Water Practice & Technology

© 2024 The Authors Water Practice & Technology Vol 19 No 4, 1071 doi: 10.2166/wpt.2024.072

Implicating the effects of consuming water with a high level of arsenic content: highlighting the cause and consequences of arsenic contamination in drinking water

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ABSTRACT

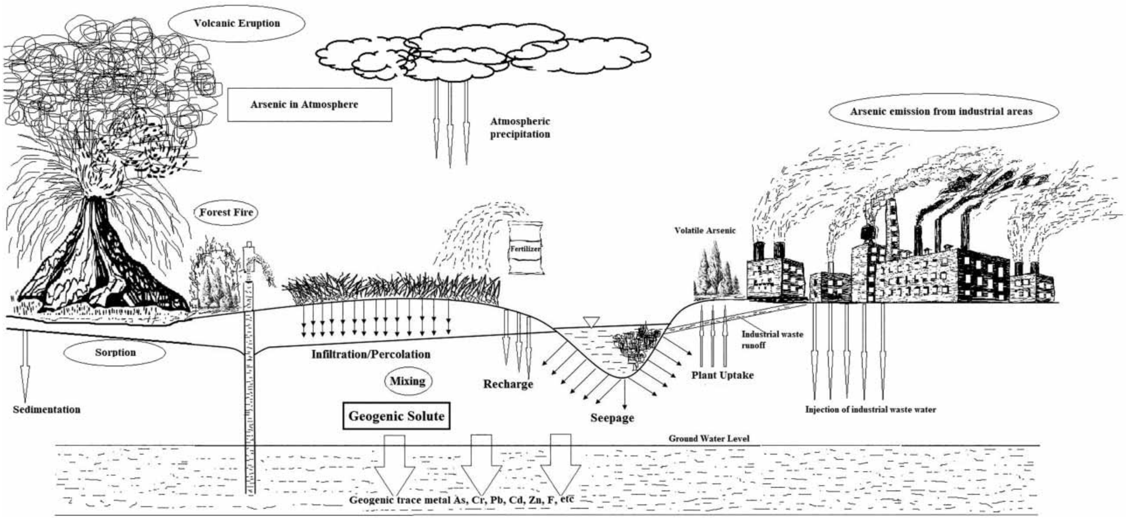
Contamination of groundwater due to arsenic (As) and problems faced by drinking the contaminated water have been identified worldwide. The integration of biogeochemical processes has led to the dissolution of naturally occurring As into the groundwater. The goal of this investigation is mainly to determine the presence of As in drinking water and consequences faced by human beings by drinking such contaminated water. Scope of this issue has not yet undergone a full epidemiological examination in any Indian region. However, in India, little is known about the disease caused by arsenicosis. Therefore, the present study discusses various natural and anthropogenic sources of As in groundwater involving its speciation and mobilization pattern in groundwater. Appropriate review on the issues of As contamination in groundwater has been conducted in various regions across the globe followed by the epidemiology and toxicity mechanisms of As in human beings. Various remediation techniques have been adopted for mitigating the major impact of As contamination depending upon the conventional, modern, and hybrid technologies for removing the As from several regions of India.

Key words: arsenic contamination, arsenic content, drinking water, groundwater, health issues, toxicity

HIGHLIGHTS

- A detailed discussion has been done on global groundwater contamination through various sources with ranges, the mechanism of arsenic contamination within the groundwater system, the sources, speciation, and mobility of arsenic.
- A detailed discussion has been done on health risks caused by the consuming water contaminated with arsenic.
- Effective techniques for the removal are studied.

GRAPHICAL ABSTRACT



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1. INTRODUCTION

Arsenic (As) is a semi-metallic element belonging to Group 15 of the periodic table and it is steel-grey. As is found at a concentration of 1.8 parts per million (ppm) in the crust of the Earth. It is not found in its elemental form; instead, it can be found as sulfides (As_2S_3) and sulfosalts such as arsenopyrites (FeAsS). As is deadly in all of its forms. As is an element with redox-sensitive, and its mobility in the groundwater is influenced by pH and redox potential (Perkins 2022). Under normal redox potential conditions in aquatic systems, As is stable in four oxidation states: (−3, +3, +5, and 0). Trivalent arsenite (As^{3+}) and pentavalent arsenate (As^{5+}) are, nevertheless, the most common types. The different As species mainly vary regarding toxicity in the following order such as arsenite > arsenate > monomet hylarsonate (MMA)>dimethyl arsenate (DMA) (Young *et al.* 2018).

