# Bioremediation Strategies to Mitigate Arsenic Contamination

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## ABSTRACT

In recent years, several reports of excessive levels of arsenic (As) in water environments have been testified from various regions of the world, primarily due to anthropogenic activities. Understanding bioremediation techniques to reduce or mitigate the toxicity of arsenic in polluted water is the overall goal of this work; this is achieved through reviewing latest literatures on As- remediation, and exploring some of the resent techniques of mitigating arsenic contamination. More than thirty (30) microorganisms, including bacteria, archaea, and fungi, were discovered. Moreover, there are many technologies for removal and mitigating of arsenic from contaminated water including application of nanoparticles meanwhile some successful cases of remediation were reported in this study. It is recommended more research should be carried out to further understand the microorganisms responsible and techniques for reducing water contaminates.

## INTRODUCTION

Environmental water pollution is major global concern and is rising as a result of human activities, growing population, unsustainable agricultural practices, and rapid industrialization (Ojha *et al.,* 2021). Water pollution continues to be one of the most significant worldwide problems due to the rate of increasing populations, technological developments, and subsequent rise in industrial and agricultural practices (Pezeshki *et al.,* 2023).

Achieve universal access to water and sanitation with sustainable management is the SDG6; the objective has goals for water usage efficiency, ensuring water quality, and the management of water resources that ought to be fulfilled by 2030 (Zait *et al.,* 2022).

The targets for water quality can be reached through lowering pollution from agricultural, industrial, and municipal sources, reducing hazardous chemical releases, reducing the amount of untreated wastewater, and boosting recycling of wastewater and safe reuse (Zait *et al.,* 2022).

According to Cancer Treatment Centers of America (CTCA, 2022) High amounts of arsenic in drinking water have been linked to skin and lung cancers as well as bladder cancer. The World Health Organization (WHO) has classed arsenic poison as a Class I element of carcinogen (Yin *et al.,* 2022[b]). Moreover, arsenic is also corrosive (Bundschuh *et al.,* 2021).

There many sources of Arsenic which include natural and anthropogenic sources like metal mining, industrial wastes and smelting, As-containing herbicides or pesticides, and irrigation with Arsenic contaminated water (Wang *et al.,* 2023).

Bioremediation is a systematic way used to remove contaminants from the environment (Ibrahim *et al.,* 2022). It represents a novel technique that is capable of being used in a variety of water as well as soil environments depending on microorganisms' adaptability to remove hazardous pollutants (Saravanan et al., 2023[a]). Using bioremediation, polluted groundwater, soil, and even entire habitats can be cleaned by accelerating natural biological processes (Mukherjee *et al.,*2021). Bioremediation of arsenic-contaminated

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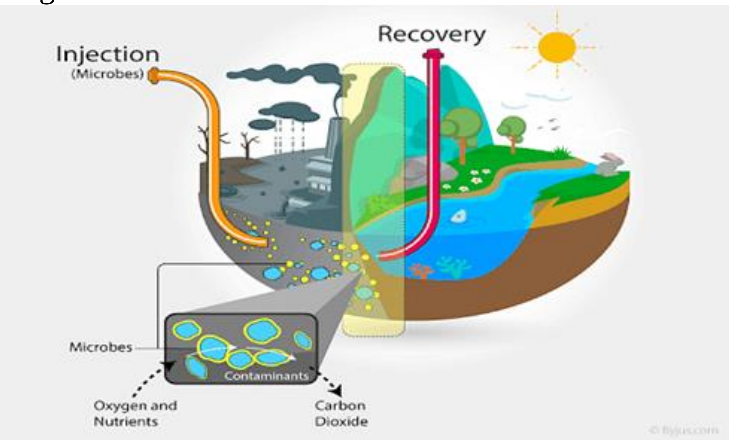
water is financially sensible procedure (Hare *et al.*, 2020).

## BIOREMEDIATION

Bioremediation is a method for treating contaminated media, such as soil, subsurface material, and water, by changing the environment to promote the growth of microbes and reduce the amount of the target contaminants (Ibrahim *et al.*, 2021). In other words; The process of removing pollutants from the environment using bacteria, fungi, algae, and yeast is called bioremediation. Given that bioremediation involves the removal, degradation, detoxification, and immobilization of contaminants, microorganisms are crucial to the process (Bala *et al.*, 2022).

