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A review on different arsenic removal techniques used for decontamination of drinking water

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ABSTRACT

Arsenic (As) contamination is one of the most serious forms of environmental pollution caused by human activities. Numerous concerned authorities around the world are now focusing on the As decontamination. The technologies for removing As have grown in importance since it is understood that even very low amounts of As in drinking water can have serious negative effects on health. This review provides a thorough explanation of the various well-established and cutting-edge technologies, including ion exchanges, adsorption, membrane process, electrokinetic processes, electrocoagulation, precipitation, phytoremediation, inexpensive useful methods, emerging remedial techniques, nanoparticles and nano based adsorbents that can be used to remove As impurities from the drinking water. The low cost, simplicity and easy operational mechanism of adsorption technique gained much attention globally, however, it is also believed that nanotechnology will be essential in supplying clean, inexpensive water to suit human needs.

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1. Introduction


Arsenic is the 20th-highest natural metalloid found in the earth's crust, is well known for its adverse effects on both humans and marine life. The majority of environmental As pollution results from human activity, and this contamination exposes millions of people to potentially fatal problems through the use of tainted water, contaminated food, and water used for irrigation. Researchers and authorities have identified As contamination as the disaster of the 20th and 21st centuries.

The two biggest problems with water supply currently facing the world are water scarcity and the availability of clean drinking water. According to estimates from world health organization [1], more than 663 million people worldwide are suffering from lack of clean drinking water. Even at low quantities, contaminants including iron, manganese, As, pesticides, nitrate, fluoride, and others produced by natural and manmade sources can reduce the quality of water. More than 1.8 billion people consume drinking water that is faecally contaminated, according to a WHO research, and two out of five people in Africa do not have access to improved safe drinking water sources.

The concern authorities have put in place a number of regulations to address the issues caused by As contamination, and the following requirements must be met: A reliable source of supply must be identified, and effective treatment procedures must be developed in order to obtain this water (the suggested maximum concentration level is 10 µg/L) [2]. Additionally, background treatment

charges ought to be affordable for the majority of the inhabitants of the affected areas. Therefore, regular monitoring and routine maintenance are required to ensure that treatment frameworks can operate without interruption for a long period of time [3]. It is important to use proper removal techniques in order to prevent secondary contamination from one region to another [4]. Arsenic removal technologies utilized by various nations around the world shown in Table 1.

The oxidation-reduction, adsorption-desorption, dissolution-precipitation, mineralogy of the aquifer, organic content, and aquifer features are some of the processes that have an impact on the geochemistry of As. As issues are caused by the mobilization of minerals (such as pyrite, sulphide compounds and hydrous iron oxides) under natural conditions as well as human activities like mining, burning fossil fuels, using as pesticides, herbicides, crop desiccants, livestock feed additives, and wood preservation. Controlling As retention and release in the subsurface environment depends heavily on the geochemical properties of the aquifer material and their interactions with the aqueous media [5,6]. The form of As and its transit are influenced by a wide range of variables, including the pH, redox potential (Eh), concentrations of iron, metal sulphides, sulphate ions, salinity, temperature, microbes, etc. Long-term use of As through drinking water and eating specific foods at certain quantities is linked to a number of major health problems,

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Table 1. Different As rejection technologies used around the world.

Country	Medium	Methods	References
France [Carnoulès]	Acidic water	Oxidation	11
Italy [Calabria Region]	Groundwater	Nanofiltration	12
Denmark [Skovby water-works]	Well water	Oxidation/filtration	13
Slovakia [Poproč]	Mine-impacted waters	Zero-valent iron filing [Adsorption]	14
Greece [Malgara]	Groundwater	Biological oxidation	15
Turkey [Sivas-Sarkisla]	Groundwater	Electrocoagulation	16
Canada [Nova Scotia]	Groundwater	Adsorption	17
India	Groundwater	Chemical free treatment; electrocoagulation	18,19
Pakistan	Groundwater	Evaporation, oxidation and co-precipitation	20
Bangladesh [Sonargaon]	Groundwater	Coagulation and filtration	21
USA [Colorado]	Groundwater	Coagulation and filtration	21
Japan [Kyushu]	Geothermal waters	Adsorption	22
China	Groundwater	Nanofiltration	23
Mexico [Comarca Lagunera]	Well water	Electrocoagulation	24
Argentina [Chaco-Pampean Plain]	Groundwater	Adsorption	25
Vietnam	Groundwater	Sand filter (sorption or co-precipitation)	26
Burkina Faso (Western Africa)	Groundwater	Zero-valent iron filters [Adsorption]	27

including skin cancer, melanosis, hyperkeratosis, peripheral vascular disease, restrictive lung disease and gangrene [8]. According to [9], who utilized a random forest machine-learning model based on geographic environmental characteristics, among millions of individuals worldwide, the vast majority of who reside in Asia, may be exposed to high As concentrations in groundwater. Bangladesh has the largest population that is at risk from groundwater As poisoning globally, followed by the state of West Bengal in eastern India [10].

Potable water contaminated with As is one of the main concerns for human health, according to numerous research conducted over few previous decades. In order to lessen the health concerns connected with impure drinking As-contaminated water, techniques to prevent groundwater contamination must be devised, as well as ways to mitigate its effects. This review presents the conventional As removal technologies as well as performances of various nanoparticles and nano based adsorbents for As removal from aqueous solutions. Arsenic removal using metal, metal oxides, and mixed metal nanoparticles, as well as some commercially available and low-cost nanoparticle-impregnated adsorbents, nanotubes, biological method and various useful inexpensive technologies their characteristics are emphasized in this study. This research paper aims to provide an update on the field's technological advancements in the removal of traces of As, provide insight into the drawbacks and potential of various treatment methods, as well as highlight areas for future development and adaptation to rural settings.

2. Chemistry and occurrence of arsenic

Arsenic has an atomic weight of 74.9, a specific gravity of 5.73, a boiling point of 613°C, and a vapour pressure of 1 mmHg at 372°C. It is a silver-gray crystalline solid. It usually sublimes around 616°C [28], but it melts at

817°C. Arsenic can be found in oxidation states of -3 , 0 , $+3$, and $+5$. Arsenic acids (H_3AsO_4 , $\text{H}_3\text{AsO}_4\text{-H}_3\text{AsO}_4^{2-}$), arsenious acids (H_3AsO_3 , $\text{H}_3\text{AsO}_3^{2-}$), arsenites, arsenates, methylarsenic acid, dimethylarsinic acid, arsine, etc. are examples of environmental forms. Hard acid As(III) preferentially forms compounds with oxides and nitrogen. As(V), on the other hand, exhibits soft acid behavior and forms complexes with sulfides. Arsenic most frequently occurs in water supplies in inorganic forms. $3-$, which are designated as As(III) and As(V), respectively. Among heavy metalloids, As is the only one that is particularly susceptible to mobilization (pH 6.5–8.5) and in both oxidizing and reducing environments.