Groundwater contamination from naturally occurring high As concentrations in deeper layers of groundwater is known as As contamination. As is a prevalent component in groundwater all across the world, and the Ganga–Brahmaputra region is among the most heavily contaminated regions worldwide. The use of tubewells for water delivery in the Ganges Delta is an issue, resulting in chronic As poisoning. Arsenous acid (H_3AsO_3) and As acid (H_3AsO_4), or their derivatives, can be found in As-contaminated water. Arsenate ($H_2AsO_4^-$) and arsenite are the two most common inorganic forms of As in water (H_2AsO_3). Water redox and pH potential affect the stability of As(V) and As(III) in aquatic environments (Engwa *et al.* 2019). At low pH (NpH 6.9), $H_2AsO_4^-$ predominates, whereas at higher pH, $HAsO_4^{2-}$ levels are high. In extremely acidic and alkaline circumstances, H_3AsO_4 and AsO_4^{3-} respectively, may be present. As a result, understanding the chemical forms of As is critical for accurate data on the geological cycle of As as well as toxicological importance. In drinking water, the amount of inorganic As (iAs) is usually N95% of total As (tAs), which is easily absorbed in the gastrointestinal system. The gastrointestinal tract and lungs absorb approximately 80–100% of the As breathed and consumed. Conversely, methylation in the kidneys eliminates up to 50–70% of the absorbed As, which is then excreted through urine. As tends to accumulate in the nails, hair, and other tissues when more As is consumed than eliminated (Moulick *et al.* 2021).

Discussions about locating substantial sources of As contamination in groundwater are still being considered. However, the origin of the As in groundwater has previously been identified by geological surveys conducted by the Central Ground Water Board and India. As per the organization's perspective, sedimentation is caused by the current drainage system of rivers or water bodies. Additionally, As might be sourced from the coalfields, which would transport As minerals to the sediments from the mine workings. In particular, a commonly accepted thought is that As in groundwater in the lower Gangetic delta has come from As-rich sediments carried from the highlands of Chotonagpur-Rajmahal (Kononenko & Frishman 2021). As leaching in groundwater, according to some researchers, is caused by the extensive groundwater use for irrigation purposes. During the 1980s in seven districts of West Bengal, summer paddy cultivation expanded throughout the area resulting in a significant change in the irrigation sector. To obtain groundwater at the time of cropping of Boro mainly relies on the use of tubewells. Hence, on groundwater levels, Boro irrigation has a significant effect. The major source of As in the As sulfite minerals formed with the clay in the reducing environment in groundwater, which occurs mainly in the shallow zone, i.e., 20–60 M (Qiu *et al.* 2020). As sulfides were oxidized and made soluble in water by aeration, which was brought on by the summer session's rapid decline in groundwater levels.

Contamination of groundwater due to As and problems faced by drinking contaminated water have been identified globally. Many countries have reported As poisoning in their drinking water, including Chile, China, Myanmar, Mexico, Thailand, Nepal, Argentina, the United States, Taiwan, and Cambodia, but the degree of contamination in India and Bangladesh is unique. Skin cancer, keratosis, and pigmentation are thought to be common indications of chronic As toxicity brought on by consuming contaminated water (with water) over an extended period. In 1983, when some peasants in India were diagnosed with Asosis after drinking As-contaminated water, considerable As poisoning in groundwater was discovered. From previous studies, it has been known that almost 6 million individuals have been exposed to As-contaminated groundwater (>50 μg/L). From the perspective of contaminated water in India, As has also been found in groundwater in Bihar, Jharkhand, Chhattisgarh, Uttar Pradesh, and Assam (Tchounwou *et al.* 2019). Inactivation of the enzyme system by interacting with diverse biological ligands is the most typical form of As toxicity in humans. Some of these harmful consequences on human health are currently being reported in Pakistan because of the ingestion of As-contaminated surface water and groundwater. Hyperpigmentation, particularly on the trunk, and keratosis on the palms and soles are the most typical signs of As exposure. Although lower latencies have been documented,

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these skin lesions usually appear 5–10 years after the initial exposure (Adeloju *et al.* 2021). In Haque *et al.* (2003), a nested case–control study was conducted for characterizing the dose–response relation between As-induced skin hyperpigmentation and keratoses and low concentration of As in drinking water. Here, the findings showed that the average latency for skin lesions after initial exposure was 23 years, with average peak As concentrations in drinking water of 180 g/L for controls and 325 g/L for cases. The researchers also noted strong dose–response gradients with average and peak As water concentrations. The researchers herein observed that chronic cough, lung crepitation, diabetes mellitus, hypertension, and weakness are only a few of the other signs and symptoms that have been reported. Asosis causes a variety of symptoms, including peripheral vascular disease (PVD), chronic respiratory disease, weakness, liver fibrosis, peripheral neuropathy, and so on. Furthermore, it is also a matter of concern that safe drinking water which is free of As is not available in all of the state's As-affected villages (Yang *et al.* 2020).

