



DISTRIBUTION AND SPECIATION OF ARSENIC IN THE ENVIRONMENT AND THEIR SOCIO-ENVIRONMENTAL IMPACTS: A REVIEW WITH AN EMPHASIS ON ANALYTICAL STRATEGIES

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Abstract : Arsenic Accumulation and speciation in different agricultural crops and vegetable samples of Chhattisgarh Central Regions was highlighted in this review. Arsenic is quite widely distributed in natural waters and is often associated with geological sources, but in some location's anthropogenic inputs, such as the use of arsenical insecticides and the combustion of fossil fuels, can be extremely important additional sources. The intake and exposure depending on the chemistry of the pumped water, the chemical speciation of As in soils and the behaviour of individuals are mentioned in this review. This review also indicating that the chemical specification and accumulation of arsenic in the environment are also incorporated in the review. In addition, the occurrence, distribution, origin and mobility of as have received a lot of attention in the last two decades for these organic and inorganic toxicants. Acute arsenic intoxication and adversely effect of arsenic on human and plant species are also reported by the authors in this proposed compilation. In last, we report the worldwide scenario of arsenic contamination and their particular permissible limit in this review.

IndexTerms - Arsenic, chemical speciation, accumulation, Risk assessments, Sources, Analytical Methodologies.

I. INTRODUCTION

Arsenic (As) is an element of natural origin extensively widely distributed in the atmosphere, hydrosphere and biosphere. Environmental As is associated connected mainly with two types of sources natural processes such as weathering, biological activity and volcanic emission human activities such as mining, industrial processes, smelting of metals, production of pesticides, wood preservatives and use of fossil fuels. Although natural mineralization and microbial activities increase the mobilization of as in the environment, human activities exacerbate as contamination in soil and in water supplies [1] Consumption of arsenic-rich rice grains is a global health concern [2]. Chemical structures for different species of arsenic are displayed in **Table 1**. Consequently, arsenic translocation in soil-rice plant systems has attracted substantial research interests in the past decade [3,4]. There have also been increasing interests in arsenic uptake by and accumulation in other crops and vegetables [5] Leafy vegetable is an important part of the daily diet in many Asian countries. Therefore, ingestion of arsenic via leafy vegetable consumption could significantly contribute to human intake of arsenic in the areas contaminated by arsenic. In general, research on leafy vegetables is limited due to the huge variety of vegetable plants being grown, which are not well covered by the available reports. In addition, most of the published work only concerned the level of as in the edible portion of the leafy vegetables without investigating the As level in the roots and soils [6-10]. This does not allow understanding of the soil-root-leaf translocation of bio char produced from paralysis of biomass has been proposed as a cost-effective soil conditioner for remediation of soils contaminated by trace elements of potential toxicity [11]. However, immobilization of arsenic by biochar is only effective when the biochar is protonated [12].

The contamination chain of heavy metals almost always follows a cyclic order: industry, atmosphere, soil, water, foods and human health and life [13]. In spite of the fact that toxicity and threat to human health are, of course, a function of concentration, chronic exposure to heavy metals and metalloids at relatively low levels can have adverse health effects [14]. While focusing on developing countries the conditions is getting more disastrous due to increase in industrial complexes with minimal follow up of environmental and pollution control guidelines [15,16]. Arsenic is one of the most toxic elements Earth's crust and has been identified as carcinogenic to humans, Arsenic is a metalloid. His exist in natural environment in several inorganic and organic chemical forms: arsenite (As^{3+}), arsenate (As^{5+}), monomethylarsonic acid (MMAs), dimethylarsonic acid (DMAs), trimethyl

arsine oxide (TMAO), arsenobtanite (AsB), etc. in the environment [17-19]. The element is rarely found in nature as a free element, but is more commonly found in sulphur-containing ores, where it occurs as metal arsenides [20]. Arsenic is quite widely distributed in natural waters and is often associated with geological sources, but in some location's anthropogenic inputs, such as the use of arsenical insecticides and combustion of fossil fuels can be a very important source of additional energy.

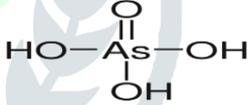
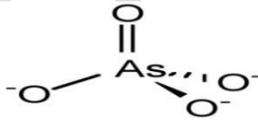
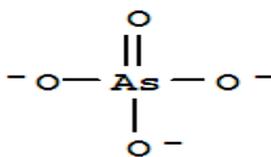
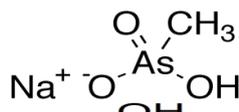
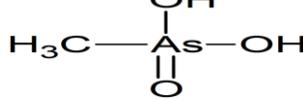
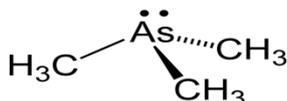
The adverse effects of arsenic in irrigation groundwater on crops and aquatic ecosystems are also of major concern. The fate of arsenic in agricultural soils is less well understood than in groundwater. However, the accumulation of arsenic in rice field soils is of concern and its introduction into the food chain through uptake by the rice plant is of major concern mainly in Asian countries [21,22]. However, if the absorption takes place in an excessive or accidental condition, the situation can easily turn into a dangerous health issue, if the contaminated plant is ingested by a human or inserted in the food chain. Hence, rice is the most intensively studied plant organism in the As speciation because of its high consumption by humans as well as its high ability to accumulate arsenic in greater amounts than other grains. Additionally, the soil used for rice cultivation can also increase the concentration of As [23]. Although it is well known that As is mostly found in plant tissues in its inorganic, and thus poisonous, form, more research is needed to assess the matrix's responsiveness to various extraction processes. Both organic and inorganic forms of arsenic are found in the environment. The inorganic forms are much more toxic and groundwater, surface water and many foods. It is the main cause of many adverse health effects like cancer (skin, lung, liver, kidney and bladder), and cardiovascular and neurological effects [24-26].