Figure 1: Bioremediation Process




Source: Amruta (2023)

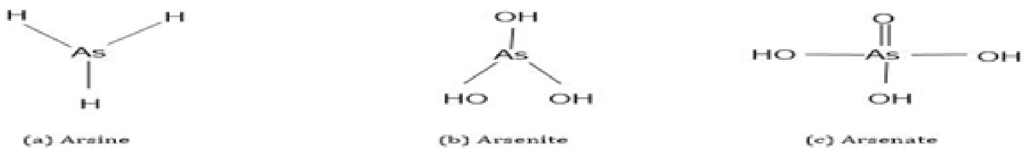
It is important to know that the microbes can be isolated somewhere else and then brought to the contaminated site, or they might be local to the contaminated area. Bioremediation will only be effective when the environment favors microbial development and activity.

### 2.1 Arsenic

In 1993, arsenic contamination was originally discovered in tube well water of a district in northern Bangladesh, (Ahmad *et al.*, 2018). Arsenic is an extremely poisonous cancerous substance (Dilpazeer *et al.*, 2023). Arsenic can be in four (4) different oxidation states, including arsenite (As (III)), arsenate (As(V)), arsine (As (III) and arsenic (As (0))). The inorganic forms are arsenate and arsenite, which are frequently found in water, are the most widespread forms of these four arsenic types (Nicomel *et al.*, 2016). Arsenic is one of the hazardous metalloids (Biswas *et al.*, 2023), it is found in more than 200 various mineral forms, of which 60% are typically arsenates, 20% are sulphosalts and sulphides, and the remaining 20% are silicates, oxides, arsenite, arsenide, and elemental arsenic (Lim *et al.*, 2014). The soluble inorganic arsenic species are usually considered to be more hazardous compare to the organic species (Bahar *et al.*, 2013). The largest population poisoning in history is said to be arsenic contamination (Thathapudi *et al.*, 2023).

#### 2.1.1 The Structure of Arsenic

Figure 2: Structures of inorganic arsenic species




Source: Preetha et al., (2023)

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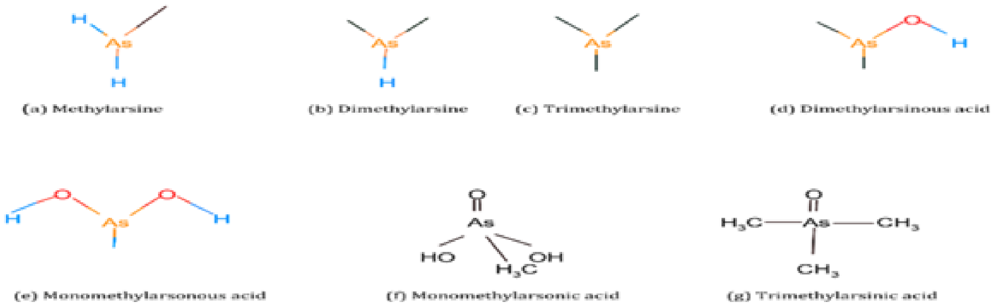
Figure 3: Structures of organic arsenic species

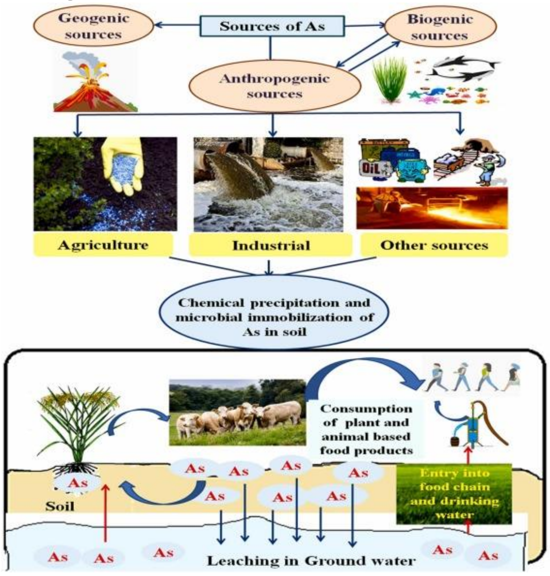



Source: Preetha et al., (2023)

### 2.1.2 Source of Arsenic

The primary sources of arsenic in ecosystems are both natural and anthropogenic sources (Reyna & Macías, 2022). For instance, Geogenic arsenic (As) is an outcome of human activities that involve the mining and processing of natural resources (Guerra *etal.*, 2023). It widely occurs in soil, rocks, water, sediments, and the atmosphere (Zhao *et al.*, 2023).