2. LITERATURE REVIEW

2.1. Global overview of groundwater As contamination

One of our planet's most valuable natural resources is groundwater. It has been extensively exploited in many places of the world, with substantial increases in extraction in recent decades because of the availability of less expensive and new pumping as well as drilling technology. In groundwater use, hydrogeologists refer to this significant development as the silent revolution because it happened in many countries in an unplanned and generally uncontrollable manner (Bustaffa *et al.* 2020). With regard to development activities and the increasing population around the world, high-quality groundwater demand has skyrocketed. One of the century's biggest difficulties with the world's 7.8 billion inhabitants is providing safe drinking water. Groundwater quality issues were limited at the turn of the century, with pH and total dissolved solids being primary characteristics to be concerned about. However, in the 21st century, a greater focus is there in tackling issues related to groundwater quality on a global scale. Depending on the inputs from various non-natural and natural sources, the duration of rock–water contact, and the kind of aquifer groundwater chemical quality varies greatly (Manczak *et al.* 2020). From diverse chemical constituents, contamination of groundwater from aquifers has been recorded around the world in the past decade, and in many cases, the water has become non-potable since the contents exceed WHO guidelines.

Globally, there have been reports of As pollution in groundwater, with South American and South Asian regions accounting for the majority of these cases (Danes *et al.* 2021). Countries that get severely affected include India, Nepal, China, Laos, Cambodia, Vietnam, the USA, Myanmar, and Indonesia. Some other countries also get affected such as Hungary, South Africa, Chile, Mexico, Pakistan, Canada, and Argentina. Southeast as well as South Asian Belt, which includes Bangladesh, China, Vietnam, Nepal, and India, is considered the most As-polluted region (Bhowmick *et al.* 2018). In groundwater, As contamination is also more in affluent countries, such as the United States and Canada than others in Asian countries, but concentrations are typically lower. According to a recent study, As poisoning in groundwater affects 107 nations (maximum limit of 10 ppb allowed by WHO), with reports coming from majorly Europe (31) and Asia (32), followed by North America (11), Australia (4), South America (9), and Africa (20). The majority of hotspots in As pollution are found near deltaic areas and current mountain belts in sedimentary basins. Tropical climates are especially sensitive to As contamination because the weather conditions encourage As release from compounds of As. Information on the 108 affected countries is displayed on a world map. According to the research done by Ravenscroft *et al.* (2011), the natural contamination of As in groundwater has been seen in more than 70 different countries, and the concentration of As in groundwater ranges from 0.5 to 5,000 ppb. According to Shankar & Shanker (2014), aquifers around the world have been the site of some of the most significant incidents of groundwater contamination by As. In this regard in the Ghazni region of Afghanistan, it has been noted that the ppb ranges from 10 to 500, wherein the permissible limit (ppb) by WHO is 10. In regions of Bangladesh like Noakhali, where the permissible limit (ppb) as per WHO is 50, the groundwater As level (ppb) has been recorded to be within the wide range of <1–4,730. In China, where according to WHO's guidelines the permissible limit (ppb) is 50, whereas the groundwater level (ppb) is 50–4,440. The status of natural groundwater contamination in different nations along with the permissible limit can be effectively elaborated in Table 1.

Based on the above-provided table, it can be inferred that the generally set As concentration in groundwater is 10 ppb, though it can reach up to 50 ppb. It is on the basis of the provided comparison based on which it can be

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Table 1 | Status of natural groundwater contamination in different nations

Country	Region	Groundwater As level (ppb)	Permissible limit (ppb)
Cambodia	Prey Veng and Kandal-Mekong delta	Up to 900 1–1,610	10 (WHO)
Canada	Nova Scotia (Halifax county)	1.5–738.8	10 (WHO)
Finland	Southwest Finland	17–980	10 (WHO)
India	West Bengal Uttar Pradesh	10–3,200	50 (WHO)
Greece	Fairbanks (mine tailings)	Up to 10,000	10 (WHO)
Japan	Fukuoka Prefecture (southern region)	1–293	10 (WHO)
Nepal	Rupandehi	Up to 2,620	50
Taiwan	–	10–1,820	10 (WHO)
Pakistan	Muzaffargarh (southwestern Punjab)	Up to 906	50
Thailand	Ron Phibun	1– > 5,000	10 (WHO)
Vietnam	Red River Delta (Northern Vietnam) Mekong Delta (Southern Vietnam)	<1–3,050	10 (WHO)
USA	Tulare Lake	Up to 2,600	10 (USEPA)

opined that As contamination in groundwater is a major concern across the globe and the provided guidelines are being exceeded to a large extent.

Volcanic activity and geothermal fluids are the major sources of As pollution in groundwater in Latin America (Cui *et al.* 2020). The main source of drinking water in Mexico (North America) is groundwater (40%) and significant concentrations of As >10 ppb have been observed in several sections of the country's groundwater. In Mexico, among the total population, 1.5 million people drink water with an As concentration of more than 25 g/L, and by As over 150,000 people are poisoned (Abdul *et al.* 2015). According to a new study, presently 8.81 million individuals are exposed to groundwater with elevated As levels. Conversely, in water resources high As content has been found in North American regions such as El Salvador and Guatemala, whereas volcanic source has been recognized as the main reason behind it, can be effectively elaborated as shown in Figure 1.