The scope of this review will be to give an overview of toxicant arsenic concentrations in various environmental samples and it is important to explain how these parameters can be applied to assess environmental risks in ecosystems and human health. Emphasis in this review will, therefore, be placed on the use of chemical speciation and accumulation responses in air, soils, water and plants, as monitoring tools for the assessment of the risks and hazards of environmental toxicants concentrations for the ecosystem, as well as on its limitations.

II. STRUCTURAL CLASSIFICATION OF ARSENIC

Table 1 display the chemical structure for different species of arsenic. On the basis of structural properties and chemical bonding, the arsenic is classified into following types such as arsonous acids (RAs(OH)_2), rare arsenous acid (As(OH)_3), arsinous acids (R_2AsOH), rare arsinic acids ($\text{R}_2\text{As(O)OH}$), which are commonly illustrated by cacodylic acid ($\text{R} = \text{CH}_3$) and phenylarsonic acid ($\text{R} = \text{C}_6\text{H}_5$). The chemistry of compounds containing a chemical bond between arsenic and carbon is called organoarsenic chemistry. Limited organoarsenic compounds, also named "organoarsenicals," are produced industrially with uses as insecticides, herbicides and fungicides [27]. In wide-ranging, these applications are lessening in step with growing concerns about their impact on the environment and human health. As(V) compounds typically feature the functional groups RAsO(OH)_2 , where R is aryl or alkyl groups. Arsenic typically occurs in the oxidation states (III) and (V), illustrated by the halides AsX_3 ($\text{X} = \text{Cl, I, F, Br}$) and AsF_5 . Consistently, organoarsenic compounds are commonly found in these two oxidation states [28].

Table 1. Chemical structure for different species of arsenic.

| S. No. | Name | Abbreviation | Structure |
|--------|-----------------------------|--------------|--|
| 1. | Arsenic | As |  |
| 2. | Arsenite | As(III) |  |
| 3. | Arsenate | As(V) |  |
| 4. | Mono sodium methyl Arsenate | MMA(V) |  |
| 5. | Dimethyl arsenic | DMAs |  |
| 6. | Trimethyle Arsenic | TMAAs |  |

Source of Arsenic

Acute arsenic poisoning can occur due to several sources, including natural, industrial, and accidental. Children unintentionally ingesting arsenic and adults attempting to commit suicide are examples of unintentional arsenic consumption. In nature As commonly found in the form of inorganic compounds in a wide range of minerals such as arsenopyrite or mispickel (FeAsS), realgar (AsS), and orpiment (As_2S_3). These minerals are usually associated with sulfide ores or other metal ores and act as a major source for the introduction of As into the environment [29]. Arsenic is existing in the aquatic system by both natural and anthropogenic activities. Volcanic eruption, weathering of rocks and wild land fires are some of the natural sources of as in groundwater [30,31]. Anthropogenic sources include mining, smelting, semi-conductor manufacturing, burning of coal, wood preservatives, disposal and incineration of municipal and industrial wastes, applications of arsenical pesticides, and insecticides in agriculture [32,33]. In the recent two decades, there has been a lot of focus on the prevalence, distribution, origin, and mobility of as. Knowledge of natural geochemical and biological processes that control as transportation and transformation in the environment is necessary for gaining a better understanding on As contamination. Fig. 1 shows the occurrence and flow paths of As in the environment [34] As is transported and transformed in the environment by sorption-desorption, precipitation-dissolution, wet and dry deposition, microbial activity, and oxidation-reduction. Biota is central, accepting As flowing into various compartments and exchanging As between other compartments. Arsenic poisoning (Acute) Acute arsenic toxicity symptoms occur usually after 30 minutes of ingestion but may delay if arsenic is consumed with food [35]. At first, the patient may experience a metallic taste with a garlicky odour, as well as trouble swallowing. Acute arsenic intoxication can be characterized by muscle pain, weakness, and shivering. Severe symptoms may include nausea, vomiting, abdominal pain, and diarrhea. Mucosal vascular supply is severely harmed by arsenic toxicity, resulting in mucosal vesicle development and tissue fragment sloughing. Numbness in the feet and hands, muscle spasms, and a great thirst may be experienced by the patient. On extreme intoxication, it leads to coldness of skin and can also result in circulatory collapse along with kidney damage with decline in urine output [35]. This is caused by multisystem organ damage following gastrointestinal collapse. If death does not occur from irreversible circulatory failure within the first 24 hours, then renal or hepatic failure can occur after a few days of intoxication. Cardiac manifestations can be acute cardiomyopathy, electrocardiographic changes and subendocardial haemorrhages [35]. Arsenic poisoning (chronic) chronic arsenic poisoning is highly insidious in nature; it often requires multiple hospital admissions before proper diagnosis can be made. Skin, liver, lungs and blood system manifestations can occur in most of the chronic arsenic toxicity cases [36]. First diagnosis was confirmed in west Bengal and Bangladesh by at school of Tropical medicine Calcutta in December 1984 [37]. The patient's skin colouring seems uneven and has been described poetically as "raindrops on a dusty roa." [38]. A chronic disease resulting from exposure to arsenic for a long time is known as arsenicosis. Chronic arsenic exposure studies in humans tend to concentrate on skin manifestations due to their diagnostic specificity. However, data on clinical case studies, population studies of inorganic arsenic consumption in drinking water, occupational exposure and environmental exposure show that multi organ systems of humans get adversely affected by chronic exposure to arsenic [38]. There are a variety of symptoms associated with arsenicosis, which are dependent mostly on the magnitude and duration of exposure. The occurrence of symptoms in an arsenic-exposed population varies dramatically. All members of the affected family do not have the same symptoms; the cause for this variation in disease manifestation is unknown.