Figure 4: Arsenic's source, how it is distributed through water and soil, and how it accumulates in living things

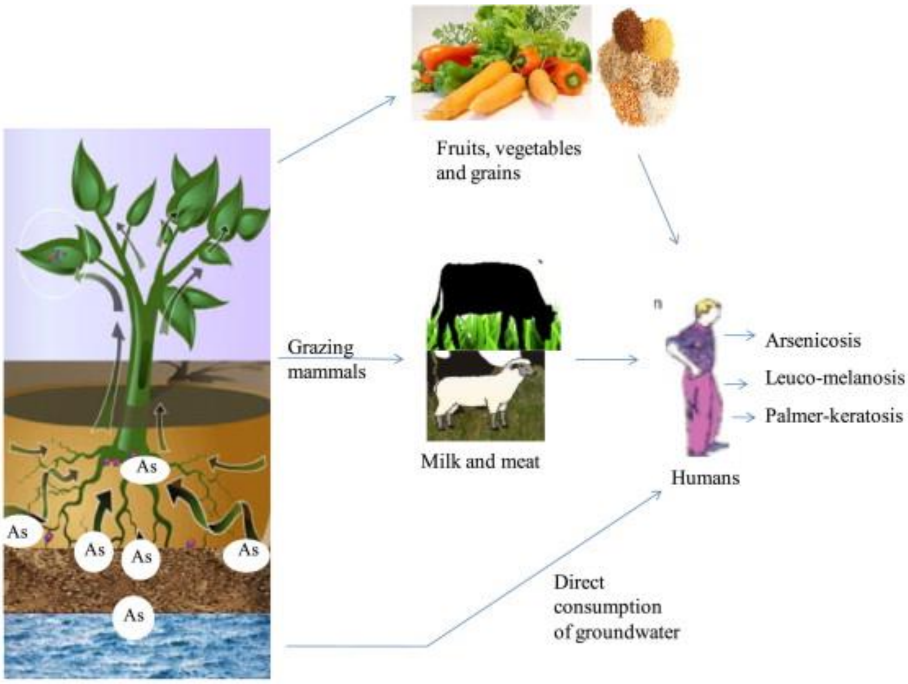



Source: Anand et al., (2022)

### 2.1.3 Bioaccumulation of Arsenic

The term "bioaccumulation" describes the buildup of arsenic inside an organism's cell. The organisms in question could be fungi, plants, algae, or bacteria. Through cell membrane pores, arsenic can enter and gather, and it can be stored in cytoplasm and vacuoles (Fayiga & Saha, 2016). In fish, the gastrointestinal system is where dietary arsenic enters the body then arsenic is transferred to the organs via the circulatory system after absorption by the digestive tract (Zhang *et al.*, 2022). Studies showed that most tissues in contaminated areas accumulated a lot of arsenic (Pei *et al.*, 2019). Therefore, Arsenic is classified as a persistent, bio-accumulative carcinogen and a pollutant with harmful impacts on the environment (Kulshreshtha *et al.*, 2021).

Figure 5: Arsenic transport from water and soil to people via food chains is depicted in a schematic graphic.




Source: Fayiga & Saha (2016).

Arsenic affects humans, plants, and animals negatively and is a carcinogen (Meghana, & Sayantan, 2021). In fact, many ailments are brought on by human arsenic consumption.

### 2.1.4 The Effects of Arsenic on Human Beings

Contaminated surroundings by Arsenic might spread across long distances and enter the food chain, posing health risk to human (Reyna & Macías, 2022). According to the National Institute of Environmental Health Sciences (NIEHS, 2023) various organs or systems are affected by arsenic, include skin, nervous system, circulatory system, cardiovascular system kidney, bladder, liver, and prostate, immune system, endocrine system and process of development as shown below:

Figure 6: How does arsenic affect people?


Source: NIEHS (2023)

Through eating, inhalation, or skin absorption, arsenic can enter the body. Most of arsenic that is consumed and inhaled is absorbed into the bloodstream through the digestive system and lungs. Over 95% of the trivalent arsenic that is consumed is absorbed by the digestive system (Hare *et al.*, 2020).

