

Review

Arsenic Contamination in Indian Groundwater: From Origin to Mitigation Approaches for a Sustainable Future

Deepali Marghade ^{1,*}, Girish Mehta ², Sagar Shelare ², Ganesh Jadhav ³ and Keval Chandrakant Nikam ³

¹ Department of Applied Chemistry, Priyadarshini College of Engineering, Nagpur 440019, Maharashtra, India

² Department of Mechanical Engineering, Priyadarshini College of Engineering, Nagpur 440019, Maharashtra, India; girishmehta1980@gmail.com (G.M.); sagmech24@gmail.com (S.S.)

³ Department of Mechanical Engineering, Dr. D. Y. Patil Institute of Engineering, Management and Research, Akurdi, Savitribai Phule Pune University, Pune 411404, Maharashtra, India; drganeshjadhavdyp@gmail.com (G.J.); nikamkeval26@gmail.com (K.C.N.)

* Correspondence: deepalichem@gmail.com

Abstract: The presence of arsenic in Indian groundwater poses a significant threat to both the ecosystem and public health. This review paper comprehensively addresses the topic, encompassing the underlying causes and potential solutions. Health consequences examines the serious health risks of drinking water contaminated with arsenic. Arsenic's complex geochemical processes of mobilization, transport, and distribution in groundwater are investigated. Mathematical models, geographical analysis, and data-driven modeling are discussed in the context of Indian groundwater. A comprehensive assessment of removal methodologies and the various factors influencing the mobility of arsenic is addressed. It was documented that community water purifiers and plants have successfully eliminated approximately 90% of arsenic, and the implementation of rainwater collection systems has also enhanced the overall quality of water. This review aims to address existing knowledge gaps and assess various strategies aimed at ensuring a more secure and sustainable water supply for the regions in question. The ultimate goal is to enhance the overall well-being of the population and protect the integrity of local ecosystems.

Keywords: groundwater pollution; health hazards; arsenic mobilization; removal techniques; groundwater management



Citation: Marghade, D.; Mehta, G.; Shelare, S.; Jadhav, G.; Nikam, K.C. Arsenic Contamination in Indian Groundwater: From Origin to Mitigation Approaches for a Sustainable Future. *Water* **2023**, *15*, 4125. <https://doi.org/10.3390/w15234125>

Academic Editor: Domenico Cicchella

Received: 30 October 2023

Revised: 21 November 2023

Accepted: 24 November 2023

Published: 28 November 2023



Copyright: © 2023 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

1. Introduction

With the escalation in world population and the intensification of development initiatives, there is a corresponding escalation in the need for dependable and uncontaminated water resources. To make up for the disparity between water demand and available surface water in the 21st century, there has been a growing trend towards the utilization of groundwater. However, this increased reliance on groundwater has led to a decline in its quality. The introduction of human-made substances into groundwater and the amplification of geochemical reactions resulting from aquifer recharge contribute to the deterioration of groundwater quality [1].

Arsenic is a geogenic, insipid, transparent, and odorless toxic metalloid. In recent decades, arsenic contamination has garnered significant scientific interest owing to its adverse effects on the well-being of individuals, ecological systems, and socio-economic progress. This challenge is particularly noteworthy due to the widespread distribution of high arsenic content in over 70 nations worldwide. As per the *World Water Report* by the United Nations, there is a correlation between declining groundwater levels and the degradation of global water quality. Approximately 66% of the global extracted groundwater is concentrated on the severity of arsenic poisoning in Asia, particularly in South and Southeast Asia [2]. The Indian context pertaining to catastrophic geogenic contamination in

aquifers of the Ganga–Brahmaputra–Meghna River basin comprises West Bengal, Assam, Bihar, Jharkhand, Uttar Pradesh, and other affected areas.

When arsenic concentration in groundwater surpasses the drinking water threshold established by the World Health Organization by a factor of 10 $\mu\text{g}/\text{L}$, it results in arsenic-enriched groundwater. The International Agency for Research on Cancer and the United States Environmental Protection Agency have both designated arsenic as a Group 1 and Group A carcinogenic agent, respectively [3,4]. The presence of arsenic in groundwater has been associated with a range of adverse health effects, such as keratinization of the skin [5], hyperpigmentation of the palms and soles, arsenicosis, hyperkeratosis, coronary heart disease, bronchiectasis, Bowen's disease, etc.

The hydrogeochemical properties of groundwater with elevated levels of arsenic indicate that the origins and movement mechanisms are linked to multiple factors, such as the dissolution of arsenic-bearing minerals, the redox reaction between arsenic-bearing sulfides [6,7] and arsenic-bearing Fe/Mn-oxyhydroxides with the groundwater [8], the adsorption/desorption mechanism [9], the role of mineral phases (e.g., Fe/Mn oxide and hydroxide, arsenopyrite, arsenate, siderite, goethite, rhodochrosite), and groundwater extraction [9,10].

For groundwater management, many theoretical, statistical, isotopic, mathematical, graphical, prediction, and geochemical modeling techniques have been developed [11–13]. Artificial intelligence (AI) and machine learning (ML) have evolved as robust approaches for doing exploratory data analysis (EDA) on environmental factors [14,15]. The complex relationship between arsenic mobilization and groundwater composition must be understood using various numerical and geochemical modeling methods to apply effective management measures [16]. Comprehending these intricacies is crucial for efficient mitigation and policy formulation.

The goal of this paper is to investigate arsenic contamination in Indian groundwater. The review examines arsenic pollution in Indian groundwater sources by location and prevalence. The afflicted locations, aquifers, and contamination levels are certain to be discussed. Arsenic sources, chemical species, adsorption, desorption, and oxidation-reduction conditions can be investigated. The multiple modeling technique may use mathematical models, geographical analysis, and data-driven modeling. These models' virtues and weaknesses in Indian groundwater will be debated scientifically. This study examines the many methods and technologies used to reduce arsenic contamination and improve water access, noting their complexity. Our main goal is to improve understanding of this topic and lay the groundwork for novel methods to protect vulnerable individuals and ecosystems.

2. Occurrence of Arsenic in Indian Groundwater

Arsenic is a minor constituent found in the Earth's crust, occurring at an average concentration of 1.8 mg/kg. Realgar (As_2S_2), orpiment (As_2S_3), arsenopyrite (FeSAs), and enargite (Cu_3AsS_4) are some of the most prevalent arsenic-rich minerals [17,18]. Arsenite As(III) is the reduced form of arsenic, commonly found in anaerobic (low-oxygen) groundwater environments and more soluble and mobile in water [19]. Whereas arsenate As(V), or H_2AsO_4^- and HAsO_4^{2-} , depending on pH, is the oxidized form of arsenic [20]. The +3 state is of particular concern due to its increased toxicity and tendency to persist undissociated (e.g., H_3AsO_3) in groundwater over a broad pH range [21]. Organic arsenic compounds can be found in groundwater with As(III) and As(V). Methylated forms of arsenic, including dimethylarsinic acid and monomethylarsonic acid, are examples of organic molecules that are often less poisonous than their inorganic counterparts [22]. Volcanic eruptions have the potential to release gases and ash that contain arsenic, which can subsequently contaminate both surface and groundwater sources. The release of arsenic into the environment can occur during mining activities, particularly in regions where arsenic is naturally found [23]. Improper disposal of devices and batteries in landfills and dumpsites has the potential to result in the leaching of arsenic into groundwater [24].

Podgorski et al. [25] analyzed 132,028 sampling points to identify regions at risk of high groundwater arsenic levels ($>10 \mu\text{g/L}$), as illustrated in Figure 1. In this study, Podgorski and team created a random forest model using 132,028 pieces of data and surface environmental indicators. The data from Bihar and West Bengal were balanced by averaging readings within 1-km^2 pixels, resulting in 23,799 points. The updated data distribution, with 42% above $10 \mu\text{g/L}$, was utilized to develop a binary model classifying concentrations as above or below. Groundwater arsenic contamination in India can be subdivided into two main regions: the alluvial regions of West Bengal, Bihar, Jharkhand, Uttar Pradesh, Assam, and Punjab, and the hard-rock regions of Karnataka and Chhattisgarh. Alluvial aquifers constitute the primary source (90%) of arsenic contamination in India. Whereas, hard rock aquifers comprise only 10% of the total affected regions [26]. A recent scientific study has documented that arsenic presence in groundwater in India surpasses a maximum contaminant level, thereby posing a potential risk to over 100 million individuals [27].

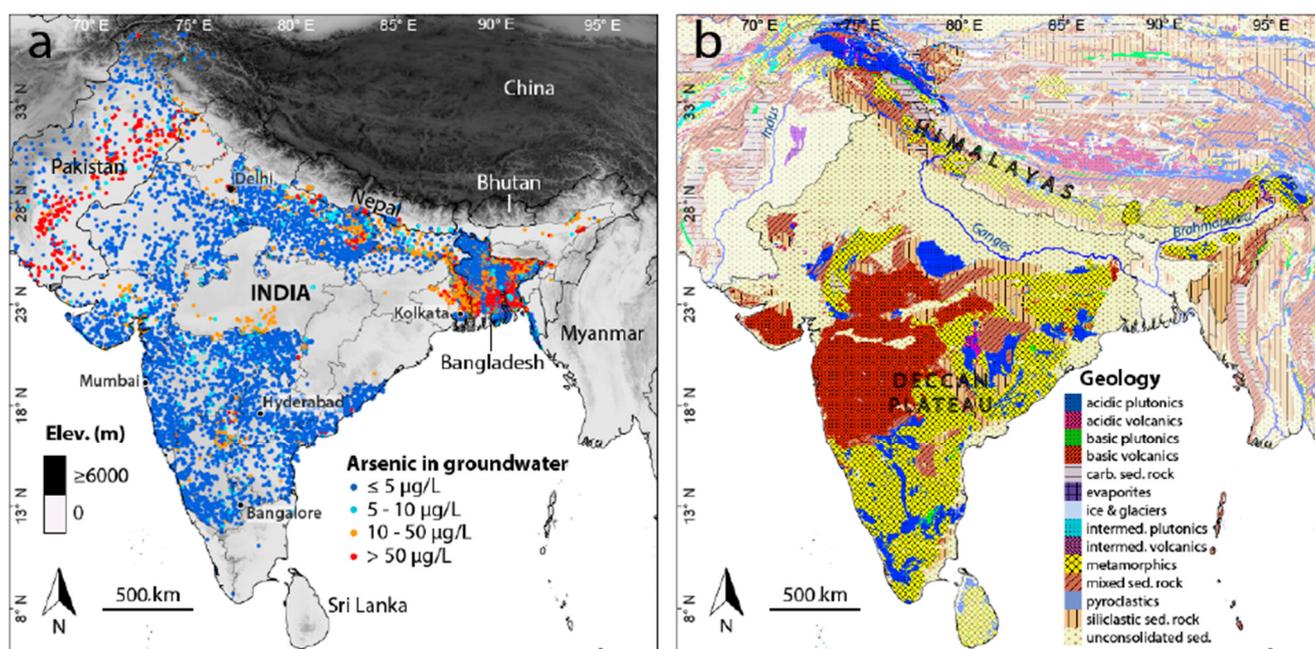


Figure 1. Arsenic concentration in Indian groundwater (a) topographical representation of averaged arsenic data points in Indian groundwater (b) Indian lithology [25].

The alluvial region, primarily the Ganga/Brahmaputra/Meghna River basin of the Indian subcontinent, experiences significant impacts from groundwater arsenic contamination [28,29]. The Ganga–Brahmaputra–Meghna River encompasses around 26% of the total area of India and supports a population exceeding 500 million individuals. The Bengal basin, a component of the larger Ganga–Brahmaputra–Meghna River basin, is inhabited by a substantial population and has had the highest incidence of individuals impacted by groundwater arsenic contamination [30,31]. The Bengal Basin comprises portions of the Indian states of Assam, Tripura, and West Bengal. The occurrence of arsenic has also been documented in Uttar Pradesh, Jharkhand, and Bihar within a floodplain of the Ganga River, as well as in Assam and areas of Punjab situated in a floodplain of the Ravi River [32].

West Bengal demonstrates a significant level of arsenic contamination relative to other states in India, with major frequency seen in the districts of Nadia, Murshidabad, South 24 Parganas, and North 24 Parganas [26,33]. According to a study, a total of 79 blocks distributed throughout eight districts were found to exhibit arsenic levels that exceeded $50 \mu\text{g/L}$ [28]. In a study covering nine different districts, it was shown that three of them have over 95% of their blocks with arsenic concentrations higher than the safety limit of $50 \mu\text{g/L}$ [29]. More than 50 million people are said to be affected by the high levels of

arsenic in drinking water along the Ganga and Brahmaputra basins [24]. The Burdwan region exhibited the most elevated concentration of arsenic in groundwater, as reported by Sarkar et al. [31].

Bihar has garnered scientific interest due to the detection of significant levels of arsenic pollutants in 12 districts and 32 blocks situated along the Ganga River [28,29]. The Ganges River basin in Bihar encompasses Holocene alluvial plains that have deposits of arsenic minerals in many regions, including Patna (the capital city of the state), Vaishali, Bhagalpur, Munger, and Buxar [34]. The Kosi River basin in northern Bihar exhibits Holocene alluvial sedimentation. Holocene alluvial deposits have been identified in the Gandak River/Sone River/Punpun River basin [35]. Water samples from the Maner block in the Patna district were found to be contaminated with arsenic at a mean value of 52 g/L and a maximum concentration of 231 g/L, according to research by Singh and Ghosh. Arsenic is vertically distributed in a layer of fine-grained clay that is 4.5–7.5 m thick [36]. Arsenic in the drinking water poses a serious threat to the lives of an estimated 10 million people in Bihar [32,33].

Uttar Pradesh is geographically situated in the central and upper regions of the Ganga basin in the northeastern section of India [37]. There are a total of 70 districts in Uttar Pradesh, but 20 of them have arsenic-contaminated groundwater [38]. The district of Ballia has been reported to demonstrate a substantial occurrence of arsenic at elevated levels [39]. Multiple districts in Uttar Pradesh have been documented to exhibit contamination of arsenic in their subterranean water sources [40]. The mean arsenic concentration in the postmonsoon was 38.3 mg/L, which is significantly less than the mean arsenic concentration in the premonsoon (259.5 mg/L⁻¹) [36]. As per the research conducted by Raju [22], the results indicate a reduced degree of arsenic retention and contamination in the central region of the Ganga Plain in comparison to the Bengal Delta. The study found that Singhaour, with an average arsenic concentration of 180 mg/L, had the highest concentration. Groundwater in the Shuklaganj neighborhood of Kanpur–Unnao was studied by Chauhan et al., who found that the vast majority of the samples tested positive for both trivalent and pentavalent arsenic [41]. The study reveals a causal association between arsenic and cancer incidence in an arsenic-exposed population in Bihar, where blood samples from cancer patients contain increased arsenic levels [42].

Numerous districts in Jharkhand, particularly those situated in the Gangetic Plains and on the Chotanagpur plateau, exhibit the presence of arsenic contamination within their groundwater resources. The presence of the highest arsenic contamination (133 µg/L) in Jharkhand is primarily observed in the Sahibganj district, which is located along the banks of the Ganga River [26,43].

The central ground water board of India has documented the significant arsenic presence, with a maximum concentration of 397.5 µg/L, in twelve distinct locations across five districts within Punjab [44]. The districts affected by arsenic exposure are situated along the river courses of the Ravi and Beas, which likewise have origins in the Himalayas. The Malwa area of Punjab was separated from the other regions by the left bank of the Sutlej river. Hundal et al. (2009) conducted a study in the Malwa region of Punjab, where they discovered that hand pumps and canal water exhibit higher levels of arsenic contamination compared to the permissible limits set by the World Health Organization (WHO) [45]. Their findings shed light on the geogenic source of arsenic in groundwater [45].

In Assam state, located in northeastern India, initially, a limited number of samples collected from the districts of Karimganj, Dhubri, and Dhemaji exhibited groundwater with an arsenic concentration exceeding 50 parts per billion (ppb) [46,47]. Subsequently, in the study done by Patel et al., it was found that a proportion of around 19.4% of the groundwater samples analyzed displayed arsenic concentrations that were beyond the acceptable limits [40,41].