On the other hand, groundwater As with high concentrations (45.9 g/L) has recently been found in Bolivia, South America, with the source being Neogene volcanic deposits. In the southern half of Argentina's Chaco-Pampean plain in a similar manner, the groundwater is characterized by Tertiary aeolian loess-type deposits and high As levels in the Pampean plain, as well as quaternary and tertiary river sediments (Rai *et al.* 2019). Additionally, in many nations in a report of Europe, in groundwater supplies high As levels have been found (particularly Greece, Hungary, Turkey, Croatia, Spain, Romania, and Serbia) (Katsoyiannis *et al.* 2015). In the same way, the groundwater resources of the Pannonian Basin (Romania, Serbia, Hungary, and Croatia), water is naturally As with significant levels. Zuzolo *et al.* (2020) conducted a study that found As pollution in groundwater resources in central Italy. On the contrary, Togo, Morocco, Burkina Faso, Ethiopia, South Africa, Zimbabwe, Tanzania, Botswana, Ghana, and Nigeria are among the African countries that have been hit the hardest. As contamination affects both surface and groundwater resources in all of these African countries, albeit the extent of the contamination varies by location.

2.2. Mechanism of As contamination within the groundwater system

As is mostly found in the terrestrial environment in the form of an inorganic compound, which, under aerobic conditions, exists as pentavalent As(V) and under anaerobic conditions presents as trivalent As(III).

At the physiological pH of an aqueous solution, As(III) is commonly encountered as a species that is neutral in nature ($As(OH)_3$, pKa = 9.2). Toxicity is varied for As(III) and As(V). A pore protein, namely, Aquaglyceroporins for tiny organic molecules, like urea and glycerol transportation, can transport As(III) into cells because of its

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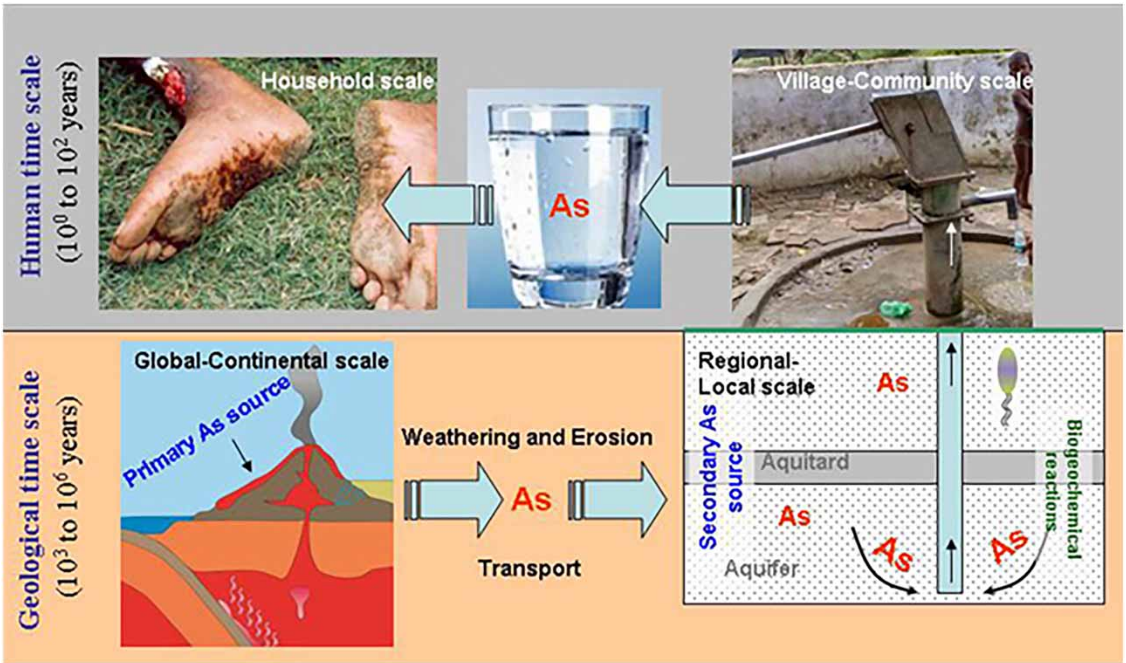

Figure 1 | Global geological processes and As contamination at a local scale influencing individual human health. Adapted from Mukherjee *et al.* (2019).