Biological processes, geochemical processes, volcanic emissions, and other anthropogenic activities all mobilize As. Arsenic mobilization under natural circumstances is the main cause of environmental As issues. However, further effects are also caused by mining operations, the burning of fossil fuels, the use of As insecticides, herbicides, crop desiccants, and feed additives for cattle [29]. Arsenic is primarily transported in the environment by water. The problem of As pollution of surface and subterranean waterways is widespread; investigations have been conducted in many nations, including Serbia, Italy, India, Bengal, Chile, USA, Canada Taiwan, Hungary, Vietnam, and others [30]. Many regions of the world have naturally occurring levels of As in their water, typically in the soluble forms of As (III) (arsenite) and As (V) (arsenate). Arsenic species in natural water are primarily influenced by the water's pH and redox potential (Eh). Pentavalent As, which exists in the forms of oxyanionic compounds (H_3AsO_4 , H_2AsO_4^- , HAsO_4^{2-} and AsO_4^{3-}) and As acid, is the dominating species under oxidizing circumstances. Under anoxic conditions, the form of trivalent As is thermodynamically stable (H_3AsO_3 , H_2AsO_3^- and HAsO_3^{2-} and AsO_3^{3-}). While the trivalent arsenite species predominate in moderately reducing anaerobic conditions, such as groundwater, the pentavalent As

species do so in habitats rich in oxygen [31]. In highly acidic and alkaline settings, respectively, H_3AsO_4 and AsO_4^{2-} prevail while under oxidizing conditions, HAsO_4^{2-} dominates at a high pH regime. At low pH (6.9), H_2AsO_4 dominates. The uncharged species H_3AsO_3 will predominate in reducing circumstances at a pH lower than 9.2. This indicates that As (III) is maintained in natural water as a neutral molecule [30]. Organic substances including dimethyl arsenic acid (DMA (III)), monomethyl arsenic acid (MMA (III)), and monomethyl arsenic acid (MMA (V)) can also be discovered in natural watercourses. According to [32], this organic As occurs at quantities less than 1 g/L and is not particularly significant in the treatment of drinking water.

3. Arsenic induced toxicity

Taiwan was the first place where a significant health issue brought on by naturally occurring As was recognized and documented in 1968. The pollution case in Chile was acknowledged as such in the 1970s. The issues in Mexico, India, Ghana, and several other nations were recorded in the 1980s. Bangladesh undoubtedly has the largest pollution case to date. Patients from Bangladesh began traveling across the border to hospitals in India in the early 1990s, but it took until 1995 for the issue to be formally investigated. After 1997, the volume of studies and projects increased quickly, which led to the realization that the majority of the nation should be regarded as being at considerable risk [33].

Arsenic exposure in humans can happen through ingesting it, inhaling it, or absorbing it through the skin. However, ingesting As is the most common way to consume it. The most common way to consume As is by ingestion, though. Acute toxicity from high doses of As might include gastrointestinal symptoms (such as low appetite, vomiting, and diarrhoea), disturbances of the circulatory and nervous systems and other symptoms (34). The earliest obvious signs of exposure to low levels of As in drinking water are aberrant black-brown colouring of the skin called melanosis and hardening of the palms and soles called keratosis. If the use of As continues, leukomelanosis, which is characterized by white spots that resemble raindrops, results from the skin's depigmentation. Arsenic poisoning can harm internal organs without producing any obvious exterior signs, making it challenging to detect. Prior to the onset of obvious outward symptoms, elevated quantities of As in the blood, urine, hair, and nails may indicate that a person has been exposed to it. Arsenic-related symptoms and indications seem to vary between people, demographic groups, and geographical locations. Thus, the sickness brought on by As lacks a common definition. This makes it more difficult to determine how harmful As is to human health.

Additionally, there is no way to distinguish internal cancer cases brought on by As from cancers brought on by other reasons. The World Health Organization (WHO) has lowered the recommended level of As in drinking water from 50 $\mu\text{g/L}$ to a preliminary 10 $\mu\text{g/L}$. This restriction was incorporated into the drinking water standards of the majority of western nations. On the other hand, due to a lack of competent testing facilities, many impacted countries continue to use the 50 $\mu\text{g/L}$ threshold.

4. Arsenic removal technologies

Arsenic removal is influenced by the redox potential, oxidation state, and pH of the media. As a result, the chemistry involved in the removal of As is highly intricate, making it difficult for scientists and environmental engineers to understand. It should be mentioned that boiling water will not get rid of the As. The oxidation state of the As, the pH of the groundwater, and a variety of other parameters affect the choice of an As removal technology for a specific area. There are various technologies that have been developed to remove As, many of which are successful in the laboratory, however, less successful in actual ground conditions. As a result, the following difficulties should be considered when building any method for removing As from groundwater and putting it into practice: (a) In different regions of the world, the amount of As in water varies greatly. (b) Arsenic removal efficiency is impacted by the presence of cations and anions of other elements in a range of concentrations. (c) Setting the pH of water to the right range is crucial for removing As. (d) Long-term As removal also requires proper technological operation and maintenance. (e) It is difficult to manage the vast amount of hazardous garbage. (f) Considerations in terms of technology, economy, and society should all be considered while choosing an As removal method.

Arsenic removal from aqueous media has been proposed and accomplished using a variety of approaches. Chemical precipitation, adsorption, ion exchange, membrane filtration, phytoremediation, and electrocoagulation are the currently available technologies.

However, each technology has drawbacks and benefits, particularly in terms of effectiveness and price, which determine the treatment that is used (Table 2). Other elements impacting the selection of an appropriate As treatment include regional standards for As levels in drinking water, the stage of development of the nation, and requirements and limitations placed on water treatment technology by authorities. As a result, there are numerous diverse technologies in use today. Additionally, in order to cut costs, the overall trend in water treatment is to utilize as few chemicals and energy as feasible. The following section will cover the As removal methods in more detail.

Table 2. Pros and cons of different As removal methods.

Methods	Positive	Negative
Ion exchange	The medium and capacity are clearly stated. The technique is less sensitive to the pH of the water. Arsenic removal using a unique ion-specific resin	Expensive medium. It requires high-tech maintenance and operation. An issue with sludge disposal results from regeneration. As (III) is challenging to eliminate. Resin regeneration is worn out. Useful for low-TDS. Resin's lifespan. Adsorption bed becomes worn out. Adsorbent material replenishment on a regular basis. It creates solid hazardous waste.
Adsorption	This technique is reasonably well-known and readily available in commerce, high efficiency of elimination. simple handling and operation. Less expensive, Free of additional chemicals and muck. No undesirable byproducts.	Generates poisonous sludge It might be necessary to pre-oxidize, which can lead to dangerous disinfection byproducts. principally eliminates As (V) and low removal of As(III), oxidation, sedimentation, and filtering of chemicals are required. Maintenance and operation cost is high. Hazardous waste water may produce. Pre-treatment is required.
Chemical precipitation	Simple handling and operations, accessible common chemicals, and relatively minimal capital costs.	A strong foundation is required. not offered commercially. Effective design and operating criteria must be the focus.
Membrane technique	There are no hazardous solid wastes created. capable of eliminating bacteria and other pollutants. No chemicals	Maintenance and operation cost is high. Hazardous waste water may produce. Pre-treatment is required.
Electrocoagulation	Chemical precipitation substitute. devoid of chemicals. innovative and promising approach. efficient, inexpensive, and simple to maintain.	A strong foundation is required. not offered commercially. Effective design and operating criteria must be the focus.
Phytoremediation	Ecologically sound. devoid of chemicals.	A strong foundation is required. not readily available in stores.