In addition to the alluvial flood plain, the presence of arsenic contamination was observed in the hark rock terrain across 11 villages in the Rajnandgaon district of Chhattisgarh state [24] and a few locations in Karnataka [48]. According to reports, a significant number of individuals in the state of Chhattisgarh were subjected to exposure to arsenical

skin lesions, resulting in the identification of several patients afflicted with keratosis [24]. Arsenic contamination of groundwater has been documented in parts of Karnataka where gold mining and related operations have taken place. The Hutti Gold mining zone of Raichur district, as well as the abandoned gold mining zones of the present Yadgir district, serve as notable examples. Chemical waste was discharged into surrounding areas after gold extraction. Arsenic leached from arsenopyrite-containing dumping materials into groundwater during the rainy season, which led to localized arsenic enrichment in the nearby underground aquifer [48].

3. Health Implications of Arsenic Contamination

The arsenic pollution in the groundwater of India poses significant health hazards, encompassing a spectrum of adverse effects such as skin lesions, cancer, and cardiovascular ailments (Figure 2). Table 1 displays the distribution of arsenic in Indian states.

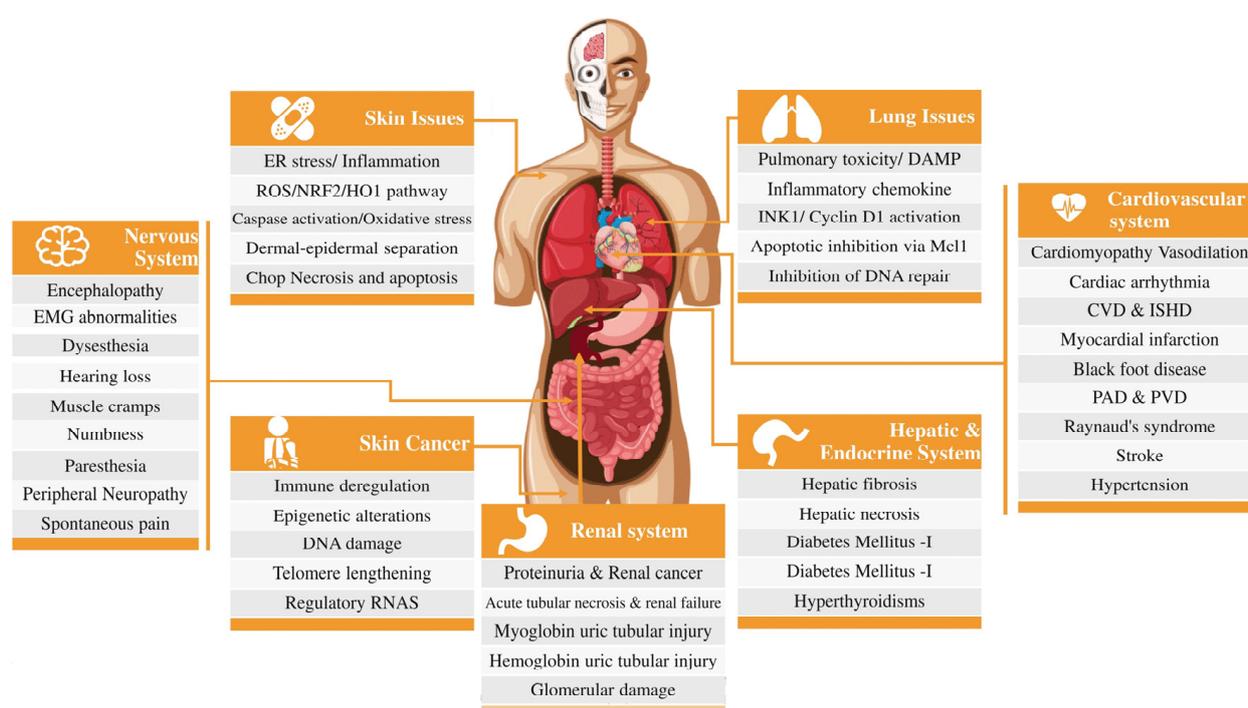


Figure 2. Impact of prolonged ingestion of arsenic enriched water on human health.

In the lowlands of West Bengal, Bihar, and Uttar Pradesh in India, particularly in the Ganga–Meghna–Brahmaputra (MGB) region, around 3000 communities have arsenic concentrations above 50 ppm, endangering 6 million people [49]. Long-term exposure to arsenic, primarily from the ingestion of polluted groundwater, is linked to a diverse array of severe and frequently irreversible health consequences (Figure 2). Halder et al. [50] found premature hair graying, aging, and cancer death in Jajjal village, Bathinda, Punjab. At least 40 of Uttar Pradesh's 75 districts have arsenic levels above permissible limits, endangering 23 million individuals [51]. The reproductive system is susceptible to adverse effects since studies have established a correlation between arsenic exposure and severe pregnancy outcomes such as spontaneous abortion, stillbirth, and preterm birth. Wu et al. used the population-attributable fraction (PAF) method to estimate the number of deaths in India and its individual states, territories, and districts that can be attributed to drinking groundwater with high concentrations of arsenic (>10 g/L). The research findings indicate that 0.3–0.6% of cardiovascular disease deaths can be attributed to the presence of elevated levels of arsenic in groundwater. premature cardiovascular disease-related deaths in India that could be prevented by avoiding chronic exposure to arsenic-contaminated groundwater [52].

Table 1. State wise distribution of Arsenic in India.

State	District	Range of Concentration of Arsenic ($\mu\text{g/L}$)	Probable Mechanism	References
West Bengal	24 Parganas (North and South)	0.77–69.65	Dissolution of Arsenopyrite mineral	[53]
	Kolkata	0–825	Reductive dissolution of FeOOH facilitated in presence of high organic carbon	[54]
	Hooghly	0–481	Carbonate dissolution and Fe-oxyhydroxide reduction	[55]
	Howrah	3–100	Reductive dissolution of FeOOH facilitated in presence of high organic carbon	[56]
	Burdwan	5–138	Reductive dissolution and sedimentation	[57]
	Malda	0–800	Reductive dissolution of FeOOH facilitated in presence of high organic carbon	[58]
	Murshidabad	10–4622	Pleistocene/Holocene sediments, reductive dissolution	[59]
	Nadia	3–206	oxidation of arsenic-bearing minerals	[60]
Bihar	West Champaran	0–397	--	[61]
	Siwan	0–150	Ferric arsenate hydrolysis of arsenopyrite.	[53]
	Shahpur	0–500	--	[62]
	Samastipur	0.19–135	Organic matter oxidation and iron oxyhydroxide reduction	[63]
	Patna	5–300	Dissolution of Arsenopyrite mineral	[64]
	Bhagalpur	3–143	--	[65]
	Buxer	10–550	Reductive dissolution of FeOOH facilitated in presence of high organic carbon	[66]
	Bhojpur	10–1805	Carbonate dissolution and Fe-oxyhydroxide reduction	[67]
Uttar Pradesh	Begusarai	21.5–94.3	Carbonate dissolution and Fe-oxyhydroxide reduction	[68]
	Moradabad	0–224	Oxidation of Arsenic-rich Sulfide Minerals	[69]
	Lakhimpur Kheri	10–510	Oxidation of Arsenic-rich Sulfide Minerals	[70]
	Ghazipur district	10–96	arsenolite minral dissolution	[71]
	Ballia	0–300	Fe Oxyhydroxide Reduction	[72]
	Unnao	151–448	Industries and agriculture input	[41]
Jharkhand	Ballia	4.18–75.60	Reductive dissolution of Fe Oxyhydroxide	[73]
	Sahebgunj	7–115	Phosphate adsorption	[74]
Punjab	Ropar	2–11	Reductive dissolution of Arsenopyrite	[75]
	Malva	61–187	Phosphate adsorption	[76]
	Amritsar	11.4–688	Oxidation of Arsenic-rich Sulfide Minerals	[77]
	Ferozpur	0–255.6	Carbonate dissolution and Fe-oxyhydroxide reduction	[78]
	Pathankot	4.35–23.25	Phosphate adsorption	[79]
	Assam	Sonitpur	0–11.15	Arsenic bearing minerals dissolution
Darrang		10.1–93.05	Transport after Kushiara river	[80]
Karimganj		1.3–16.4	Dissolution of Arsenic-bearing Minerals	[81]

Table 1. Cont.

State	District	Range of Concentration of Arsenic ($\mu\text{g/L}$)	Probable Mechanism	References
Assam	Dhemaji	0.1–569	Reductive dissolution of FeOOH facilitated in presence of high organic carbon	[82]
	Barpeta	0–36.88	Reductive dissolution of FeOOH facilitated in presence of high organic carbon	[83]
Chhattisgarh	Rajnandgaon	148–985	Reductive dissolution of FeOOH facilitated in presence of high organic carbon ductive dissolution	[84]
	Korba	36–154	Reductive dissolution of FeOOH facilitated in presence of high organic carbon	[85]
Karnataka	Raichur	0.19–10.55	Phosphate adsorption	[86]

4. Fate and Transport of Arsenic in Groundwater

The mobilization of arsenic ions in the aquifer occurs through a synergistic combination of natural and anthropogenic processes [22]. The following discussion will elucidate several prominent geochemical mechanisms (Figure 3) that can facilitate the liberation of arsenic in groundwater.

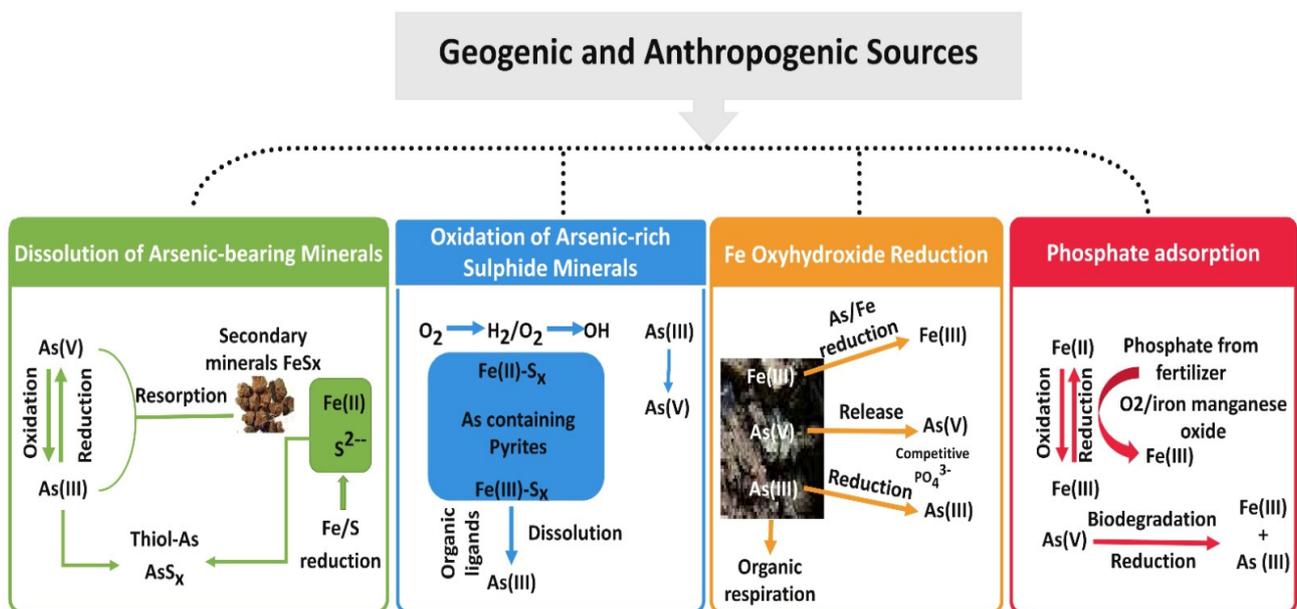


Figure 3. Geochemical Mechanisms for Fate and mobilization of Arsenic in Groundwater.

4.1. Dissolution of Arsenic-Bearing Minerals

Different forms of arsenic-containing minerals, such as arsenopyrite (FeAsS), realgar (As_4S_4), and orpiment (As_2S_3), occur naturally. The precise fraction of the released arsenic ions is determined by parameters such as pH and redox conditions. Arsenite (As(III)) is released into groundwater in acidic conditions characterized by reduction. The solubility and mobility of arsenite are greater compared to arsenate (As(V)), which is more prevalent in oxidizing settings.

In the Bengal delta plain, potential origins of arsenic include the transportation of Gondwana coal from a Rajmahal trap area, situated to the west of a basin, through the River Ganges and its tributaries. The facilitation of material transportation from the base-metal deposits in Gorubathan, located in the eastern Himalayas, is achieved through the

utilization of the north Bengal tributaries of Bhagirathi and Padma. The sedimentary soil found in West Bengal, India, is composed of various minerals, including pyrite rich in arsenic, magnetite, hematite, quartz, and calcite. Additionally, the soil contains rozenite ($\text{FeSO}_4 \cdot 2\text{H}_2\text{O}$), a hydrated iron sulfate compound. The phenomenon of the spontaneous occurrence of arsenic in groundwater within specific regions of the Bengal delta plains (BDP) in the West Bengal state of India has been extensively recorded and studied [87]. Clay layers or low-hydraulic-conductivity aquifer materials can hold arsenic-contaminated groundwater and prevent it from flushing out. This can cause groundwater arsenic buildup. The analysis of bore-hole samples revealed elevated levels of arsenic exclusively inside soil strata that exhibit a significant presence of iron pyrites, as reported by Das et al. [30].

4.2. Oxidation of Arsenic-Rich Sulfide Minerals

Geological deposits frequently contain sulfide minerals that are abundant in arsenic, such as arsenopyrite (FeAsS), realgar (As_4S_4), and orpiment (As_2S_3). These minerals demonstrate a significant level of stability when located at significant depths on the earth's surface and are effectively protected from the presence of oxygen and water. Natural weathering processes or human operations such as mining expose these minerals to atmospheric conditions, which can lead to oxidation. Upon the introduction of molecular oxygen (O_2) derived from the surrounding atmosphere and water (H_2O) to the arsenopyrite sample, the commencement of the oxidative degradation process was observed. In this reaction, arsenic in the sulfide mineral is oxidized from its original state (usually arsenic in a sulfide form) to arsenate (AsO_4^{3-}), which is highly soluble in water [88].

This phenomenon arises because bedrock aquifers have experienced a transition towards oxidizing conditions in response to a decrease in groundwater levels observed during dry seasons [89]. This results in the creation of Fe^{2+} , which is then released into groundwater. In conjunction with the generation of arsenate, the process of sulfur oxidation in the sulfide mineral concurrently yields SO_4^{2-} ions [90]. The soluble ions of arsenate and sulfate have the potential to undergo leaching, thereby infiltrating the adjacent soil, groundwater, and surface water.

According to reports, the metamorphic and granitic Himalayan parent rocks that the Ganga, Brahmaputra, and Meghna rivers flow through are the primary source of the sulfide minerals found in the fluvial silt [91]. It was highlighted that the low correlation of arsenic with bicarbonate (HCO_3^-) suggests that competitive adsorption by bicarbonate may not be the primary mechanism for the mobilization of arsenic in the Ganga and Ghagra River basins. In Bihar, fluvial geomorphology may have an effect on arsenic's dispersal, as it appears to be most concentrated near the Ganges River. The identification of a reduced level of SO_4^{2-} and NO_3^- ions, along with their restricted correlation with arsenic, indicates that the mobilization of arsenic is impacted by redox processes [92].

The regions of Chhattisgarh and Karnataka that have been impacted by the hard rock terrain are characterized by the presence of acidic volcanic rocks and granite formations. Natural deposition of arsenic-rich pyrite and microbial respiration of organic carbon cause groundwater contamination in Chhattisgarh [93].

4.3. Fe Oxyhydroxide Reduction

The process of iron oxyhydroxide (FeOOH) reduction plays a pivotal role in the liberation of arsenic into the groundwater within the Ganga–Brahmaputra delta region of India with the deltaic and alluvial deposits. The expanding extent of rice farming and the biodegradation of peat inside sedimentary deposits are contributing factors to the emergence of restrictive environmental conditions. In the respiration of microbes, iron oxyhydroxides play a crucial function as electron acceptors. During the decomposition of iron oxyhydroxides, Fe(III) becomes Fe(II) and As(V) becomes As(III) [38].