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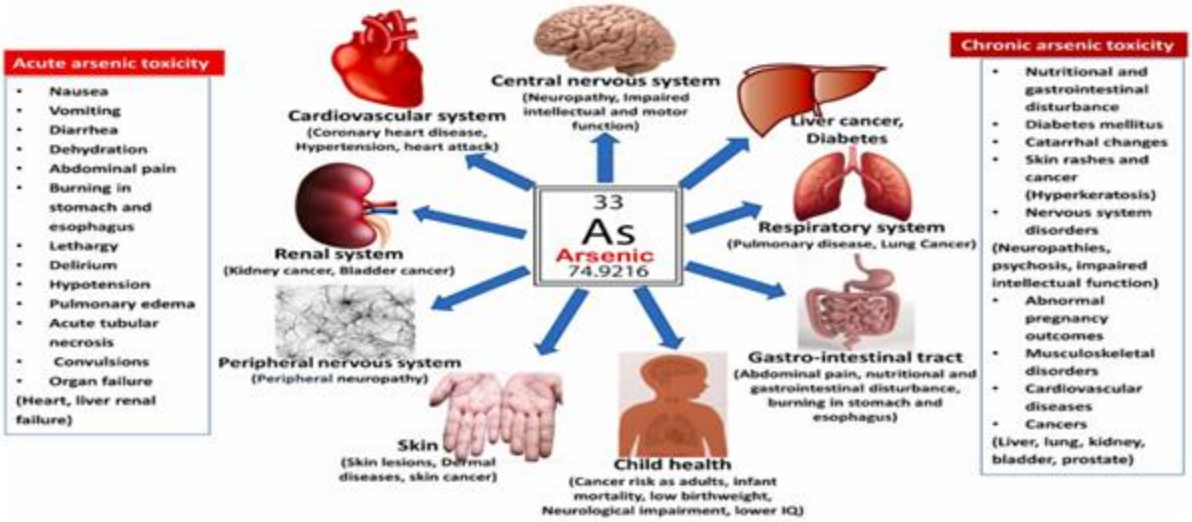
Figure 7: Arsenic Contamination Effects on Health




Source: Dilpazeer et al., (2023)

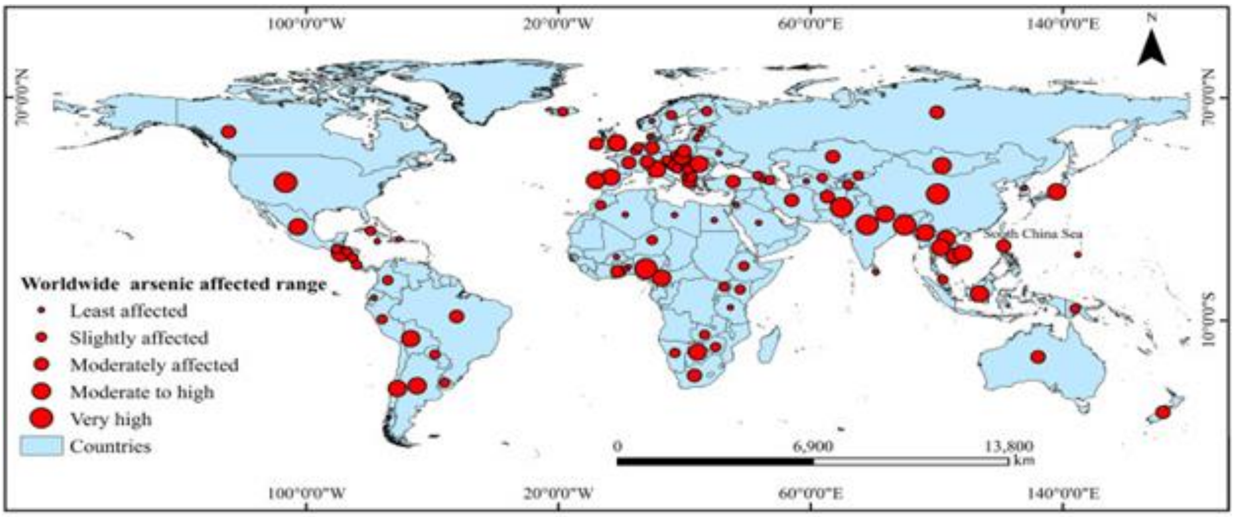
### 2.3 Ground Water Contamination

The most popular type of drinking water used worldwide is groundwater. More than 2.5 billion people globally depend on groundwater for drinking, making the provision of high-quality drinking water is one of the greatest pressing issues facing human society (Shaji *et al.*, 2021).