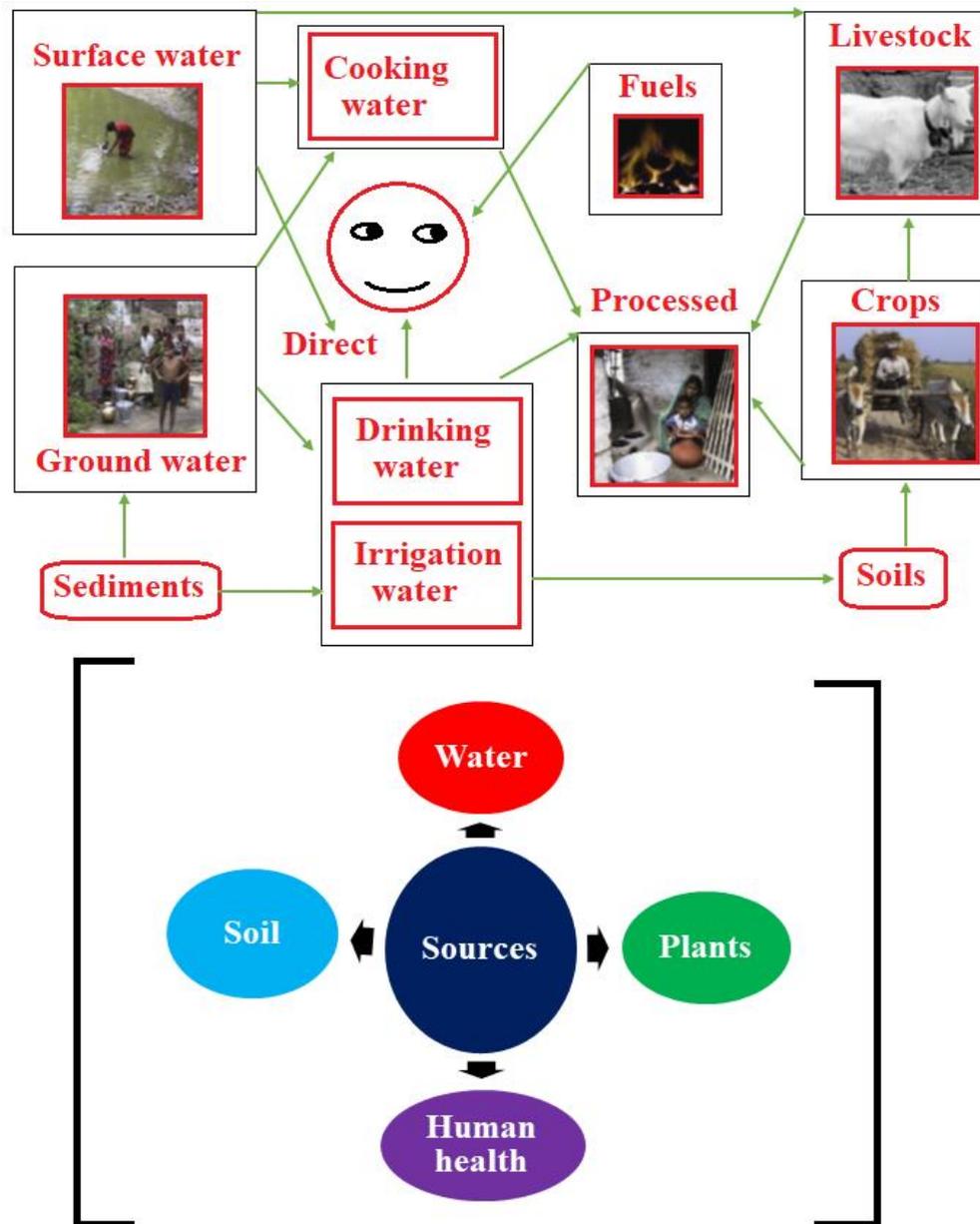


Fig. 1 Source of arsenic in environment and natural geochemical and biological processes that control as transportation and transformation in the environment is necessary for gaining a better understanding on As contamination.

