ARSENIC GROUNDWATER CONTAMINATION

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Summary

In Bangladesh high arsenic contamination in groundwater is currently believed to exist in around 47 out of 64 districts. Around 4 million tube-wells in Bangladesh supply drinking water to the people and around 1.1 million of them are contaminated with arsenic. About 75 million people in arsenic contaminated districts are at risk. More than

one million people in West Bengal, India are also drinking arsenic contaminated well waters, and tens of millions more may be at risk in areas not yet tested for arsenic contamination.

It is now believed that the high arsenic levels in the groundwater in both Bangladesh and West Bengal have a natural geological source. Nationwide survey needs to be continued to clarify the extent of natural arsenic occurrence. Arsenic removal techniques are now well known, but their adaptation to the case of Bangladesh and West Bengal needs further investigation.

Supply of surface waters with appropriate treatment and rainwater harvest with hygienic methods may be as effective as other relief measures, depending on the local conditions. Point of use arsenic removal devices for individual house water supply may be effective as one of the emergency measures, but people need training in basic skills and management techniques.

1. Introduction

Arsenic occurs naturally; it is the 20th most abundant element in the Earth's crust, and is a component of more than 245 minerals. Humans are exposed to arsenic primarily from air, food, or water. Arsenic is also a well-known poison if ingested in large amount. This acute effect has not been observed with drinking water supplies, but, nevertheless, ingestion of drinking water is an important source of arsenic exposure. Total arsenic concentration is generally higher in groundwater than in surface water.

Groundwater contamination by arsenic may be a consequence of mining operations, industrial discharges, or mobilization of naturally occurring arsenic in the aquifers. There is a very serious problem of groundwater arsenic contamination in the West Bengal region of India and the southern and western part of Bangladesh. This chapter describes the scale of the problem, sources of arsenic contamination, chemical characteristics of arsenic, human health effects of ingested arsenic, technologies for arsenic mitigation, and ongoing arsenic mitigation activities in Bangladesh.

2. Scale of the problem

High arsenic contamination has been reported in water supply wells in certain area of Taiwan (up to around 1.8 mg L^{-1}), Hungary (exceeding 0.1 mg L^{-1}), Mexico (exceeding 0.4 mg L^{-1}), India (excluding West Bengal) (0.05 mg L^{-1} to 1.9 mg L^{-1}), Bangladesh (maximum concentration detected:14 mg L^{-1}). Of these areas, a devastating health crisis is unfolding in West Bengal in India and southern and western Bangladesh. Groundwater is the main source of drinking water in Bangladesh and India. Estimates from the World Health Organization (WHO) shows that the number of people in West Bengal, India, drinking water containing more than 0.05 mg L^{-1} is as high as ten million.

Bangladesh is a country with a total population of 120 million and a total area of 148 393 square km. Based on relevant information, such as 1.12 million out of a total of 4.0 million tube wells are contaminated with arsenic, it has been estimated that the total population in Bangladesh exposed to more than 0.01 mg L^{-1} (WHO guideline value) and

0.05 mg L^{-1} (Bangladesh guideline value) are around 51 million and 25 million, respectively. According to the analysis of 22 003 hand tube-well water samples from 64 districts in Bangladesh, arsenic in groundwater is above 0.01 mg L^{-1} in 54 districts, and above 0.05 mg L^{-1} in 47 districts.

So far, 32 districts had been surveyed for arsenic patients, and in 30 districts, patients with arsenical skin lesions have been identified. Altogether 17 896 people had been examined at random from the affected villages for patients having arsenic skin lesions and to date 3688 (20.6%) have been identified with skin lesions. Consequently, it appears that the arsenic calamity in Bangladesh may be extremely serious, as shown comparatively in Table.1

Location	**Number of people exposed**	**People showing arsenic skin lesions**
Chile	130,000	About 16%
Argentina	10,000	Many
Mexico	200,000	21%
Taiwan	About 103,000	19%
West Bengal, India	1,000,000	20%
Bangladesh	6,000,000	About 20%

Table 1. Arsenic contamination in the world

3. Chemical characteristics, species, and toxicity of arsenic

3.1. Chemical characteristics and species of arsenic

Arsenic is a nonmetal group in the periodic chart, but as the physical appearance of arsenic resembles that of metal, it is referred to as a metalloid to distinguish it from a true nonmetal. As shown in Table 2, arsenic exists in different valence state (oxidation states) such as “0”(arsenic), “−III”(arsine), “+V”(arsenate), and “+III” (arsenite). In this article roman numerals such as “III”, and “V”, are used to represent oxidation states. Valence state (or the oxidation state) indicates the capacity of the atom to combine with other atoms and is used to denote the form of arsenic.

Properties	**Arsenic**	**Sodium Arsenite**	**Arsenic Trioxide**	**Sodium Arsenate**
Chemical formula	As	$NaAsO_2$	As_2O_3	Na_2HAsO_4
Molecular weight	75	130	198	186
Valence state	0	+III	+III	+V
Water solubility	Insoluble	Very soluble	Slightly soluble	Soluble

Table 2. Properties of selected inorganic arsenic compounds

The oxidation state represents a hypothetical charge that an atom would have if the arsenic or molecule were to dissociate. In water, arsenic is generally found in the arsenate (pentavalent arsenic) form, but some arsenite (trivalent arsenic) is usually also present. In aerated water, arsenite tends to be oxidized to arsenate, especially at high pH. Organic compounds containing arsenic also exist in the natural environment, but they usually constitute a small percentage of the total arsenic present.

Organic arsenic compounds; monomethylarsonic acid, dimethylarsinic acid, and trimethylarsine oxide are considered of little significance compared with inorganic species in drinking water. Observed toxicity is known to be primarily associated with inorganic arsenic. In reducing waters such as groundwater, arsenic is found primarily in the trivalent form. It has been shown that trivalent arsenic is difficult to remove from water using conventional treatment processes.

