



Review

The global menace of arsenic and its conventional remediation - A critical review



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HIGHLIGHTS

- Presence of arsenic in the groundwater has threatened the human health around the world.
- Dissolution of arsenic into the groundwater is influenced by various physicochemical and biological activities.
- Long term exposure to arsenic can cause cancer and other deadly diseases.
- It has been found that the As(III) is more toxic than the As(V).
- Various techniques have been employed to remediate arsenic from groundwater to make the water safe for drinking.

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ABSTRACT

Arsenic is a ubiquitous element found in the earth crust with a varying concentration in the earth soil and water. Arsenic has always been under the scanner due to its toxicity in human beings. Contamination of arsenic in drinking water, which generally finds its source from arsenic-containing aquifers; has severely threatened billions of people all over the world. Arsenic poisoning is worse in Bangladesh where As(III) is abundant in waters of tube wells. Natural occurrence of arsenic in groundwater could result from both, oxidative and reductive dissolution. Geothermally heated water has the potential to liberate arsenic from surrounding rocks. Inorganic arsenic has been found to have more toxicity than the organic forms of arsenic. MMA and DMA are now been considered as the organic arsenic compounds having the potential to impair DNA and that is why MMA and DMA are considered as carcinogens. Endless efforts of researchers have elucidated the source, behavior of arsenic in various parts of the environment, mechanism of toxicity and various remediation processes; although, there are lots of areas still to be addressed. In this article, attempts have been made to lay bare an overview of geochemistry, toxicity and current removal techniques of arsenic together.

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1. Introduction

In modern days, with deteriorating environmental quality, human life is exposed to numerous types of threats. The food for appeasing hunger, water for quenching thirst and air for breathing, have all become unsafe these days. Incurable diseases have proved the daily hazards of human life. There are number of harmful chemicals around us; ingestion, breathing or any kind of exposure to them can affect the human health tremendously. Arsenic, being a toxic element has made the human life miserable in the areas with a higher concentration of it in soil, water and to some extent, in air. The global attention is mainly focused on the presence of arsenic beyond its safe limit in water (0.01 mg/L) (World Health Organization, 2010), specifically in groundwater, as the major part of global population from the countries like India, Bangladesh, China, Nepal, Thailand, Brazil, United States, Canada, England relies on groundwater to meet the purpose of drinking. Arsenic contamination in groundwater is generally caused by the natural sources. Mining, smelting of arsenic-bearing minerals are among the anthropogenic sources of arsenic contamination in the environment. Arsenic exists in the environment in different forms; –III, 0, +III and +V depending on the prevailing physicochemical conditions of the environment. Incessant consumption of arsenic-rich water causes different types of chronic diseases like the Blackfoot disease, pigmentation, keratosis, nausea and most importantly cancer in human. Inorganic arsenic compounds are found to have more toxic effects than the organic forms. Methylated arsenic acids are the organic forms of arsenic and believed to have the carcinogenic effect in human. Scientists and researchers have been working to discover more advanced and apt ways to mitigate this problem since it has risen in the global horizon. A number of measures are already been in practice for treating the arsenic contaminated water by chemicals, activated carbon, reverse osmosis, adsorption on nanomaterials etc. With the emergence of nanotechnology, various nanomaterials have been used for treating water and it lived up to the expectation. In this article we shall seek to discuss briefly the geochemistry, sources of arsenic, the fate of arsenic in soil and groundwater, global view of the arsenic affected area, effects of arsenic exposure in the human body. We shall also concentrate our efforts to depict the current scenario of arsenic mitigation in lights of various removal techniques.

2. Arsenic in relation to the environment: a brief overview

Arsenic is a metalloid with atomic number 33, atomic mass 74.92 and electronic configuration $4s^23d^{10}4p^3$, found as a trace element in the earth's crust. It is the twentieth most abundant element in the earth's crust. In the continental crusts, the average arsenic content generally varies from 2 mg to 3 mg/kg (Tanaka, 1988; Cullen and Reimer, 1989). Out of 200 mineral forms of As,

the major mineral forms can be categorized as the arsenates (~60%), the sulfides and the sulfo-salts (~20%) of arsenic. The rest are the silicates and native arsenic (Nriagu, 1994). The arsenate minerals are those, which contain oxyanions of As such as AsO_4^{3-} , $AsO_3(OH)^{2-}$. Orpiment (arsenic trisulfide As_2S_3), realgar (tetraarsenic tetrasulfide As_4S_4), α and β -dimorphite (tetraarsenic trisulfide As_4S_3), tetraarsenic pentasulfide (As_4S_5) are some well known arsenic sulfide minerals, whereas, arsenopyrite ($FeAsS_2$), cobaltite ($CoAsS$), are two examples of the mixed sulfides of arsenic [M(II) AsS].

In the environment, among the oxidation states of arsenic, +III and +V are the mostly encountered in soil and water environments. As(V) is the dominant species in an oxidative environment whereas, As(III) is the dominant one in the reducing environment.

The sulfides are least resistant to weathering; arsenic-containing sulfides easily get weathered compared to the other arsenic minerals. Oxidation of arsenic sulfides allows arsenic to spread out into the various components of the environment such as soil, water and air (Murdoch and Clair, 1986; Welch and Stollenwerk, 2007).

2.1. Arsenic in relation to air, water and soil

2.1.1. Arsenic in air

In the air, the ambient arsenic concentration is generally very marginal. It is lesser in rural areas and higher in urban areas. In rural areas, the aerobic arsenic concentration is reported to range between 0.02 ng/m^3 and 4 ng/m^3 , whereas in urban areas it is found to be lying in between 3 ng/m^3 and 200 ng/m^3 which is 50–150 times more than that of rural areas (Chappell et al., 2001). The atmospheric arsenic concentration is always subjected to local level contamination magnitude. In many cases, arsenic in the air is contributed by the volcanic eruption, mining and smelting of arsenic-bearing minerals and burning of fossil fuels, especially coal. Coal samples of some mines have been reported to contain arsenic upto 1.5 g/kg arsenic where the average arsenic content of average coal samples is around 13 mg/kg (Bissen and Frimmel, 2003). The arsenic species in air are greatly adsorbed by the particulate matters. Polynucleated Aromatic Hydrocarbons (PAH) having a size range from 1 to $20 \mu\text{m}$ provide the site to the metals and metalloids present in the atmosphere to get adsorbed on it. Arsenic species in air, are generally washed out by rain or get precipitated by various physicochemical processes of the atmosphere.

2.1.2. Arsenic in relation to water

Arsenic concentration in water varies from one water body to another water body. We have observed a great variation in the aqueous arsenic concentration reported by various scholars in their articles. Chappell et al. (2001), reported the oceanic arsenic concentration to lie between 1 and $2 \mu\text{g/L}$; Welch et al. (1988) reviewed

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