Ground water contamination with arsenic is a serious issue because drinking it can cause serious health risks such as diabetes, peripheral neuropathy, hepatotoxicity, ventricular arrhythmias, neurotoxicity, axonal degeneration, coronary heart disease, hypertension, and encephalopathy (Ghosh & Sarkar, 2023).

Inorganic arsenic levels in drinking water in the United States are limited to 10 parts per billion (ppb) NIEHS (2023). The permitted limit for arsenic, giving by the World Health Organisation (WHO), is 10 ?g/L, although literatures revealed that several nations had arsenic concentrations significantly higher as shown in the scale below (Dilpazeer *et al.*, 2023). As contamination affects at least 108 different nations as shown in figure 7 below (Reyna & Macías, 2022).

Figure 8: The scale of the plots indicates how much arsenic affected various nations of the world.




Source: Shaji, et al., (2021).

Many countries, including Japan, China, India, Vietnam, Nepal, Bangladesh, Myanmar, Cambodia, Mongolia, Thailand, Sri Lanka, Pakistan, the United States, Afghanistan, Brazil, Mexico, Bolivia, Argentina, Chile, Hungary, Ghana, Romania, and Greece, have high arsenic concentrations in their groundwater (Yin *et al.*, 2022 [a]).

### 2.4 Microorganisms Involved in The Bioremediation of Arsenic

Although arsenic cannot be broken down (non-degradable), it can be detoxified and removed through altering its solubility and how it behaves using microorganisms (Rahman & Singh, 2020).

Table 1: As-Remediating Bacteria, Archaea and Fungi

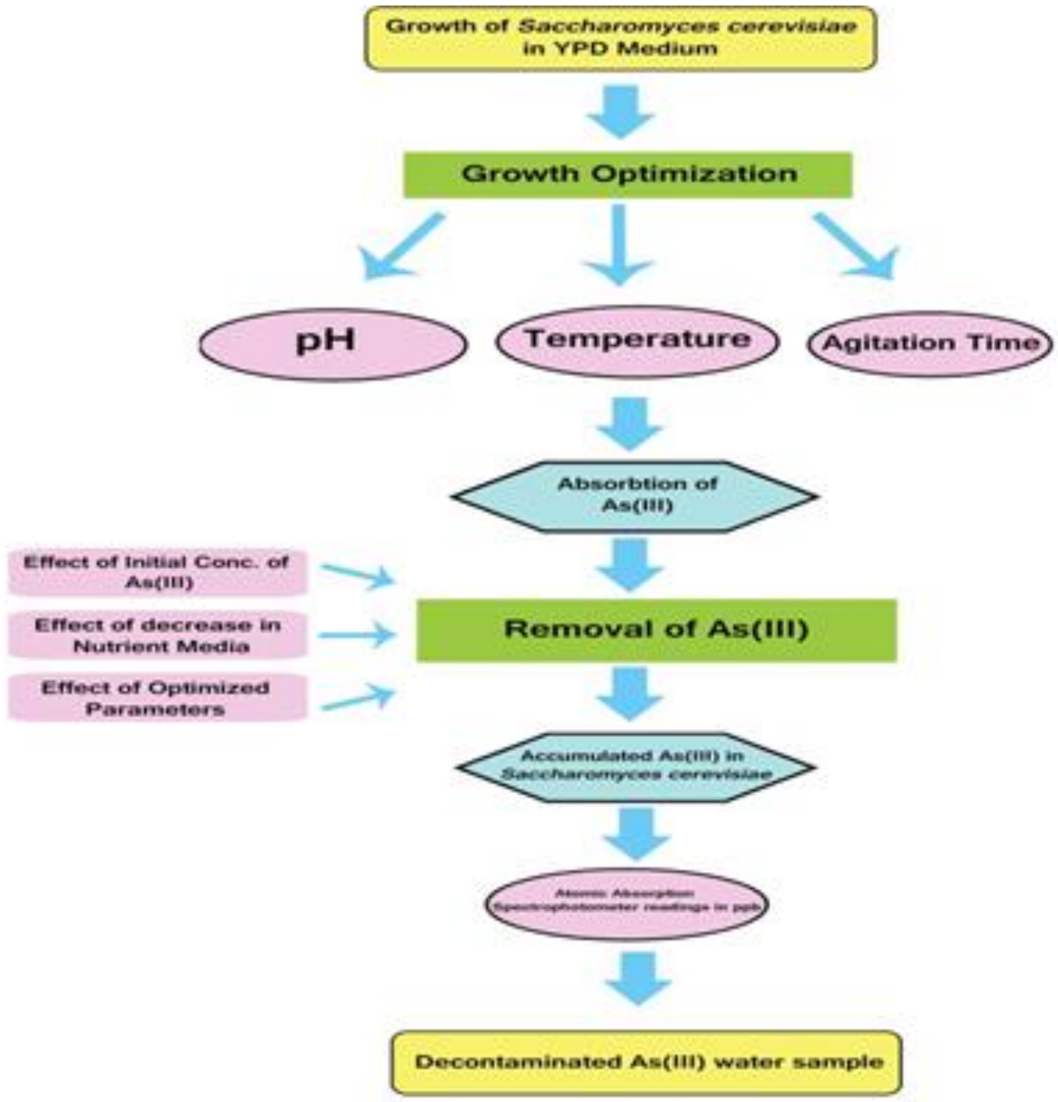
| Bacteria | Archaea | Fungi |
|---|---|---|
| Stenotrophomonas spp. | Halorubrum spp. | Aspergillus spp. |
| Ancylobacter sp | Sulfolobus acidocaldarius | Penicillium |
| Paracoccus sp. | Pyrobaculum arsenaticum | Talaromyces |
| Thiomonas sp. | Halobacterium | Emericella |
| Thiobacillus sp. | Haloarcula | Rhizopus |
| Bosea sp. | Methanosarcina | Rhizomucor |
| Arthrobacter sp. | | Neocosmospora |
| Hydrogenophaga sp. | | Acremonium |
| Bacillus spp. | | Fusarium |
| Delftia sp | | Humicola |
| Shinella sp. | | Fusarium |
| Shewanella sp. | | Trichoderma |
| Desulfobulbus sp. | | Sordaria |

