs, elevated arsenic levels, above ten to thousand times the Interim Maximum Acceptable Concentration (IMAC), have been reported in air, soil and sediment, surface water and groundwater, and biota in several regions. Most arsenic is of toxic inorganic forms. It is critical to recognize that such contamination imposes serious harmful effects on various aquatic and terrestrial organisms and human health ultimately. Serious incidences of acute and chronic arsenic poisonings have been revealed. Through examination of the available literature, screening and selecting existing data, this paper provides an analysis of the currently available information on recognized problem areas, and an overview of current knowledge of the principal hydrogeochemical processes of arsenic transportation and transformation. However, a more detailed understanding of local sources of arsenic and mechanisms of arsenic release is required. More extensive studies will be required for building practical guidance on avoiding and reducing arsenic contamination. Bioremediation and hyperaccumulation are emerging innovative technologies for the remediation of arsenic contaminated sites. Natural attenuation may be utilized as a potential in situ remedial option. Further investigations are needed to evaluate its applicability.

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Keywords: Arsenic; Speciation; Biota; Canada; Mining; Soil; Sediments; Water

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1. Introduction

Arsenic is of increasing concern due to its high toxicity and widespread occurrence in the environment. It is widely distributed throughout the rocks and soils, and natural waters and is present in trace amounts in all-living matter. Elevated levels of arsenic have resulted from both natural and anthropogenic occurrence. Most arsenic compounds are odorless and tasteless and readily dissolve in water, which creates an elevated health risk. Ingesting food or water containing more than 0.01 mg/L of inorganic arsenic is harmful to the body, while an inorganic arsenic content exceeding 60 mg/L can be fatal

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(WHO, 1993). Many cases of acute and chronic arsenic poisoning have been reported in various part of the world (Gray et al., 1989; WHO, 1993; Senesse et al., 1999; Saha, 2003). Symptoms of acute poisoning usually occur within 30 min of ingestion and may result in gastrointestinal discomfort, vomiting, coma, and sometimes even death, while chronic poisoning is much more insidious in nature, resulting in anemia, leucopenia, skin cancer, and other internal cancers (WHO, 1993; Gorby, 1994). It is also demonstrated that arsenic can cause toxic effects for plants or may accumulate in plants and thereby enter the animal and human food chain. An average toxicity threshold of 40 mg inorganic arsenic/kg soil was established for rice plants (Sheppard, 1992). Higher arsenic concentrations will introduce inhibitory effects for crop yields.

Arsenic exists essentially in four oxidation states (−III, 0, +III, and +V), as both inorganic and organometallic species. The forms of arsenic present are dependent on the type and amounts of sorbents, pH, redox potential (Eh), and microbial activity (Yong and Mulligan, 2004). Arsenic metal rarely occurs and the (−III) oxidation state is found only in extremely reduced environment. Arsenate ions [As(V)] are most prevalent in oxic conditions whereas arsenite ions [As(III)] are found in anaerobic conditions. Methylated arsenic species, such as monomethylarsonous acid [MMA(III)], monomethylarsonic acid [MMA(V)], dimethylarsinous acid [DMA(III)], dimethylarsinic [DMA(V)], trimethylarsine [TMA(III)], and trimethylarsenic oxide (TMAO), can be formed through biomethylation by microorganisms under favorable conditions (Challenger, 1945; Braman, 1975; Cullen and Reimer, 1989). The toxicity and mobility of arsenic species differ with their chemical forms and oxidation states (NRC, 1999; Thomas et al., 2001). Generally, inorganic forms are more toxic and mobile than organoarsenic species, while arsenite is considered to be more toxic and mobile than arsenate (Gulens et al., 1979; Squibb and Fowler, 1983; Xu et al., 1988; Lamble and Hill, 1996). Gulens et al. (1979) reported that As(III) is 5 to 8 times more mobile than As(V) in a non-adsorbing sandy loam. Squibb and Fowler (1983) found that As(III) was 10 times more toxic than As(V) and 70 times more toxic than MMA(V) and DMA(V). However, the trivalent methylated arsenic species [i.e., MMA(III) and DMA(III)] have been found to be more toxic than inorganic arsenic because they are more efficient at causing DNA breakdown (Styblo et al., 2000; Dopp et al., 2004). The potency of the DNA damage decreases in the order DMA(III)>MMA(III)>[As(III), As(V)]>MMA(V)>DMA(V)>TMAO(V) (Dopp et al., 2004).

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 Fig. 1. Arsenic is used mainly in metallurgical applications and in the manufacture of wood preservatives. Release from natural 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

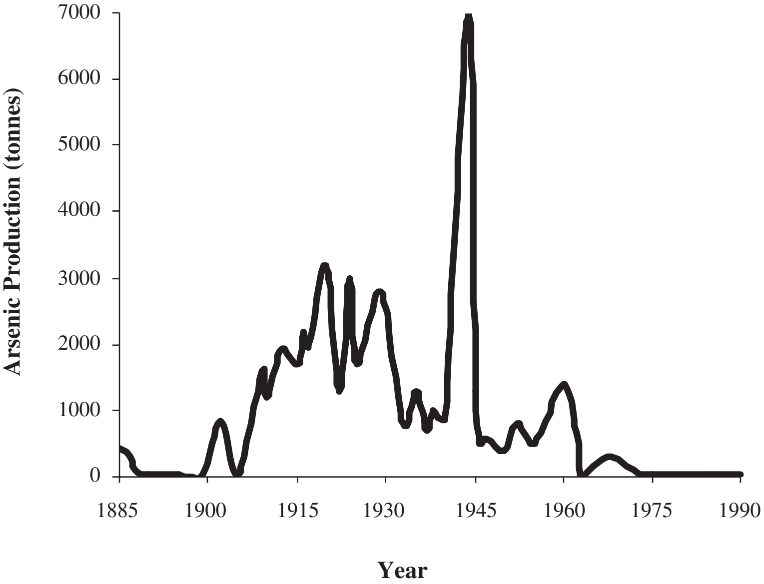

Fig. 1. Canadian arsenic production, 1885–1990 (modified from Cranstone, 2001).

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