structural similarities to glycerol (Corradini *et al.* 2018). In animals and human cells, however, As(V) follows a different route. They have similar dissociation values as phosphate analogs (pKa of As acid is 11.3, 6.76, and 2.26; pKa of phosphoric acid is 7.21, 12.3, and 2.16). As oxyanions in solution, As(V) is present in water, such as $HAsO_2^{2-}$ and $H_2AsO_2^-$ at pH lies between 5 and 7, similar to phosphate. They fight to reach the entrance into transporters of phosphate because they are chemical analogs (Das 2019). As(V) is quickly converted to As(III) after entering human and animal cells. Then, as the methyl donor using S-adenosylmethionine (SAM), As(III) passes through a series of stages in cells via arsenite methyltransferase (AS_3MT) it can be effectively elaborated in Figure 2. This particular step resulted in methylated As compound formation including MMA(III), DMA(III), MMA(V), and DMA(V). The traditional As methylation route was first postulated by Challenger. As methylation, according to him, requires a series of oxidation and reduction processes (Liu *et al.* 2021). Following that, it has been proposed that As(III) can be methylated nonenzymatically in the presence of both glutathione and methylcobalamin. Researchers then investigated the process of As methylation in various experiments and determined that enzymes play a critical role in the methylation of As. A new metabolic pathway has been discovered with enzymatic reaction properties for As methylation. $As(OH)_3$ by glutathione moieties get replaced by its –OH groups, resulting in $As(GS)_3$ and GSH conjugates As $(GS)_2$–OH (Singh *et al.* 2019). Then to dimethylarsinic glutathione DMA and to monomethylarsonic diglutathione $MMA(GS)_2$, As(III)-glutathione complexes methylated, which are the primary substrates for AS_3MT(GS). Due to the instability of DMA(GS), to pentavalent DMA(V) it quickly gets oxidized, which is ejected from cells and is known to be the main metabolite.

2.3. In groundwater mobility, speciation, sources of As

The groundwater pollution with As is attributed to a number of natural and manmade sources. Dissolution and desorption of alluvial sediments and naturally occurring As-bearing minerals, even if the As concentration in the solid phase is not high, result in high As concentrations in groundwater in alluvial and deltas plains. As is a crucial component of more than 200 minerals, and dissolution as well as desorption of naturally occurring alluvial sediments and As-bearing minerals, in groundwater in the case of alluvial plains and deltas even though the As excess metalloid concentrations may be linked to ore deposits where As is primarily found in sulfidic minerals like pyrite and arsenopyrite result in high As concentrations. The As-containing mineral known as the most abundant one is namely Arsenopyrite (FeAsS) usually found in anaerobic conditions, as well as in rock-forming minerals with a variety of other measures such as oxide, silicate, carbonate, phosphate, and sulfide (Huang

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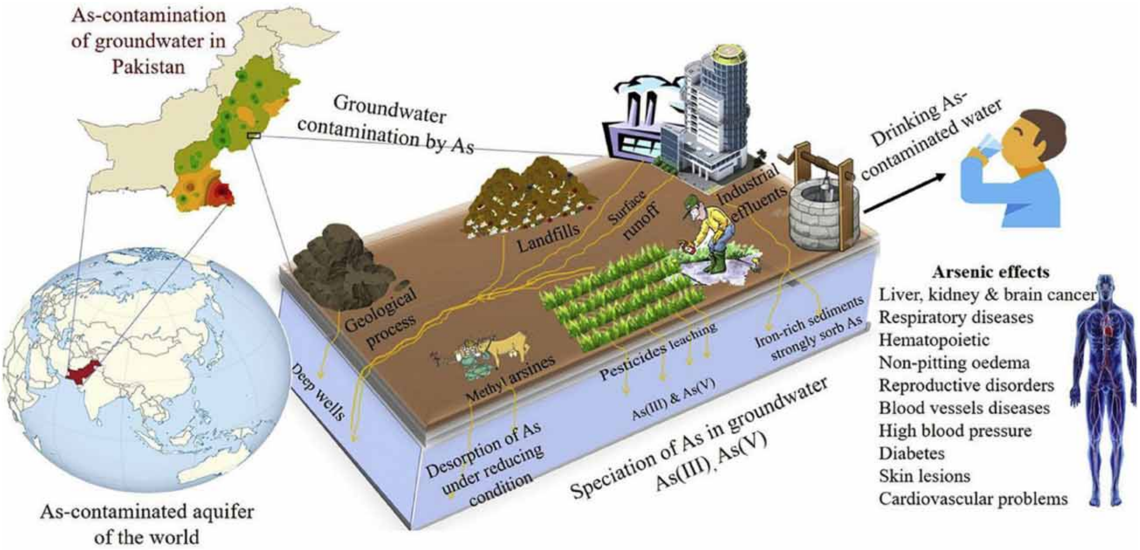

Figure 2 | Various sources and effects of As contamination. Adapted from Shahid *et al.* (2018).

et al. 2018). Of certain sulfide minerals in the crystal lattice, as a replacement for S, it exists. The two most prevalent reduced forms of As are realgar (As_4S_4) and orpiment (As_2S_3), whereas oxidized forms of As are present in arsenolite (As_2O_3) (Shaji *et al.* 2021). In sediments of 1 kg, depending on the texture and structure of minerals As can be found under concentrations belonging to 3 mg to 10 mg. In comparison to other oxides, sediments in places with large quantities of pyrites, hydrous metal oxide, or Fe oxide have As in extremely high levels. As concentration steadily increases with increasing sediment depth and its concentration in decreasing sediments is high (Alka *et al.* 2021). The accumulation of As and Fe oxides in sediment increases groundwater contamination. Predominant release mechanism of As is presently seen in addition to the activity of indigenous metal-reducing bacteria directly affecting the reductive dissolution of As and Fe metal oxides. Mining fossil fuels the combustion of in agriculture wood preservatives, as well as the use of herbicides, insecticides, and arsenical fungicides, are the major anthropogenic sources of groundwater As pollution. Coal combustion has a significant impact on As pollution in the environment. As is released into the environment due to the volatilization of As_4O_6 caused by coal combustion, the flue system condenses and is eventually transferred in water reservoirs (Shaji *et al.* 2021).