The Jharkhand is overlaid by metamorphics of the pre-Cenozoic era, alluvial deposits from the Riverian area, and recent-aged alluvial deposits of the Himalayas [94]. The high concentration of organic carbon present in a narrow alluvial stratigraphy facilitates its

transportation downwards through the process of water percolation resulting from rainfall infiltration. The presence of organic carbon in the environment enhances microbial respiration and initiates the process of reductive dissolution of arsenic (As) and iron (Fe) in the solid phase. This process additionally yields HCO_3^- ions, thereby establishing the correlation between arsenic and HCO_3^- in shallow groundwater. In their study, Mukherjee et al. [95] observed that the redox-sensitive variables exhibited consistent reducing situations throughout the sampled aquifers without any discernible depth variation.

The tube-wells in the submerged channels and floodplains of Holocene Newer Alluvium deposits along the concave Ganga River in Varanasi have a high concentration of As [22]. The Siwalik foreland, located to the east of the lower Himalayas, is drained by three major rivers, namely the Ganga, Meghna, and Brahmaputra. It has been observed that these rivers have a higher concentration of arsenic than rivers that originate from the Himalayas' higher elevations. Iron is Fe(II) in reducing settings and Fe(III) in redox conditions. In neutral to alkaline pH, the Fe(III)/Fe(II) and As(V)/As(III) redox limits are close [96]. Significant portions of the more recent alluvial belt located within the middle Ganga Plain exhibit extended waterlogging, thereby serving as areas conducive to the accumulation of biomass. The organic carbon originating from biomass is transported via vertical groundwater percolation, which is facilitated by the infiltration of precipitation and bodies of water [96].

4.4. Phosphate Adsorption

The escalation in water utilization for irrigation purposes and the application of fertilizers have led to the movement of phosphate from fertilizers towards shallow aquifers [22]. The process of reductive dissolution of Fe(III) from bigger sediment particles in the aquifer results in the release of PO_4^{3-} and As into the groundwater. It is observed that PO_4^{3-} and As also exhibit a positive association since arsenic and phosphorus have comparable chemical characteristics [97].

5. Factors Influencing Arsenic Mobility and Transport

A number of vital factors influence the hydrochemistry of arsenic-contaminated groundwater in India, as illustrated in Figure 4.

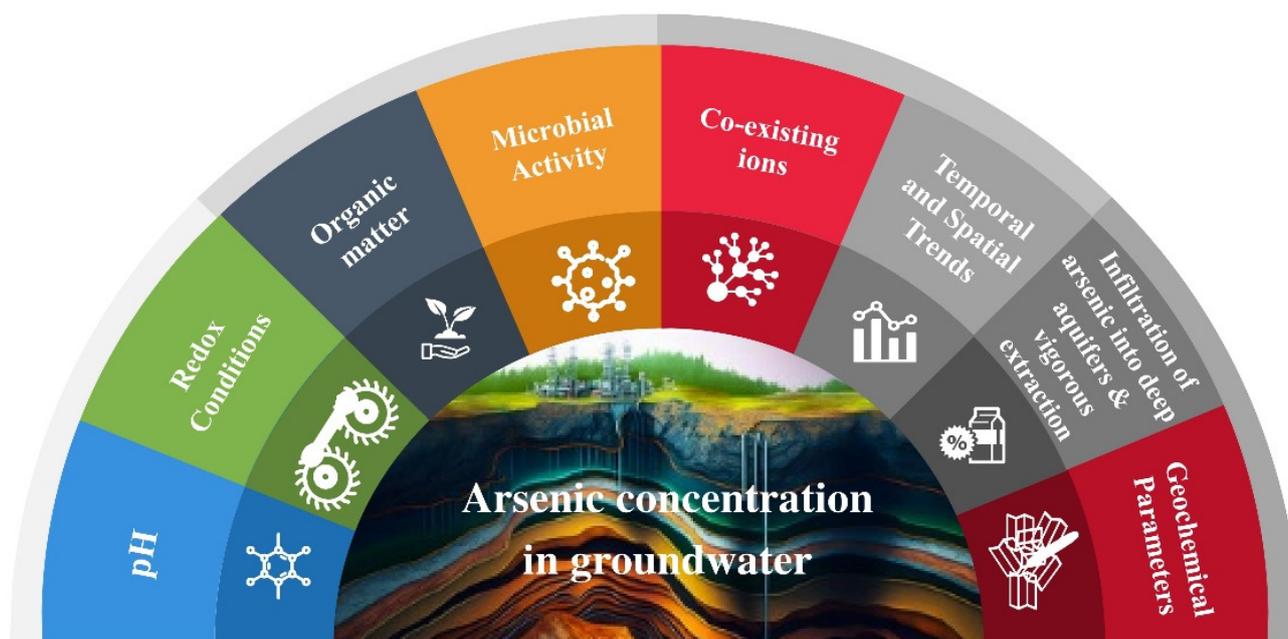


Figure 4. Key factors influencing the hydrochemistry of arsenic enriched groundwater.

5.1. pH

The pH levels of groundwater in India have a notable influence on the mobilization of arsenic, with the specific consequences being contingent upon the hydrogeological and geochemical conditions present in the local area. In situations where the pH ranges from acidic to neutral ($\text{pH} < 7$), the prevailing species is arsenite (As(III)). The mobility and toxicity of arsenite are greater in comparison to arsenate (As(V)). Arsenate (As(V)) occurs more frequently in neutral to slightly alkaline conditions ($\text{pH} > 7$). Arsenate has lower ion mobility and a higher adsorption propensity on mineral surfaces. Manning and Goldberg [98] highlighted that the highest arsenic adsorption capacity on kaolinite occurs at a pH level of 5. However, adsorption capacity declines significantly when the pH exceeds 6.5. When compared to montmorillonite, which has a pH of 5, the illite mineral has a more desirable range of values between 6 and 8. In their work, Anawar et al. [99] revealed that arsenic desorption starts at pH 9.

5.2. Redox Conditions

The process of organic matter degradation in groundwater systems initiates a sequence of intricate REDOX reactions in which arsenic is released into the groundwater through the breakdown of Fe and Mn oxides. Typically, reductive dissolution occurs in anaerobic or suboxic environments, such as groundwater, where oxygen (O_2) is scarce or non-existent and facilitates the solubilization of arsenic in groundwater.

The process of reduction can be initiated by a variety of chemical or biological agents. Anaerobic microorganisms utilize metal oxides as electron acceptors within their metabolic pathways. The released electrons are used in microbial respiration, whereas the released protons (H^+) lower the pH of the surrounding environment. Arsenic solubilization is accelerated by the observed fall in pH. Groundwater's dissolved organic matter acts as a carbon supply for microorganisms' metabolic activity and as a catalyst, speeding up the biogeochemical process of arsenic. Iron and manganese oxides in groundwater are more difficult to dissolve due to the synergistic effect of organic materials and microbes [100]. Within the subsurface, the process of sulphate ions (SO_4^{2-}) being transformed into sulphide ions (S^{2-}) can take place via a reduction reaction within an environment that is significantly depleted of oxidizing agents. Therefore, the presence of sulphide ions will affect the distribution of arsenic and iron throughout the groundwater system.

The Mn(IV)-oxyhydroxides in solid form are believed to have a significant impact on redox buffering. It rapidly oxidizes As(III) to As(V) and adheres As(V) to effectively remove arsenic from water [91]. Several parts of the Bengal basin have been shown to contain high manganese (Mn) concentrations despite having relatively low iron and arsenic contents, respectively. Vega et al. [101] provide a thermodynamic argument that suggests that in an oxygen- and nitrate-depleted aquifer, manganese in its +4 oxidation state (Mn(IV)) is the primary electron acceptor for the microbial organisms involved in respiration. Microbes frequently engage in the reduction of Fe(III) subsequent to the enhancement of Mn(IV) accessibility. Furthermore, research has indicated that Mn(IV)-oxides possess the capability to facilitate the oxidation of Fe(II) to Fe(III) , resulting in the subsequent formation of Fe(III) precipitates. As a result, new sites are created where arsenic can be adsorbed and decrease arsenic levels in groundwater.

5.3. Desorption of Arsenic in the Alkaline Environment

Under alkaline conditions, the process of arsenic desorption can take place through a range of different mechanisms. Elevated levels of hydroxide ions (OH^-) can engage in competitive interactions with arsenic to occupy binding sites on soil and sediment particles, resulting in the process of desorption. In alkaline environments, the breakdown of iron and manganese oxides may occur, leading to the liberation of adsorbed arsenic into groundwater.

In some regions of Uttar Pradesh's Mid-Gangetic floodplains, a significant increase in the concentration of arsenic was observed within the pH range of 8 to 9 during the

post-monsoon period. The observed occurrences can be explained by the desorption of arsenic from iron (hydr)oxides during aquifer recharge. The increased pH levels in the Mid-Gangetic floodplains are also thought to play a role in the weathering and dissolution of silicate minerals, both of which contribute to the release of arsenic [102]. The hydrological characteristics based on the water facies of the water table of Lakhimpur district, which lies in the top portion of the Brahmaputra floodplain (UBF), indicate that high arsenic-enriched groundwater due to the presence of alkalinity in the water plays a role in facilitating the dissolution of arsenic [103].

5.4. Organic Matter

The dissolved organic matter found in groundwater acts as a carbon source, promoting the process of reductive dissolution facilitated by microorganisms. In the realm of organic matter, the key mechanisms facilitating the release of arsenic encompass complexation, adsorption, competition, and electron transfer. Organic matter in groundwater can adsorb arsenic ions onto its surfaces and form complexes with arsenic, leading to a reduction in the mobility of arsenic. The microbial process of organic matter reduction can result in the creation of optimum conditions for the solubility of arsenic in iron oxyhydroxide minerals in a reductive condition. It has been hypothesized that buried peat deposits play a role in creating favorable redox conditions for the liberation of arsenic ions from iron oxyhydroxide (FeOOH) minerals [104]. The Bengal basin shows a large distribution of peat deposits [105]. Petroleum reservoirs have been detected within the geographical area at a depth of approximately 5.6 km in the Bengal basin. The petroleum may have risen to shallower habitats, where it was subjected to biodegradation processes helped along by microorganisms. Additional comprehensive investigations are required to ascertain the presence of organic mass originated from carbonaceous deposits in other regions of the Bengal basin aquifers [105].

Organic matter particles contain functional groups such $-\text{COOH}$, $-\text{OH}$, $-\text{O}-$, and $-\text{CONH}_2$. These functional groups coordinate with arsenic, improving sediment adsorption [106]. The process of jute processing yields a substantial quantity of dissolved organic carbon that is accountable for the arsenic enrichment observed in the Bengal basin [107]. The influence of organic matter on arsenic mobility is site-specific and depends upon the organic matter's composition and concentration, the aquifer's geochemistry, and other factors.

5.5. Microbial Activity

Aquifers with a shallow depth and a high concentration of organic matter are prone to experiencing biogeochemical processes involving arsenic, which are primarily impacted by microbial activity. Various mechanisms by which microbes can affect arsenic's movability are elaborated upon below.

5.5.1. Microbial Reduction

Arsenate (As(V)) can be converted to the less mobile and less poisonous form, arsenite (As(III)), by microbes such as iron/sulfate-reducing bacteria [101]. The microbial community, predominantly composed of *Acinetobacter*, *Sideroxydans*, *Brevundimonas*, *Alkanindiges*, *Desulfuromonas*, *Pelobacter*, and other species, plays a crucial role in shaping the biogeochemical processes and the mobilization of arsenic in areas of the Bengal basin that are rich in organic matter and contaminated with arsenic [108].

The local bacterial population possesses the capacity to modify the redox conditions, facilitating the reductive dissolution of arsenic from Fe/Mn-oxyhydroxides as well as from iron (Fe) and manganese (Mn) compounds. It has been revealed that the iron-reducing bacterium *Shewanella alga* can dissolve FeOOH, making it easier to mobilize arsenic from ferric arsenate and sorption sites in sediment [23]. Organisms such as *Geospirillum barnesii* exhibit the ability to enzymatically reduce both Fe(III) and As(V), thereby facilitating the process of arsenic adsorption onto iron oxides. This enzymatic activity promotes the mobilization of arsenic [23].

5.5.2. Microbial Oxidation

Certain bacteria possess the ability to undergo the process of oxidizing arsenite (As(III)) into arsenate (As(V)), especially in environments with high levels of microbial activity and ample oxygen supply. Furthermore, effective precipitation of As(V) can be achieved with the use of aluminum (Al) or iron (Fe) oxide or hydroxide [109].

5.5.3. Sorption and Sequestration

Microbes have the ability to immobilize arsenic either by directly adsorbing it onto their surfaces or by forming biofilms that effectively trap arsenic molecules [91]. In a broad sense, arsenic has the ability to attach itself to the functional groups (-COOH, -NH₂, -SH, -OH, and -PO₄) present on the surface of microbial cells [110]. The process of binding takes place through various mechanisms, including ion exchange, chelation, and physical adsorption. Binding sites can be found in the cell membranes, cell walls, and even extracellular polymeric molecules of a microbe. In both Gram-negative and Gram-positive bacteria, phosphate groups and peptidoglycan chains serve as the principal sites for cationic and anionic binding, respectively [110].

5.6. Competition for Electron Acceptors

Arsenic and microbes struggle for environmental electron acceptors [111]. Arsenic may be less mobile if sulfate-reducing bacteria, for instance, use sulfate as an electron acceptor instead of arsenic. In order to forecast the impact of microorganisms on the behavior of arsenic and devise effective approaches for reducing arsenic pollution in groundwater and sediments, it is imperative to possess a comprehensive comprehension of the microbial ecology and geochemical conditions specific to a particular area [110].

5.7. Co-Existing Ions

The rate of binding of As(III) at various levels is hindered by the aggressive interaction between other negative ions and As(III) anions. The inhibitory effect is enhanced when the concentration of anions in the solution increases [65]. In this circumstance, chloride ions and sulfate ions are extremely effective in preventing arsenic (III) attachment to diverse surfaces [9]. Biswas and colleagues conducted a study to examine the impact of co-existing ions on the solubilization of arsenic in the aquifer of the Bengal basin. They used surface complexation modeling to analyze the changes with time in arsenic concentration. Evidence suggests that PO₄³⁻ displays the highest degree of competition, followed by Fe²⁺, silicic acid, and HCO₃⁻ in that sequence of decreasing intensity [24].

5.8. Temporal, Seasonal, and Spatial Trends

Numerous studies conducted worldwide have reported substantial seasonal fluctuations in arsenic levels while observing minimal or negligible temporal fluctuations in arsenic concentration at the exact sampling site [65]. Raju performed a comprehensive examination of litho-facies sequences in sediment samples obtained from boreholes in the Varanasi region of India [22]. The researcher reached the conclusion that the concentration of element arsenic is higher in litho-types characterized by finer black clay and clay grains compared to materials with coarser silt and fine sand grains [22]. Arsenic levels in the ground can be lowered by allowing rainfall to infiltrate and mix with existing water supplies. The process of recharging initiates a series of biogeochemical reactions as a result of alterations in redox conditions caused by the introduction of oxygenated water into the aquifer. These activities promoted arsenic sorption, resulting in a rapid decrease in arsenic levels in groundwater. Arsenic's mobility and concentration may be reduced in an aquifer due to increased oxidation during the dry season, when groundwater levels are low [112]. The Murshidabad district of West Bengal, India, exhibited a marginal yet discernible decline in concentrations of element arsenic from the premonsoon to the postmonsoon period, as reported by Farooq and team [107]. In the study conducted by Choudhury et al. (2016), it was discovered that among the 927 deep tube wells distributed across an area of

180 km² in Araihasar, Bangladesh, only nine of them, located in late Pleistocene aquifers, contained arsenic levels exceeding 50 parts per billion [113]. In five out of the nine instances, the deep groundwater was found to be contaminated with arsenic as a result of seepage and the inclusion of extra screens in the shallow aquifer zone.

The presence of arsenic concentrations exceeding 10 parts per billion (ppb) in the deep aquifers of the Bengal basin, which formed during the late Pleistocene epoch, may be the result of extensive groundwater extraction [113].

