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Editorial

Arsenic ecotoxicology: The interface between geosphere, hydrosphere and biosphere

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Although arsenic (As) has been known since ancient times as a powerful toxin, it was not before the end of the 20th century that the occurrence of As originating from natural sources has been reported in groundwater in different parts of the globe [1–8]. However, the problem did not receive much global attention until the 1980s when the biggest As calamity in the world was first reported in the Bengal delta in Southeast Asia [9–11]. This was the starting point for an exponentially widespread scientific, policy and public interest regarding environmental contamination by As. Until now, it has been reported that there are over 70 countries around the world where elevated As levels have impacted the ecosystem, freshwater resources and human health [12–16]. The source of As, affecting large areas throughout the globe, are predominantly of geogenic origin, whereas anthropogenic As may be of local relevance. Mining includes the influence from both components as As is geogenic but released through anthropogenic activities affecting water resources covering large areas. From the ingestion of As-contaminated water alone, over 200 millions of people are estimated to be at risk of As exposure.

Understanding the ecotoxicological effects of As in the environment is primordial to mitigating its deleterious effects on ecological and human health. Interaction of As with organisms is the precondition of quantifying As risk exposure. In order to understand how As might affect organisms at individual and population levels we should admit that As does not act as an individual form but interacts with other physical and biological stressors (e.g., trace metals and organic contaminants). Therefore interactions of As with different stressors are of significant interest.

This special section focuses on the ecotoxicology of As and its interfacial processes between the geosphere, hydrosphere and biosphere. It constitutes a multidisciplinary scientific endeavor that is problem-driven and aiming to assist society by providing up-to-date knowledge and advance the understanding of the adverse effects that As has on the environment. Through the wide range of topics covered in this special section it provides a holistic approach for interpreting human exposures to groundwater derived As. This includes pathways of predominantly geogenic As, from its occurrence in rocks and mineral forms, subsequent release due to biogeochemical processes – which are partly catalyzed by microbial activities – into soil and aqueous environments such as hydrosphere, pedosphere, and biosphere, and ultimately transfer to humans through drinking and ingestion of rice and vegetables.

Section I of this special section has eight articles on the topic “Arsenic and the Geo- and Hydro-sphere Interface”. These articles discuss the primary source and occurrence of As in rocks and minerals and mechanism of its release into ground- and surface-water (and vice versa, i.e., sequestration of dissolved As by mineral

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phases), and processes that control mobility and speciation of As in groundwater and soil environments. Arsenic release from crystalline rocks is discussed by Pili et al. [17], whereas Basu and Schreiber [18] dealt specifically with As mobilization from arsenopyrite weathering. Banning et al. [19] addressed the impact of changing redox conditions on As mobility. In the following articles, Bhowmick et al. [20] and Ormachea et al. [21] indicated how different geogenic and anthropogenic activities, including mining, can mobilize/sequester As in the groundwater environment using examples from West Bengal (India) and Poopó basin (Bolivia), respectively. Neidhart et al. [22] showcased their research results on how groundwater extraction has impacted As concentration distributions in groundwater of West Bengal (India). The article by Bundschuh et al. [23] addresses geochemical processes related to geothermal activity which showed potential impacts on freshwater resources in Western Turkey. The last article of this section by Alarcón-Herrera et al. [24] addresses the co-occurrence of As and fluoride in semi-arid regions of Latin America and they provided a detailed assessment of genesis, mobility and remediation options.

Section II "Geo/Hydrosphere – Organic Matter and Microbes Interface" addresses the role of organic matter and microbial assisted geochemical processes on the mobilization of As in the aqueous environment. Al Lawati et al. [25] and Liu et al. [26] presented their research results on how organic matter influences As mobility in a reduced coastal aquifer and mud volcanoes, respectively, both study areas are located in southwestern Taiwan. The last two articles by Islam et al. [27] and Bahar et al. [28] showcased research outcomes on biochemical behaviors of As through understanding of mineral–microbe interactions in soil and groundwater environments.

Section III "Arsenic Exchange Processes at Geosphere-Biosphere interface" comprises five articles dealing with bioavailability and bioaccessibility of As from soil and water to plant species. Toujaguez et al. [29] evaluated As bioaccessibility in mine tailings to obtain an improved health risk estimate through utilization of mineralogical techniques. Karczewska et al. [30] examined As solubility and its uptake by two grass species grown in strongly polluted soils from Poland. Usman et al. [31] investigated heavy metal extractability in As and Pb contaminated soils. Quazi et al. [32] showcased their research results on As bioavailability and potential lifetime cancer risk due to chronic As exposure in a greenhouse setting. The last article of this section by Srivastava et al. [33] isolated and characterized As resistant bacteria from As contaminated soils and evaluated the As phytoremediation potential of Indian mustard plant [*Brassica juncea* (L.) Czern. Var. R-46].

