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Geogenic Arsenic in Groundwater in India- A short review

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Abstract: This short review deals with geogenic arsenic (sources, behaviour, and distribution) in groundwater in India. Arsenic is a metalloid that occurs naturally, being the 20th most abundant element in the earth's crust, and is a component of more than 245 minerals. Arsenic pollution constitutes a serious threat as far as geogenic contaminants are concerned. Recently there has been increasing consternation concerning arsenic-related problems and the occurrence of arsenic contamination has been reported in Argentina, Chile, China, Mexico, Hungary, Canada, and more recently in West Bengal (India), Bangladesh, and Vietnam. The extensive naturally occurring arsenic groundwater issue within the Bengal Basin typically manifests in two distinct environments. Firstly, it is prevalent in inland or enclosed basins situated in arid or semi-arid regions. Secondly, it is found in reducing aquifers originating from alluvial deposits. Arsenic contamination also occurs in specific regions, including the Dongargarh Proterozoic rift zone in Central India and certain localized areas of the Damodar fan delta. In the Dongargarh rift zone, arsenic enrichment is observed in felsic magmatic rocks and weathered rocks and soils within the vicinity. As these are geogenic, their presence in groundwater in certain areas can't be prevented. With the increasing dependence on groundwater for meeting drinking and domestic uses, more and more people are likely to be affected. Arsenic and its release into the groundwater system can occur due to various geological processes, making it challenging to prevent contamination at its source. However, possible remedies such as source identification, alternative water resources (rainwater harvesting, treated water, etc.), water treatments (effective water treatment technologies to remove or reduce arsenic levels in contaminated groundwater), policy implementations, R&D on cost-effective technologies, etc. are very much essential for combating geogenic contamination in groundwater resources and to ensure access to clean and portable drinking water.

Keywords: Geogenic, Arsenic, Groundwater, India.

Introduction

Water is perhaps one of the most important resources for sustaining life on Earth. It is also critical to the commerce, industry, and agriculture sectors. Elevated levels of toxic or other substances exceeding safe thresholds for human consumption can occur as a result of aquifer material dissolution (Singhal and Gupta, 2010). Typically, this form of contamination is responsible for heightened levels of arsenic, fluoride, iron, and various heavy metals in groundwater. Groundwater pollution could be from geogenic or anthropogenic resources (Pradhan and Biswal, 2018). Geogenic contaminations caused by naturally occurring contaminants namely, Arsenic (Nickson et al., 1998; Smedley and Kinniburgh, 2002; Amini et al., 2008; Mukherjee et al., 2008; Mukherjee et al., 2009a; Ladon and Belitz, 2012), while anthropogenic contaminations are caused by human activities (Neumann et al., 2009) such as Nitrate, heavy metals, pesticides, pathogens, salinity due to water logging, sea water ingress, etc. Notably, there has been a considerable research on arsenic over the last few years to understanding of the processes involved has improved as a result of studies carried out in India and its subcontinent (Bhattachrya et al., 1997; Chakraborti et al., 1999; Chowdhury et al., 2000; Nickson et al., 2000; Acharyya et al., 2002; Bhattacharya et al., 2002; Dowling et al., 2002; Chakraborti et al., 2003; Stuben et al., 2003; Acharyya et al., 2005; Ravenscroft et al., 2005; Singh et al., 2006; Michael and Voss, 2008; Mukherjee et al., 2009b) (Fig. 1) and elsewhere (McArthur et al., 2001; Kim et al., 2002; Ning et al., 2002; Nordstrom et al., 2002; Smedley and Kinniburgh, 2002; Schreiber et al., 2003; Ahmed et al., 2004; Anawar et al., 2004; Bhattacharya et al., 2004; Zheng et al., 2004; Charlet et al., 2006; Naidu et al., 2006; Pedersen et al., 2006; Wang et al., 2006; Seddique et al., 2008; Nguyen and Itoi, 2009; Neumann et al., 2009; Fendorf et al., 2010; Radloff and VanGeen, 2011; Phuong et al., 2012) (Fig. 2). Several proposed mechanisms are responsible for arsenic release to the groundwater are oxidation of arsenic bearing sulphides (Welch et al., 2000; Peters et al., 2003) desorption of arsenic from hydr(oxides) coupled with the reduction of the adsorbed arsenate to arsenite (Fuller et al., 1993; Dzombak et al., 1990; Smedley and Kinniburgh, 2002) chemical reductive dissolution of arsenic bearing Fe (hydr)oxides in the aquifer sediments (Nickson et al., 2000; Harvey et al., 2002; Horneman et al., 2004; Gault et al., 2005; Postma et al., 2007; Shamsudduha et al., 2008) release of Arsenic from geothermal water (Welch et al., 2000). The World Health Organization (WHO) guidelines, as well as the Indian Bureau of Standards (BIS, 2012) permissible limit of water for drinking purposes is 10 $\mu g l^{-1}$. This paper presents a comprehensive review of geogenic arsenic in groundwater with special reference to India.