Arsenic in soil

The residence time of arsenic in soil is ~1000 to 3000 years, which is much higher than its residence time in the atmosphere [39]. As arsenic migrates and transforms in soil, it is determined by the types and valences of arsenic, which are in turn determined by the soil environment. Various types of organic matter and metallic elements in soil have strong arsenic adsorption abilities, which impact arsenic's biological effectiveness and migration ability [40-44] stated that soil rich in organic carbon, such as humic and fulvic acid, has a higher concentration of arsenic, and the dissolved organic matter can inhibit the adsorption of arsenic species on iron oxides, iron hydroxides, alumina, kaolinite, or quartz present in the soil [44-45]. Thus, there is a direct link between arsenic and oxidizable organic carbon (OOC) and organic matter (OM) in soil [46]. Anthropogenic arsenic is generally deposited on topsoil through burning of fossil fuels, mining and smelting activities, incineration of waste, cement production, and application of arsenic-containing fertilizers and pesticides [47]. Arsenic is associated with primary sulphides, (hydro) oxides of aluminum, iron, and manganese, phosphates, carbonates, and sulfates in the Bengal Delta [48]. The distribution and mobility of arsenic in soil are also affected by the size of soil grains. The surface area of fine-grained particles is large and thus can absorb more arsenic. Arsenic in the soil typically occurs in the pentavalent As(V) state under oxidizing conditions, while under reducing conditions, trivalent As (III) species may be prevalent, which are more mobile and bioavailable, persistent [49]. As the arsenic-contaminated groundwater is being used for irrigation, it is likely to be adsorbed in the irrigation channels [49]. Fields dominated with tube-well irrigation facilities generally receive different amount of arsenic based on their distance from the wellhead and the rate of arsenic loss in distribution channels [50,51]. Because soil used for paddy cultivation is purposefully being puddled to hold water on the surface to develop a compacted, impervious plow pan [52]. reported that topsoil arsenic levels in irrigated soil were several times higher than the arsenic levels in irrigated deeper soil [53]. As a result, factors that contribute to seasonal gains and losses of arsenic in soil should be studied throughout a broad variety of environmental and agricultural conditions in which rice is grown and the inter-annual variability of meteorological and hydrological conditions observations over the past years are needed [54].

Arsenic toxicity in plants

Arsenic has no known biological significance in plants. It is known to induce toxicity in plants as pointed out by previous research [53]. Arsenic speciation and its level of toxicity vary for different plant species. In aerobic conditions, As(V) is often

taken by the roots of plants in combination with phosphate metabolism. Arsenate reductase is responsible to reduce less toxic As(V) into more toxic As(III) inside the root cell. As (III) is predominantly taken up by plants in the reducing environment [25], revealed that enhanced arsenic regimes in soil disrupt various plant functions and metabolism, affect the plant growth, nutrient acquisition as well as productivity [54]. Arsenic affects the morphological, physiological, biochemical and metabolic attributes like root-shoot length and biomass, chlorophyll content, photosynthetic rate, stomatal conductance, transpiration rate, relative water content of leaf, sugar metabolism, instigates biochemical stress by triggering membrane disruption, generation and accumulation of toxic superoxide ions (O_2^-), hydrogen peroxide (H_2O_2) and malondialdehyde (MDA) level in the plant tissues [55]. The plasma membrane of the plant cells is more susceptible to arsenic toxicity-cause cellular damage, reduce stomatal conductance, affect nutrient uptake and impart disruption in the transpiration process of the plants [56]. Arsenic entry inside the plant cell even at minute level induces deleterious effects on the physiological parameters. A generalised overview of the toxic effects of arsenic on the morpho-physiological attributes of the plants is mentioned in Table 2. Seed priming experiments conducted by [46] revealed that arsenic toxicity remarkably reduced the germination of rice seedlings by 70% and posed detrimental effect on the growth by reducing the root and shoot length and seedling biomass by 1.3, 1.6 and 1.4-fold, respectively [57]. Likewise, [67] reported severe arsenic toxicity on the seed germination and growth of the rice plants [58]. In similar research, the effect of arsenic toxicity on the physiological response of *Cistus salviifolius* was documented by [14,59]. The authors pointed pessimistic effects on the growth parameters of *Cistus salviifolius* when the plants were grown under 20 mg kg⁻¹ and 30 mgkg⁻¹ arsenic treatment. Arsenic absorption by the plant roots affect the light-harvesting system of the plants due to the reduction in chlorophyll content and photosynthetic activity [60]. [4] reported a notable decrease in photosynthetic efficiency of two maize cultivars Run Nong and Dong Dan exposed under the combined treatment of cadmium (100 µM) and arsenic (200 µM) [61]. The reason for the decreased photosynthetic efficiency is ascribed to the decrease in chlorophyll level and inhibition in the activities of enzymes involved in CO₂ fixation. The structural deformation and degradation of chloroplast membranes is another possible reason associated with the reduced photosynthetic rate of the maize cultivars. The degradation of chloroplast membrane under arsenic stress is correlated with the downregulation in the activity of RuBis CO and protochlorophyll reductase and synthesis of aminolevulinic acid. Correspondingly, opined that the reduction in pigment concentration is directly related with decreased photosynthetic activity of *Vigna mungo* in the presence of different arsenic treatments (100 µM and 200 µM) [62]. The reduction in chlorophyll is corroborated of the plants. Arsenic causes biochemical and molecular damage in plants by two different mechanisms: 1) concomitant increase in ROS generation and accumulation in plant tissues that disturbs cellular redox homeostasis. 2) Inactivation of vital enzymes or the alteration of crucial ions from enzyme active sites [63]. Arsenic stress in plants induces ROS generation in the plant tissues in the form of superoxide anion (O_2^-), singlet oxygen (1O_2), hydrogen peroxide (H_2O_2), and hydroxyl radical ($OH\cdot$). The stress caused in plants by the accumulation of SAR depends on the intensity of the stress, the speciation of the metal and its concentration in the fungus. Lipid peroxidation is regarded as the indicator of oxidative stress, involves oxidative degradation of poly-unsaturated fatty acyl residues of biological membranes [64]. Presence of arsenic ions induces lipid peroxidation, increase the concentration of unsaturated fatty acid and reduce the content of saturated fatty acids in plants [65], demonstrated the catastrophic effect of high arsenic concentration in the growth medium on the oxidative status of *Vicia faba* seedlings [66]. Plants were grown in the nutrient medium for 35 days under 5 µM sodium arsenate treatments. A dose dependent increase in the generation of toxic radicals like O_2^- , H_2O_2 was observed in the plant tissues illustrating the peroxidation of lipid membranes that induced oxidative damage in the plants [67]. Likewise, the reports related to arsenic induced oxidative damage to the plant tissues was observed in *Ricinus communis* [68] and *Pisum sativum* [69] with the ability of magnesium and toxic arsenic ions in the chlorophyll molecule causes their substitutions and ultimately leads to the destruction of photosynthetic activity. Arsenic concentrations in edible parts of a plant depend on the pervasiveness of arsenic in the soil and the accumulation and translocation ability of the plant [70]. Generally, in plants, arsenic gets accumulated in root and translocated to shoot and grains [71]. Besides this, xylem has been found as translocator tissues in the root-shoot system have discovered that xylem promotes the accumulation of As (V), i.e., a higher proportion of pentavalent arsenic than As (III) [72]. The trivalent form of arsenic is promoted in plants. The capacity of certain plant species to collect arsenic from soil has been identified. The Chinese brake fern (*Pteris vittata*) was discovered to be a hyperaccumulator of arsenic [73]. Many researchers have studied arsenic-affected areas in Murshidabad, West Bengal, India, and found that arsenic accumulation in various food composites such as potato skins, vegetable leaves, rice, wheat, cumin, turmeric powder and cereals in the ranged of 0.0004 to 0.693 mg/Kg [70-73]. Table 2 shows the effect of arsenic on plants and their concentration, microorganism and span time.