4.1 Ion exchange

Arsenic can be removed through ion exchange in physicochemical processes. The electrostatically held ions on the solid phase surface may be swapped with ions with a similar charge from the solution [35]. This efficient technique is mostly used to extract chemicals from contaminated water or wastewater, such as arsenate, selenite, nitrate, and chromate anions, and to reduce hardness of water. A significant number of ionizable groups are electrostatically linked to the solid resin, which is typically an elastic three-dimensional hydrocarbon network. These groups are exchanged for in-solution, similarly charged ions with a greater affinity for the resin. According to [36], strong base anion exchange resins are typically employed to remove As because the oxy-anionic species of As (V) effectively interchange with the anionic charged functional group of the resin. This results in effluents with low concentrations of As (V). Using strong-base anion exchange resin in the form of chloride or hydroxide makes it simple to extract As (V). A container contains an ion exchange resin that has chloride ions attached at the exchange sites. Arsenic anions replace the chloride ion as the arsenic-containing water is pumped through the resin bed. The water exiting the resin bed has a higher chloride content than the water going into the vessel but a lower As content. The resin becomes depleted when all or the majority of the exchange sites are taken up by As or other anions by swapping out chloride ions. Salt (sodium chloride) is used to replenish the depleted resin [37]. Pre-oxidation of As (III) to As (V) increases the effectiveness of the ion exchange process, however before the ion exchange, the excess oxidant must frequently be eliminated to prevent damage to sensitive resins. As a result, the resin type, alkalinity, influent, solution pH, competing ion concentration – particularly that of sulfates and nitrates – and competing ion concentration impact greatly on the effectiveness of the ion exchange

process for As (V) removal. Arsenic anions are not as preferred by the resin as sulfate ions, thus the sulfate ions are exchanged for chloride ions first. Arsenic content, Total Dissolved Solids (TDS), resin type, competing ions, and high sulfate (salts) are some of the variables impacting As removal with the ion-exchange resin [38]. High total dissolved solids content might have a negative impact on an ion exchange system's performance. Only low-TDS, low-sulfate source waters can use ion exchange for As removal. When compared to strong-base ion-exchange resins, metal-loaded polymers (also known as chelating or ion-exchange metal-loaded resins) have been suggested as being preferable since they can overcome anions' interferences and offer the option of removing both As and As (III, V). The ion exchange procedure has the drawback of discharging hazardous chemical reagents used in regeneration of resin [39]. Although, hybrid Ion Exchange/Electrodialysis (IXED) technique has been utilised to produce level of As below the allowable limit (10 µg/L), however, the impact of several unaccounted-for As(V) ion species, are the cause of discrepancies in results. A semi-permeable membrane is not necessary when using Hybrid Ion Exchange Processes (HIX-CO₂) to remove As from water. However, there are still few studies on the removal of As by ion exchange.

4.2 Adsorption and precipitation treatment

Adsorption is a method for extracting compounds from liquid or gaseous solutions by using particles. Because of its high removal efficiency, ease of operation and handling, low cost, and sludge-free nature, the adsorption method has been utilized the most frequently. The chemical nature of the adsorbate has a significant impact on an adsorbent's adsorptive activity. Commercial activated carbon, activated alumina, iron-based sorbents, zeolites, and other traditional

sorbents are utilized in water treatment. Numerous other substances, including sand, biomaterials, clay minerals, other natural and manufactured oxides, modified activated carbons, and clay minerals, have been suggested as suitable low-cost adsorbents for the removal of As [40]. The goal is to discover a cure for contaminated water that is both effective and affordable, especially for poor nations. Several materials have been used in their native states, with little additional processing [41]. Adsorption is a viable As removal technique that has been reported to have more than 95% quantitative efficiency for the remediation of As(III) and As(V), does not require chemical addition, and is simple to employ in impoverished nations with insufficient skilled labor and unstable electrical supplies. Specifically, electrostatic forces between molecules that have been adsorbed and the van der Waals separation process depends on this [42]. It should be mentioned that this method's effectiveness is influenced by the temperature, exposure time, acting pH, presence of other chemical species, amount of adsorbent, and initial As concentration [38]. Since pH and As speciation both affect how much As can be removed by adsorption procedures, As (V) removals at pH levels below 7 outperform As removals at higher pH levels. Other ions including phosphate, silica, alkalinity, and Ca^{2+} that compete for adsorption sites also affect capacity and adsorption rate [43]. Granular adsorbents, metal oxides coated on sand, engineered biochar [44], zero-valent iron, clinoptilolite-rich zeolitic tuff, iron/olivine composite, activated carbon, agriculture wastes, and other As adsorbents have all been used successfully for As remediation. A contemporary iron/olivine hybrid, surface response methodology, and artificial neural network were applied for As adsorption [45]. As evidence of their adsorption capabilities to treat arsenite-spiked water, [46], used new and affordable agricultural waste to extract As(III) from polluted water. To improve the adsorption kinetics of As removal, alum sludge containing sodium alginate, batch-test capabilities, and calcined polyvinyl alcohol

was employed in column studies [47]. Compared to non-loaded biochar, the modification of birnessite biochar exhibits the ability to enhance As adsorption in soil and water.

Adsorption happens when uneven attractive forces from the bulk interact with the adsorbent's (for example, charcoal) surface particles, yet these surface particles are not completely encircled by atoms or molecules. They have imbalanced attractive forces. The adhering of the adsorbate (for example, methylene blue) particles to the adsorbent's surface is caused by these forces (Figure 1) Adsorption increases with an increase in the adsorbent's surface area per unit mass at a specific temperature and pressure.

Metal loads, fluxing agents, oxides, ash, and furnace linings from steel manufacturing processes are all included in the fusion by-product known as metallurgical slags, which is separated during the smelting of metals. Compared to other adsorbents, the iron slag surface area is quite small (between 0.50 and 6.65 m^2/g). By performing an elemental chemical analysis using X-ray fluorescence (XRF), the principal constituents of metallurgical slags are identified and are expressed in terms of metal oxides. Mechanism of As removal by slag present in Figure 2.

At first, the iron oxide in contact with the aqueous solution undergoes a hydrolysis process that results in the formation of oxyhydroxides on the surface of the iron slag where the active sites are situated. Then, one of the active sites of the adsorbent may react with the adsorbate in ionic form (arsenite or arsenate ion). The pH of the solution should be basic for the optimum outcomes and finally, the adsorption process takes place. A nucleophilic reaction happens between the ions of arsenites or arsenates and the ions of OH that are present on the surface of the adsorbent [48]

Biochar is a porous, carbon-rich substance that is produced by heating organic biomass at temperatures between 300°C and 800°C in the absence of oxygen using plant- or animal-based feedstocks (such as

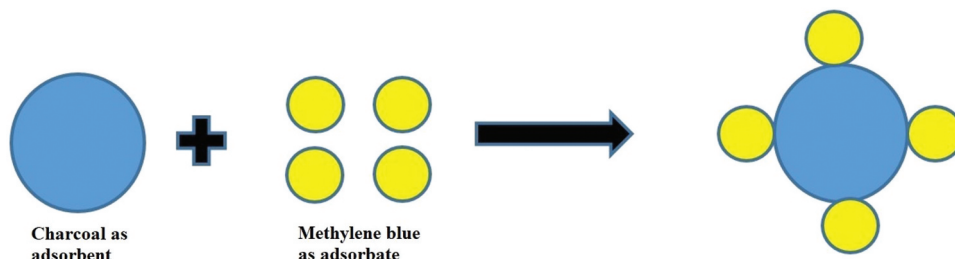


Figure 1. Mechanism of adsorption.