Geochemistry and Geochemical Processes in Groundwater System

Groundwater refers to the water found within the pore spaces and fractures in rock and sediment beneath the Earth's surface. Both surface and groundwater resources fulfil the world's water needs, with groundwater being particularly advantageous due to its widespread distribution and comparative freshness, as opposed to surface water. The increasing global population and their growing requirements have led to escalating threats to groundwater, as indicated by recent studies (Pradhan et al., 2021; Pradhan et al., 2022). Consequently, the demand for groundwater for domestic, industrial, and agricultural purposes has surged, placing immense pressure on this resource (Brindha and Elango, 2011). Unfortunately, overexploitation and inadequate management have also resulted in contamination of groundwater. This degradation can be attributed to either natural factors, such as inherent geological conditions, or human activities, including the release of wastewater from sewage treatment plants, industrial discharges, improper solid waste disposal, the use of agrochemicals, runoff from agricultural fields, and leaks from underground storage tanks, among others (Brindha and Elango, 2011). When the chemical composition of groundwater exceeds prescribed standards for drinking, irrigation, or industrial use, it becomes unsuitable. Contaminants like arsenic, fluoride, nitrate, iron, manganese, boron, various heavy metals, and radionuclides are of particular concern when they exceed permissible limits (Singhal and Gupta, 2010; Pradhan and Biswal, 2018). Groundwater geochemistry study gives an idea of whether the groundwater is suitable for drinking purposes or other uses and also able to know about groundwater pollution. Understanding groundwater chemistry can also tell us a great deal about groundwater flow systems, particularly the relationships between different aquifers, recharge mechanisms, and the relation between groundwater and surface bodies. The various chemical constituents, based on their concentration in water, can be classified as, (a) Major constituents (>1 mgl^{-1}) viz. Ca, Mg, Na, K, HCO_3, SO_4, Cl, NO_3, and SiO_2 (b) Minor constituents (1–0.1 mgl^{-1}) viz. Fe, Mn, F, B and, (c) Trace elements (<0.1 mgl^{-1}), viz. Al, As, Hg, Pb, Cr, Zn, and other heavy metals (Singhal and Gupta, 2010). In addition to the dissolution of rock material, the other processes which change the chemical compositions of groundwater are includes ion exchange (Behera et al., 2019; Pradhan et al., 2022), membrane effect, sulfate reduction, etc.

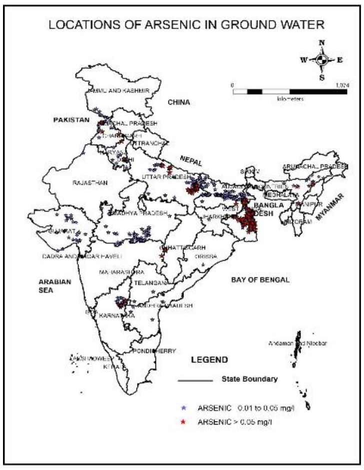

Fig. 1. Arsenic-affected areas in India (Source: https://vikaspedia.in/)

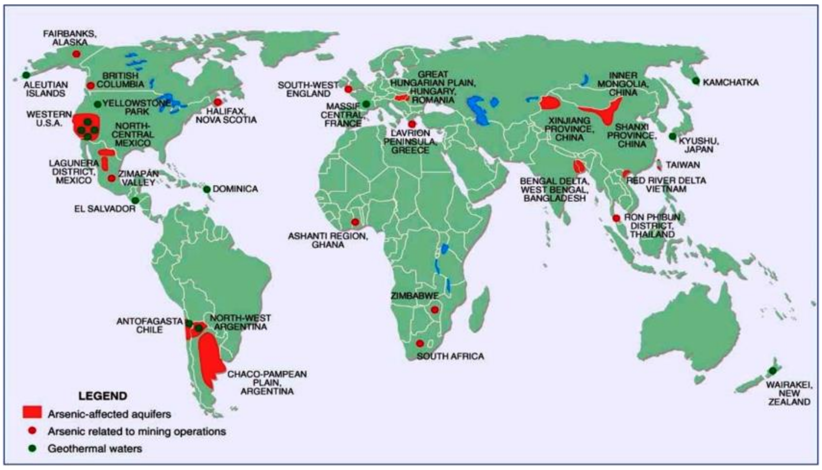

Fig. 2. Arsenic-affected areas in the World (after Smedley and Kinniburgh, 2002).