Table 2. Effect of arsenic on plants and their concentration, microorganism and span time

| S.No | Plant name | Arsenic concentration | Microorganism | Span Time | Effect on plant | Reference |
|------|--------------------------------------|--|--|----------------|---|-----------|
| 1. | <i>Pisum sativum</i> | 50,100 mgkg ⁻¹ | <i>Glomus mosseae</i> | 60 Day | Glyoxalase I and glyoxalase II enzymes, enzymes associated with glutathione-ascorbate cycle | 74 |
| 2. | <i>Medicago sativa</i> | 10, 25, 75 mgkg ⁻¹ | soil <i>Rhizophagus irregularis</i> | 60 day | Mycorrhizal colonisation induced arsenic methylation, enhanced phosphorus nutrition, upregulated the expression of P-transporter gene (MsPT4) and metallothionein gene (MsMT2) | 75 |
| 3. | <i>Lepidium apetalum</i> | 5 mgkg ⁻¹ | <i>Rhizophagus irregularis</i> | 45 days | AMF colonisation promoted the growth, biomass production and influenced the plant to cope arsenic toxicity by decreasing its concentration in roots. | 76 |
| 4. | <i>Helianthus annuus</i> | 250 mgkg ⁻¹ | Plant-growth promoting fungi <i>Trichoderma</i> sp. MG | 2–3 weeks | In the inoculated plants, the activities of crucial enzymes like phosphatase, invertase, dehydrogenase, cellulase, urease and amylase increased significantly along with 59% increase in arsenic concentration in the shoots. | 77 |
| 5. | <i>Vigna radiata</i> | 5.4 mgkg ⁻¹ | (2) Endophytic bacteria <i>Acinetobacter lwoffii</i> (RJB-2) | 7, 15, 30 days | Bacterial inoculation increased plant growth, chlorophyll content, carotenoid content, lowered the percentage of electrolyte leakage and minimise oxidative stress induced by reactive oxygen species. | 78 |
| 6. | <i>Betula celtiberica</i> | 30 mgkg ⁻¹ | <i>Ensifer adhaerens</i> strain (91R) | 30 days | Inoculation of plants with indigenous bacteria exhibited arsenic resistance by forming growth promoting factors and enhanced the capacity to reduce As(V) to As(III). | 79 |
| 7. | <i>Betula celtiberica</i> consortium | 30 mgkg ⁻¹ | <i>Variovorax paradoxus</i> | 30 days | Endophytic bacterial consortium enhanced the release of siderophore and indole-3-acetic acid, promoted arsenic accumulation in the leaves and roots. | 80 |
| 8. | <i>Solanum nigrum</i> | Pre-contaminated arsenic | Endophytic consortium isolated from <i>Lantana camara</i> | not mentioned | The consortium improved phosphate nutrition, enhanced oxidative defense in the plants, converted As (V)–As (III) and influence long-distance arsenic transport and detoxification | 81 |
| 9. | <i>Vallisneria denseserrulata</i> | 0.25, 2.5 mgkg ⁻¹ | hydroponics <i>Bacillus</i> sp. XZM | 20 days | The combined partnership showed remarkably high arsenic removal efficiency. Arsenic was mostly retained (85%) in roots and 77% in the vacuoles of leaves cells. | 82 |
| 10. | <i>Pteris vittata</i> | Pre-contaminated arsenic soil | <i>Pseudomonas vancoverensis</i> strain (m318) | 30 days | Bacterial inoculation enhanced the proportion of microbial aioA-like genes in the rhizosphere. Arsenic accumulation in the tissues increased by 48–146%, respectively. | 83 |
| 11. | <i>Pteris multifida</i> | As(III) 1, 2, 4, 6, 16 mM, As(V) 1, 10, 80, 160 mM | <i>Pseudomonas vancoverensis</i> strain (m318) | 30 days | Bacterial inoculation enhanced tolerance in the plant species towards arsenic stress. Arsenic accumulation in the tissues increased by 42–233% respectively. | 84 |
| 12. | <i>Hydrilla verticillata</i> | 2.0 µM | Hydroponics Epiphytic bacteria | 48 h | Bacterial inoculation decreased arsenic accumulation by ~64.44%, enhanced arsenic efflux by ~ 8-fold, hence promoted plant tolerance against arsenic stress. | 85 |