6. Modeling Arsenic Enrichment in Indian Groundwater

A detailed overview of the key modeling tools and methodology utilized in the study of arsenic pollution in groundwater within the context of India is discussed below:

6.1. Hydrogeological Modeling

Arsenic's mobility and distribution in aquifers, as well as the identification of pollution sources and the development of relevant mitigation methods, are all aided by these models. In order to simulate groundwater flow and estimate hydraulic conductivity and other aquifer parameters, the modular groundwater flow model (MODFLOW) is frequently used in India [114,115]. It is widely utilized in coastal aquifers [116]. Hydraulic conductivity measurements can be effectively interpolated through the utilization of geostatistical techniques such as kriging as well as advanced machine learning models like artificial neural networks (ANNs). Subsurface imaging is achieved through the utilization of ground penetrating radar (GPR), while potential aquifer sites are identified with the assistance of remote sensing data. Spatial analysis involves the application of geographic information systems (GIS) to facilitate the processing and understanding of data [117].

6.2. Transport Modeling

Transport models are utilized in order to gain an understanding of the movement of arsenic within the aquifer. These models utilize simulation methodologies to evaluate the dispersion of pollutants, considering aspects such as advection, dispersion, and other pertinent transport mechanisms [11]. These models facilitate the prediction of temporal and spatial arsenic concentration fluctuations [118,119].

Logistic regression models (LRMs) have been widely utilized for the prediction of global spatial distributions of arsenic [11,13]. The research conducted by Bindal and Singh sought to examine twenty direct predictor variables in order to comprehensively characterize the geochemical conditions, water level, and land cover that contribute to the contamination of arsenic [51]. Golia and Vassilios used robust quadratic regression analysis on several variables to predict Fe and Cd concentrations at different soil depths [120]. The regression categorization tool and regression tree can be combined in the RF machine learning tool for minimal changes in the bagging algorithm. The hybrid random forest ensemble model forecasts the cartographic depiction of Arsenic with a high level of accuracy, reaching an overall precision rate of 84.67% [51]. The hybrid random forest ensemble model successfully classified seven districts in Uttar Pradesh as exhibiting a substantial level of risk [121,122]. The aforementioned districts encompass Ballia, Gorakhpur, Ghazipur, Gonda, Faizabad, Barabanki, and Lakhimpur Kheri. The model's prediction probabilities for the aforementioned districts span from 0.8 to 1.0, with a value of 1.0 denoting the highest probability of occurrence [39]. Saha et al. employed hybrid random forest models, namely RF, RF-GOA, RF-GWO, and RF-PSO, within the context of the elevated arsenic contamination zone located in the contaminated Ganges delta region in India. The vulnerability maps have been utilized by the team of investigators, who concluded that the approximate range of 6.35–13.5% and 2.22–9.39% of the study region demonstrate elevated levels of susceptibility to groundwater vulnerability. The mentioned vulnerable locations are predominantly situated within the north-western and middle-central regions [32]. In their study, Shaheen and Iqbal utilized the RF function of the Boruta algorithm to analyze

soil depth as a classifier. They proceeded to rank the key soil contamination characteristics, namely Cd, Cr, Pb, P, and EC, in proportion to their respective depths [123].

Khan et al. used principal component analysis to understand more about the possible mechanisms that regulate the geochemical parameters of groundwater in a particular area of the upper Gangetic Plain in Uttar Pradesh. The main component shows 36.4% of the variance, with loadings for EC, TDS, Na⁺, Ca²⁺, Mg²⁺, Cl⁻, and SO₄²⁻. These factors highlighted the significant modification of the composition of groundwater by both natural and anthropogenic factors [124].

6.3. Geochemical Modeling

Hydrogeological models frequently incorporate geochemical modeling techniques to forecast the dynamics of geogenic contaminants in the aquifer [125]. The research also examines the impact of different chemical reactions and equilibria on the movement, distribution, and binding of arsenic to solid surfaces. The processes are simulated using geochemical modeling software like PHREEQC, or Geochemist's Workbench [32].

6.4. Risk Assessment Models

Probabilistic risk assessment (PRA), dose-response modeling, GIS, and multi-criteria decision analysis are the common risk assessment models [126]. A population exposed to arsenic-contaminated groundwater is assessed for health risks using probabilistic risk assessment. Dose-response models of arsenic exposure are utilized to quantify the probability of particular health effects [52]. These models assess the potential carcinogenic and non-cancerous health effects linked to arsenic exposure in India. Geographic information system tools are utilized to delineate the spatial distribution of arsenic contamination, analyze exposure patterns, and identify populations that demonstrate increased susceptibility to its adverse effects. Multi-criteria decision analysis (MCDA) models are employed to determine the prioritization sequence for mitigation and intervention locations by considering a range of variables, including health hazards and socioeconomic aspects.

The GIS-machine learning model for groundwater in Murshidabad district, West, yields calculated areas below the curve of random forest, support vector machine, and support vector regression of 0.901, 0.923, and 0.897 in training datasets and 0.899, 0.910, and 0.891 in validation datasets. The vector regression approach is effective for locating arsenic-vulnerable zones in Murshidabad district, West Bengal, India [32]. Saha et al. conducted an assessment of the health hazards in the Ganges delta region using the human health hazard index. He concluded that a high health hazard zone is located in the southern region, as well as certain sections of the northern area, within the Ganges delta. The risk assessment categorizes zones as low (35.94%), moderate (24.52%), high (23.30%), very high (12.46%), and extremely high (3.77%), respectively [32].

According to the findings of Goswami et al., the presence of arsenic exceeding 10 µg/L⁻¹ (WHO) was detected in the groundwater of Majuli, Assam [127]. The results indicated a statistically significant and positive correlation between the quantities of arsenic seen in the biological samples and the comparable values detected in the groundwater. The variability may be attributed to factors such as differences in health status, malnutrition, socioeconomic factors, the use of safe drinking water, and the conditions in which water is stored [103]. In another study in Nagaon, Assam, and the Lakhimpur region, drinking water exposure analysis showed residents are exposed to carcinogenic and non-carcinogenic health concerns [128]. Dwivedi et al. (2023) emphasized that an estimated 17 million individuals face the threat of arsenic poisoning in the Ghaghara basin [40]. This puts them at a lifetime incremental cancer risk that is more than two orders of magnitude greater [40].

7. Mitigation Strategies for Arsenic Contamination

A variety of methods are commonly employed to remove arsenic from drinking water treatment (Figure 5). These various technologies are described below:

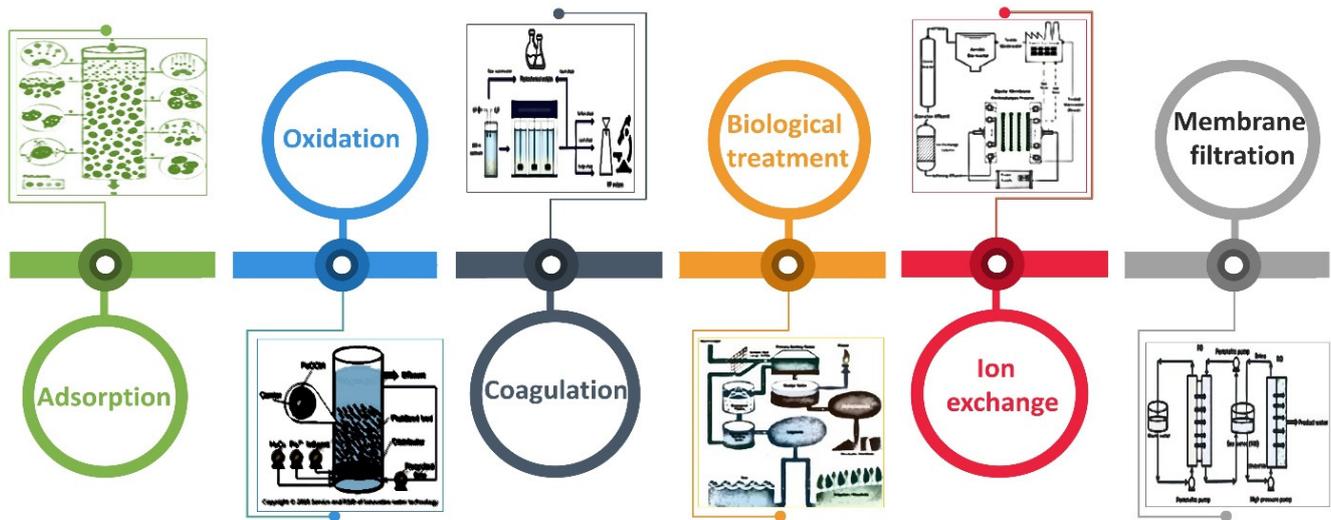


Figure 5. Various Mitigation Methods for Arsenic Contamination.

7.1. Adsorption

Adsorption is a commonly utilized physico-chemical phenomenon within the realm of water purification. In the context of arsenic adsorption, various substances utilized encompass activated carbon [129], activated alumina [130], granular ferric hydroxide [131], and iron oxide-coated sand [132], among various alternatives.

In recent times, there has been an increasing scholarly interest in the utilization of bio-adsorbents, such as modified fly ash [133], chitosan [134], jute stick powder, sugarcane powder, rice husk [114,115], powdered eggshells, chicken feathers [135] and nano-materials derived from iron and copper oxides [136] or carbon nanotubes [137], for the purpose of eliminating arsenic from contaminated water [138]. Chitosan, a naturally occurring polysaccharide with a non-linear structure, exhibits significant efficacy in the adsorption of arsenic ions. This effectiveness can be attributed to its hydrophilic nature, biocompatibility, biodegradability, and possession of antibacterial activities [139]. According to Karthikeyan et al. [140], the presence of an amino group in chitosan facilitates the formation of chelation sites. The successful utilization of chitosan-Fe composites for arsenic cleanup has been documented by Gupta et al. [141]. Granular ferric oxide/hydroxide is another commendable alternative for arsenic adsorption. In situ iron oxide/hydroxide is preferred over pre-formed iron oxide/hydroxide due to its ability to provide a large surface area, as supported by the findings of He et al. [142]. Aluminum hydroxide has emerged as a notable adsorbent for removing arsenate, thereby gaining increased attention. The reaction between arsenate and aluminum results in the formation of an aluminum hydroxide-arsenate complex. The adsorption process of this complex is influenced by factors such as oxidation and the pH state of arsenic [143]. Samsuri et al. [144] found rice husk-activated carbon adsorbs 1.3 mg/kg at pH 8. Budinova et al. [145] discovered that the activated carbon derived from bean pod waste by standard physical activation techniques exhibited a relatively modest maximal loading capacity for As(III) at 1.01 mg/g. Tuna et al. [146] also observed enhanced efficacy of iron-enriched activated carbon compared to the initial activated carbon sourced from apricot stone [147,148].

7.2. Oxidation

The process of oxidizing more toxic As(III) present as non-ionic H_3AsO_3 , to As(V) has emerged as the prevalent pre-treatment approach [149]. To attain thorough elimination of arsenic from groundwater, it is frequently imperative to pre-oxidize arsenite into arsenate before implementing coagulation–precipitation or adsorption methods [150]. UV radiation in conjunction with TiO_2 has demonstrated notable efficacy in the oxidation of As(III), as evidenced by the findings of Nguyen et al. [151]. Fu et al. [152] investigated alternative

methodologies to effectively eliminate As(III) and tetracycline through co-oxidative processes. Advanced oxidation processes (AOPs) have the potential to produce by-products that may possess toxicity when they react with components present in the aqueous matrix, like halide ions and dissolved organic matter [153].

7.3. Coagulation

Coagulants play a dual role by assisting in eliminating contaminants and enhancing the processes of sludge settling, dewatering, and stability [154,155]. As a result, the utilization of coagulation, in combination with filtration and/or flocculation, has been extensively employed in the remediation of polluted groundwater [156]. Meng et al. [157] conducted a study to assess the effectiveness of FeCl₃ in the removal of both As(V) and As(III). According to their findings, a pH of 6 and a Fe(III) concentration of 1 mg/L eliminated roughly 95% of As(V) at an initial concentration of 0.1 mg/L. An attention of 0.05 mg/L of As(III) resulted in a maximum removal efficiency of 80% when 3 mg/L of Fe(III) was utilized at a pH of 9.5 [158].

7.4. Biological Treatment

The microbial-mediated arsenic redox reaction is a prominent mechanism for the bio-remediation of arsenic [159]. The conversion of arsenic compounds is carried out by several mechanisms, including microbial oxidation, biological adsorption, methylation, and other related activities [160]. Ye J et al. [161] conducted a study that revealed that cyanobacteria and other closely similar algae had mechanisms that enabled the oxidation and methylation of As(III). Wang Y et al. [162] shed light on an additional aspect, unveiling the capacity of these microbes to mitigate the presence of As(V) effectively. In a study conducted by Xue XM et al. [163], it was demonstrated that specific types of algae can produce harmful lipids and granulated sugars as a reaction to exposure to arsenic.

7.5. Ion Exchange and Membrane Filtration

The ion exchange technology has attracted considerable attention due to its potential application in purifying drinking water contaminated with hazardous substances, such as arsenic [164]. To implement this approach, groundwater is sent through a resin-packed column after undergoing post-filtration to eliminate suspended particulate matter.

In addition to ion exchange, membrane filtration has been recognized as a viable alternate approach for removing arsenic [145,146]. These methods have exhibited considerable effectiveness in the removal of arsenic. The main obstacle to these methods pertains to the financial aspect, as both the acquisition of the membrane and the ongoing operational costs are very substantial.

A comparative analysis of various arsenic mitigation technologies is presented in the Table 2.

Table 2. Comparison of different water treatment technologies.

Reference	Technology	Overview	Description	Significance	Limitations
[138,156,165–167]	Adsorption	Adsorbents bind Arsenic.	Activated alumina, iron-modified zeolites, and biochar.	<ul style="list-style-type: none"> Available adsorbents include activated alumina and iron-based. Useful for point-of-use. 	<ul style="list-style-type: none"> Costly and unsuitable for large-scale treatment. Adsorbents deplete and need replenishing.

Table 2. Cont.

Reference	Technology	Overview	Description	Significance	Limitations
[168–170]	Oxidation	Arsenate (As(V)) is easier to treat	Exposure to air (aeration) or chemical oxidants such as potassium permanganate, hydrogen peroxide, or chlorine.	<ul style="list-style-type: none"> This technique converts arsenite to arsenate (with easy removal method). It can be coupled with other processes for better removal. 	<ul style="list-style-type: none"> Needs further filtration for complete Arsenic removal.
[132,158,171]	Coagulation	Chemical coagulants create Arsenic-binding precipitates. Filters remove these precipitates.	Ferric chloride, ferric sulfate, and alum.	<ul style="list-style-type: none"> Removes arsenate (As(V)) well and handles high Arsenic concentrations. 	<ul style="list-style-type: none"> Sludge disposal issues. pH and coagulant dosage must be optimal.
[172–174]	Biological Methods	Microorganisms can convert or absorb Arsenic.	Use Arsenic-respiring algae or bacteria.	<ul style="list-style-type: none"> Microorganisms convert arsenite to arsenate for simpler removal. Eco-friendly and sustainable technique. 	<ul style="list-style-type: none"> Biocontrol and health risks. Large-scale Arsenic removal is new.
[175–177]	Ion Exchange	Specific resins exchange Arsenic ions for non-hazardous ones.	Anion exchange resins.	<ul style="list-style-type: none"> Regenerative and reusable. Removes arsenite and arsenate. 	<ul style="list-style-type: none"> May need pre-treatment to eliminate interfering ions. Ion competition sensitive.
[156,165,178]	Membrane Technologies	These methods remove Arsenic from water using semipermeable membranes.	Reverse osmosis and nanofiltration.	<ul style="list-style-type: none"> Nano-filtration targets specific ions. Arsenic may be removed 95% via reverse osmosis. 	<ul style="list-style-type: none"> Required brine disposal or treatment. Operating costs and energy use are high.