It is usually necessary to change the arsenic to the pentavalent form by adding an oxidant such as chlorine. Pentavalent arsenic is normally found in surface water as arsenic acid. A large proportion of the arsenic in some of the groundwater is removed by filtration through a 0.45 μm pore size membrane filter. This result indicates that particulate arsenic accounts for a large fraction of the total arsenic in some of the groundwater.

3.2. Toxicity of arsenic

3.2.1 Metabolism in humans

Arsenate is better absorbed than arsenite because arsenate is less reactive with membranes of the human gastrointestinal tract. Once absorbed, arsenic is transported by the blood to different organs of the human body, mainly in the form of methylarsonic acid. Metabolism of arsenic in the body involves two process. After entering a human cell, arsenate (pentavalent arsenic) is reduced to arsenite (trivalent arsenic). Arsenite is then methylated to form methylarsonic acid and dimethylarsinic acid. Arsenate and arsenite have different mechanisms of action. Arsenite has a high affinity for thiol ($^{-}$SH) groups in proteins, causing inactivation of a variety of enzymes.

Because organic arsenic such as methylarsonic acid or dimethylarsinic acid does not bind strongly to molecules in the human body, the relative toxicity of organic arsenic forms is less than that of inorganic arsenic forms. Inorganic arsenate (pentavalent arsenic) is one tenth as toxic as inorganic arsenite (trivalent arsenic), and organic arsenic is less toxic than inorganic arsenate.

3.2.2 Acute high dose exposure

Health effects of arsenic may be categorized as follows: Acute toxicity (high arsenic exposure for a short time period causing health effects other than cancer), chronic toxicity (relatively low arsenic exposure for a long period of time causing health effects other than cancer), and cancer effects (the risk of contracting cancer at differing lifetime exposure levels). Acute high dose exposure can result in a variety of adverse health effects.

The severity of the effect depends on the level of arsenic exposure. It has been estimated that an acute lethal dose of ingested inorganic arsenic in human is 1 to 4 mg As kg^{-1} for an adult. Short-term exposure to doses higher than 0.5 mg As kg^{-1} day^{-1} can have serious adverse effects on gastrointestinal, hemal and neural systems, and may lead to death. When over 12 000 infants were poisoned with dried milk contaminated with inorganic arsenic (15-24 mg As kg^{-1}), it was estimated that the infants had ingested 1.3 to 3.6 mg of arsenic daily, and 130 deaths were reported. When 220 patients were poisoned by soy sauce contaminated with inorganic arsenic at a concentration of 100 mg L^{-1}, estimated arsenic ingestion per person was 3 mg per day for two to three weeks. This corresponds to dose about 0.05 mg As kg^{-1} day^{-1} in a 60 kg adult. The main findings were anorexia, and upper respiratory symptoms followed by skin lesions.

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Biographical Sketches

Tasuku Kamei is Associate Professor of Engineering at Hokkaido University, where he has been in his present post since 1984. He received degree of Bachelor of Agriculture in Forest Resource Science in 1967 and Master of Agriculture in 1969. In 1970, he started his vocational career at Faculty of Engineering, Hokkaido University where he took a research instructor post in the Department of Sanitary Engineering. In the meantime, he also obtained a Ph.D. in Engineering from Hokkaido University in 1984 on Design of Taxonomy for the Evaluation of Water and Wastewater Process. From 1981 to 1982, he executed a study at University of North Carolina as a research associate. Again he was invited overseas to Thailand from 1995 to 1997. He worked for the Asian Institute of Technology (AIT) in Bangkok as Associate Professor. His two-year dedication in AIT resulted in an Excellent-in-Teaching Award from the Institute. Since 1997, he has been installed at the Environmental Risk Engineering Laboratory, Department of Urban Environmental Engineering, where his research topic covers coagulation and flocculation, absorption and adsorption, membrane technology, health risk issues including halogenated hydrocarbons, arsenic, and endocrine disrupting chemicals.

Dr. Kamei has written books on chlorination, organic removal, and humic substances in water. He has been the author or co-author of more than 100 research articles. He was commended by the Japan Water Works Association for his research of water quality matrices.

He is a member of the Japan Society of Civil Engineers, Japan Water Works Association, and Japan Society of Water Environment.

Yasumoto Magara is Professor of Engineering at Hokkaido University, where he has been on faculty since 1997. He was admitted to Hokkaido University in 1960 and received the degree of Bachelor of Engineering in Sanitary Engineering in 1964 and Master of Engineering in 1966. After working for the same university for 4 years, he moved to National Institute of Public Health in 1970. He served as the Director of the Institute since 1984 for Department of Sanitary Engineering, then Department of Water Supply Engineering. He also obtained a Ph.D. in Engineering from Hokkaido University in 1979 and was conferred an Honorary Doctoral Degree in Engineering from Chiangmai University in 1994. Since 1964, his research subjects have been in environmental engineering and have included advanced water purification for drinking water, control of hazardous chemicals in drinking water, planning and treatment of domestic waste including human excreta, management of ambient water quality, and mechanisms of biological wastewater treatment system performance. He has also been a member of governmental deliberation councils for several ministries and agencies including Ministry of Health and Welfare, Ministry of Education, Environmental Agency, and National Land Agency. He meanwhile performs the international activities with JICA (Japan International Cooperation Agency) and World Health Organization. As for academic fields, he plays a pivotal role in many associations and societies, and has been Chairman of Japan Society on Water Environment.

Professor Magara has written and edited books on analysis and assessment of drinking water. He has been the author or co-author of more than 100 research articles.