In groundwater, As or As is generally found as oxyanions, which can be either As (+5), which is known as arsenate, or As, known as arsenite. With two different oxidation states: As As(V) (arsenate) and As As(III) (arsenite), these oxyanions usually come. Within thepH range from 6 to 9, both As(III) and As(V) occur. Uncharged H_3AsO_3 is the most common As(III) species, while monovalent H_2AsO_4 and divalent $HAsO_2^{4-}$ are the most common arsenate species. The major form is As(III) or As(V), depending on the geology and groundwater environment. Although in anoxic waters As(III) and As(V) in oxic waters are thermodynamically preferred, in both of the cases, they coexist. In understanding and explaining the properties, as well as behavior of As in the environment (mobility, solubility, etc.) in a number of localized investigations the importance of As speciation information has been described (Palma-Lara *et al.* 2020). As(III) and As(V) have different levels of removability and As-related toxicity. As(III) is more hazardous than As(V) and more difficult to extract from the water.

2.4. Health risks due to consumption of water with As content

The exposure of As in water for consumption has shown a major health impact on humans due to the ingestion of inorganic As content. The presence of inorganic As pollution coming from natural sources has been demonstrated by the long-term exposure of the As level in water for consumption. Additionally, natural resources have been used to create pollution from the industry. The sources of the exposure of As content are present in the form of industrial effluent, medicinal use of As, and arsenical pesticides. Contaminated drinking water has been considered a major health hazard among developing countries as infectious diseases are prevalent involving the different pathogens and parasites to cause major health risks to the population (Baker *et al.* 2018). The

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pathogenic bacteria are responsible for impacting the appearance and taste of the water for consumption. Along the pathogens and parasites in drinking water, the occurrence of naturally occurring As in the groundwater affects millions of populations who have been prone to drinking contaminated groundwater for several years (Palansooriya *et al.* 2020).

As is found naturally in the rocks and its little amount gets dissolved into the groundwater that is further used for consumption. As in drinking water increases the risk associated with cancer and other major health concerns (Abdul *et al.* 2015). The As even present in a lower amount in drinking water over a longer duration is concerned with diabetes and elevated risk of cancer of the lungs, bladder, liver, and other organs. As also is responsible for causing the risk of cardiovascular and respiratory diseases with reduced intelligence in children, causing skin problems involving lesions, discoloration, and the development of corns. The changes in the skin involve thickening and pigmentation. The exposure level of As in drinking water leads toward increasing cases of skin changes, lung and bladder cancer and even consumption with a concentration of 50 μg/L, or even lower. Also, exposure to As content in the workplace is caused due to inhalation causing lung cancer (Ahmed *et al.* 2021).

As has been known to affect approximately 150 million individuals across the globe with its increasing exposure level with higher concentration in the water for consumption (Stroud *et al.* 2011). The effects of As in drinking water have been mainly observed among the regions of large deltas along major river basins across the globe (Chakraborti *et al.* 2010; Fendorf *et al.* 2010; Shukla *et al.* 2010; Mirlean *et al.* 2014). Hence, the presence of As in the food chain will directly enter the food chain of human beings, thus resulting in long-term risks to humans and the ecological system (Tuli *et al.* 2010). Some of the major variants of As have a major effect on the human body when consumed in the form of drinking water. The variant of As As(III) shows more toxicity when compared with As(V) as representing inorganic As to be more toxic than organic As (Petrick *et al.* 2000; Thomas & Bradham 2016). Methylation and excretion have been considered as the detoxification system in the past decades. But in the modern day, when taking into account human metabolism, these methylated forms have been known as the most harmful forms of arsenic. The long-term ingestion of As through drinking water has mainly resulted in the emergence of different types of cancer in human beings. The symptoms and ill effects of consuming arsenic-contaminated drinking water involve the region-specific along with individual specific to some extent. The reports have revealed that the individuals who are well-nourished are suffering from less damage due to As contamination when compared with those individuals who are malnourished. The first care of ill effects caused due to As contamination in drinking water was noted in human beings in the form of skin lesions in the Department of Dermatology, School of Tropical Medicine, Calcutta, India in 1983 (Saha 2003). This makes it essential to discuss the epidemiology. As has been well-known as a human carcinogen. Shankar & Shanker (2014) mentions in this context that there are elevating number of evidence that establishes that a series of gene proliferation processes (i.e., cell cycle, and differentiation, DNA repair and damage) are hindered by arsenic, which also distorts signal transduction pathways. Shi *et al.* (2004) noted that As induces ROS formation, which is known to play a major role in triggering cancer. Further research has revealed that the methylation metabolites of As are strong carcinogens. In Wei *et al.* (2002), it has been demonstrated that among rats, DMA causes urinary bladder cancer. Apart from being identified as a well-known carcinogen, Janssen *et al.* (2002) mentioned that AS can also be reported to cause various other conditions including hypertension, diabetes mellitus, and cardiovascular conditions, which are in alignment with the study conducted by Chakraborti *et al.* (2016). The study by Paul *et al.* (2007) stated that trivalent arsenicals (DMA^{III}, MMA(III), and As(III)) has the ability to induce diabetes through distortion of glucose metabolism, which has been observed on the basis of intact pancreatic islets from mice. Navas-Acien *et al.* (2006) noted that As led inhibition of α-ketoglutarate dehydrogenases and pyruvate, which has been noted to be the major cause of diabetes. It is further mentionable here that hypertension is closely associated with cardiovascular disease.