Groundwater pollution and pollutants

A pollutant is any substance or chemical element, anthropogenic or natural source that accumulates in the environment and can produce adverse effects on organisms, ecosystems, and human health. Groundwater pollution occurs when pollutants released into the ground and make their way down to the groundwater, forming a contaminant plume within the aquifer. The movement and dispersion of water within the aquifer cause the pollutant to spread over a broader area, creating an advancing boundary often referred to as a plume edge. This plume edge can intersect with groundwater wells or reach the surface through seeps and springs, thereby making water supplies unsafe for both humans and wildlife. To understand the interaction of groundwater contamination with surface waters, hydrology transport models are employed for analysis. These models help in studying the movement and behavior of pollutants, enabling researchers to assess potential impacts on both groundwater and surface water resources (Acharyya et al., 2000; Chakraborti et al., 2001; Ahmed et al., 2004; Gurung et al., 2005; Shamsudduha et al., 2008; Mukherjee et al., 2009a; Singhal and Gupta, 2010; Bian et al., 2012; Pradhan and Biswal, 2018; Pradhan et al., 2022). In a given area, there can be various types of geological formations, such as layers of sandy soil, fractured bedrock, clay, or hard rocks. Areas of karst topography on limestone bedrock are sometimes vulnerable to surface pollution from groundwater. Earthquake faults can also serve as pathways for contaminants to enter the groundwater system. The status of the water table plays a significant role in various aspects such as providing drinking water, supporting agricultural irrigation, managing waste (including nuclear waste), preserving wildlife habitats, and addressing ecological concerns. Groundwater contamination primarily results from both natural (geogenic) and human-induced (anthropogenic) activities.

Arsenic: Sources, behaviour, and distributions

Pollution occurs through the interplay between the source of pollutants and the existing soil moisture and groundwater flow system. Over time and as they travel, pollutants in groundwater typically undergo a decrease in concentration or get removed. Multiple mechanisms govern the movement of pollutants in groundwater, including dispersion, dilution, filtration, absorption, and ion exchange. Some pollutants may maintain their composition largely unaltered even after entering a groundwater reservoir (Zaporozec, 1981) (Fig. 3). An important aspect of groundwater is that once it is polluted, the effect may remain for years, decades, or centuries (Meyer, 1973; Zaporozec, 1981). In marked contrast with surface water, the average residence time of groundwater is on the order of 200 years (Everett, 1983; Pradhan et al., 2022). The pollutant typically remains in the stream for about ten days, whereas it often takes extended periods of groundwater flow to flush pollutants from contaminated aquifers. In some cases, groundwater pollution can lead to irreparable damage to the aquifers or specific portions of them (Zaporozec, 1981). Multiple shreds of evidence are needed to distinguish the release mechanisms of arsenic to groundwater in a particular setting. To understand the release mechanisms of arsenic, it is important to discuss (a) the Geologic setting to constrain the petrological, stratigraphic, and/or structural controls on the occurrence of the arsenic-bearing units (b) Mineralogy to determine the mineralogical (c) Hydrogeological settings to delineate groundwater flow paths, processes and to understand the rock water interactions (d) Water chemistry to establish the relationship between arsenic and other chemical parameters and (e) Isotopes to infer release mechanisms.

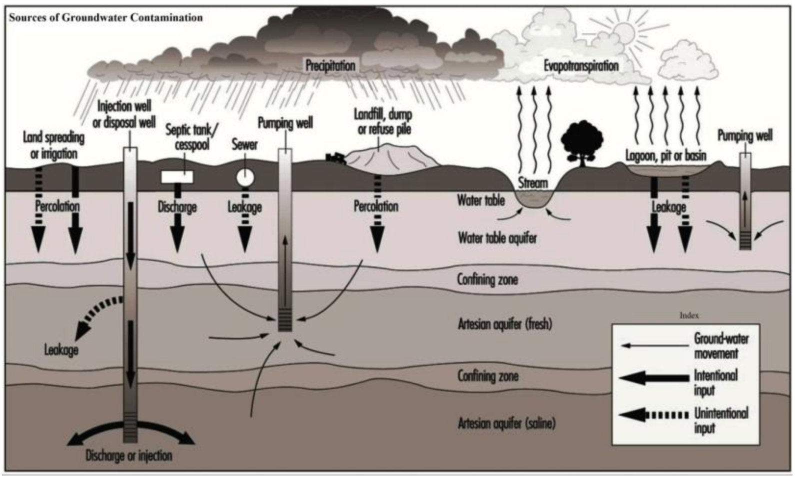

Fig. 3. Hydrologic cycle and movement of pollutants in groundwater (after Preul, 2011).