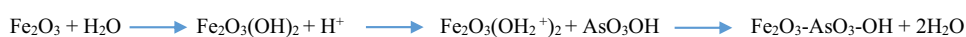


Figure 2. As removal mechanism by metallurgical slag.

pinewood, oak wood, perilla leaf, and others). In particular, by adjusting the pH of the solution, activated biochars can change their surface charge, which can be positive or negative. The charcoal surface is said to display negative charges at higher pH levels. Low sorption rates are the result of repelling forces between negatively charged As ions and charcoal [49]. Additionally, biochar adsorption can be considerably enhanced during or even after the initial manufacturing. Post-pyrolysis Ni/Mn modification can provide a larger adsorption capacity (6.52 g/kg) than pre-pyrolysis modification (0.549 g/kg). Chemical, physical, steam activation, gas purging, impregnation of metals or their oxides, and other processes are used to improve biochar sorption depending on the target pollutant.

Agricultural bio-adsorbent such as tea waste, wheat straw and peanut shells are used to decontaminate the As-contaminated water. The type, initial As concentration in water, and solution pH all have a significant impact on how effective agricultural biosorbents are at removing As. All of the biosorbents were observed to effectively remove As from raw water [50]. For an initial As concentration of 400 $\mu\text{g/L}$, the greatest As removal (up to 92%) was noted. Low pH (5 and 6) notably enhances As removal at high starting As concentrations (200 and 400 $\mu\text{g/L}$). In comparison to peanut shells (89%) and wheat straw (88%), tea waste biosorbent shown a significant ability of eliminating As (up to 92%).

To remove As from groundwater, Fixed-Bed Up-flow Bioreactors approach [51] uses biological oxidation of Fe and Mn ions. By turning these metals into insoluble oxides and then separating them using a filter medium, the oxidized forms of these metals can be eliminated. Because the resulting metal oxides are efficient adsorbents for As, removing these metals would also remove it. In ideal circumstances, up to 80% of the As and 97% of the metal oxides can be eliminated. This approach could be a low-cost substitute for physicochemical treatments for As since they typically involve the addition of oxidizing chemicals to oxidize As(III), such as coagulation. This method frequently offers applied linear velocities that are higher than those achieved through physicochemical treatments. The continual in-situ production of iron and manganese oxides eliminates the need to monitor the breakthrough point. Another benefit of this technology is that it eliminates Fe, Mn, and As in a single treatment.

An inorganic sorbent called activated alumina is utilized to extract As(V), and the pH affects how well it can adsorb As. The As ions are adsorbed onto the alumina during the activated alumina process, which involves passing influent water through a column filled with activated alumina. The anion exchange process and the activated alumina method are comparable in this regard. Similar to ion exchange resins, spent

activated alumina can either be locally regenerated or used up completely before being replaced with new media. For the removal of As, activated alumina can be utilized as a fixed adsorbent. It is required to remove iron before putting groundwater through an activated alumina column in order to prevent fouling because Fe^{2+} , which is frequently present in high concentrations in groundwater, oxidizes to insoluble Fe^{3+} when exposed to air. Additionally, As(III) must be oxidized due to the fact that it adheres weakly to activated alumina. On the other hand, zeolites are a significant class of minerals because of their abilities as catalysts, sieves, and exchangers. They are naturally abundant and could be inexpensive materials for removing As. When the As effluent concentrations reach unacceptable levels, the treatment bed must be regenerated. Four steps make up the regeneration process. The alumina bed is backwashed, regenerate, neutralize, and rinse during this procedure before being put back into service. The most prevalent regenerant is sodium hydroxide, and sulfuric acid is usually employed to neutralize or condition the bed [52].

Research carried out on natural sand to determine how well it removed As from water. At a dose of 2.5 g adsorbent in 50 mL contaminated water, Skye sand naturally occurring in Australia was discovered to be the most efficient, with a removal effectiveness of 89%. According to the results of the XRF investigation, the iron in the Skye sand is Fe_2O_3 . Haematite, goethite and various clay minerals found on the surface of the Skye sand. Kaolinite and montmorillonite comprised the majority of the clay minerals. For the elimination of As, Fe_2O_3 and goethite work well [53]. Additionally, the clay minerals kaolinite and montmorillonite are crucial for the direct adsorption of As(III) to the surface of Skye sand without the need for oxidation. In a wide range of pH values, montmorillonite also able to remove As(III) successfully.

An adsorbent called granular ferric hydroxide (GFH) was created to remove As from natural water. It can be used in fixed bed reactors, comparable to those for activated carbon or alumina. In both natural waters and model systems, GFH has a high potential for adsorption. Until the new German and WHO drinking water limit for As of 10 $\mu\text{g/L}$ was surpassed, the application of GFH in test adsorbents demonstrated a high treatment capacity of 30,000–40,000 bed volumes. This method leaves behind a solid waste that has been As enriched. The average residual mass is between 5 and 25 g/m^3 of treated water. This novel technology for removing As offers a quick and efficient solution, however, especially for small water facilities [54].

While As(III) is more challenging to remove, As(V) can be removed with ease by adsorption onto iron-based adsorbents. The low-cost catalyst ilmenite (FeTiO_3) is thus suggested for use in this work as a photocatalyst as well as an adsorbent in the UV-A

aided Catalytic Wet Peroxide Oxidation (UV-CWPO) process. This technology's primary goal is to oxidize As(III) into As(V), which will then be adsorbed onto the Fe sites of the catalyst. In both ultra-pure water and groundwater taken from Lastras de Cuéllar (Segovia, Spain), this approach has been shown to be successful in the oxidation and removal of 10 mg/L As(III) at 1000 mg/L ilmenite, 60 mg/L H_2O_2 , pH 7, and room temperature (25°C) [55].

To treat simulated As-containing fluids in the lab, Fe-Mn composite oxide porous materials (Fe_1Mn_1-300) were created without the use of a template. The findings demonstrate that Fe-Mn oxide materials exhibit excellent adsorption performance and high As(III) removal rates through oxidation and synergistic adsorption procedure, which improve the material's As removal capacity and offer interesting application possibilities in high As groundwater remediation. When the amount of Fe or Mn in the material's bipolarity grew or the calcination temperature rose, the material's ability to bind As dramatically diminished. When the ratio of iron to manganese was 1:1 and the calcination temperature was 300°C, the material's As absorption capacity peaked [56]. The performance of As adsorption of Fe-Mn composite oxide porous materials significantly influenced by the initial concentration of As, pH, equilibrium period, solid-liquid ratio and competing ions.