The table 1 above shows some microorganisms that are capable of removing arsenic include; bacteria (such as *Stenotrophomonas spp*. and *Bacillus spp.*), archaea (such as *Halorubrum spp*. and *Methanosarcina*), and fungi (such as *Aspergillus spp*.) (Yin *et al.*, 2022 [b]).

### 2.5 Bioremediation of Arsenic in Contaminated Water

Using baker yeast *Saccharomyces cerevisiae* as a biosorption to bioremediate Arsenic (III) in groundwater

Figure 9: Process of biosorption in general schematic form




Source: Roy et al., (2013)

Table 2: Percentage (%) of Arsenic (III) removal by Sacchromyces cerevisiae in relation to initial and final concentrations

| Arsenic (As) species | Microorganism | Initial Conc. (mg/l) | Final Conc. (mg/l) | Conc. removed (mg/l) | % of removal |
|---|---|---|---|---|---|
| As III | *S.cerevisiae* | 0.2 | 0.062 | 0.138 | 69% |
| As III | *S.cerevisiae* | 0.3 | 0.063 | 0.237 | 79% |
| As III | *S.cerevisiae* | 0.4 | 0.0284 | 0.171 | 85.50% |

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### 2.5 Treatment Technologies of Arsenic Contaminated Water

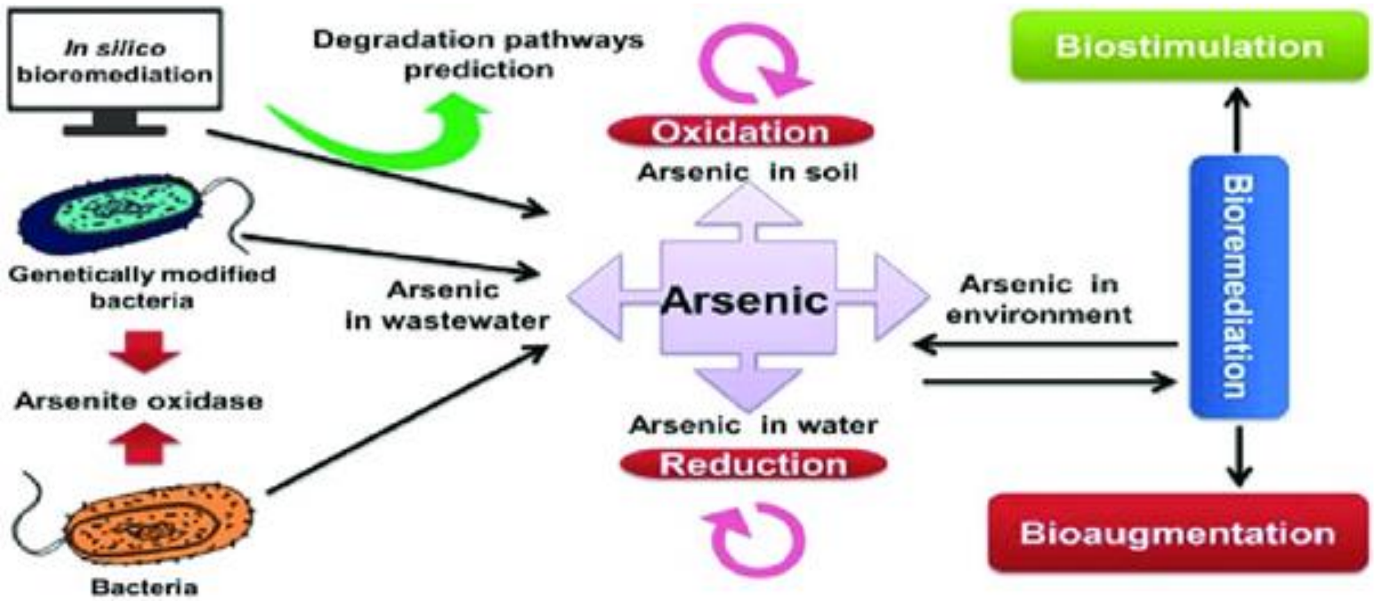
The six guiding principles for the various technologies used to eliminate arsenic from contaminated water are as follows: (Jain & Singh, 2012; Adeloju *et al.*, 2021):

1. Biological oxidation: As (III) is converted to as (V) by microbes, which is then eliminated by manganese and iron oxides.
2. Oxidation and filtration
3. Adsorption: Iron-based sorbents, hydrated iron oxide, zero-valent iron, activated alumina, activated carbon, etc.
4. Co-precipitation: Coagulation, sedimentation, and filtration are performed after oxidizing As (III) to As (V) by introducing the appropriate oxidizing agent.
5. Using appropriate anion and cation exchange resins for ion exchange.
6. Membrane technology: Nanofiltration, electrodialysis, and reverse osmosis

Other technologies include:

1. Stimulation of natural Sulfate-reducing bacteria (Saunders *et al.*, 2018)
2. Phytoremediation using macrophytes; *Azolla pinnata*, *Lemna minor*, and *Hydrilla verticillate* (Kumar & Banerjee, 2018)
3. Conventionally used methods include membrane, oxidation, and coagulation-flocculation methods.