Arsenic in water

Since millions of people are exposed to excessive As through the intake of contaminated drinking water, As poisoning has become one of the world's main health concerns [77] Arsenic can enter the human body through food, water, soil, and air. Arsenic pollution has been reported in air, soil and sediment, surface water and groundwater, and biota in several regions of the world [81] Arsenic pollution of water can occur by both natural processes and anthropogenic activities. Natural sources are universally distributed throughout the crust and can be reached by rainwater and contaminate groundwater and surface water. Historically, many As compounds have been used in agriculture, medicine, livestock, electronics, industry, and metallurgy. As a result, a huge amount of As has been discharged into the water bodies by humans [74-76]. Arsenic mobilised from the aforementioned sources has been reported at concentrations up to $24000 \mu\text{g L}^{-1}$ in surface and groundwater sources (Table 3). The World Health Organization [76] guideline is down from $10 \mu\text{g L}^{-1}$ to $50 \mu\text{g L}^{-1}$ in 1993. As a result, many parts of the world exceed the limits set for safe drinking water supplies. Arsenic exposure can cause immune-suppression in humans [78]. The generation of reactive oxygen species (ROS) is one of the possible mechanisms suggested for arsenic toxicity [79-82]. Arsenic metabolism can be characterized by two main types of reactions such as redox reactions of arsenate to arsenite and oxidative methylation reactions in which arsenite are sequentially methylated to form mono-, di- and trimethylated products using S-adenosyl methionine (SAM) as the methyl donor and glutathione (GSH) as an essential co-factor High arsenic levels have been reported in Argentina, Australia, 118 New Zealand, Mexico, India and Thailand. However, the highest levels of arsenic in water resources reported were for Bangladesh and India, where nine districts in West Bengal, India, and 59 districts in Bangladesh had arsenic levels in excess of the WHO guideline value ($10 \mu\text{g/l}$) [74, 79, 85].



Table 3. Arsenic concentration in groundwater in different states and districts of India (acceptable limit 0.01 mg/L, permissible limit 0.05 mg/L)

| S. No. | State | District | Type of water | Minimum Value (mg/L) | Maximum Value (mg/L) | References |
|--------|----------------|---|--|----------------------|----------------------|------------|
| 1 | Andhra Pradesh | Medak | Hand pump, bore well, dug well, industrial effluents and open stream | 0.00 | 1.26 | 72 |
| 3 | Bihar | Bhojpur, Patna and Samastipur | Test wells, Tube Wells | BDL | 0.14 | 74 |
| 4 | Chhattisgarh | Rajnandgaon | Tube wells and dug wells | 0.15 | 0.99 | 79 |
| 5 | Haryana | Ambala, Kurukshetra, Yamuna Nagar, Panchkula, Kaithal, Fatehabad, Karnal, | | | | 81 |
| 6 | Jharkhand | Ranchi | Wells and bore wells | 0.00 | 0.20 | 84 |
| 7 | Karnataka | Yadgir and Raichur | Tube well and dug well | 0.00 | 0.30 | 85 |
| 8 | Maharashtra | Thane | Bore well and dug well | 0.01 | 0.50 | 62 |
| 9 | Manipur | Bishnupur and Imphal East, West, Thoubal and Bishnupur | Tube well | 0.01 | 0.50 | 73 66 |
| 10 | New Delhi | Central and southeast districts of NCT | Hand pumps and bore wells | 0.00 | 0.10 | 64 |
| 11 | West bengal | Nadia | Drinking water, and shallow tube wells | BDL | 1.36 | 85 |
| 12 | Uttar Pradesh | Ballia and Ghazipur | Hand pumps, deep bore well and tube wells | 0.00 | 0.62 | 60 |
| 13 | Punjab | Bathinda, Barnala, Ludhiana, Bari Doab Region, Faridkot, Ferozpur, and Muksar Sangrur | Tube well and dug well, hand pump, municipal water supply | BDL | 0.26 | 77 |
| 14 | Tamil Nadu | Thoothukudi | Open wells and bore wells | 0.00 | 0.08 | 86 |