Arsenic is a group V element, together with nitrogen, phosphorus, antimony, and bismuth. Its electronic configuration is [Ar] 3d104s24p3 and it has an atomic weight of 75 and commonly occurs naturally in two oxidation states, þ5, þ3, and, more rarely, in the 0 or –3 states but in natural waters is mostly found in inorganic form as oxyanions of trivalent arsenite (As (III)) or pentavalent arsenate (AS(V)) (Smedley and Kinniburgh, 2002; Singhal and Gupta, 2010). Arsenic is classified as a metalloid in that it has a chemical nature intermediate between that of metals and non-metals. The environmental presence of arsenic derives from both natural and anthropogenic sources (Naidu and Bhattacharya, 2006; Singhal and Gupta, 2010) (Fig. 4). Arsenic is widely distributed and is present in the Earth’s crust at an average abundance of about 5 mg/kg. It occurs naturally in more than 200 mineral forms, of which approximately 60% are arsenates, 20% sulfides, and sulfosalts, with the remaining 20% comprising arsenides, arsenites, oxides, silicates, and elemental arsenic (Onishi, 1969; Singhal and Gupta, 2010). Typical arsenic concentration in different rock-forming minerals is in Table 1.

Arsenic primarily resides in minerals like arsenopyrite, orpiment, and realgar, existing as As (III) compounds shaped within reducing subsurface environments. When these compounds encounter Earth's surface conditions, they undergo oxidation, transforming into pentavalent forms such as iron arsenate. In calcareous soils, they can manifest as calcareous arsenolite. Arsenic, in its most readily extractable form, appears in trace amounts within minerals like iron pyrite, galena, and chalcopyrite. (Goldschmidt, 1937; Goldschmidt, 1958; Singhal and Gupta, 2010) (Table 1). Arsenopyrite (FeAsS), or more significantly, pyrite rich in arsenic (Fe (S, As)₂), is believed to be the most prevalent arsenic-containing mineral. Ferric hydroxides are particularly effective at adsorbing arsenic, while aluminium and manganese hydroxides also represent potential adsorbents for this purpose (Mahanta et al., 2012). The range of arsenic concentrations detected in natural waters varies significantly, spanning from less than 0.5 µg/L to over 5000 µg/L. Typically, freshwater contains arsenic at levels below 10 µg/L, often even below 1 µg/L. Occasionally, much higher concentrations are observed, particularly in groundwater. In such regions, over 10% of wells may exhibit elevated levels (defined as exceeding 50 µg/L), and in the most severe cases, this percentage may surpass 90%. These widespread natural arsenic groundwater issues tend to manifest in two primary types of environments: firstly, in inland or enclosed basins within arid or semi-arid regions, and secondly, in highly reducing aquifers, often originating from alluvial deposits (Smedley and Kinniburgh, 2002). Both environments tend to contain geologically young sediments, flat and low-lying areas where groundwater flow is very slow.

Table 1. Typical Arsenic Concentration in Rock-Forming Minerals (after Smedley and Kinniburgh, 2002).

Mineral	**Arsenic range (mg kg^{-1})**	**Mineral**	**Arsenic range (mg kg^{-1})**
Sulfide minerals		***Carbonate minerals***	
Pyrite	100–7,000	Calcite	1-8
Pyrrhotite	5-100	Dolomite	<3
Marcasite	20–126,000	Siderite	<3
Galena	5–10,000	Sulfate minerals	<1–6
Sphalerite	5–17,000	Gypsum/anhydrite	
Chalcopyrite	10–5,000	Barite	<1–12
Oxide minerals		Jarosite	34–1,000
Hematite	up to 160	***Other minerals***	
Fe-oxide (undifferentiated)	up to 2,000	Apatite	<1–1,000
Fe (III) oxyhydroxide	up to 76,000	Halite	<3–30
Magnetite	2.7–41	Fluorite	<2
Ilmenite	<1		
Silicate minerals			
Quartz	0.4–1.3		
Feldspar	<0.1–2.1		
Biotite	1.4		
Amphibole	1.1–2.3		
Olivine	0.08–0.17		
Pyroxene	0.05–0.8		

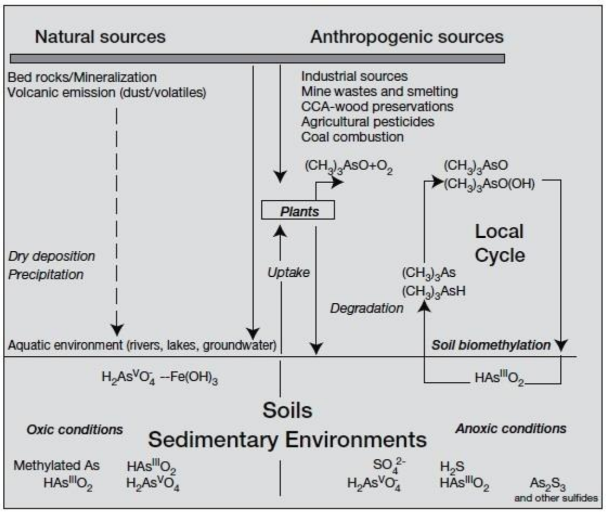

Fig. 4. Natural and anthropogenic sources and biogeochemical cycling of arsenic in a sedimentary environment (after Naidu and Bhattacharya, 2006).