2.5. Removal of As content from groundwater

The elimination of As is entirely dependent on the chemistry and composition of the arsenic-contaminated water. The occurrence of As is mainly found in the form of As(III) and oxidation of As(III) to As(V) has been known as the satisfactory elimination of As from the groundwater. The chronic toxic impact of As can be mitigated using the consumption of safe drinking water along with the intake of nutritious food and adequate physical exercise. The integration of appropriate watershed treatment and cost-effective conjunctive of water with the motive of generating mass awareness has shown efficacy in solving the As crisis (Shakya & Ghosh 2019). Microbial-based biochemical transformation is undertaken in the presence

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of inorganic As involving the replacement of the hydroxyl group of As acid by the methane group which leads to transformation into a non-toxic form. This activity of the methylation process is promoted by sulfate-reducing bacteria. Also, the fungal species have contributed to the reduction of arsenic.

Along with the use of bacteria, different types of technologies are also being integrated into the elimination of As contamination from the groundwater in various regions across the globe. Electrocoagulation is one of the most efficacious techniques for treating arsenic-contaminated water and fulfilling the standards of the quality of drinking water effectively (Mendoza-Chávez *et al.* 2020). The remediation of heavy metals from the groundwater is mainly carried out by a cement-based filter medium (CBFM) (Holmes *et al.* 2019). Other treatment technologies used for the removal of As content from groundwater include chemical oxidation, coagulation, advanced oxidation processes (AOPs), ion exchange, membrane filtration (nano-filter), adsorption, and reverse osmosis (Table 2).

Table 2 | Summarizing the advantages/disadvantages of some of the key remediation approaches

Remediation approach	Advantages	Disadvantages	Reference
Microbial-based biochemical transformation	Undertaken in the presence of inorganic As involving the replacement of the hydroxyl group of As acid by the methane group which leads to transformation into a non-toxic form.	–	Shakya & Ghosh (2019)
Electrocoagulation	Treats As-contaminated water and fulfills the standards of the quality of drinking water.	–	Mendoza-Chávez *et al.* (2020)
Cement-based filter medium (CBFM)	Remediation of heavy metals from the groundwater	–	Holmes *et al.* (2019)
Oxidation	Oxidation of arsenite by oxygen, ozone, free chlorine, permanganate, hydrogen peroxide, etc.	–	Wegelin *et al.* (2000)
Bucket Treatment Unit (BTU)	Fulfills the household needs	–	Guha Mazumder (2003)
Solar oxidation	Oxidizes As into transparent bottles for the reduction of the As content of drinking water	–	Mukherjee *et al.* (2007)
Biological oxidation	Accelerates biotic-oxidation of iron while making the appropriate situation for adsorbing As	–	Pallier *et al.* (2010)
Nano-filtration (NF) membrane configuration	Removal of As from groundwater	–	Song *et al.* (2015)
Aquifer recharge	Removal of As from groundwater	–	Nguyen *et al.* (2020), Thanh Nguyen *et al.* (2020)

The oxidation process involves the oxidation of arsenite by free chlorine, oxygen, ozone, hydrogen peroxide, permanganate, etc. Atmospheric oxygen, hypochlorite, and permanganate have been frequently used in developing countries. The mechanism of air-oxidation of As is undertaken at a slower rate, but chemicals, such as chlorine and permanganate, are capable of oxidizing arsenite to arsenate at a faster rate under broader aspects (Wegelin *et al.* 2000). Adsorption and co-precipitation are other important processes for removing As content from groundwater involving the treatment of water with coagulants such as aluminum alum, ferric chloride, activated alumina, and ferric sulfate, which are mainly known for the appropriate elimination of As from water. The presence of ferric salts as coagulants has been considered as an efficacious agent for the removal of As content when compared with other coagulants such as alum depending on the weight and showing efficacy at broader aspects of pH. These coagulants have shown efficacy in the removal of pentavalent As when compared to the removal of trivalent arsenic.