8. Community-Based Mitigation Initiatives and Their Effectiveness

The active involvement and participation of the community are crucial components in tackling arsenic contamination in India's groundwater [179]. In the context of India, there is growing optimism surrounding grassroots initiatives, the utilization of locally produced water filters, and various joint endeavors. Non-governmental organizations are proactively engaged in disseminating knowledge to rural communities regarding the hazards associated with arsenic exposure [180]. Following these awareness efforts, there was a notable decrease in the proportion of homes utilizing contaminated water, declining from 70% to 40%. The qualitative review of arsenic treatment technologies revealed that adsorption or ion exchange techniques, which have low or moderate environmental impact, are sustainable [20]. Membrane technology requires large investments. Numerous households residing in regions impacted by arsenic contamination employ household-level filters using activated laterite designed for arsenic removal. These filters are inexpensive and simple to maintain, which makes them a practical way for households to obtain potable water. These systems cater to more extensive populations and necessitate more substantial infrastructure. The electrochemical arsenic remediation method employed in West Bengal exhibited encouraging outcomes; however, the cost associated with treating each cubic meter of water is considerably elevated at USD 0.8 [179].

Community water purifiers have become increasingly prevalent in West Bengal and Bihar. Arsenic removal plants (ARPs) based on the adsorption process are used by mu-

municipal authorities to clean water for distribution to residents in cities. Implementing these filtration systems has resulted in a significant reduction of arsenic concentrations in water, with levels lowered by as much as 90%. The main issues with ARPs are dealing with sludge and keeping the unit from getting clogged up from sand spilling [20,181,182]. Kumar et al. conducted an investigation on the performance of ARPs that were installed in Uttar Pradesh. Their findings led them to conclude that the primary factor contributing to the long-term failure of the installed units was the lack of availability of adsorption media in local markets [183]. Systematic water quality testing and monitoring are routinely carried out to evaluate the efficacy of arsenic removal methodologies and to detect regions experiencing persistent contamination problems [182].

In addition to providing a reliable source of potable water, rainwater collection contributes to the restoration of regional groundwater resources. The test results show that the concentration of arsenic in the collected rainwater is below the safe limit of 10 µg/L [184]. This strategy has led to improved water quality in numerous locations [185,186]. According to the available local health data, there has been a significant reduction of approximately 40% in health issues associated with arsenic exposure. Additionally, there has been a notable 30% increase in the sustainability index, which serves as a metric for evaluating the long-term viability of the initiatives [187].

9. Policy and Regulatory Measures to Address Arsenic Contamination

One essential suggestion is to create a national monitoring system using GIS to identify arsenic hotspots. Water sources are regularly tested, especially in vulnerable areas, to ensure up-to-date and accurate records. Public programs to raise awareness about the toxicity of arsenic-bearing drinking water and promote safe water are being implemented. Local communities should have access to testing and purification for their water sources, and supporting technology R&D is vital [179]. The aim is to create cost-effective and adaptable techniques for eradicating arsenic from households and communities while also supporting arsenic removal facilities, especially in severely affected regions. In arsenic-rich locations, rainwater collection, treated surface water, and dug-well sources are alternatives to deep tube wells. Medical surveillance has been highlighted, with recommendations for regular health checks in impacted regions and arsenic testing in public health programs [187]. Intense penalties and strict enforcement of rules are imposed on arsenic offenders to ensure industry compliance [135]. India is also encouraged to collaborate with overseas arsenic mitigation companies to share knowledge and technology. As research and technology evolve, policies must adapt to reduce arsenic in India's groundwater [135]. Success can only be achieved through collaboration between governments, communities, scholars, and global partners. All stakeholders must cooperate and combine their efforts to achieve the desired outcomes.

10. Conclusions

The issue of groundwater arsenic contamination in India is a substantial concern that has a widespread impact on a large population. The issue predominantly impacts alluvial regions, including West Bengal, Bihar, Jharkhand, Uttar Pradesh, Assam, and Punjab. The Bengal basin has the highest incidence of arsenic contamination, with areas like Patna, Vaishali, Bhagalpur, Munger, and Buxar affected. Other regions, like Jharkhand, Punjab, and Assam, also face arsenic contamination. The presence of arsenic pollution has been documented in hard-rock terrain situated in the states of Chhattisgarh and Karnataka.

In the Ganga–Meghna–Brahmaputra region, there are approximately 3000 communities exhibiting arsenic concentrations exceeding 50 parts per million (ppm), thereby posing a significant risk to the well-being of approximately 6 million individuals. Prolonged exposure to arsenic results in significant health ramifications, such as the development of skin lesions, premature hair depigmentation, accelerated aging, and carcinogenesis.

It was highlighted that in West Bengal, India, sedimentary soil contains pyrite, magnetite, hematite, quartz, and calcite minerals that release arsenic through mineral dis-

solution mechanisms. Bihar's fluvial geomorphology may affect arsenic dissemination, resulting in lower SO_4^{2-} and NO_3^- levels and a limited association with arsenic. Pre-Cenozoic metamorphics and Riverian alluvial deposits release arsenic in the groundwater of Jharkhand, which is further enhanced in the presence of organic carbon.

To mitigate the arsenic contamination in India's groundwater, community involvement and participation are crucial. Arsenic mobility and removal factors indicate challenges and answers. Removal technologies are evaluated for efficacy, affordability, and scalability. Non-governmental organizations, sustainable techniques, and affordable household filters are being used. Community water purifiers and arsenic removal plants have reduced arsenic concentrations by up to 90%. Rainwater collection also contributes to water quality improvement. The significant health risks posed by arsenic exposure underscore the urgency of addressing this problem comprehensively. Strategies and interventions must be tailored to the unique challenges and geological conditions of each affected area. The study suggests the development of a regular national monitoring system using GIS to identify arsenic hotspots. Furthermore, collaborative efforts involving policymakers, researchers, and local communities are essential to mitigate the adverse effects of arsenic contamination and ensure safe drinking water for the affected populations.

Author Contributions: D.M.: Conceptualization, investigation, resources, data curation, writing—original draft, visualization; G.M.: visualization, data curation, writing—original draft; S.S.: data curation, diagrams, writing—original draft; G.J.: writing—review and editing; K.C.N.: writing—review and editing. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: No original data were generated during this research.

Conflicts of Interest: The authors declare no conflict of interest.

References

- Li, Q.; Lu, L.; Zhao, Q.; Hu, S. Impact of Inorganic Solutes' Release in Groundwater during Oil Shale In Situ Exploitation. *Water* **2022**, *15*, 172. [[CrossRef](#)]
- UNESCO World Water Assessment Programme. *The United Nations World Water Development Report 2022: Groundwater: Making the Invisible Visible*; United Nations Educational, Scientific and Cultural Organization: Paris, France, 2022; pp. 1–225.
- WHO International Agency for Research on Cancer. *IARC Monographs on the Evaluation of Carcinogenic Risks to Humans Report of the Advisory Group to Recommend Priorities for IARC Monographs during 2015–2019*; WHO International Agency for Research on Cancer: Lyon, France, 2019.
- Agency for Toxic Substances and Disease (ATSDR). *Registry Support Document to the 2019 Substance Priority List*; Agency for Toxic Substances and Disease Registry (ATSDR): Atlanta, GA, USA, 2020; pp. 1–9.
- Tabassum, R.A.; Shahid, M.; Dumat, C.; Niazi, N.K.; Khalid, S.; Shah, N.S.; Imran, M.; Khalid, S. Health Risk Assessment of Drinking Arsenic-Containing Groundwater in Hasilpur, Pakistan: Effect of Sampling Area, Depth, and Source. *Environ. Sci. Pollut. Res. Int.* **2019**, *26*, 20018–20029. [[CrossRef](#)] [[PubMed](#)]
- Ju, J.; Lieke, T.; Saul, N.; Pu, Y.; Yin, L.; Kochan, C.; Putschew, A.; Baberschke, N.; Steinberg, C.E.W. Neurotoxic Evaluation of Two Organobromine Model Compounds and Natural AOBr-Containing Surface Water Samples by a Caenorhabditis Elegans Test. *Ecotoxicol. Environ. Saf.* **2014**, *104*, 194–201. [[CrossRef](#)] [[PubMed](#)]
- Chakraborty, M.; Mukherjee, A.; Ahmed, K.M. A Review of Groundwater Arsenic in the Bengal Basin, Bangladesh and India: From Source to Sink. *Curr. Pollut. Reports* **2015**, *1*, 220–247. [[CrossRef](#)]
- Liu, C.W.; Wu, M.Z. Geochemical, Mineralogical and Statistical Characteristics of Arsenic in Groundwater of the Lanyang Plain, Taiwan. *J. Hydrol.* **2019**, *577*, 123975. [[CrossRef](#)]
- Zhang, L.; Qin, X.; Tang, J.; Liu, W.; Yang, H. Review of Arsenic Geochemical Characteristics and Its Significance on Arsenic Pollution Studies in Karst Groundwater, Southwest China. *Appl. Geochem.* **2017**, *77*, 80–88. [[CrossRef](#)]
- Zhang, Z.; Guo, H.; Liu, S.; Weng, H.; Han, S.; Gao, Z. Mechanisms of Groundwater Arsenic Variations Induced by Extraction in the Western Hetao Basin, Inner Mongolia, China. *J. Hydrol.* **2020**, *583*, 124599. [[CrossRef](#)]
- Thakur, A.; Kumar, A.; Kaya, S.; Vo, D.-V.N.; Sharma, A. Suppressing Inhibitory Compounds by Nanomaterials for Highly Efficient Biofuel Production: A Review. *Fuel* **2022**, *312*, 122934. [[CrossRef](#)]
- Zhu, G.; Liu, Y.; Shi, P.; Jia, W.; Zhou, J.; Liu, Y.; Ma, X.; Pan, H.; Zhang, Y.; Zhang, Z.; et al. Stable Water Isotope Monitoring Network of Different Water Bodies in Shiyang River Basin, a Typical Arid River in China. *Earth Syst. Sci. Data* **2022**, *14*, 3773–3789. [[CrossRef](#)]

13. Dai, Z.; Ma, Z.; Zhang, X.; Chen, J.; Ershadnia, R.; Luan, X.; Soltanian, M.R. An Integrated Experimental Design Framework for Optimizing Solute Transport Monitoring Locations in Heterogeneous Sedimentary Media. *J. Hydrol.* **2022**, *614*, 128541. [[CrossRef](#)]
14. Mhanna, R.; Naveau, A.; Bueno, M.; Shmeit, M.; Ismail, F.; Fontaine, C.; Porel, G.; Bassil, J.; Caner, L. Concomitant Behavior of Arsenic and Selenium from the Karst Infillings Materials of the Fractured Carbonate Dogger Aquifer (Hydrogeological Experimental Site, Poitiers, France). *Chemosphere* **2021**, *275*, 129935. [[CrossRef](#)] [[PubMed](#)]
15. Jang, W.S.; Engel, B.; Yeum, C.M. Integrated Environmental Modeling for Efficient Aquifer Vulnerability Assessment Using Machine Learning. *Environ. Model. Softw.* **2020**, *124*, 104602. [[CrossRef](#)]
16. El Bilali, A.; Taleb, A.; Brouziyne, Y. Groundwater Quality Forecasting Using Machine Learning Algorithms for Irrigation Purposes. *Agric. Water Manag.* **2021**, *245*, 106625. [[CrossRef](#)]
17. Zhao, Z.; Meng, Y.; Yuan, Q.; Wang, Y.; Lin, L.; Liu, W.; Luan, F. Microbial Mobilization of Arsenic from Iron-Bearing Clay Mineral through Iron, Arsenate, and Simultaneous Iron-Arsenate Reduction Pathways. *Sci. Total Environ.* **2021**, *763*, 144613. [[CrossRef](#)] [[PubMed](#)]
18. Masue, Y.; Loeppert, R.H.; Kramer, T.A. Arsenate and Arsenite Adsorption and Desorption Behavior on Coprecipitated Aluminum:Iron Hydroxides. *Environ. Sci. Technol.* **2007**, *41*, 837–842. [[CrossRef](#)]
19. Liu, Y.; Zhang, Z.; Zhao, X.; Wen, M.; Cao, S.; Li, Y.; Liu, Y.; Zhang, Z.; Zhao, X.; Wen, M.; et al. Arsenic Contamination Caused by Roxarsone Transformation with Spatiotemporal Variation of Microbial Community Structure in a Column Experiment. *J. Groundw. Sci. Eng.* **2021**, *9*, 304–316. [[CrossRef](#)]
20. Yadav, M.K.; Saidulu, D.; Gupta, A.K.; Ghosal, P.S.; Mukherjee, A. Status and Management of Arsenic Pollution in Groundwater: A Comprehensive Appraisal of Recent Global Scenario, Human Health Impacts, Sustainable Field-Scale Treatment Technologies. *J. Environ. Chem. Eng.* **2021**, *9*, 105203. [[CrossRef](#)]
21. Sarkar, A.; Paul, B. Evaluation of the Performance of Zirconia-Multiwalled Carbon Nanotube Nanoheterostructures in Adsorbing As(III) from Potable Water from the Perspective of Physical Chemistry and Chemical Physics with a Special Emphasis on Approximate Site Energy Distribut. *Chemosphere* **2020**, *242*, 125234. [[CrossRef](#)]
22. Raju, N.J. Arsenic in the Geo-Environment: A Review of Sources, Geochemical Processes, Toxicity and Removal Technologies. *Environ. Res.* **2022**, *203*, 111782. [[CrossRef](#)]
23. Jha, P.K.; Tripathi, P. Arsenic and Fluoride Contamination in Groundwater: A Review of Global Scenarios with Special Reference to India. *Groundw. Sustain. Dev.* **2021**, *13*, 100576. [[CrossRef](#)]
24. Biswas, T.; Chandra Pal, S.; Saha, A.; Ruidas, D. Arsenic and Fluoride Exposure in Drinking Water Caused Human Health Risk in Coastal Groundwater Aquifers. *Environ. Res.* **2023**, *238*, 117257. [[CrossRef](#)] [[PubMed](#)]
25. Podgorski, J.; Wu, R.; Chakravorty, B.; Polya, D.A. Groundwater Arsenic Distribution in India by Machine Learning Geospatial Modeling. *Int. J. Environ. Res. Public Health* **2020**, *17*, 7119. [[CrossRef](#)] [[PubMed](#)]
26. Shaji, E.; Santosh, M.; Sarath, K.V.; Prakash, P.; Deepchand, V.; Divya, B.V. Arsenic Contamination of Groundwater: A Global Synopsis with Focus on the Indian Peninsula. *Geosci. Front.* **2021**, *12*, 101079. [[CrossRef](#)]
27. Das, A.; Mondal, S. Geomorphic Controls on Shallow Groundwater Arsenic Contamination in Bengal Basin, India. *Environ. Sci. Pollut. Res. Int.* **2021**, *28*, 42177–42195. [[CrossRef](#)] [[PubMed](#)]
28. *IS 10500*; Drinking Water Specification (Second Revision). Bureau of Indian Standards: New Delhi, India, 2012.
29. Bhowmick, S.; Pramanik, S.; Singh, P.; Mondal, P.; Chatterjee, D.; Nriagu, J. Arsenic in Groundwater of West Bengal, India: A Review of Human Health Risks and Assessment of Possible Intervention Options. *Sci. Total Environ.* **2018**, *612*, 148–169. [[CrossRef](#)] [[PubMed](#)]
30. Das, A.; Banerjee, A.; Roy, A. Hydrogeochemical Contrast between Two Study Areas of Bengal Delta, India: A Comparative Insight to Understand Arsenic Mobilization Process in Shallow Aquifers. *Geochemistry* **2021**, *81*, 125680. [[CrossRef](#)]
31. Sarkar, A.; Paul, B.; Darbha, G.K. The Groundwater Arsenic Contamination in the Bengal Basin—A Review in Brief. *Chemosphere* **2022**, *299*, 134369. [[CrossRef](#)]
32. Saha, A.; Pal, S.C.; Chowdhuri, I.; Roy, P.; Chakraborty, R. Effect of Hydrogeochemical Behavior on Groundwater Resources in Holocene Aquifers of Moribund Ganges Delta, India: Infusing Data-Driven Algorithms. *Environ. Pollut.* **2022**, *314*, 120203. [[CrossRef](#)]
33. Chakraborti, D.; Das, B.; Rahman, M.M.; Chowdhury, U.K.; Biswas, B.; Goswami, A.B.; Nayak, B.; Pal, A.; Sengupta, M.K.; Ahamed, S.; et al. Status of Groundwater Arsenic Contamination in the State of West Bengal, India: A 20-Year Study Report. *Mol. Nutr. Food Res.* **2009**, *53*, 542–551. [[CrossRef](#)]
34. Richards, L.A.; Kumari, R.; Parashar, N.; Kumar, A.; Lu, C.; Wilson, G.; Lapworth, D.; Niasar, V.J.; Ghosh, A.; Chakravorty, B.; et al. Environmental Tracers and Groundwater Residence Time Indicators Reveal Controls of Arsenic Accumulation Rates beneath a Rapidly Developing Urban Area in Patna, India. *J. Contam. Hydrol.* **2022**, *249*, 104043. [[CrossRef](#)]
35. Datta, S. *Hydrological Aspects of Arsenic Contamination of Groundwater in Eastern India*; Elsevier: Amsterdam, The Netherlands, 2015; Volume 132, ISBN 9780128021354.
36. Kumar, V.; Maity, A.; Kumar, A.; Saha, S.; Kay, P.; Singh, B.; Mukherjee, T. Critical Review on Uranium and Arsenic Content and Their Chemical Mobilization in Groundwater: A Case Study of the Malwa Region Punjab, India. *Sci. Total Environ.* **2023**, *885*, 163885. [[CrossRef](#)] [[PubMed](#)]

