

## Arsenic and its management in soil

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### ABSTRACT

Arsenic (As) is a toxic metalloid and carcinogenic element that occurs widely in environment around the world. Arsenic is introduced into soil and water through geological (weathering of rocks and minerals) and anthropogenic pathways (mining, pesticides, fertilizers, timber treatment *etc*). Irrigation of agricultural land with As-contaminated groundwater or wastewater, particularly in India, Bangladesh and South-East Asia resulted in the accumulation of arsenic in both soils and plants posing risks to soil ecosystems and human health. Arsenic in soil and water exists in a different valence state, but predominantly as toxic As(III) and less toxic As(V) form. Arsenic toxicity is one of the most challenging problems in drinking water, as well as food crops (Samal *et al.*, 2021). With greater public awareness of arsenic poisoning in animals and human nutrition, there has been growing interest in remediation technologies for mitigating As-contaminated ecosystems. Remediation of As-contaminated soil improves physical, chemical and biological approaches that may achieve either partial/complete removal of arsenic from soil and water. Many technologies like bioremediation, phytoremediation, soil mixing, soil washing, soil capping, filtration, adsorption and immobilization are used for arsenic removal from soil and water. Phytoremediation is a bioremediation process that uses various types of plants to remove, transfer, stabilize, and/or destroy contaminants in the soil and groundwater. But most of the arsenic still remains in the environment and there is always a risk of leaching caused by changes in the environmental conditions. Integrated approach involving a combination of physical, chemical and biological technologies is needed for the successful and effective management of As-contaminated environment.

*Key words* : Arsenic, Soil, Sediments

### Introduction

Arsenic (As) is a toxic metalloid found in rocks, soil, water, sediments, and air. It enters into the terrestrial and aquatic ecosystems through a combination of natural processes such as weathering reactions, biological activity and volcanic emissions, as well as a result of anthropogenic activities. Arsenic in terrestrial and aquatic ecosystems attracts worldwide attention primarily because of its adverse impact on human health. The general population may be exposed to As from air, food, and water of the various

sources of As in the environment, drinking water probably poses the greatest threat to human health. Arsenic toxicity is one of the most challenging problems in drinking water, as well as food crops (Samal *et al.*, 2021). People drinking As-contaminated water over prolonged periods often show typical arsenical lesions, which are a late manifestation of As toxicity. *Albertus Magnus* discovered by Arsenic and it is also called "King of poison" because of its lethal potency and undetectable. Arsenic has been unequivocally demonstrated to be both toxic and carcinogenic to humans and animals. When present in

high concentrations in drinking water, arsenic has been found to adversely affect human health.

China was the top producer of white arsenic with almost 70 per cent world share, followed by Morocco, Russia and Belgium. It is a ubiquitous element which is 20<sup>th</sup> in abundance in the earth's crust, 14<sup>th</sup> in the water bodies and 12<sup>th</sup> inside the human body.

### Source and occurrence

Arsenic is found in the natural environment in abundance in the Earth's crust and in small quantities in rock, soil, water and air. The average concentration of arsenic in the continental crust is 1-2 mg kg<sup>-1</sup>. The mean concentration of arsenic in igneous rocks ranges from 1.5 to 3.0 mg kg<sup>-1</sup>, whereas in sedimentary rocks it ranges from 1.7 to 400 mg kg<sup>-1</sup>. About one third of the arsenic in the atmosphere comes from natural sources. Volcanic action is the most important natural source of arsenic. The next most important natural source is the arsenic-containing vapor that is generated from solid or liquid forms of arsenic salts at low temperatures. The rest two third comes from man-made sources. Mining, metal smelting, burning of fossil fuels and coal-fired power plants are the major industrial processes that contribute arsenic contamination to air, water and soil. Elemental arsenic is produced commercially from arsenic trioxide. Arsenic contamination of surface and groundwaters occurs worldwide and has become a sociopolitical issue in several parts of the globe. For example, several million people are at risk from drinking As-contaminated water in West Bengal (India) and Bangladesh.

### Arsenic occurs in different chemical forms

Organic and inorganic form in the environment in four different oxidation states: -III, +III, 0 and V. It exists as arsine (-III), arsenite (+III), arsenic (0) and arsenate (V) in inorganic forms. Organic forms of arsenic include monomethylarsinic acid, dimethylarsinic acid, trimethylarsine oxide, arsenobetaine, arsenocholine and arsenosugars.

In the earth's crust, arsenic normally can be found associated with sulfur forming sulfide minerals such as realgar (As<sub>2</sub>S<sub>2</sub>), orpiment (As<sub>2</sub>S<sub>3</sub>), and arsenopyrite (FeAsS) which are also goldbearing ores. Arsenic compounds can be classified into three major groups which are organic, inorganic, and gas (*i.e.*, AsH<sub>3</sub>, a highly poisonous and flammable gas) Inorganic arsenic is the predominant species in the envi-

ronment and more toxic than organic arsenic. Arsenite or As (III) (a trivalent species) and arsenate or As(V) (a pentavalent species) are the two oxidation states of inorganic arsenic available in soil.