Due to unique physical and chemical characteristics, iron sulfides are thought to hold promise for the efficient removal of As from waste water. Researchers employed naturally occurring two most prevalent iron sulfide minerals (pyrite and pyrrhotite) as adsorbents, which eliminates target pollutants with a negative charge from aqueous solutions to the surfaces of those minerals and subsequently bind physiochemically with the adsorbate via electrostatic interactions. Arsenic elimination depends critically on the pH level. Since As(III) and As(V) occur in a variety of species at varied pH levels, pH will have an impact on how those species behave electrically on their surfaces. While As(V) are quickly abstracted by an oxidized pyrite surface primarily in a slightly acidic or neutral environment (pH 3.5–7) with the initial As concentration of 50 mg/L, As(III) can be removed easily in an alkaline medium (pH 7–9). At pH 5, the concentration of As(V) in the aqueous solution can be reduced from an initial value of 10 mg/L to 10 µg/L by adding 5 g/L of powdered dried waste pyrite to the solution. However, they emphasized that pyrite oxidation has a major impact on the elimination of As [57]. When employing pyrite and pyrrhotite as adsorbents, the pH level affects the stability of the adsorbed As, which in turn affects how effectively As is removed. The adsorption impact of pyrite and pyrrhotite on As can also be influenced by the particle size, reaction time and ionic strength.

Laterite soil is a clay-rich, reddish soil with a high iron concentration that contains aluminum silicates, iron oxides, aluminum hydrosilicates, and iron hydroxides. Red soil is quite effective in adsorbing As. Soil made of ferralite from Purulia, Bankura, and Medinipur (India) has a high capacity to remove As to above 80% at pH 8.5. The weathered soil known as Oxisol, which had a surface area of 35.7 m²/g and contained Al₂O₃ (26%), Fe₂O₃ (11%), Al-silicates (16%), and quartz (44%) has been found to be an effective adsorbent removal material for all As oxidation states in aqueous solutions at pH 5.5 [58].

Numerous significant uses for zero-valent iron (Fe^0) are found in environmental chemistry. By using reductive precipitation, it has been used to eliminate inorganic pollutants like CrO_4^{2-} and destroy chlorinated hydrocarbons. Fe^0 has also shown to be effective at removing As(III) and As(V), with surface precipitation or adsorption appearing to be the main mechanistic mechanisms [59]. Since Fe^0 is a potent reduction, it works well to remove both inorganic and organic As. Fe^0 is nontoxic and affordable, which is an added benefit. According to published evidence, Fe^0 is effective at removing As from low pH and very sulfurous water. At both neutral and basic pH, the hydroxide species that develop on the surface of Fe^0 are efficient adsorption sites for both As(V) and As(III), despite the fact that the reducing strength of Fe^0 dramatically reduces at this pH [60].

In tropical areas, there is an abundance of laterite, which is vesicular clay residue. Iron and aluminum hydrous oxides make up the majority of its composition. After undergoing equilibrium for 20 minutes, laboratory testing revealed that As removal efficiency for 5 g of additional laterite per 100 mL of water was between 50 and 90%. After being treated with 0.01 M HNO_3 , laterite showed an increased capacity for adsorption [61]. In a recently conducted study in Nepal, both As(III) and As(V) species of As were successfully removed from the contaminated groundwater by using acid-activated laterite as an adsorbent. A batch investigation revealed that for treated laterite, the most effective/optimum particle size is 0.165 mm, the adsorbent dose is 40 g/L, and the detention time is 4 h [62]. The research showed that the greatest efficiency of As(V) adsorption on laterite was 99.66% at pH 3 and that the maximum efficiency of As(III) adsorption on laterite was 98.84% at pH 8.

As a rare-earth element, lanthanum (La) is among the least expensive. A study [63] looked into the removal of the As(V) ion from aqueous solutions using lanthanum hydroxide (LH), lanthanum carbonate (LC), and basic lanthanum carbonate (BLC). In the neutral to basic pH range where La does not dissolve, adsorption by exchange of CO_3 and/or OH group

with As^{5+} ions and precipitation of insoluble lanthanum arsenate, LaAsO_4 , in the acid pH range are two hypothesized methods for the removal of As by lanthanum compounds.

Titanium dioxide (TiO_2) is the most widely utilized semiconductor photocatalyst in water or wastewater treatment due to its low toxicity, chemical stability, and inexpensive cost. TiO_2 serves as a photocatalyst and an adsorbent when exposed to UV light or sunlight, but only as an adsorbent when not exposed to these light sources (Figure 3) [64, 65]. Reactive oxygen species (ROS), particularly superoxide and hydroxyl radicals, are efficiently produced by TiO_2 photocatalysts under UV-A radiation, allowing for sunlight activation. In addition to eliminating infections, ROS also destroy organic pollutants [66]. The volume electron/hole (e/h^+) recombination of nano- TiO_2 can be reduced by noble metal doping, particle optimization for contaminant adsorption, and surface treatment. According to Jézéquel and Chu [67] a rise in pH inhibited As(V) adsorption on TiO_2 nanoparticles by lowering the number of positively charged binding sites on the surface of the adsorbent. Additionally, it has been demonstrated that the maximal adsorption capacity, was higher at lower pH (i.e pH 4) than at neutral pH. Divalent cations (Mg and Ca) were added to boost the As(V) absorption at neutral pH, and at a concentration of 7 mM.

Goethite nanoparticles were cited by [68], as an effective adsorbent for the removal of As(V). According to the findings, pH 3.0 was the optimal adsorption pH. The greatest experimentally measured adsorption capacity was 72.4 mg/g, which was nearly matched to the monolayer adsorption capacity derived from the Langmuir isotherm of 76.3 mg/g. The adsorption results fit the Langmuir isotherm equation well, indicating that the adsorption was monolayer. Additionally, it was demonstrated that a solution containing 50 mg/L of As could be removed

from the environment with an adsorbent dosage of 6 g/L, which removed upto 99% of the As(V). It was also clear that As-loaded adsorbent could be regenerate with an alkaline solution of pH 13.

The ability of calcium peroxide (CaO_2) nanoparticles to successfully remove As from polluted aqueous solution. By raising the pH and the concentration of As in the solution, CaO_2 nanoparticles' efficacy in the adsorption processes reduced [69]. The amount of CaO_2 nanoparticles used and the contact time demonstrated a clear correlation with removal efficiency. By using nanoparticles at a concentration of 40 mg/L for half an hour while maintaining a pH of 7.5, up to 88% of the As could be removed. At pH 6.5, the maximal removal of As(III) was found to be 91%, proving that this removal method is successful in lowering the As content below the WHO-recommended limit of 10 $\mu\text{g/L}$.