37. Kumar, A.; Ali, M.; Kumar, R.; Rahman, M.S.; Srivastava, A.; Chayal, N.K.; Sagar, V.; Kumari, R.; Parween, S.; Kumar, R.; et al. High Arsenic Concentration in Blood Samples of People of Village Gyaspur Mahaji, Patna, Bihar Drinking Arsenic-Contaminated Water. *Expo. Heal.* **2020**, *12*, 131–140. [[CrossRef](#)]
38. Chakraborti, D.; Singh, S.K.; Rahman, M.M.; Dutta, R.N.; Mukherjee, S.C.; Pati, S.; Kar, P.B. Groundwater Arsenic Contamination in the Ganga River Basin: A Future Health Danger. *Int. J. Environ. Res. Public Health* **2018**, *15*, 180. [[CrossRef](#)] [[PubMed](#)]
39. Singh, C.K.; Kumar, A.; Bindal, S. Arsenic Contamination in Rapti River Basin, Terai Region of India. *J. Geochem. Explor.* **2018**, *192*, 120–131. [[CrossRef](#)]
40. Dwivedi, S.; Mishra, S.; Kumar, V.; Agnihotri, R.; Sharma, P.; Tiwari, R.K.; Gupta, A.; Singh, A.P.; Kumar, S.; Sinam, G. A Comprehensive Review on Spatial and Temporal Variation of Arsenic Contamination in Ghaghara Basin and Its Relation to Probable Incremental Life Time Cancer Risk in the Local Population. *J. Trace Elem. Med. Biol.* **2023**, *80*, 127308. [[CrossRef](#)] [[PubMed](#)]
41. Chauhan, V.S.; Yunus, M.; Sankararamkrishnan, N. Geochemistry and Mobilization of Arsenic in Shuklaganj Area of Kanpur–Unnao District, Uttar Pradesh, India. *Environ. Monit. Assess.* **2012**, *184*, 4889–4901. [[CrossRef](#)] [[PubMed](#)]
42. Kumar, A.; Ali, M.; Kumar, R.; Kumar, M.; Sagar, P.; Pandey, R.K.; Akhouri, V.; Kumar, V.; Anand, G.; Niraj, P.K.; et al. Arsenic Exposure in Indo Gangetic Plains of Bihar Causing Increased Cancer Risk. *Sci. Rep.* **2021**, *11*, 2376. [[CrossRef](#)]
43. Nickson, R.; Sengupta, C.; Mitra, P.; Dave, S.N.; Banerjee, A.K.; Bhattacharya, A.; Basu, S.; Kakoti, N.; Moorthy, N.S.; Wasuja, M.; et al. Current Knowledge on the Distribution of Arsenic in Groundwater in Five States of India. *J. Environ. Sci. Heal. Part A* **2007**, *42*, 1707–1718. [[CrossRef](#)]
44. Central Ground Water Board. *Ground Water Quality in Shallow Aquifers of India*; Central Ground Water Board: Faridabad, India, 2018; pp. 18–21.
45. Hundal, H.S.; Singh, K.; Singh, D. Arsenic Content in Ground and Canal Waters of Punjab, North–West India. *Environ. Monit. Assess.* **2009**, *154*, 393–400. [[CrossRef](#)]
46. Borah, K.K.; Bhuyan, B.; Sarma, H.P. Lead, Arsenic, Fluoride, and Iron Contamination of Drinking Water in the Tea Garden Belt of Darrang District, Assam, India. *Environ. Monit. Assess.* **2010**, *169*, 347–352. [[CrossRef](#)]
47. Patel, A.K.; Singh, A.; Das, N.; Kumar, M. Health Risk Associated with Consumption of Arsenic Contaminated Groundwater in the Ganga and the Brahmaputra Floodplain of India. *Case Stud. Chem. Environ. Eng.* **2021**, *3*, 100103. [[CrossRef](#)]
48. Hebbar, A.; Janardhana, M.R. Arsenic Contamination in Groundwater of the Areas Surrounding Ingaldhal, Chitradurga District, Karnataka State. *Int. J. Geol. Earth Environ.* **2016**, *3*, 1–7.
49. Uppal, J.S.; Zheng, Q.; Le, X.C. Arsenic in Drinking Water—Recent Examples and Updates from Southeast Asia. *Curr. Opin. Environ. Sci. Health* **2019**, *7*, 126–135. [[CrossRef](#)]
50. Halder, A. Premature Greying of Hairs, Premature Ageing and Predisposition to Cancer in Jajjal, Punjab: A Preliminary Observation. *J. Clin. Diagn. Res.* **2007**, *6*, 577–580.
51. Bindal, S.; Singh, C.K. Predicting Groundwater Arsenic Contamination: Regions at Risk in Highest Populated State of India. *Water Res.* **2019**, *159*, 65–76. [[CrossRef](#)] [[PubMed](#)]
52. Wu, R.; Xu, L.; Polya, D.A. Groundwater Arsenic-Attributable Cardiovascular Disease (CVD) Mortality Risks in India. *Water* **2021**, *13*, 2232. [[CrossRef](#)]
53. Singh, S.P. Spatial Relationship of Various Parameters in Drinking Water in Siwan Town of Bihar (India) with Special Emphasis on Arsenic Contamination in Groundwater. *J. Chem. Sci. Rev. Lett.* **2014**, *2*, 588–595.
54. Chakraborti, D.; Das, B.; Rahman, M.M.; Nayak, B.; Pal, A.; Sengupta, M.K.; Ahamed, S.; Hossain, M.A.; Chowdhury, U.K.; Biswas, B.K.; et al. Arsenic in Groundwater of the Kolkata Municipal Corporation (KMC), India: Critical Review and Modes of Mitigation. *Chemosphere* **2017**, *180*, 437–447. [[CrossRef](#)]
55. Bhowmick, S.; Nath, B.; Halder, D.; Biswas, A.; Majumder, S.; Mondal, P.; Chakraborty, S.; Nriagu, J.; Bhattacharya, P.; Iglesias, M.; et al. Arsenic Mobilization in the Aquifers of Three Physiographic Settings of West Bengal, India: Understanding Geogenic and Anthropogenic Influences. *J. Hazard. Mater.* **2013**, *262*, 915–923. [[CrossRef](#)]
56. Sikdar, P.K.; Sarkar, S.S.; Palchoudhury, S. Geochemical Evolution of Groundwater in the Quaternary Aquifer of Calcutta and Howrah, India. *J. Asian Earth Sci.* **2001**, *19*, 579–594. [[CrossRef](#)]
57. Biswas, G. Asphyxiants. In *Review of Forensic Medicine and Toxicology*; Jaypee Brothers Medical Publishers Ltd.: New Delhi, India, 2010; p. 419.
58. Purkait, B. Application of Artificial Neural Network Model to Study Arsenic Contamination in Groundwater of Malda District, Eastern India. *J. Environ. Inform.* **2008**, *12*, 140–149. [[CrossRef](#)]
59. Sankar, M.S.; Vega, M.A.; Defoe, P.P.; Kibria, M.G.; Ford, S.; Telfeyan, K.; Neal, A.; Mohajerin, T.J.; Hettiarachchi, G.M.; Barua, S.; et al. Elevated Arsenic and Manganese in Groundwaters of Murshidabad, West Bengal, India. *Sci. Total Environ.* **2014**, *488–489*, 570–579. [[CrossRef](#)] [[PubMed](#)]
60. Das, A.; Das, S.S.; Chowdhury, N.R.; Joardar, M.; Ghosh, B.; Roychowdhury, T. Quality and Health Risk Evaluation for Groundwater in Nadia District, West Bengal: An Approach on Its Suitability for Drinking and Domestic Purpose. *Groundw. Sustain. Dev.* **2020**, *10*, 100351. [[CrossRef](#)]
61. Bhatia, S.; Balamurugan, G.; Baranwa, A. High Arsenic Contamination in Drinking Water Hand-Pumps in Khap Tola, West Champaran, Bihar, India. *Front. Environ. Sci.* **2014**, *2*, 49. [[CrossRef](#)]

62. Thakur, B.K.; Gupta, V.; Bhattacharya, P.; Chakraborty, T. Impact of Socioeconomic Factors on Households' Willingness to Pay for Arsenic-Free Safe Drinking Water—A Case Study of Bihar, India. *Groundw. Sustain. Dev.* **2022**, *19*, 100837. [[CrossRef](#)]
63. Kumar, M.; Ramanathan, A.; Bhattacharya, P. Evaluation of Arsenic and Its Controlling Factors in Aquifer Sands of District Samastipur, Bihar, India. In *One Century of the Discovery of Arsenicosis in Latin America (1914–2014) As 2014*; CRC Press/Taylor and Francis Group: London, UK, 2014; pp. 108–109.
64. Singh, S.K.; Brachfeld, S.A.; Taylor, R.W. Evaluating Hydrogeological and Topographic Controls on Groundwater Arsenic Contamination in the Middle-Ganga Plain in India: Towards Developing Sustainable Arsenic Mitigation Models BT. In *Emerging Issues in Groundwater Resources, Advances in Water Security*; Fares, A., Ed.; Springer: Cham, Switzerland, 2016; pp. 263–287, ISBN 978-3-319-32008-3.
65. Singh, N.; Singh, R.P.; Mukherjee, S.; McDonald, K.; Reddy, K.J. Hydrogeological Processes Controlling the Release of Arsenic in Parts of 24 Parganas District, West Bengal. *Environ. Earth Sci.* **2014**, *72*, 111–118. [[CrossRef](#)]
66. Shah, B.A. Groundwater Arsenic Contamination Affecting Different Geological Domains in India: Its Relation to Fluvial Geomorphology and Quaternary Stratigraphy BT. In *Geostatistical and Geospatial Approaches for the Characterization of Natural Resources in the Environment: Challenges, Processes and Strategies*; Raju, N.J., Ed.; Springer: Cham, Switzerland, 2016; pp. 267–273.
67. Chakraborti, D.; Rahman, M.M.; Ahamed, S.; Dutta, R.N.; Pati, S.; Mukherjee, S.C. Arsenic Contamination of Groundwater and Its Induced Health Effects in Shahpur Block, Bhojpur District, Bihar State, India: Risk Evaluation. *Environ. Sci. Pollut. Res.* **2016**, *23*, 9492–9504. [[CrossRef](#)]
68. Agrawal, D.; Kumar, P.; Avtar, R.; Ramanathan, A.L. Multivariate Statistical Approach to Deduce Hydrogeochemical Processes in the Groundwater Environment of Begusarai District, Bihar. *Water Qual. Expo. Health* **2011**, *3*, 119–126. [[CrossRef](#)]
69. Pathak, V.K. Hydrochemistry of Groundwater with Special Reference to Arsenic in Lakhimpur Kheri District, Uttar Pradesh, India. *IOSR J. Appl. Chem.* **2013**, *6*, 61–68. [[CrossRef](#)]
70. Shah, B.A. Groundwater Arsenic Contamination from Parts of the Ghaghara Basin, India: Influence of Fluvial Geomorphology and Quaternary Morphostratigraphy. *Appl. Water Sci.* **2017**, *7*, 2587–2595. [[CrossRef](#)]
71. Namrata, P.; Alok, L.; Mehrotra, S. Arsenic Pollution Scenario in Eastern UP, India: A Review. *Int. Res. J. Environ. Sci. Int. Sci. Congr. Assoc.* **2015**, *4*, 83–86.
72. Ahamed, S.; Kumar Sengupta, M.; Mukherjee, A.; Amir Hossain, M.; Das, B.; Nayak, B.; Pal, A.; Chandra Mukherjee, S.; Pati, S.; Nath Dutta, R.; et al. Arsenic Groundwater Contamination and Its Health Effects in the State of Uttar Pradesh (UP) in Upper and Middle Ganga Plain, India: A Severe Danger. *Sci. Total Environ.* **2006**, *370*, 310–322. [[CrossRef](#)] [[PubMed](#)]
73. Singh, A.L.; Singh, V.K. Assessment of Groundwater Quality of Ballia District, Uttar Pradesh, India, with Reference to Arsenic Contamination Using Multivariate Statistical Analysis. *Appl. Water Sci.* **2018**, *8*, 95. [[CrossRef](#)]
74. Alam, M.O.; Shaikh, W.A.; Chakraborty, S.; Avishek, K.; Bhattacharya, T. Groundwater Arsenic Contamination and Potential Health Risk Assessment of Gangetic Plains of Jharkhand, India. *Expo. Health* **2016**, *8*, 125–142. [[CrossRef](#)]
75. Sharma, S.; Kaur, I.; Nagpal, A.K. Estimation of Arsenic, Manganese and Iron in Mustard Seeds, Maize Grains, Groundwater and Associated Human Health Risks in Ropar Wetland, Punjab, India, and Its Adjoining Areas. *Environ. Monit. Assess.* **2018**, *190*, 385. [[CrossRef](#)]
76. Virk, H.S. A Survey Report on Groundwater Contamination of Malwa Belt of Punjab Due to Heavy Metal Arsenic. *Int. J. Sci. Res.* **2019**, *8*, 1721–1726.
77. Hundal, H.S.; Kumar, R.; Singh, K.; Singh, D. Occurrence and Geochemistry of Arsenic in Groundwater of Punjab, Northwest India. *Commun. Soil Sci. Plant Anal.* **2007**, *38*, 2257–2277. [[CrossRef](#)]
78. Kumar, A.; Singh, C.K. Arsenic Enrichment in Groundwater and Associated Health Risk in Bari Doab Region of Indus Basin, Punjab, India. *Environ. Pollut.* **2020**, *256*, 113324. [[CrossRef](#)]
79. Kaur, T.; Bhardwaj, R.; Arora, S. Assessment of Groundwater Quality for Drinking and Irrigation Purposes Using Hydrochemical Studies in Malwa Region, Southwestern Part of Punjab, India. *Appl. Water Sci.* **2017**, *7*, 3301–3316. [[CrossRef](#)]
80. Purkayastha, S.P.; Choudhury, M.; Deb, D.; Paul, C. Arsenic Contamination in Ground Water Is a Serious Threat in the North Karimganj Block of Karimganj District, Southern Part of Assam, India. *J. Chem. Pharm. Res.* **2015**, *7*, 371–378.
81. Buragohain, M.; Bhuyan, B.; Sarma, H.P. Seasonal Variations of Lead, Arsenic, Cadmium and Aluminium Contamination of Groundwater in Dhemaji District, Assam, India. *Environ. Monit. Assess.* **2010**, *170*, 345–351. [[CrossRef](#)] [[PubMed](#)]
82. Jain, C.K.; Sharma, S.K.; Singh, S. Physico-Chemical Characteristics and Hydrogeological Mechanisms in Groundwater with Special Reference to Arsenic Contamination in Barpeta District, Assam (India). *Environ. Monit. Assess.* **2018**, *190*, 417. [[CrossRef](#)] [[PubMed](#)]
83. Sridharan, M.; Nathan, D.S. Chemometric Tool to Study the Mechanism of Arsenic Contamination in Groundwater of Puducherry Region, South East Coast of India. *Chemosphere* **2018**, *208*, 303–315. [[CrossRef](#)]
84. Patel, K.S.; Sahu, B.L.; Dahariya, N.S.; Bhatia, A.; Patel, R.K.; Matini, L.; Sracek, O.; Bhattacharya, P. Groundwater Arsenic and Fluoride in Rajnandgaon District, Chhattisgarh, Northeastern India. *Appl. Water Sci.* **2017**, *7*, 1817–1826. [[CrossRef](#)]
85. Sharma, R.; Patel, K.S.; Lata, L.; Milos, H. Contamination of Pond Water and Sediment in Coal Burning Area. *J. Environ. Prot.* **2017**, *08*, 358–379. [[CrossRef](#)]
86. Ravichandran, K.; Bhange, S.A.; Lalitha, B.H.; Dhayamalar, D. Geochemical behaviour of uranium with other contaminants in groundwater of raichur district. *J. Indian Water Resour. Soc.* **2022**, *42*.