The wide human exposure to this compound through drinking water throughout the world causes great concern for human health [87]. Arsenic containing drinking water has been associated with a variety of skin and internal organ cancers [88]. Long-term exposure to arsenic in drinking water can lead to cancer of the liver, lung, kidney and bladder [89,90]. The higher level of arsenic in drinking water may result in an increase in childhood liver cancer mortality rate [91] reported that prostate was a target for inorganic arsenic carcinogenesis [92].

Arsenic toxicity in human

Symptoms of acute arsenic poisoning usually occur within half an hour of ingestion but may be delayed if arsenic is taken with the food. Early symptoms of arsenic intoxication may be muscular pain, abdominal pain with nausea, vomiting and diarrhea, flushing of skin. Chronic intake of inorganic arsenic causes a variety of health problems, including skin, lung, liver, kidney, and urinary bladder cancers (IARC, 1980). Increased exposure of arsenic is also associated with non-insulin dependent diabetes mellitus [60] associated with non-insulin dependent diabetes mellitus [75]. The children with high arsenic in their hairs have less height than the children with low arsenic [89]. Arsenic contaminated drinking water is also responsible for growth retardation, spontaneous abortion, stillbirth and infant mortality [65-70] and diverse health effects of arsenic are shown in Fig. 2.

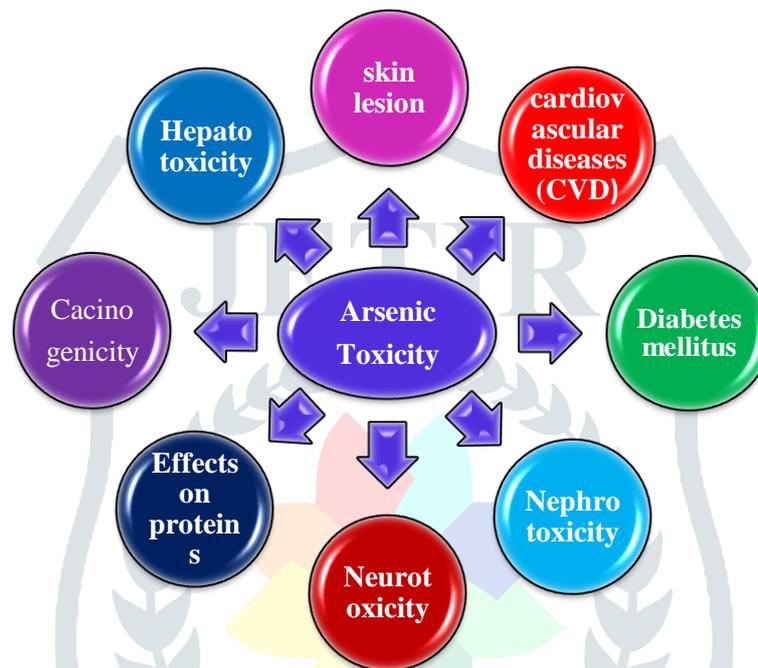


Fig. 2. Adverse health effects of arsenic

Plant uptake of arsenic from soil and irrigation methods

Arsenic distribution in soils is reported within a widely variable range upto 43,500 mg kg⁻¹ (Table 3). Arsenic above the European Union (EU) recommended maximum acceptable limit for agricultural soil (20 mg kg⁻¹) [75], has been associated with mining activities, contaminated groundwater used for irrigation and use of arsenical pesticides [93]. as summarised in Figure 2. Arsenic pollution of soil by irrigation water, followed by crop absorption, provides a serious public health danger. There are relatively few studies that have identified a positive correlation between arsenic concentrations in soil and irrigation water and between arsenic uptake by rice and arsenic in soil water [91-95]. (2009) have shown that potatoes irrigated with arsenic-rich water have 35 times more arsenic compared with other crops [96]. They also demonstrated arsenic absorption from polluted irrigation water by beet, carrot, and wheat crops. When it comes to water, the majority of monitoring studies have focused on total arsenic, with only a handful looking at the different arsenic species that are present. Studies that have measured arsenic species in soils have reported higher levels of the less toxic As⁺⁵ compared to As⁺³ [88, 97]. Similarly, have demonstrated that root, shoot and leaf tissues contained mainly inorganic As⁺³ and As⁺⁵ species, while rice grains contained predominantly DMA (85 to 94%) and As⁺³ [99]. Generally, there are few that evaluate the quantification of the influence of arsenic contaminated irrigation water, accumulation of arsenic in top soils, land degradation pattern, relationship between water-soil-plant system and risks of arsenic contaminated irrigation water to crop production, specifically from the perspective of arsenic species.