### Biogeochemistry of arsenic in the soil

As can exist in soil in different oxidation states but mostly as inorganic species, As(V) or As(III). In addition to inorganic species, microbial methylation of As in soil results in the release of organic methylarsenic compounds, such as MMA and DMA, and ultimately arsine gas. Both inorganic and organic species of As undergo various biological and chemical transformations in soils, including adsorption, desorption, precipitation, complexation, volatilization, and methylation. Some important biogeochemical reactions of As and their significance in soil and aquatic environment. The most thermodynamically stable species of As (III) and As (V) occur over the normal soil pH range of 4 to 8. The adsorption and retention of As by soils determine its persistence, reactions, movement, transformation, and ecological effects (toxicity). In general, adsorption of As (V) decreases with increasing pH. In contrast, adsorption of As (III) increases with increasing pH. The effect of pH on As adsorption varies considerably among soils and is dependent on the nature of mineral surface. In soils containing low oxidic minerals, increasing the pH has little effect on the amount of As(V) adsorbed, whereas in highly oxidic soils, adsorption of As(V) decreases with increasing pH.

### As poisoning

Arsenic poisoning is a medical condition that occurs due to elevated levels of arsenic in the body. If arsenic poisoning occurs over a brief period of time, symptoms may include vomiting, abdominal pain, encephalopathy, and watery diarrhea that contains blood.

Arsenic poisoning typically affects **the skin, liver, lungs, and kidneys**. In the final stage, symptoms include seizures and shock. This could lead to a coma or death.

### Effect of arsenic toxicity on plants

- Arsenic taken by plant tissues causes severe damage to metabolic process in mitochondria and important cellular components, such as lipids, protein, DNA and RNA.
- Arsenic toxicity symptoms include leaf wilting,

purpling and root discoloration.

- Rice: Reduces seed germination, decreases in seedling height, and reduces leaf area, dry matter production and yield.

**Arsenic toxicity in animals :** Abdominal pain, Salivation, Vomiting, Diarrhoea, Weakness, Low body temperature and Death. If arsenic exposure occurs on the skin, effects such as blisters, swelling, cracking, bleeding and infections can occur.

## Management

### Physical methods

- **Soil Mixing:** The simplest technique for reducing the toxic concentration of As in soils is mixing the contaminated soil with uncontaminated soil. This results in the dilution of As to acceptable levels.
- **Soil Capping:** Capping the contaminated sites with clean soil is used to isolate contaminated sites
- **Soil Washing:** The contaminated soil was washed with different concentrations of hydrogen fluoride, phosphoric acid, sulfuric acid, hydrogen chloride, nitric acid, perchloric acid, hydrogen bromide, acetic acid, hydrogen peroxide, 3:1 hydrogen chloride–nitric acid, or 2:1 nitric acid–perchloric acid.

### Chemical method

- **Adsorption :** The use of naturally occurring clay minerals such as zeolite as adsorbents. A number of compounds, including activated alumina, Fe-coated sand, and ion-exchange resins are used to adsorb As. In most geologic environments,  $Fe_2O_3$  carries a positive surface charge that preferentially adsorbs Arsenic (Joshi *et al.*, 2019).
- **Immobilization:-** Sorption onto a mineral surface or by precipitation as a discrete insoluble compound, increasing the number of As-binding sites. Immobilization of metal(loid)s using inorganic and organic soil amendments in order to reduce their bioavailability. Mixing the contaminated soil with uncontaminated soil, thereby increasing the number of As-binding sites.
- **Liming:** Lime addition to As-contaminated soil induces the formation of pharmacolite, thereby reducing the soluble As in the soil solution for plant uptake and leaching.

### Biological method

**Bioremediation:** As undergoes biological transfor-

mation in soil, appropriate microorganisms may be used for the remediation of As contaminated soils. Species can be exploited for bioremediation of arsenite containing wastes (Butt and Rehman, 2011).

The mechanisms of phytoremediation include

- **Phytoextraction :** Also known as phytoaccumulation, the uptake of contaminants by plant roots and the translocation/accumulation of contaminants into plant shoots and leaves
- **Enhanced rhizosphere biodegradation:** Takes place in soil or groundwater immediately surrounding plant roots
- **Phytodegradation :** Metabolism of contaminants within plant tissues
- **Phytostabilization:** Production of chemical compounds by plants to immobilize contaminants at the interface of roots and soil.
- **Hyper accumulating fern (*Pteris vittata*) has been used in the remediation of arsenic-contaminated soil, waste, and water.** This fern can tolerate as much as 1,500 ppm of arsenic in soil. Growing the arsenic hyperaccumulator *Pteris vittata* in five contaminated paddy soils to investigate arsenic uptake by rice through phytoremediation Ye *et al.* (2011). Letuzia *et al.* (2017) investigated the ability of As-hyperaccumulator *Pteris vittata* and organic amendments in reducing arsenic uptake by lettuce from a soil.

## Conclusion

Risk management of arsenic contaminated soil and water is an important issue and a great challenge; its success is necessary to promote sustainable environment health and also minimize the adverse impact on humans. A number of physical, chemical and biological technologies have been developed to remediate arsenic-contaminated soil and water. However, phytoremediation, which is relatively inexpensive, has been proven effective in remediation of metalloid contaminated sites. As a consequence innovative, effective and low cost *in-situ* and *ex-situ* technologies for arsenic removal from soil and water are highly desired.

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