The integration of the Bucket Treatment Unit (BTU) has been mainly formulated for fulfilling the household needs that eventually depend on the principles of co-precipitation, coagulation and adsorption processes. Primarily 2 buckets are involved, each with 20 L capacity being placed as one over the other. The chemicals are manually mixed with water-containing As content within 1 of the buckets by vigorous stirring and then flocculated by gentle stirring. The mixed water is further settled down for 1–2 h and later flown

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into another bucket through the installation of a sand filter in the 2nd bucket, thus avoiding settled sludge's inflow in the 1st bucket. This way, the 2nd bucket eventually consists of the treated water (Guha Mazumder 2003).

The conduction of solar oxidation has been considered as the essential technique of oxidizing As into transparent bottles for the reduction of As content of drinking water (Mukherjee *et al.* 2007). The ultraviolet light in solar oxidation is capable of catalyzing the process of arsenite oxidation along with the presence of other oxidants. Various adsorbents have been used for eliminating As species, primarily the As(III) and As(V). The removal of As(III) requires preoxidation of As(III) to As(V) by integrating the use of different oxidizing agents that result in costly processes with the production of unhealthy by-products (Zhang *et al.* 2007; Siddiqui & Chaudhry 2017). In order to eliminate the use of the preoxidation step using costly oxidizing agents, several solid materials have been developed with oxidative properties. Graphene oxide and its composites have been integrated for being used into novel adsorbents for adsorbing water pollutants because of their unique physicochemical traits (Siddiqui *et al.* 2019). Biological oxidation has been carried out by the use of major microorganisms, mainly the *Gallionellaferruginea* and *Leptothrixochracea* that are capable of supporting and accelerating biotic-oxidation of iron while making the appropriate situation for adsorbing As (Pallier *et al.* 2010). The removal of As from groundwater is done by nanofiltration membrane configuration (Song *et al.* 2015). The As content in drinking water can be also removed by managed aquifer recharge from the groundwater. Laterite is integrated with a low-cost adsorbent within the filtration system for removing As from groundwater in Vietnam (Nguyen *et al.* 2020; Thanh Nguyen *et al.* 2020).

3. DISCUSSION

The existing literature makes it clear that As contamination can spread into the groundwater system effectively because it is mobilized in aquifers and groundwater during hydraulic fracturing. As a result, its contamination may have a significant global impact. In the literature, groundwater As contamination is well documented which reveals that a large range of natural As contamination has been found in more than 70 countries ranging from $<$0.5 to 5,000 ppb (Singh *et al.* 2015). As pollution of groundwater has been observed in aquifers all around the world in severe cases. From the literature review, it is evident that As contamination is widespread and quite a severe global phenomenon, and in fact, when people consume arsenic-rich water for prolonged periods, they have been reported to suffer from severe health issues in many parts of the globe. It is now a well-established fact that As(III) is more toxic than As(V) and inorganic As is also more toxic than organic As, indicating that different organic forms of As are associated with different forms of toxicity. As enters the animal and human cells in the form of As(V) quite rapidly it gets reduced to As(III) and after that, through multi-steps in the cells forms the methylated As compounds.

Numerous studies have also shown that As poisoning in humans is a strong carcinogen that causes systemic toxicity and the bladder, lung, skin, and liver malignancies. Excessive production of Reactive Oxygen Species (ROS) harms the organisms responsible for cytotoxicity and genotoxicity (Rao *et al.* 2017). Additionally, it has been found that chronic exposure to As could result in arsenicosis that causes skin lesions, PVD, Blackfoot disease, and cancers. As toxicity causes cell cycle arrest, apoptosis, cell aberrant differentiation, autophagy, cell excess proliferation, oxidative DNA damage, deletion mutations, sister chromatid exchanges, DNA strand breaks, and chromosomal aberrations.

4. CONCLUSIONS

Globally speaking, the contamination of groundwater with As content has been seen as a serious problem. Naturally occurring As is dissolved into the groundwater as a result of the integration of biogeochemical processes. The present study has evolved the discussion on the various anthropogenic and natural sources of As in groundwater involving its mobilization and speciation pattern in groundwater. The epidemiology and toxicity mechanisms of As in humans have been studied after an appropriate examination of the problems of groundwater pollution with As in various parts of the world. Also, various remediation techniques have been adopted for mitigating the major impact of As contamination depending on the modern, conventional, and hybrid technologies for removing As in several regions of India. The various advantages and disadvantages of these technologies have been enumerated in the present study. The existing technologies have been implicated efficiently for removing As content while involving the direct elimination of As(V) and conversion of As(III) to As(V) followed by the elimination of As(V).

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ACKNOWLEDGEMENTS

The authors are grateful to Dr Iffat Ameen, D.D.U. Gorakhpur University, for her valuable advice. They also thank the Department of Civil Engineering, Madan Mohan Malaviya University of Technology, Gorakhpur, India, for providing the necessary laboratory and library facilities.

FUNDING

This research work is not supported by any funding agency.

DATA AVAILABILITY STATEMENT

Data cannot be made publicly available; readers should contact the corresponding author for details.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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First received 30 March 2023; accepted in revised form 12 March 2024. Available online 27 March 2024

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