Amorphous zirconium oxide adsorbent (am-ZrO_2) nanoparticles were synthesized for efficient As removal from aquatic environments. Both As(III) and As(V) may be effectively removed by Am- ZrO_2 nanoparticles in laboratory-made or unprocessed water samples. At pH 7, the am- ZrO_2 nanoparticles had 83.2 mg/g and 32.5 mg/g, respectively, adsorption capacities on As(III) and As(V). It was found that the inner-sphere complex mechanism is what As species adhere to while they are adsorbing on am- ZrO_2 nanoparticles. Agar powder, a food-safe ingredient, was used to create nanostructured ZrO_2 spheres from amorphous ZrO_2 nanoparticles, offering a quick, low-cost, and secure method for the synthesis. It is not essential to preoxidize or alter the pH of the As-contaminated water because the ZrO_2 spheres showed quality adsorption capability on both As(III) and As(V) in a near neutral pH environment.

For the elimination of As (III), [70], produced Fe-Ti binary oxide nanomaterial with magnetic properties. The produced $\text{Fe}_2\text{O}_3\text{-TiO}_2$ nanoparticles are

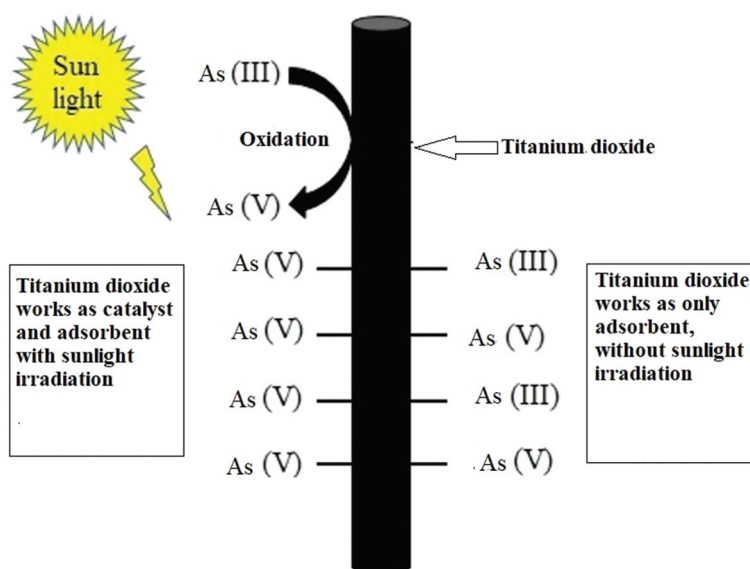


Figure 3. Application of TiO_2 to remove As from contaminated water.

distinguished by the photocatalytic activity of TiO_2 for oxidizing As(III) to As(V) and the performance of adsorption of Fe_2O_3 for the removal of As (V). At a solution pH of 7.0 and an initial concentration of 50 mg/L As(III), the maximum removal capacity was 33.03 mg/g. The findings indicated that phosphate and As were the two main competitors for the adsorptive sites on the nanomaterial's surface. Additionally, there was no discernible difference in the removal of As depending on the ionic strength or the presence of SO_4^{2-} , NO_3^- , Cl^- , Ca^{2+} or Mg^{2+} .

At a pH of 9.4 ± 0.4 , the zero point of charge (ZPC) of Cupric oxide nano particles (CuO-NP) permits the adsorption of As under the majority of naturally occurring drinking water systems. In addition, this ZPC offers the chance to regenerate and reuse the CuO-NP after As species have been adsorbed (Figure 4). Raising the pH above the ZPC of CuO ($\text{pH} > 9.4$), where the surface charge of CuO becomes negative, facilitates the regeneration process and causes the desorption of anionic As species. Arsenic may be removed from water using these nanoparticles since they are simple to regenerate. In previous research, sand was employed as the nanoparticles' supporting material for the column study, while cupric oxide nanoparticles were used in

polypropylene centrifuge tubes for the batch study [71].

A cheap biosorbents made from microorganisms and plant products with many active sites for adsorbate binding is chitosan polymer. Due to its superior ability to adsorb metal ions, biosorption is an alternative, cutting-edge non-conventional method that has attracted the interest of many researchers. Even when metal ions are present in low concentrations, the chitosan has been successfully employed to remove them. Chitosan has been changed into several forms for water treatment to further improve its adsorption capabilities (Figure 5). Crosslinkers, diepoxy octane, triphosphoric acid and sulfate salt modify chitosan for water purification [72]. These crosslinkers interact with the chitosan's amino and hydroxyl groups, forming an interconnected structure with additional adsorbate binding sites. The number of sites for metal ions to bind is reduced as a result of the crosslinkers consuming some of the functional groups of chitosan. However, chitosan that has been grafted with additional functional groups increases the amount of sites available for metal ion adsorption. Alginate, poly (acrylic acid), graphene oxide and succinyl are some of the grafting agents that have been utilized to

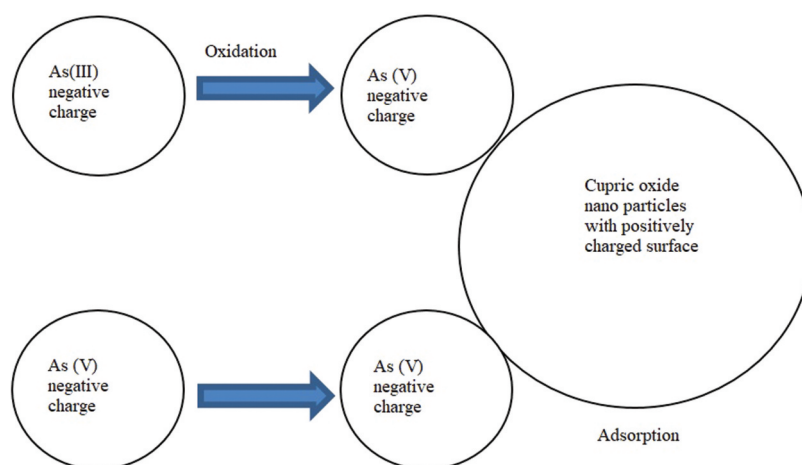


Figure 4. Application of CuO (as adsorbent) to remove As from raw water.

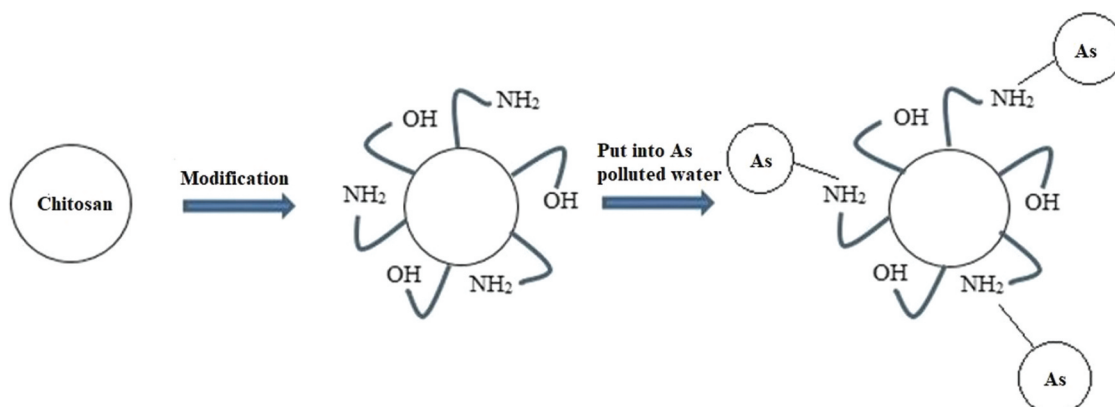


Figure 5. Schematic representation of adsorption mechanism of chitosan.

modify chitosan. In terms of their low toxicity, cost-effectiveness, biodegradability, eco-friendliness, and reusability, chitosan-based sorbents are economically more effective.