4. Use of different nanoparticles for cleaning up contaminated water (Nicomel *et al.*, 2016)
5. Electro-deionization (EDI) technique (Saravanan *et al.*, 2023).
6. two membrane processes; reverse osmosisand nanofiltration (Pezeshki *et al.*, 2023).

Figure 10: Illustration of different arsenic remediation techniques. Source: Hare et al., (2020).




The remediation techniques include: oxidation-reduction, bio-stimulation, bacterial-derived bioaugmentation, bioremediation, and in silico bioremediation which involve predicting the degrees of toxicity (Khan & Cameotra, 2013).

Bioaugmentation is the process of adding microbial cultures to contaminated locations to speed up biodegradation while the optimizing entire environmental parameters, such as by electron acceptors, adding nutrients, and vital growth factors, as well as by regulating the temperature and pH, is known as Biostimulation (Mangimbulude & Lembang, 2018).

### 2.7 Some Cases of Successful Arsenic Removal from Contaminated Water

#### 2.7.1 Arsenic-contaminated groundwater remediation using phytoremediation

In this case, a certain region's groundwater is seriously poisoned by arsenic. To lessen the contamination, the local government decides to use a phytoremediation approach. To begin, they choose suitable plant species, such ferns or willows, that are renowned for their capacity to accumulate and withstand high levels of arsenic.

The first step is to extract water from the contaminated groundwater source, treating it to remove any pollutants. Once the water is treated, it is released into constructed wetlands or ponds. These wetlands contain selected plant species with high arsenic tolerance. These plants absorb arsenic from the water through their roots, accumulating it in their shoots and leaves.

Periodic monitoring is conducted to assess the effectiveness of the phytoremediation process. The arsenic levels in the plants are tested to ensure they are absorbing the metal effectively. As the plants continue to grow, they are periodically harvested and disposed of in a controlled manner to prevent the re-release of arsenic into the environment.