87. Shah, B. Arsenic-Contaminated Groundwater in Holocene Sediments from Parts of Middle Ganga Plain, Uttar Pradesh, India. *Curr. Sci.* **2010**, *98*, 1359–1365.
88. Wang, Z.; Guo, H.M.; Liu, H.Y.; Zhang, W.M. Source, Migration, Distribution, Toxicological Effects and Remediation Technologies of Arsenic in Groundwater in China. *China Geol.* **2023**, *6*, 476–493. [[CrossRef](#)]
89. Wallis, I.; Pichler, T. Generating False Negatives and False Positives for As and Mo Concentrations in Groundwater Due to Well Installation. *Sci. Total Environ.* **2018**, *631–632*, 723–732. [[CrossRef](#)]
90. Dong, Y.; Ma, T.; Li, J.; Liu, Y. Arsenic Releasing from Poly-Metallic Sulfide Deposits at Hetao Plain, China. *Geochem. Int.* **2018**, *56*, 1179–1188. [[CrossRef](#)]
91. Chattopadhyay, A.; Singh, A.P.; Singh, S.K.; Barman, A.; Patra, A.; Mondal, B.P.; Banerjee, K. Spatial variability of arsenic in indo-Gangetic basin of Varanasi and its cancer risk assessment. *Chemosphere* **2020**, *238*, 124623. [[CrossRef](#)] [[PubMed](#)]
92. Kumar, M.; Das, N.; Tripathi, S.; Verma, A.; Jha, P.K.; Bhattacharya, P.; Mahlknecht, J. Global Co-Occurrences of Multi-(Emerging)-Contaminants in the Hotspots of Arsenic Polluted Groundwater: A Pattern of Menace. *Curr. Opin. Environ. Sci. Health* **2023**, *34*, 100483. [[CrossRef](#)]
93. Ahmed, K.M.; Bhattacharya, P.; Hasan, M.A.; Akhter, S.H.; Alam, S.M.M.; Bhuyian, M.A.H.; Imam, M.B.; Khan, A.A.; Sracek, O. Arsenic Enrichment in Groundwater of the Alluvial Aquifers in Bangladesh: An Overview. *Appl. Geochem.* **2004**, *19*, 181–200. [[CrossRef](#)]
94. Kumar, S.; Pati, J. Assessment of Groundwater Arsenic Contamination Level in Jharkhand, India Using Machine Learning. *J. Comput. Sci.* **2022**, *63*, 101779. [[CrossRef](#)]
95. Mukherjee, A.; Scanlon, B.R.; Fryar, A.E.; Saha, D.; Ghosh, A.; Chowdhuri, S.; Mishra, R. Solute Chemistry and Arsenic Fate in Aquifers between the Himalayan Foothills and Indian Craton (Including Central Gangetic Plain): Influence of Geology and Geomorphology. *Geochim. Cosmochim. Acta* **2012**, *90*, 283–302. [[CrossRef](#)]
96. Dowling, C.B.; Poreda, R.J.; Basu, A.R.; Peters, S.L.; Aggarwal, P.K.; Dowling, C.; Poreda, R.J.; Basu, A.R.; Peters, S.L.; Aggarwal, P.K. Geochemical Study of Arsenic Release Mechanisms in the Bengal Basin Groundwater. *Water Resour. Res.* **2002**, *38*, 12-1–12-18. [[CrossRef](#)]
97. Goswami, R.; Neog, N.; Bhagat, C.; Hdeib, R.; Mahlknecht, J.; Kumar, M. Arsenic in the Groundwater of the Upper Brahmaputra Floodplain: Variability, Health Risks and Potential Impacts. *Chemosphere* **2022**, *306*, 135621. [[CrossRef](#)]
98. Manning, B.A.; Goldberg, S. Adsorption and Stability of Arsenic(III) at the Clay Mineral–Water Interface. *Environ. Sci. Technol.* **1997**, *31*, 2005–2011. [[CrossRef](#)]
99. Anawar, H.M.; Akai, J.; Sakugawa, H. Mobilization of Arsenic from Subsurface Sediments by Effect of Bicarbonate Ions in Groundwater. *Chemosphere* **2004**, *54*, 753–762. [[CrossRef](#)]
100. Qiao, J.T.; Li, X.M.; Li, F.B. Roles of Different Active Metal-Reducing Bacteria in Arsenic Release from Arsenic-Contaminated Paddy Soil Amended with Biochar. *J. Hazard. Mater.* **2018**, *344*, 958–967. [[CrossRef](#)]
101. Vega, M.A.; Kulkarni, H.V.; Mladenov, N.; Johannesson, K.; Hettiarachchi, G.M.; Bhattacharya, P.; Kumar, N.; Weeks, J.; Galkaduwa, M.; Datta, S. Biogeochemical Controls on the Release and Accumulation of Mn and As in Shallow Aquifers, West Bengal, India. *Front. Environ. Sci.* **2017**, *5*, 267730. [[CrossRef](#)]
102. Kumar, M.; Patel, A.K.; Singh, A. Anthropogenic Dominance on Geogenic Arsenic Problem of the Groundwater in the Ganga-Brahmaputra Floodplain: A Paradox of Origin and Mobilization. *Sci. Total Environ.* **2022**, *807*, 151461. [[CrossRef](#)] [[PubMed](#)]
103. Goswami, R.; Kumar, M.; Biyani, N.; Shea, P.J. Arsenic Exposure and Perception of Health Risk Due to Groundwater Contamination in Majuli (River Island), Assam, India. *Environ. Geochem. Health* **2020**, *42*, 443–460. [[CrossRef](#)] [[PubMed](#)]
104. McArthur, J.M.; Ravenscroft, P.; Safiulla, S.; Thirlwall, M.F. Arsenic in Groundwater: Testing Pollution Mechanisms for Sedimentary Aquifers in Bangladesh. *Water Resour. Res.* **2001**, *37*, 109–117. [[CrossRef](#)]
105. Rowland, H.A.L.; Polya, D.A.; Lloyd, J.R.; Pancost, R.D. Characterisation of Organic Matter in a Shallow, Reducing, Arsenic-Rich Aquifer, West Bengal. *Org. Geochem.* **2006**, *37*, 1101–1114. [[CrossRef](#)]
106. Wang, S.; Mulligan, C.N. Effect of Natural Organic Matter on Arsenic Release from Soils and Sediments into Groundwater. *Environ. Geochem. Health* **2006**, *28*, 197–214. [[CrossRef](#)]
107. Farooq, S.H.; Chandrasekharam, D.; Abbt-Braun, G.; Berner, Z.; Norra, S.; Stüben, D.; Farooq, S.H.; Chandrasekharam, D.; Abbt-Braun, G.; Berner, Z.; et al. Dissolved Organic Carbon from the Traditional Jute Processing Technique and Its Potential Influence on Arsenic Enrichment in the Bengal Delta. *Appl. Geochem.* **2012**, *27*, 292–303. [[CrossRef](#)]
108. Mohapatra, B.; Saha, A.; Chowdhury, A.N.; Kar, A.; Kazy, S.K.; Sar, P. Geochemical, Metagenomic, and Physiological Characterization of the Multifaceted Interaction between Microbiome of an Arsenic Contaminated Groundwater and Aquifer Sediment. *J. Hazard. Mater.* **2021**, *412*, 125099. [[CrossRef](#)]
109. Yin, S.; Zhang, X.; Yin, H.; Zhang, X. Current Knowledge on Molecular Mechanisms of Microorganism-Mediated Bioremediation for Arsenic Contamination: A Review. *Microbiol. Res.* **2022**, *258*, 126990. [[CrossRef](#)]
110. Pratush, A.; Kumar, A.; Hu, Z. Adverse Effect of Heavy Metals (As, Pb, Hg, and Cr) on Health and Their Bioremediation Strategies: A Review. *Int. Microbiol.* **2018**, *21*, 97–106. [[CrossRef](#)]
111. Saha, A.; Mohapatra, B.; Kazy, S.K.; Sar, P. Variable Response of Arsenic Contaminated Groundwater Microbial Community to Electron Acceptor Regime Revealed by Microcosm Based High-Throughput Sequencing Approach. *J. Environ. Sci. Health Part A* **2021**, *56*, 804–817. [[CrossRef](#)] [[PubMed](#)]
112. Shih, M.C. An Overview of Arsenic Removal by Pressure-Driven Membrane Processes. *Desalination* **2005**, *172*, 85–97. [[CrossRef](#)]

113. Chatterjee, D.; Kundu, A.; Saha, D.; Barman, S.; Mandal, U. Groundwater Arsenic in the Bengal Delta Plain: Geochemical and Geomorphological Perspectives. *Procedia Earth Planet. Sci.* **2017**, *17*, 622–625. [[CrossRef](#)]
114. Sathe, S.S.; Mahanta, C. Groundwater Flow and Arsenic Contamination Transport Modeling for a Multi Aquifer Terrain: Assessment and Mitigation Strategies. *J. Environ. Manag.* **2019**, *231*, 166–181. [[CrossRef](#)] [[PubMed](#)]
115. Modeling of Arsenic Transport in Groundwater Using MODFLOW: A Case Study. Available online: https://www.researchgate.net/publication/309398014_Modeling_of_arsenic_transport_in_groundwater_using_MODFLOW_A_case_study (accessed on 17 November 2023).
116. Chowdhury, A.; Rahnema, M. Groundwater Contaminant Transport Modeling Using MODFLOW and MT3DMS: A Case Study in Rajshahi City. *Water Pract. Technol.* **2023**, *18*, 1255–1272. [[CrossRef](#)]
117. Mishra, D.; Das, B.S.; Sinha, T.; Hoque, J.M.; Reynolds, C.; Rafiqul Islam, M.; Hossain, M.; Sar, P.; Menon, M. Living with Arsenic in the Environment: An Examination of Current Awareness of Farmers in the Bengal Basin Using Hybrid Feature Selection and Machine Learning. *Environ. Int.* **2021**, *153*, 106529. [[CrossRef](#)]
118. Dummer, T.J.B.; Yu, Z.M.; Nauta, L.; Murimboh, J.D.; Parker, L. Geostatistical Modelling of Arsenic in Drinking Water Wells and Related Toenail Arsenic Concentrations across Nova Scotia, Canada. *Sci. Total Environ.* **2015**, *505*, 1248–1258. [[CrossRef](#)]
119. Morrissey, M.B.; Ruxton, G.D. Multiple Regression Is Not Multiple Regressions: The Meaning of Multiple Regression and the Non-Problem of Collinearity. *Philos. Theory Pract. Biol.* **2018**, *10*. [[CrossRef](#)]
120. Golia, E.E.; Diakouloukas, V. Soil Parameters Affecting the Levels of Potentially Harmful Metals in Thessaly Area, Greece: A Robust Quadratic Regression Approach of Soil Pollution Prediction. *Environ. Sci. Pollut. Res.* **2022**, *29*, 29544–29561. [[CrossRef](#)]
121. Singh, S.K.; Taylor, R.W.; Pradhan, B.; Shirzadi, A.; Pham, B.T. Predicting Sustainable Arsenic Mitigation Using Machine Learning Techniques. *Ecotoxicol. Environ. Saf.* **2022**, *232*, 113271. [[CrossRef](#)]
122. Nafouanti, M.B.; Li, J.; Nyakilla, E.E.; Mwakipunda, G.C.; Mulashani, A. A Novel Hybrid Random Forest Linear Model Approach for Forecasting Groundwater Fluoride Contamination. *Environ. Sci. Pollut. Res.* **2023**, *30*, 50661–50674. [[CrossRef](#)] [[PubMed](#)]
123. Shaheen, A.; Iqbal, J. Spatial Distribution and Mobility Assessment of Carcinogenic Heavy Metals in Soil Profiles Using Geostatistics and Random Forest, Boruta Algorithm. *Sustainability* **2018**, *10*, 799. [[CrossRef](#)]
124. Khan, M.U.; Musahib, M.; Vishwakarma, R.; Rai, N.; Jahan, A. Hydrochemical Characterization, Mechanism of Mobilization, and Natural Background Level Evaluation of Arsenic in the Aquifers of Upper Gangetic Plain, India. *Geochemistry* **2023**, *83*, 125952. [[CrossRef](#)]
125. Marghade, D.; Pethe, R.M.; Patil, P.D.; Tiwari, M.S. A Unified Multivariate Statistical Approach for the Assessment of Deep Groundwater Quality of Rapidly Growing City of Maharashtra Province, India, with Potential Health Risk. *Environ. Monit. Assess.* **2022**, *194*, 891. [[CrossRef](#)] [[PubMed](#)]
126. Marghade, D.; Malpe, D.B.; Duraisamy, K.; Patil, P.D.; Li, P. Hydrogeochemical Evaluation, Suitability, and Health Risk Assessment of Groundwater in the Watershed of Godavari Basin, Maharashtra, Central India. *Environ. Sci. Pollut. Res.* **2021**, *28*, 18471–18494. [[CrossRef](#)] [[PubMed](#)]
127. Goswami, R.; Rahman, M.M.; Murrill, M.; Sarma, K.P.; Thakur, R.; Chakraborti, D. Arsenic in the Groundwater of Majuli—The Largest River Island of the Brahmaputra: Magnitude of Occurrence and Human Exposure. *J. Hydrol.* **2014**, *518*, 354–362. [[CrossRef](#)]
128. Khanikar, L.; Gogoi, R.R.; Sarma, K.P. Hydrogeochemical Investigation and Health Perspective of Arsenic in the Mid-Brahmaputra Floodplain of Assam, India. In *Emerging Issues in the Water Environment during Anthropocene*; Springer: Singapore, 2020; pp. 143–158. [[CrossRef](#)]
129. Banerjee, K.; Amy, G.L.; Prevost, M.; Nour, S.; Jekel, M.; Gallagher, P.M.; Blumenschein, C.D. Kinetic and Thermodynamic Aspects of Adsorption of Arsenic onto Granular Ferric Hydroxide (GFH). *Water Res.* **2008**, *42*, 3371–3378. [[CrossRef](#)]
130. Singh, T.S.; Pant, K.K. Equilibrium, Kinetics and Thermodynamic Studies for Adsorption of As(III) on Activated Alumina. *Sep. Purif. Technol.* **2004**, *36*, 139–147. [[CrossRef](#)]
131. Badruzzaman, M.; Westerhoff, P.; Knappe, D.R.U. Intraparticle Diffusion and Adsorption of Arsenate onto Granular Ferric Hydroxide (GFH). *Water Res.* **2004**, *38*, 4002–4012. [[CrossRef](#)]
132. Mohan, D.; Pittman, C.U. Arsenic Removal from Water/Wastewater Using Adsorbents—A Critical Review. *J. Hazard. Mater.* **2007**, *142*, 1–53. [[CrossRef](#)]
133. Goswami, D.; Das, A.K. Removal of Arsenic from Drinking Water Using Modified Fly-Ash Bed. *Int. J. Water* **2000**, *1*, 61–70. [[CrossRef](#)]
134. Boddu, V.M.; Abburi, K.; Talbott, J.L.; Smith, E.D.; Haasch, R. Removal of Arsenic (III) and Arsenic (V) from Aqueous Medium Using Chitosan-Coated Biosorbent. *Water Res.* **2008**, *42*, 633–642. [[CrossRef](#)] [[PubMed](#)]
135. Khosa, M.A.; Wu, J.; Ullah, A. Chemical Modification, Characterization, and Application of Chicken Feathers as Novel Biosorbents. *RSC Adv.* **2013**, *3*, 20800–20810. [[CrossRef](#)]
136. Martinson, C.A.; Reddy, K.J. Adsorption of Arsenic(III) and Arsenic(V) by Cupric Oxide Nanoparticles. *J. Colloid Interface Sci.* **2009**, *336*, 406–411. [[CrossRef](#)] [[PubMed](#)]
137. Lata, S.; Samadder, S.R. Removal of Arsenic from Water Using Nano Adsorbents and Challenges: A Review. *J. Environ. Manag.* **2016**, *166*, 387–406. [[CrossRef](#)]
138. Sarkar, A.; Paul, B. The Global Menace of Arsenic and Its Conventional Remediation—A Critical Review. *Chemosphere* **2016**, *158*, 37–49. [[CrossRef](#)]

