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Review

# Integrated phytobial remediation for sustainable management of arsenic in soil and water

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ABSTRACT

Arsenic (As), cited as the most hazardous substance by the U.S. Agency for Toxic Substance and Disease Registry (ATSDR, 2005), is an ubiquitous metalloid which when ingested for prolonged periods cause extensive health effects leading to ultimate untimely death. Plants and microbes can help mitigate soil and groundwater As problem since they have evolved elaborate detoxification machineries against this toxic metalloid as a result of their coexistence with this since the origin of life on earth. Utilization of the phytoremediation and bioremediation potential of the plants and microbes, respectively, is now regarded as two innovative tools that encompass biology, geology, biotechnology and allied sciences with cutting edge applications for sustainable mitigation of As epidemic. Discovery of As hyperaccumulating plants that uptake and concentrate large amounts of this toxic metalloid in their shoots or roots offered new hope to As phytoremediation, solar power based nature's own green remediation. This review focuses on how phytoremediation and bioremediation can be merged together to form an integrated phytobial remediation which could synergistically achieve the goal of large scale removal of As from soil, sediment and groundwater and overcome the drawbacks of the either processes alone. The review also points to the feasibility of the introduction of transgenic plants and microbes that bring new hope for more efficient treatment of As. The review identifies one critical research gap on the importance of remediation of As contaminated groundwater not only for drinking purpose but also for irrigation purpose and stresses that more research should be conducted on the use of constructed wetland, one of the most suitable areas of application of phytobial remediation. Finally the review has narrowed down on different phytoinvestigation and phytodisposal methods, which constitute the most essential and the most difficult part of pilot scale and field scale applications of phytoremediation programs.



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## 1. Introduction

The heavy metalloid arsenic (As) ranking the group V element of the periodic table is the 20th most abundant element in the Earth's present-day crust. Evidences indicate that it was an abundant element on the primordial Earth surface and served as an energy source to some beginning life forms while posed biochemical challenge for others (Olsen et al., 1999). As the Earth cooled, heavy elements like sulfur and As were engulfed within the core and mantle leaving a little on the surface of the Earth causing life to flourish. But occasional volcanic eruptions, leaching from geologic formations caused it to surface again. Anthropomorphic sources like application of As containing fungicides, pesticides, insecticides and herbicides and irresponsible mining activities also contributed its unusual high percentage in some agricultural fields. The survival of large variety of life forms including microbes and plants in the presence of this toxic metalloid is not a surprise but a result of million years of adaptation, natural selection and evolution (Oremland et al., 2009). A large body of literature is present on biogeochemical, pharmacological and toxicological behavior of As (Oremland and Stolz, 2003; Pott et al., 2001; Smedley and Kinniburgh, 2002; Rosen, 2002).

Well-documented cases of As poisoning have been found in Argentina, Chile, China, Mexico, Taiwan, India and Bangladesh (see review by Christopher and Haque, 2012). The world's largest As-hit population would be found in the Bengal basin covering parts of Bangladesh and West Bengal, India where millions of people consume unsafe concentrations of As because of the presence of shallow tube wells (>100 m) that yield water containing >10 μg $L^{-1}$ of As which is the maximum contaminant level (MCL) of As in safe drinking water. Arsenicosis or As induced health defects due to prolonged exposure to sub-acute levels of As in drinking water include various dermatological skin lesions, cardiovascular, peripheral vascular diseases, neurological disorders, respiratory diseases, limb deformations, eye problems and various forms of cancer and death (Paul et al., 2013; Naujokas et al., 2013). Due to chronic exposure to very low levels of As that always exist in both soil and water (Smedley and Kinniburgh, 2002), As tolerance or detoxification systems has evolved in most, if not all, living organisms, including humans (Rosen, 2002). Health effects, genetic damage and As susceptibility extensively studied by our group indicates that genetic variants and poor nutritional status are responsible for As induced toxicity, susceptibility and carcinogenicity (De Chaudhuri et al., 2008a, 2008b; Banerjee et al., 2011). Ground-water used for cultivation of staple food crops such as rice, wheat contaminated with As aggravates the As epidemic (Banerjee et al., 2013; Abedin et al., 2002; Brammer, 2009; Das et al., 1995). Long term use of As contaminated irrigation water also leads to accumulation of As in the fields. Abandoned mines also cause As poisoning in the surrounding agricultural soils (Kwon et al., 2012; Susaya et al., 2010). Livestock fed on As-containing vegetation are source of As food chain contamination (Samal et al., 2011). The use of alternative source of drinking water (deep tube wells of >150 ft depth) may solve drinking water crisis locally but for irrigation purpose large scale groundwater remediation is the only sustainable solution as the overuse of deeper pumping for irrigation or large scale use other than domestic purposes, would induce downward migration of As from upper shallow aquifer to deep aquifer, permanently destroying this deep resource (Michael and Voss, 2008; Ravenscroft et al., 2013). Several water treatment technologies like adsorption, co-precipitation, ion exchange, reverse osmosis and membrane processes can effectively remove As from contaminated groundwater (Cheremisinoff, 1998). But most of them are costly and very large scale application including decontamination of the contaminated ground water reservoir is practically not possible. Bioremediation and phytoremediation are the alternative solutions that are cost-effective and environmentally friendly. In contrast to bioremediation which in general concept employs microbes, phytoremediation employs plants. Microflora associated with plants i.e. endophytic bacteria, rhizosphere bacteria and mycorrhizae assist the plants in As uptake, translocation and accumulation and this process is termed as rhizoremediation. Lynch and Moffat (2005) first used the term phytobialremediation to redefine phytoremediation assisted by microbes. The discovery of As hyperaccumulator plant *Pteris vittata* by Ma et al. (2001), paved the way for discovery of other As hyperaccumulator/accumulator plants and this made phytoremediation of As a reality from imagination.

The present review is a comprehensive complete review that has discussed all aspects of As phytobialremediation (flowchart in the graphical abstract shows the structure of the review). The main objective of the review is to address the issue that bioremediation, phytoremediation and rhizoremediation are intricately related, complementary to each other's disadvantages (Table 1) and is synergistically more effective than individual procedures alone. They should be launched together to form a holistic approach to stop the aggression of this world's greatest mass poisoning agent and save millions of lives. Along with showing the detailed mechanism of bioremediation and phytoremediation of As, the authors have discussed how plants and microbes help each other in the whole process and how