This phytoremediation strategy not only reduces arsenic levels in the groundwater but also provides an opportunity to recycle the harvested plants. The plants can be processed to extract arsenic for safe disposal or used for various purposes such as composting, biofuel production, or livestock feed (Srivastava *et al.* 2021).

#### 2.7.2 Arsenic-contaminated surface water remediation using chemical precipitation

In this scenario, a surface water body, such as a lake or river, is found to have high levels of arsenic contamination. It was successfully mitigated using chemical precipitation strategy (Neville, 2013).

The processes involved in the first step is to identify an appropriate chemical agent that can effectively react with arsenic and form insoluble precipitates, thus removing arsenic from the water. Commonly used chemicals for this purpose include iron salts (e.g., ferric chloride or ferric sulfate) or aluminum salts (e.g., aluminum chloride or aluminum sulfate).

The selected chemical agent is introduced into the contaminated surface water. The chemical reacts with arsenic, forming insoluble precipitates that settle down to the bottom of the water body. This process is called coagulation and flocculation. Coagulants are added to destabilize the arsenic particles, and flocculants help agglomerate these particles to form larger, settleable flocs.

To enhance the settling process, sedimentation basins or sedimentation ponds may be constructed, allowing the treated water to stay in the basin for sufficient time to allow the precipitates to settle down. The settled precipitates are then removed and disposed of properly to prevent re-contamination.

Regular monitoring is done to assess the effectiveness of the chemical precipitation process. Water samples are collected from various locations in the water body and tested for arsenic levels. The settling efficiency and rate of the precipitates are also monitored to optimize the treatment process.

#### 2.7.3 Arsenic-contaminated groundwater remediation using in situ chemical oxidation

This situation involves the discovery of an underground aquifer that is heavily arsenic Contaminated. For the purpose of reducing the contamination, the local authorities successfully choose to employ an in-situ chemical oxidation technique.

The first step is to identify a suitable oxidizing agent that can effectively convert the toxic forms of arsenic into less harmful forms. Commonly used oxidizing agents include hydrogen peroxide, ozone, or potassium permanganate.

The selected oxidizing agent is injected directly into the contaminated groundwater using wells or injection points. The oxidizing agent reacts with the arsenic, breaking it down into less toxic compounds or converting it to forms that are more easily removed or immobilized.

To ensure proper mixing and to enhance the oxidation process, the groundwater is circulated within the affected area using pumping or recirculation techniques. This helps in achieving a higher contact time between the oxidizing agent and the arsenic-contaminated groundwater.

Regular monitoring is conducted to assess the effectiveness of the in situ chemical oxidation process. Groundwater samples are collected from various monitoring wells and tested for arsenic levels to track the progress of the remediation. Additionally, the presence of any byproducts or changes in groundwater quality are also monitored to ensure minimal environmental impact (Mohammadian *et al.* 2022).

## SUMMARY

The adverse effects of exposure to arsenic on health of human are well established. They include carcinogenicity, a variety of diseases of the skin, black foot, encephalopathy, and peripheral neuropathy. Arsenic is categorized as a contaminant with negative effects on the environment and as a persistent, bio-accumulative carcinogen.

Utilizing microorganisms to remove or reduce environmental toxins is technique usually known as bioremediation; numerous microorganisms are capable of removing arsenic contamination in water include bacteria (like *Stenotrophomonas spp*. or *Bacillus spp.*), archaea (like *Halorubrum spp*.), and fungi (such as *Aspergillus spp*.). Bioremediation is considered as promising and the environmentally friendly process of remediation of environmental water pollutants.

## CONCLUSION

Arsenic is considered to be class 1 carcinogenic element by WHO due to high detrimental effects on humans. There are numerous sources of arsenic in the water environment either anthropogenic or natural that leads to the contamination of the water system especially the groundwater which source of drinking water in most countries; Over hundred (100) countries are affected by contamination of arsenic in the world. Meanwhile, more than thirty (30) microbes including bacteria, archaea and fungi where discovered for the bioremediation of arsenic contamination. Moreover, there are many technologies presented for removal and mitigation of arsenic from contaminated water including application of nanoparticles.

## RECOMMENDATIONS

1. Future development of environmentally friendly techniques is necessary for remediation of water contaminated with high concentration of As.
2. In addition to technological development, it is crucial to address the pervasive harmful effects of arsenic on the environment and humans.
3. Further research should be conducted for exploring more efficient and effective microorganisms responsible for the mitigation of water contaminates

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