Redox potential (Eh) and pH are the most important factors for controlling arsenic speciation. Depending upon the pH and Eh condition, arsenite, and arsenate species are present in the aquatic systems. Under oxidizing conditions, $H_2AsO_4^-$ is dominant at low pH i.e., less than about pH 6.9, while at higher pH, $HAsO_4^{2-}$ becomes dominant (Smedley and Kinniburgh, 2002). Under reducing conditions at pH less than about pH 9.2, the uncharged arsenite species $H_3AsO_3$0 will predominate (Brookins, 1988) (Fig. 5). The distributions of the species as a function of pH are given in Figure 6. In the presence of extremely high concentrations of reduced S, dissolved As-sulphide species can be significant. Reducing, acidic conditions favour the precipitation of orpiment (As_2S_3), realgar (AsS), or other sulfide minerals containing co-precipitated arsenic (Smedley and Kinniburgh, 2002; Cullen and Reimer, 1989). Therefore, elevated arsenic levels are not anticipated in areas with a high concentration of free sulfide (Moore et al., 1988). The mobilization of arsenic involves a combination of intricate natural processes (Smedley and Kinniburgh, 2002) (Fig. 6) and the most widely accepted theories explaining the widespread release of arsenic include: (a) Reductive dissolution: This process entails the reduction of sulfur-rich Fe oxides, typically caused by buried peat and other organic deposits, leading to the release of arsenic into the aquifer (McArthur et al., 2001; Bhattacharya et al., 1997; Nickson et al., 1998). (b) Alkali desorption: Under high pH conditions (>8), arsenic can desorb from metal oxides, particularly Fe and Mn, resulting in high arsenic concentrations in groundwater (Smedley and Kinniburgh, 2002, 2005; Chauhan et al., 2012). (c) Sulphide oxidation: In this mechanism, the oxidation of arsenical pyrite within alluvial sediments occurs when aquifer drawdown allows atmospheric oxygen to infiltrate the aquifer (Mallick and Rajagopal, 1996; Mandal et al., 1998; Chowdhury et al., 1999; Chauhan et al., 2012). This process is commonly referred to as the "oxidation hypothesis." (d) Geothermal reaction: This mechanism involves the mixing of geothermal solutions with fresh groundwater, potentially leading to elevated arsenic concentrations (Smedley and Kinniburgh, 2002; Chauhan et al., 2012).

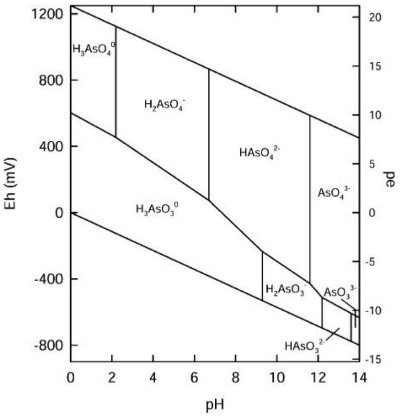

Fig. 5. Eh-pH diagram for aqueous Arsenic species in the system As–O_2–H_2O at 25°C and 1 bar total pressure (Smedley and Kinniburgh, 2002).

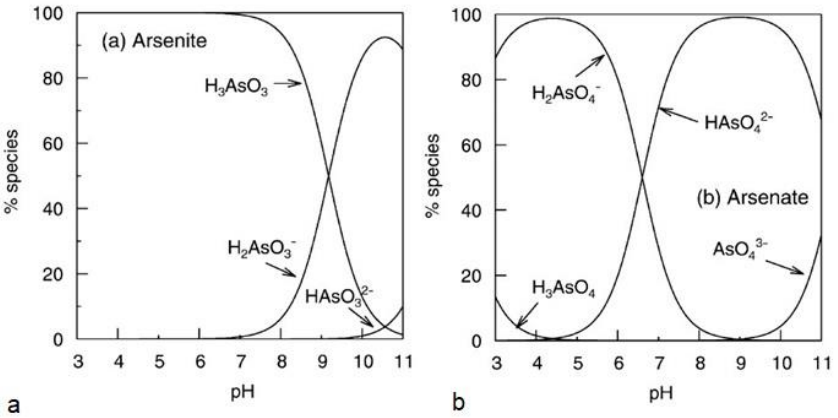

Fig. 6. (a) Arsenite and **(b)** arsenate speciation as a function of pH (ionic strength of about 0.01M). Redox conditions have been chosen such that the indicated oxidation state dominates the speciation in both cases (Smedley and Kinniburgh, 2002).