Section IV "Arsenic in the Biosphere" comprises topics of As exposure assessment, toxicity, metabolism, propagation in the food chain and uptake by human through ingestion. Chakraborti et al. [34] assessed the environmental (groundwater, soil and vegetables) and human biomarker As levels to determine health effects in a community level where arsenicosis cases were previously reported. Rahman et al. [35] determined the quantity of As and other elements ingested through drinking water and vegetables by adult members in Noakhali district, Bangladesh for exposure assessments. Phan et al. [36] also examined As exposure through estimation of daily intake and daily dose of inorganic As from food consumption in three provinces in Mekong River basin of Cambodia. O'Neill et al. [37] determined the level of dietary intake of As through consumption of traditionally cooked rice by local populations in two villages of Cambodia. Chen et al. [38] developed receptor-specific risk maps toward management of As contaminated regions in Taiwan. Bhattacharya et al. [39] carried out a greenhouse pot experiment to investigate the uptake and distribution of As in different fractions of rice plant in West Bengal (India). Li et al. [40] investigated the effects of arbuscular mycorrhizal fungi (AMF) on the temporal variation of speciation and accumulation of As in rice plants under different growth periods subjected to flooded conditions. Schneider et al. [41] further studied AMF in mining impacted As contaminated areas in Brazil where they observed an inverse relationship between As content in soils and the mycorrhizal colonization, density of spores and species richness. Chan et al. [42] showcased their research results on the role of AMF in As uptake by upland rice and further reported the effect of AMF on the yield. The last article of this section by Dave et al. [43] examined the contrast in tolerance of rice genotypes exposed to various levels of As(III) and As(V). They further examined some contrasting As responsive genotypes for As accumulation, antioxidant properties and amino acid response at different As exposure levels.

Section V "Hydrosphere – Human Health" addresses the exposure risks and toxic effects of As on human health. The article by Lin et al. [44] highlighted the toxic effects of drinking As contaminated water on mortality of liver cancer in Blackfoot disease endemic areas and other areas in Taiwan. Wang et al. [45] compared multiple stressors on bladder cancer risks to humans through hospital-based case–control study in Taiwan. Zhang et al. [46] developed a statistical model to predict locations of risk areas with As concentration above 50 $\mu g L^{-1}$ in Shanxi Province, Northern China. Zhang et al. [47] studied the impact of long-term exposure to low-level As in drinking water on blood pressure, pulse pressure and mean arterial blood pressure in a study population in the Hetao plain of Inner Mongolia. Liu et al. [48] investigated the health status of a local population based on the analysis of biomarkers to gain an insight of the effectiveness of the water intervention over a longer time period upon chronic As exposure in Xinjiang, PR China.

Section VI "Treatment" comprises of five articles that used indigenous materials to remove As from drinking water. Majumder et al. [49] explored the applicability of natural citrate sources from tomato in order to efficiently remove As from drinking water following solar radiation technique that developed by a group of researchers from ETH, Switzerland [50]. Maiti et al. [51] monitored the performance of two household filters made of indigenous locally available materials laterite (sometimes referred as ferralite, see Bhattacharyya et al. [52]) for in situ removal of As. Labastida et al. [53] identified the best indigenous limestone to create a passive treatment system to efficiently treat As and heavy metals in acidic leachates in Zimapán, Mexico. Lopes et al. [54] characterized the red mud and phosphogypsum collected from a mining site in Brazil to improve As retention capacity. Bujňáková et al. [55] examined the improvement of As sorption behavior on changing surface and structural properties of natural magnetite by mechanical activation.

Section VII "New Advances in Arsenic Research" includes five articles. Parsons et al. [56] developed a field-portable sensor to quantify As in soils. Liu and Cai [57] showcased their research on testing SEC–UV–ICP-MS method capable of directly determining DOM-bound As. Ruppert et al. [58] developed an appropriate sampling technique to qualitatively identify and characterize the volatile organoarsenical compounds released from the soil–rabbitfoot grass (*Polypogon monspeliensis*) system. Alava et al. [59] tested HPLC-ICP-MS technique to monitor the determining factor on the metabolic potency of human gut microorganisms toward As. The last article of this issue by Schneider et al. [60] investigated As interactions in plant–soil systems using microscopic techniques.

We hope that these selected special section articles covering wider subjects of 'arsenic ecotoxicology' would be useful to the wider scientific community and provide up-to-date knowledge and understanding towards mitigating the problem of As exposure affecting millions of populations worldwide (especially in southeast Asia).

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