139. Calvo, P.; Remuñán-López, C.; Vila-Jato, J.L.; Alonso, M.J. Novel Hydrophilic Chitosan-Polyethylene Oxide Nanoparticles as Protein Carriers. *J. Appl. Polym. Sci.* **1997**, *63*, 125–132. [[CrossRef](#)]
140. Karthikeyan, G.; Anbalagan, K.; Andal, N.M. Adsorption Dynamics and Equilibrium Studies of Zn (II) onto Chitosan. *J. Chem. Sci.* **2004**, *116*, 119–127. [[CrossRef](#)]
141. Gupta, A.; Yunus, M.; Sankararamkrishnan, N. Zerovalent Iron Encapsulated Chitosan Nanospheres—A Novel Adsorbent for the Removal of Total Inorganic Arsenic from Aqueous Systems. *Chemosphere* **2012**, *86*, 150–155. [[CrossRef](#)]
142. He, J.; Bardelli, F.; Gehin, A.; Silvester, E.; Charlet, L. Novel Chitosan Goethite Bionanocomposite Beads for Arsenic Remediation. *Water Res.* **2016**, *101*, 1–9. [[CrossRef](#)]
143. Anderson, M.A.; Ferguson, J.F.; Gavis, J. Arsenate Adsorption on Amorphous Aluminum Hydroxide. *J. Colloid Interface Sci.* **1976**, *54*, 391–399. [[CrossRef](#)]
144. Samsuri, A.W.; Sadegh-Zadeh, F.; Seh-Bardan, B.J. Adsorption of As(III) and As(V) by Fe Coated Biochars and Biochars Produced from Empty Fruit Bunch and Rice Husk. *J. Environ. Chem. Eng.* **2013**, *1*, 981–988. [[CrossRef](#)]
145. Budinova, T.; Savova, D.; Tsyntsarski, B.; Ania, C.O.; Cabal, B.; Parra, J.B.; Petrov, N. Biomass Waste-Derived Activated Carbon for the Removal of Arsenic and Manganese Ions from Aqueous Solutions. *Appl. Surf. Sci.* **2009**, *255*, 4650–4657. [[CrossRef](#)]
146. Tuna, A.Ö.A.; Özdemir, E.; Şimşek, E.B.; Beker, U. Removal of As(V) from Aqueous Solution by Activated Carbon-Based Hybrid Adsorbents: Impact of Experimental Conditions. *Chem. Eng. J.* **2013**, *223*, 116–128. [[CrossRef](#)]
147. Arcibar-Orozco, J.A.; Josue, D.-B.; Rios-Hurtado, J.C.; Rangel-Mendez, J.R. Influence of Iron Content, Surface Area and Charge Distribution in the Arsenic Removal by Activated Carbons. *Chem. Eng. J.* **2014**, *249*, 201–209. [[CrossRef](#)]
148. Liu, Z.; Zhang, F.-S.; Sasai, R. Arsenate Removal from Water Using Fe₃O₄-Loaded Activated Carbon Prepared from Waste Biomass. *Chem. Eng. J.* **2010**, *160*, 57–62. [[CrossRef](#)]
149. Zhu, H.; Jia, Y.; Wu, X.; Wang, H. Removal of Arsenic from Water by Supported Nano Zero-Valent Iron on Activated Carbon. *J. Hazard. Mater.* **2009**, *172*, 1591–1596. [[CrossRef](#)]
150. Mercer, K.L.; Tobiason, J.E. Removal of Arsenic from High Ionic Strength Solutions: Effects of Ionic Strength, PH, and Preformed versus in Situ Formed HFO. *Environ. Sci. Technol.* **2008**, *42*, 3797–3802. [[CrossRef](#)]
151. Nguyen, T.V.; Vigneswaran, S.; Ngo, H.H.; Kandasamy, J.; Choi, H.C. Arsenic Removal by Photo-Catalysis Hybrid System. *Sep. Purif. Technol.* **2008**, *61*, 44–50. [[CrossRef](#)]
152. Fu, D.; Kurniawan, T.A.; Gui, H.; Li, H.; Feng, S.; Li, Q.; Wang, Y. Role of CuxO-Anchored Pyrolyzed Hydrochars on H₂O₂-Activated Degradation of Tetracycline: Effects of Pyrolysis Temperature and PH. *Ind. Eng. Chem. Res.* **2022**, *61*, 8847–8857. [[CrossRef](#)]
153. Kurniawan, T.A.; Lo, W.; Chan, G.Y.S. Radicals-Catalyzed Oxidation Reactions for Degradation of Recalcitrant Compounds from Landfill Leachate. *Chem. Eng. J.* **2006**, *125*, 35–57. [[CrossRef](#)]
154. Tahaiht, M.; El Habbani, R.; Ait Haddou, A.; Achary, I.; Amor, Z.; Taky, M.; Alami, A.; Boughriba, A.; Hafsi, M.; Elmidaoui, A. Fluoride Removal from Groundwater by Nanofiltration. *Desalination* **2007**, *212*, 46–53. [[CrossRef](#)]
155. Kurniawan, T.A.; Aytar, R.; Singh, D.; Xue, W.; Dzarfan Othman, M.H.; Hwang, G.H.; Iswanto, I.; Albadarin, A.B.; Kern, A.O. Reforming MSWM in Sukunan (Yogyakarta, Indonesia): A Case-Study of Applying a Zero-Waste Approach Based on Circular Economy Paradigm. *J. Clean. Prod.* **2021**, *284*, 124775. [[CrossRef](#)] [[PubMed](#)]
156. Choong, T.S.Y.; Chuah, T.G.; Robiah, Y.; Gregory Koay, F.L.; Azni, I. Arsenic Toxicity, Health Hazards and Removal Techniques from Water: An Overview. *Desalination* **2007**, *217*, 139–166. [[CrossRef](#)]
157. Meng, X.; Korfiatis, G.P.; Bang, S.; Bang, K.W. Combined Effects of Anions on Arsenic Removal by Iron Hydroxides. *Toxicol. Lett.* **2002**, *133*, 103–111. [[CrossRef](#)] [[PubMed](#)]
158. Wickramasinghe, S.R.; Han, B.; Zimbron, J.; Shen, Z.; Karim, M.N. Arsenic Removal by Coagulation and Filtration: Comparison of Groundwaters from the United States and Bangladesh. *Desalination* **2004**, *169*, 231–244. [[CrossRef](#)]
159. Zhu, F.; Yang, M.; Luo, Z.; Yu, R.; Hu, G.; Yan, Y. Bioaccumulation and Biotransformation of Arsenic in *Leptolyngbya Boryana*. *Environ. Sci. Pollut. Res.* **2020**, *27*, 29993–30000. [[CrossRef](#)]
160. Zhaojuan, Z.; Binbin, S.; Cuiqing, M.; Haiwei, Z.; Chao, G.; Fei, S.; Ping, X. Relative Catalytic Efficiency of LdhL- and LdhD-Encoded Products Is Crucial for Optical Purity of Lactic Acid Produced by *Lactobacillus* Strains. *Appl. Environ. Microbiol.* **2012**, *78*, 3480–3483. [[CrossRef](#)]
161. Ye, J.; Rensing, C.; Rosen, B.P.; Zhu, Y.-G. Arsenic Biomethylation by Photosynthetic Organisms. *Trends Plant Sci.* **2012**, *17*, 155–162. [[CrossRef](#)]
162. Wang, Y.; Wang, S.; Xu, P.; Liu, C.; Liu, M.; Wang, Y.; Wang, C.; Zhang, C.; Ge, Y. Review of Arsenic Speciation, Toxicity and Metabolism in Microalgae. *Rev. Environ. Sci. Bio/Technol.* **2015**, *14*, 427–451. [[CrossRef](#)]
163. Xue, X.-M.; Yan, Y.; Xiong, C.; Raber, G.; Francesconi, K.; Pan, T.; Ye, J.; Zhu, Y.-G. Arsenic Biotransformation by a Cyanobacterium *Nostoc* Sp. PCC 7120. *Environ. Pollut.* **2017**, *228*, 111–117. [[CrossRef](#)] [[PubMed](#)]
164. Vaaramaa, K.; Lehto, J. Removal of Metals and Anions from Drinking Water by Ion Exchange. *Desalination* **2003**, *155*, 157–170. [[CrossRef](#)]
165. Ng, K.-S.; Ujang, Z.; Le-Clech, P. Arsenic Removal Technologies for Drinking Water Treatment. *Rev. Environ. Sci. Biotechnol.* **2004**, *3*, 43–53. [[CrossRef](#)]
166. Košutić, K.; Furač, L.; Sipos, L.; Kunst, B. Removal of Arsenic and Pesticides from Drinking Water by Nanofiltration Membranes. *Sep. Purif. Technol.* **2005**, *42*, 137–144. [[CrossRef](#)]

167. Rahmani, M.; Kaykhaii, M.; Sasani, M. Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy Application of Taguchi L16 Design Method for Comparative Study of Ability of 3A Zeolite in Removal of Rhodamine B and Malachite Green from Environmental Water Samples. *Spectrochim. Acta Part A Mol. Biomol. Spectrosc.* **2018**, *188*, 164–169. [[CrossRef](#)] [[PubMed](#)]
168. Wang, J.-D.; Li, X.-X.; Qu, C.-T. A Global Proteomic Change in Petroleum Hydrocarbon-Degrading *Pseudomonas Aeruginosa* in Response to High and Low Concentrations of Petroleum Hydrocarbons. *Curr. Microbiol.* **2019**, *76*, 1270–1277. [[CrossRef](#)] [[PubMed](#)]
169. Elmobarak, W.F.; Hameed, B.H.; Almomani, F.; Abdullah, A.Z. A Review on the Treatment of Petroleum Refinery Wastewater Using Advanced Oxidation Processes. *Catalysts* **2021**, *11*, 782. [[CrossRef](#)]
170. Vicente, J.; Rosal, R.; Díaz, M. Noncatalytic Oxidation of Phenol in Aqueous Solutions. *Ind. Eng. Chem. Res.* **2002**, *41*, 46–51. [[CrossRef](#)]
171. Ghurye, G.; Clifford, D.; Tripp, A. Iron Coagulation and Direct Microfiltration to Remove Arsenic from Groundwater. *J. AWWA* **2004**, *96*, 143–152. [[CrossRef](#)]
172. Kalaimurugan, D.; Sivasankar, P.; Durairaj, K.; Lakshmanamoorthy, M.; Ali Alharbi, S.; Al Yousef, S.A.; Chinnathambi, A.; Venkatesan, S. Novel Strategy for Biodegradation of 4-Nitrophenol by the Immobilized Cells of *Pseudomonas Sp. YPS3* with Acacia Gum. *Saudi J. Biol. Sci.* **2021**, *28*, 833–839. [[CrossRef](#)]
173. Agyekum, E.B.; Nutakor, C.; Agwa, A.M.; Kamel, S. A Critical Review of Renewable Hydrogen Production Methods: Factors Affecting Their Scale-Up and Its Role in Future Energy Generation. *Membranes* **2022**, *12*, 173. [[CrossRef](#)]
174. Dałbrowski, A. Adsorption—From Theory to Practice. *Adv. Colloid Interface Sci.* **2001**, *93*, 135–224. [[CrossRef](#)]
175. Shelare, S.; Kumar, R.; Gajbhiye, T.; Kanchan, S. Role of Geothermal Energy in Sustainable Water Desalination—A Review on Current Status, Parameters, and Challenges. *Energies* **2023**, *16*, 2901. [[CrossRef](#)]
176. Thirunavukkarasu, O.S.; Viraraghavan, T.; Subramanian, K.S. Removal of Arsenic in Drinking Water by Iron Oxide-Coated Sand and Ferrihydrite—Batch Studies. *Water Qual. Res. J.* **2001**, *36*, 55–70. [[CrossRef](#)]
177. Vilve, M.; Vilhunen, S.; Vepsäläinen, M.; Kurniawan, T.A.; Lehtonen, N.; Isomäki, H.; Sillanpää, M. Degradation of 1,2-Dichloroethane from Wash Water of Ion-Exchange Resin Using Fenton’s Oxidation. *Environ. Sci. Pollut. Res.* **2010**, *17*, 875–884. [[CrossRef](#)]
178. Ahmed, F.E.; Hashaikeh, R.; Hilal, N. Solar Powered Desalination—Technology, Energy and Future Outlook. *Desalination* **2019**, *453*, 54–76. [[CrossRef](#)]
179. Hernandez, D.; Boden, K.; Paul, P.; Bandaru, S.; Myapati, S.; Roy, A.; Amrose, S.; Roy, J.; Gadgil, A. Strategies for Successful Field Deployment in a Resource-Poor Region: Arsenic Remediation Technology for Drinking Water. *Dev. Eng.* **2019**, *4*, 100045. [[CrossRef](#)]
180. Robles, D. Indigenous Water Governance in the Anthropocene: Non-Conventional Hydrosocial Relations Among the Wayuu of the Guajira Peninsula in Northern Colombia. Ph.D. Thesis, Florida International University, Miami, FL, USA, 2020.
181. Scott, I.S.P.C.; Scott, F.; McCarty, T.; Penn, C.J. Techno-Economic Analysis of Phosphorus Removal Structures. *Environ. Sci. Technol.* **2023**, *57*, 12858–12868. [[CrossRef](#)] [[PubMed](#)]
182. López-Guzmán, M.; Alarcón-Herrera, M.T.; Irigoyen-Campuzano, J.R.; Torres-Castañón, L.A.; Reynoso-Cuevas, L. Simultaneous Removal of Fluoride and Arsenic from Well Water by Electrocoagulation. *Sci. Total Environ.* **2019**, *678*, 181–187. [[CrossRef](#)] [[PubMed](#)]
183. Kumar, A.; Roy, M.B.; Roy, P.K.; Wallace, J.M. Assessment of Arsenic Removal Units in Arsenic-Prone Rural Area in Uttar Pradesh, India. *J. Inst. Eng. Ser. A* **2019**, *100*, 253–259. [[CrossRef](#)]
184. Raimondi, A.; Quinn, R.; Abhijith, G.R.; Becciu, G.; Ostfeld, A. Rainwater Harvesting and Treatment: State of the Art and Perspectives. *Water* **2023**, *15*, 1518. [[CrossRef](#)]
185. Lin, L.; Yang, H.; Xu, X. Effects of Water Pollution on Human Health and Disease Heterogeneity: A Review. *Front. Environ. Sci.* **2022**, *10*, 880246. [[CrossRef](#)]
186. Abedin, M.A.; Shaw, R. Community-Level Arsenic mitigation Practices in Southwestern Part of Bangladesh. In *Water Insecurity: A Social Dilemma*; Community, Environment and Disaster Risk Management; Emerald Group Publishing Ltd.: Bingley, UK, 2014; Volume 13, pp. 51–73, ISBN 978-1-78190-882-2.
187. Martin, R.; Dowling, K.; Pearce, D.; Sillitoe, J.; Florentine, S. Health Effects Associated with Inhalation of Airborne Arsenic Arising from Mining Operations. *Geosciences* **2014**, *4*, 128–175. [[CrossRef](#)]

Disclaimer/Publisher’s Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.