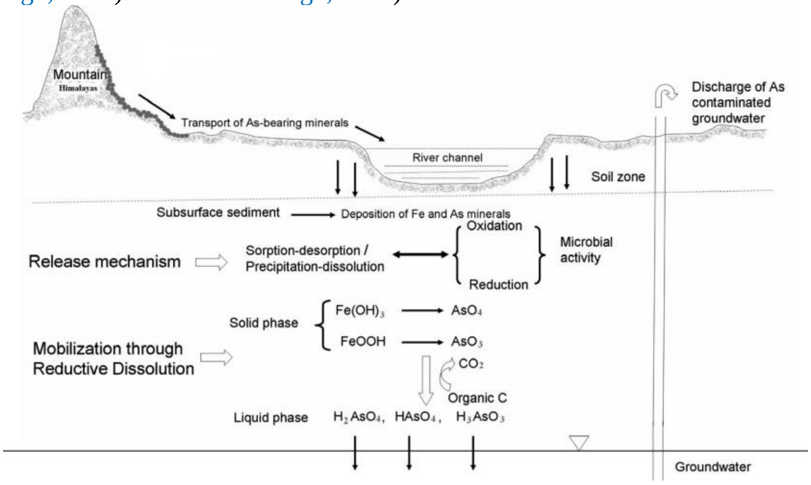

Fig. 7. A conceptual model for the West Bengal aquifer describing the release mechanism of arsenic into groundwater (Kar et al., 2010).

Distribution of Arsenic in India

The recommended safe limit for arsenic in drinking water has been reduced from 50 to 10 µg/L in India (BIS, 2012). The first report of high Arsenic in drinking water in India was reported from the Chandigarh area, Panjab (Datta, 1976; Datta and Kaul, 1976). The occurrence may not be geogenic. Arsenic pollution of groundwater in West Bengal was first reported in the early eighties. Kar et al. (2010) developed a conceptual model to understand the release mechanism of West Bengal aquifers (Fig. 7). Central Ground Water Board (CGWB) have revealed that arsenic contamination (> 0.05 mg/L) is affecting the states of West Bengal, Bihar, Uttar Pradesh, Assam, and Chhattisgarh. The Bengal Delta Plain (BDP), which spans across Bangladesh and West Bengal in India, is the most severely affected region by groundwater arsenic contamination. This problem of arsenic contamination in the vast expanse of alluvial aquifers in Bengal, Bihar, and Uttar Pradesh has impacted a population of approximately 50 million across various districts in India, as reported by Acharyya et al. (2002; 2005), Bhattacharya et al. (2002), and Chauhan et al. (2012).

West Bengal, India

Approximately 6.3 million residents of West Bengal State reside within the region known for arsenic contamination, encompassing 69 affected blocks (Acharyya et al., 2002; Bhattacharya et al., 2002; Chakraborti et al., 2001). Arsenic levels in groundwater have been documented within a range of 0.05-3.2 mg/L in shallow aquifers across 61 blocks spanning 8 districts of West Bengal (Malda, Murshidabad, Nadia, North and South 24 Pargana, Bardhaman, Howrah, and Hoogly). In this area, the source of arsenic is geogenic, linked to iron pyrites present in arsenic-rich layers found in the alluvial deposits along the Ganga River (Singh et al., 2006; Shamsudduha et al., 2008). The excessive use of groundwater for irrigation has contributed to the availability of arsenic in these areas. Arsenic concentrations in groundwater have been detected above the permissible limit of 0.05 mg/L in localized patches, particularly in Murshidabad and North 24-Pargana Districts of West Bengal. For instance, in the Ramnagar and Domkal blocks of Murshidabad district, arsenic levels range from 0.06 mg/L to 1.90 mg/L, while in North 24-Parganas, they vary from 0.66 to 0.9 mg/L.

Table 2. Arsenic in groundwater in India.