CNTs (carbon nanotubes) has superior adsorption capability and their composites have received a lot of interest in the removal of pollutants from water or the enrichment of metals in wastewater. The removal effectiveness of metal ions by CNTs was shown to range between 10% and 80%; however, by selectively functionalizing CNTs with organic ligands, this efficiency may be increased to close to highest (upto 100%) [73]. Carbon nanotubes (CNTs) operate as an excellent supporting material for other adsorbents and provide enough adsorption sites. There has been very few research on the elimination of As using CNTs. CNTs have a hollow structure and are very permeable. The CNTs are a widely investigated adsorbent due to their large specific surface area, light mass density, purity, and strong interaction with pollutant molecules. Despite these beneficial characteristics, the adsorption capabilities of metal ions utilizing raw CNTs are quite poor. However, after being oxidized with HNO_3 , NaClO , and KMnO_4 solutions, this capacity can be greatly boosted [74].

Since the composite not only inherits the benefits of the parent metal oxides but also manifests a clear synergistic impact, developing composite sorbents containing two or more metal oxides has received substantial interest. To achieve this, [75] used a simple co-precipitation technique to create a nanostructured Fe-Cu binary oxide. Fe-Cu binary oxide with a Cu/Fe molar ratio of 1:2 produced excellent As removal efficiency, and the maximum adsorption capacities for As(V) and As(III) at pH 7.0 were 82.7

and 122.3 mg/g, respectively. Arsenic removal effectiveness was decreased by coexisting ions like phosphates, but was unaffected by sulfates and carbonate ions.

Only fine powder versions of the majority of nano-materials, which are typically created as suspensions in aqueous solution, are commercially available. Due to their limited hydraulic conductivity, these fine powders should not be used in column applications [76]. Nano adsorbents can only be employed in fixed-bed columns if they are supported on comparably larger size porous materials, such as polymers, sand, the parent materials of the used nano adsorbents, activated carbon, etc. because of their lower particle size. However, choosing the right supporting materials for nanoparticles is similarly difficult. Many researchers examined the supplementary materials, and some of them discovered promising findings. Table 3 compiles several supporting materials reported in the literature that is currently available.

Because of usefulness in adsorbing significant amounts of As from contaminated water, magnetite has attracted a lot of attention. The material's magnetic characteristics make dispersing and removing it from an aqueous solution. The study by [77], demonstrated that synthesized magnetite is an effective sorbent for As removal from aqueous solutions, with maximal capacities observed of roughly 30 mg/g As of solid magnetite. Magnetite nanocomposites could be used to clean up As contamination (Figure 6). Arsenic diffuses onto these nanocomposites when they are applied to contaminated water. These nanocomposites and As might be eliminated using an appropriate magnet. It was discovered that magnetite nanoparticles could bind As. This arsenic-magnetite

Table 3. Nano adsorbents and supporting materials.

Material supporting	Nano adsorbent	References
Polymer	Aluminium Substituted Manganese Copper Ferrite	78
Activated carbon	Nanoscale zero-valent iron	79
Mesoporous silica media	Nanoscale aluminium oxides	80
Immobilization on Sand	Nanocrystalline titanium	81
Zeolite	Magnetic nanoparticles coated zeolite	82
Glass wool	Iron cross-linked alginate nano adsorbent	83
Glass beads	Iron doped phenolic resin based activated carbon nanoparticle	84
Ascorbic acid coating	Fe_3O_4 nanoparticles	85
Activated Al_2O_3	Iron hydroxide	86

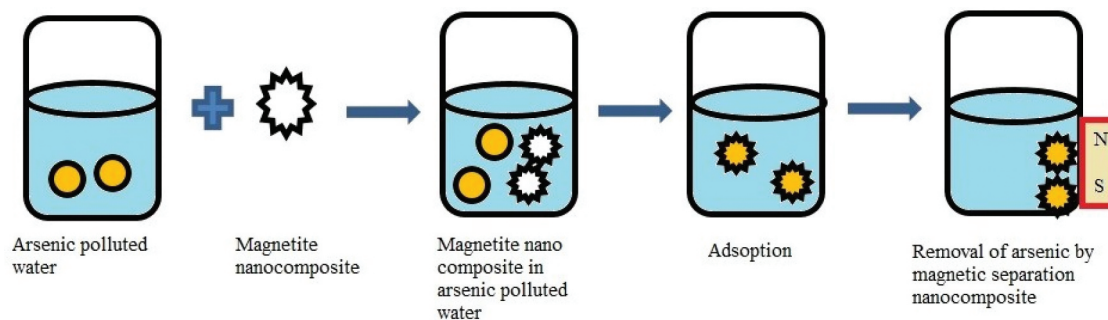


Figure 6. Magnetite nanocomposites to remove As from contaminated water (modified from [87]).

waste might be effectively removed by an appropriate magnetic field, cleaning the water, thereby. The number of reuse cycles and the material's regeneration are essential for an adsorbent's practical use in order to improve the adsorption process and lower operating expenses [87].

In order to remove As(III) and As(V), [88], assessed the efficiency of nanocrystalline titanium dioxide. TiO₂ suspensions produced in a NaCl solution and challenge water containing competing anions were used in batch adsorption and oxidation tests (phosphate, silicate, and carbonate). It took 4 hours for the elimination of As(V) and As(III) to reach equilibrium. TiO₂ showed a maximal removal capability for As(III) around pH 7.5 and was effective for As(V) removal around pH 8. In comparison to fumed TiO₂ (Degussa P25) and granular ferric oxide, the adsorption capacity of TiO₂ for As(V) and As(III) was significantly higher. At an equilibrium As concentration of 0.6 mM, the TiO₂ absorbed more than 0.5 mmol/g of As(V) and As(III).

Other adsorbents come in a variety of forms (Table 4), such as rice polish, alum sludge, yeast biomass, leather waste, iron hydroxide-coated rice straw, iron-modified activated carbon, bead cellulose modified with magnetic iron oxide etc. for the removal of inorganic As. Many variables, including temperature, pH, contact time, dose of adsorbent, concentration and functional groups connected to the adsorbents, affect a material's ability to adsorb As [89].

Due to the following benefits, adsorption has received a lot of attention: it typically requires less space and fewer chemicals than other methods of removing as well as being simpler to set up, less expensive, and producing no toxic byproducts. On the other hand, the sorbents must be replaced every four to five regenerations or over time as the adsorption bed becomes more and more saturated and fatigued, losing its ability to perform additional separations until finally none are possible [90]. Adsorption-based processes do not self-monitor, therefore from a quality standpoint, they continue to generate water even after the

adsorption bed runs out. For such devices, regular adsorbent material change is necessary [41].