Carcinogenicity: Long-term effect of chronic expose to inorganic arsenic causes skin, lung, liver, kidney and urinary bladder cancer (IARC, 1980). Carcinogenic agents are classified as either genotoxic or non-genotoxic. Inorganic arsenic is indirect-genotoxic carcinogen of lungs, skin and several internal organs in the humans (IARC, 1987). The biochemical action of inorganic arsenic carcinogenicity includes inhibition of DNA repair enzyme and DNA methylation, interference with tubulin dynamics and mitosis, induction of oxidative stress, and promotes cell clone immortalization (USEPA, 1997). The genotoxicity of inorganic arsenic includes both structural and numerical chromosomal abnormalities, increase in sister chromatid, gene amplification, and cell transformation [99-100]. Thus, arsenic is probably a promoter or progre1987). Arsenic has been associated with lung cancer in the workers of manufacturing unit and to people, who worked in the industries of arsenic containing pesticides, chemical and metals smelting area rather than a true carcinogen (IARC).

Neural Toxicity: Both the peripheral and central components of the nervous system can be damaged by arsenic [101]. The adverse effects of chronic exposure to drinking arsenic water on nervous system are reversible peripheral neurological damage. Exposure to inorganic arsenic for a long period was associated with cerebrovascular disease cerebral infarction and peripheral neuropathy, which is similar to the Guillain-Barre syndrome [58]. Chronic arsenic exposure can lead to mental retardation and developmental disabilities such as physical, cognitive, psychological, and sensory as well as speech impairments [51-60]. Besides these problems, arsenicosis diseases may cause psychological harms and affect mental health [60]. The other effects of arsenic exposure are change in behaviors, confusion, disorientation, memory loss and cognitive impairment [61-67].

III. STANDARD METHODOLOGIES FOR DETECTION OF ARSENIC

Standard methodologies for detection of arsenic have been reported with and without using sample pre-concentration or extraction method till date. As the analysis of arsenic generally relies on collection media for pre-concentration, regardless of their phase, one needs to know how effectively their extraction proceeds in the sampling stage [102]. It has always been a challenge to extract the entire target species with sufficiently good efficiency due to large variations in their physicochemical properties (e.g., volatility and reactivity). For the investigations, a substantial volume of raw water samples was collected at a time from various arsenic-affected areas of Rajnandgaon, such that all sites investigated would be from the same source for a series of trials. Hydride generation-atomic absorption spectrophotometry (HG-AAS) with an ABCD (Manufacturer, Location) apparatus is commonly used. Other HMs (Cr, Mn, Cu, Zn and Pb) were analysed by graphite furnace-spectrophotometry (GF-AAS) and 5 inductively coupled plasma-atomic emission spectrometry (ICP-AES). High-Performance Liquid Chromatography-Hydride Generation-Atomic Fluorescence Spectrometry (HPLC-HG-AFS) is used to detect the levels of As(III), As(V), monomethylarsonic acid (MMA) and dimethylarsinic acid (DMA) present in apropos of quality control/quality assurance, standard calibration curves were prepared for the analysis of As and other elements in the water samples using the multi element standard solution for analysis [95]. The relevant reference material is used for analysis of the elements in the solid samples. For arsenic four standards were prepared for the calibration of the atomic absorption spectrophotometer. These are as follows: 1.0000 mg/L, 2.0000 mg/L, 3.0000 mg/L and 4.0000 mg/L. The calibration curve prepared and absorption should be a linear curve. 5.0 mL of 0.5 mol/L H₃PO₄ were added to 0.2 g of sample in centrifuge tubes, which can shake overnight so that the acid and the sample reacted completely, ensuring good As extraction [103]. The next day, the samples were taken off the shaker and placed in the centrifuge for 10 min at ABCD rpm. The extract was filtered using 0.45 µm PTFE disc filters. 2.0 mL aliquots were taken from each sample and were then diluted to 10 mL with sodium phosphate buffer (filtered), which are the mobile phase for HPLC. High-Performance Liquid Chromatography-Hydride Generation-Atomic Fluorescence Spectrometry (HPLC-HG-AFS) was used to detect the levels of As(III), As(V), monomethylarsonic acid (MMA) and dimethylarsinic acid (DMA) present in apropos of quality control/quality assurance, standard calibration curves can prepared for the analysis of As and other elements in the water samples using the multi element standard solution for analysis [104-115]. The relevant reference material can also use for analysis of the elements in the solid samples. Analysis of the arsenic in the water samples is done with the use of the atomic absorption spectrophotometer (AAS) following the method of environmental protection agency (EPA) for flame absorption spectrophotometry. AAS not only detect the arsenic but, it is also providing the concentration of arsenic in part per million (ppm). Four trials were run on each water sample and the average of the concentration is then taken.

IV. CONCLUSIONS

The measured plant uptakes were generally best correlated to cadmium arsenic concentration. This would indicate that arsenate concentration should be of as much concern as cadmium concentration in the ground water and soils. This paper also favours the significant plantation of *Calotropis Procera* (oak) and *parthenium* as a better phytoremediation species in combating the soil arsenic cadmium levels for those areas facing excess arsenic contamination owing to it being a wild nature, easy growth in terrestrial and arid environment. For the same vegetable species, the uptake of As was largely determined by the combined effects of As in the soil solutions; plant uptake of As tended to be reduced with increasing ratio of soluble arsenic to soluble As in the soils. However, it was clear that vegetable plants with the highest plant tissue-borne As was limited to the sampling locations with lower concentration of soluble.

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