Sl. No.	States	As (ppb)	References
1	Assam	50-200	Bhattacharya et al. (2015)
2	Bihar	10-50	CGWB and PHED (2005) Chakraborti et al. (2016)
3	Chhattisgarh	>250	Pandey et al. (1999) Acharyya et al. (2001) Mukherjee et al. (2009b) Shukla et al. (2010)
4	Haryana	0-10	Poonia et al. (2021)
5	Jharkhand	1-133	Alam et al. (2015)
6	Karnataka	10-303	Chakraborti et al. (2013)
7	Madhya Pradesh	>50	Chakraborti et al. (1999)
8	Manipur	150-200	Chakraborti et al. (2008)
9	Odisha	0-10	CGWB (2018)
10	Punjab	11-828	Rasool et al. (2015)
11	Rajasthan	10-50	Duggal et al. (2012)
12	Tamil Nadu	0-28	Sridharan and Nathan (2018)
13	Uttar Pradesh	10-300	Ahamed et al. (2006)
14	West Bengal	>50	Chakraborti et al. (2001) Acharyya et al. (2002) Bhattacharya et al. (2002) Bhowmick et al. (2018)

Chhattisgarh, India

Arsenic contamination in Chhattisgarh refers to the presence of elevated levels of arsenic in groundwater sources within the state of Chhattisgarh, India. This contamination poses a significant public health and environmental concern as it can lead to various health issues when arsenic-contaminated water is consumed or used for irrigation. Arsenic contamination in Chhattisgarh is not limited to a single area but can be found in various regions of the state. It often occurs due to geological factors, with arsenic-rich rocks or minerals releasing arsenic into the groundwater over time (Mukherjee et al., 2009b). The contamination is typically more pronounced in areas where specific geological formations and hydrogeological conditions are conducive for the mobilization of arsenic into the water supply. In the Ambagarh Chowki block regions of Rajnandagaon district, Chhattisgarh, varying degrees of arsenic contamination have been observed in groundwater, with small localized patches affected. This issue has been documented in studies by Acharyya et al. (2002), Chakraborti et al. (1999), Pandey et al. (1999), Acharyya et al. (2001), Acharyya et al. (2005) and Mukherjee et al. (2009b). These patches of contamination are associated with the N-S trending Dongargarh-Kotri rift zone, which predominantly features early Proterozoic metavolcanic rocks and magmatic granites (Mukherjee et al., 2009b). The most severe arsenic contamination in water has been recorded in the villages of Kaurikasa, Sonsaytola, Joratarai, and Jadutola in the Rajnandagaon district. Dugwells in the Kaurikasa area have shown arsenic concentrations exceeding 50 µg/L, while some have levels below 10 µg/L (Mukherjee et al., 2009b). In other areas, the dugwell water has arsenic concentrations of 10 µg/L or less (Acharyya et al., 2005; CGWB, 2006) (see Table 2). These severely affected villages are situated on rhyolite and granite rocks closer to the shear zone. The presence of arsenic in groundwater in these areas is influenced by various geological, structural, hydrogeological, and geochemical factors. Groundwater in basic rock aquifers, for example, contains arsenic concentrations ranging from 0.009 to 0.049 mg/L (Mukherjee et al., 2009b).

Bihar, India

Arsenic contamination in Bihar was first identified in 2002 in the Semariya-Ojhapatti villages of the Bhojpur district. Further investigations across the Gangetic Plain of Bihar uncovered widespread arsenic occurrences on both sides of the Ganga River. The distribution of arsenic displays significant spatial variability, resulting in localized areas of contamination. These high groundwater arsenic zones, with concentrations exceeding 0.05 mg/L, are primarily located in the newer alluvial regions along the Ganga River (CGWB, 2005; Kunar et al., 2009). Notably, the contamination is limited to the upper approximately 50 meters of thick sediment layers consisting of sand, clay, sandy clay, and silty clay sequences. A total of fifty-seven blocks spanning fifteen districts on both banks of the Ganga River are affected by arsenic contamination (CGWB, 2005; Kunar et al., 2009) (see Table 2).

Uttar Pradesh, India

In early 2003, the detection of arsenic in groundwater at a level of 0.05 mg/L was documented in Balia district, Uttar Pradesh. Subsequent surveys revealed contamination in seven blocks spanning Gazipur, Balia, and Varanasi districts (see Table 2). These districts experiencing arsenic contamination are predominantly located along a linear stretch of the Ganga River, similar to what has been observed in Bihar and West Bengal (Kunar et al., 2009). However, the specific causes for this phenomenon have yet to be determined.

Jharkhand, India

The School of Environmental Studies (SOES), Jadavpur University has reported significant arsenic contamination in groundwater (>0.05 mg/l) in three blocks of Sahebganj district in Jharkhand. In the years 2006-07, the Central Ground Water Board (CGWB) conducted studies that indicated high arsenic levels in one block, namely Sahebganj block, within the district (Kunar et al., 2009). Subsequent studies conducted by the Public Health Engineering Department (PHED) and CGWB further confirmed that three blocks in the district, namely Rajmahal, Udohwa, and Sahebganj, are affected by high arsenic contamination. It is worth noting that these blocks are situated on alluvial deposits (CGWB, 2009) (Table 2).

North Eastern States, India

Studies by the School of Environmental Studies (SOES), Jadavpur University reveal that 27 villages in the Dhemaji and Karimganj districts of Assam, as well as parts of Thumbil and Imphal districts of Manipur, are affected by arsenic contamination (Kunar et al., 2009). The specified threshold for contamination is greater than 0.05 mg/l (milligrams per liter). This indicates that the concentration of arsenic in the water sources in these regions exceeds the permissible level, posing potential health risks to the residents relying on these water supplies (CGWB, 2009) (Table 2).

Remediation of arsenic in groundwater

Arsenic contamination in groundwater can have serious health implications, as arsenic is a highly toxic element (Jiang, 2001; Srivastava et al., 2009; Viraghvan and Pokhrel, 2006; Mondal et al., 2013). Managing arsenic levels in drinking water becomes more intricate in regions like rural India, where multiple individual water sources, such as hand pumps and wells, are commonly utilized. In this context, it is essential to take immediate remedial measures to safeguard human health and society. The technological options for the safe water supply in the arsenic-affected area could be (i) the use of alternate water resources like ponds, dug wells, rivers, etc., (ii) tapping of alternate aquifers for arsenic-free groundwater, (iii) artificial recharge and rainwater harvesting, and (iv) removal of Arsenic from groundwater. Various arsenic removal technologies are available to eliminate arsenic from drinking water (Srivastava et al., 2009). These methods encompass co-precipitation, ion exchange, adsorption, membrane separation, bioremediation, as well as oxidation of Arsenic (III) and Iron (II) (Jiang, 2001; Bhattacharya et al. 2007; Srivastava et al., 2009; Mondal et al., 2013). These approaches have been found significant use in improving water quality. Therefore, it is essential to thoroughly investigate all potential arsenic removal methods for drinking water and identify an appropriate, economically feasible, and socially acceptable technology that can effectively upgrade water quality in areas affected by Arsenic contamination.

Conclusions

Arsenic contamination in groundwater is prevalent in several Indian states, notably in areas such as West Bengal, Bihar, Uttar Pradesh, and Assam. These contaminated aquifers are situated within post-Pleistocene deltaic, alluvial, and lacustrine sediments. Different regions exhibit varying geological distributions of arsenic in groundwater. However, a common similarity among them is the substantial presence of arsenic in groundwater within loose and unconsolidated sediments. Typically, these sediments belong to the Quaternary Period but are often limited to the Holocene age. However, in Chhattisgarh, on the other hand, contamination is associated with a sulfide belt located in the Dongargarh-Kotri zone within a Precambrian terrain. Kunar et al. (2009) highlighted that arsenic sources within the Bengal Delta Plain (BDP) encompassed two primary pathways: Firstly, the Ganges River and its tributaries were identified as potential carriers, transporting arsenic originating from Gondwana coal seams located in the Rajmahal trap regions. Secondly, the North Bengal tributaries of Bhagirathi and Padma were considered as potential conduits, potentially transporting arsenic from the Gorubathan base-metal deposits situated in the eastern Himalayas. Consideration of transportation with fluvial sediments from the Himalayas, which is currently the most widely accepted hypothesis. In West Bengal, arsenic-free aquifers have been identified by the Central Ground Water Board (CGWB) at depths ranging from 120-160 meters below ground level (mbgl) and 200-250 mbgl. Tube wells have been strategically installed in these zones to access uncontaminated water free from arsenic. In Bihar, arsenic contamination is believed to be a geogenic origin, where arsenic in the solid phase is released into groundwater under redox-controlled conditions. High concentrations of arsenic in groundwater in Bihar are primarily confined to the newer alluvial areas along the Ganga River as revealed by Kunar et al. (2009), affecting both active and older floodplains. The contaminated water is relatively young, typically less than 40 years old. Furthermore, Mukherjee et al. (2009b) proposed in Chhattisgarh that arsenic in groundwater is controlled by various geological, structural, and hydrogeochemical factors. Govt. of India and various NGOs have been working to address the issue through arsenic mitigation projects, which involve providing access to safe drinking water and awareness campaigns to educate people about the risks of consuming arsenic-contaminated water. Moreover, implementing effective arsenic remediation methods is vital to safeguard human health and ensure the sustainable use of groundwater resources. Despite efforts to combat the problem, challenges remain, including the scale of the issue, financial constraints, and the difficulty of identifying and treating all affected areas.

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