Arsenic can be removed using coagulation-flocculation techniques that use alum, ferric chloride, or ferric sulfate. They have undergone more thorough testing in laboratory and field investigations than other technologies because they are the most well-known As treatments. Arsenate must be oxidized to achieve optimal removal effectiveness because both alum and ferric salts are more effective at removing arsenate. Iron salts are more effective at removing As than alum on a weight basis. Compared to alum, ferric salts are more effective at removing As over a wider pH range [91].

By linking the As removal impact with lead hydroxide, lead nitrate, and lead oxide, however, aqueous chloride solution produces precipitants during the removal of As using lead oxide [92]. Additionally, after the As is removed, there is no addition of impure anions and the mimetite stability is increased. Chemical precipitation was employed to evaluate the removal of sulfates as barite or ettringite mineralogical phases from pre-oxidized leachate [93]. Precipitation of barite was more advantageous as a finished good with added value and required fewer reactants. Following the elimination of barite from the sulfur compounds using H₂O₂-mediated catalytic oxidation and chemical precipitation, the leachate was suitable for biological treatment, and a sizable portion of the biotic charge was subsequently biologically oxidized. It was researched how to recover phosphorus and nitrogen from digested sludge center using chemical precipitation in conjunction with dual-chamber microbial electrochemical systems (MEC) and cation exchange membranes (CEM) [94]. The sludge is fermented to offer quickly biodegradable carbon sources for the biological process of nutrient removal, which is boosted by using microbial electrolysis and chemical precipitation at local wastewater facilities. To directly breakdown organic dyes during the lanthanum tungsten

Table 4. Different adsorbents used for removal of As in contaminated water.

Adsorbent	Adsorption capacity (mg/g)	References
Iron coated seaweeds	4.2 for As(III), 7.3 for As(V)	95
Biochar (derived from rice husk)	19.3 for As(III), 7.1 for As(V)	7
Nanocrystalline magnetite	3.65 for As	96
Leather waste	26 for As(V)	97
Iron impregnated activated carbon	51.3 for As(III), 38.8 for As(V)	98
Bead cellulose loaded with iron oxyhydroxide	99.6 for As(III), 33.2 for As(V)	99
Magnetite	0.964 for As(V)	100
Alum sludge	62.9 for As(V)	101
Red mud modified biochar	5.92 for As(V)	102
Iron oxyhydroxide-coated rice straw	19.96 for As(V)	103
Ferrihydrite loaded maize straw biochar	1.31 for As(III), 1.32 for As(V)	104
Manganese oxide pillared clay	25.6 for As(III), 26.1 for As(V)	105
Iron oxide modified pillared clay	17.6 for As(III), 25.8 for As(V)	105
Rice polish	0.138 for As(III), 0.147 for As(V)	106
Fe ₁ Mn ₁ -300	59.44 for As(III), 31.68 for As(V)	56

synthesis, the Chemical Precipitation technique employs nanoparticles $\text{La}_2(\text{WO}_4)_3$ [107].

Pre-oxidation of As(III) allows for the obvious observation of differences in removal efficiency for precipitation technology. Without pretreatment, removal efficiency ranged from 10 to 80%, but when Cl_2 pretreatment introduced to the system, As was removed at a substantially greater level. Similar to this, for instance, three drinking water sources in New Zealand that were severely As contaminated have been treated using aluminum-based coagulation. The final As(V) content was less than 0.0005 mg/l, with removal efficiencies for As(V) removal after pre-chlorination ranging between 94 and 98% [108]. The generation of byproducts, the release of flavor and odor compounds as a result of chlorination, and issues with floc disposal and post-treatment are some potential drawbacks of precipitation technology.

4.3 Electrocoagulation (EC)

Although it has some difficulties, such as electrode passivation, EC reactors design optimization, and large-scale power consumption applications, EC is a complicated and interdependent process with a compact treatment plant, full automation, and high-efficiency removals [109]. With a removal effectiveness of between 93% and 99.9%, EC is a useful method for removing As(III) and As(V) from water [110]. In the EC, sacrificial anode electrodes are made of metals like iron or aluminum. Sacrificial aluminum anodes are less effective than iron electrodes. By destabilizing colloidal suspensions and dissolving various heavy metals with electrical energy, EC causes pollutants to flocculate and float. The synthesis of cationic monomer species as a result of the electrolyte dissolving at the sacrificial anode causes the release of OH at the cathode when the charge is charged, which causes the production to happen [110]. As(V) is converted into the Fe^{3+} complex after the elimination of As by the Fe electrode with EC. Due to the presence of species in water that interfere with the removal of As, researchers claim to employ synthetic solutions made from drinking water that change the composition of their finished products [109]. There are major knowledge gaps in As removal, making it difficult to compare continuous EC reactor performance, because research is often conducted in laboratory-based systems rather than long-term EC field operations, where treated water is limited to 8 hours long running experiments (>100 L) [4]. Each metal promotes a different level of efficiency when used in the electrocoagulation process to remove As from water. By preventing the crystalline form of iron oxides, aluminum substitution increases the surface area for As adsorption. Copper-copper and zinc-zinc electrodes were used in an improved experiment to remove As. To maximize the removal of As from

wastewater, a response surface methodology was applied [111]. Recent studies on the EC cycle have been applied to water treatment systems to remove As [112]. The implementation of a Metal-Air Fuel Cell EC (MAFCEC) alternative technique is suggested as a way to address a number of drawbacks, including the high energy consumption of the present EC cycle [113]. In addition to producing power, it is utilized to clean up As polluted water sources. The handling of waste sludge, power (energy), and various As-removal techniques are some additional drawbacks of the EC cycle. Solar energy can be used to minimize energy need in the EC process in place of more expensive sources. The price of purifying plant water is also decreased by using this method. Simply said, EC is a method that successfully reaches the WHO (World Health Organization) standard on healthy drinking water (10 $\mu\text{g/L}$) without having a long-term negative health effects. In order to establish the EC cycle's effectiveness as a method for addressing the removal of As-contaminated water flow, in general, more research is required [113].

4.4 Membrane treatment

One of the most effective solutions, membrane technology has the capacity to reduce maximum amount of the As poisoning in groundwater. In addition to preventing bacteria from penetrating the membrane, it removes As from contaminated water without collecting it. During this procedure, water is passed through specialized filter material that physically traps any pollutants in the water. The pressure difference between the membrane's two sides can act as a driving force for molecules to travel across the membrane. Water that will be treated using membrane technology must be devoid of suspended particulates and contain pentavalent As. However, the majority of membranes are not resistant to oxidizing agents. In earlier investigations, As(III) was oxidized to As(V), which was considered as being undesirable because it might damage the membrane [3]. It costs more than other As treatment procedures and generates high residual volumes. Reverse osmosis (RO), nanofiltration (NF), microfiltration (MF), ultrafiltration (UF) and electrodialysis (ED) are membrane-based processes that can remove all types of dissolved particles from water, including As. The pore size of the membrane determines how these processes separate; For MF and UF membranes, mechanical sieving is used to separate the materials, whereas capillary flow or solution diffusion is used to separate NF and RO membranes [114]. NF and RO have proven to be the most effective methods for selectively removing As from contaminated water [115]. By squeezing the feed side, water can pass across a hydrophilic membrane and be purified of the necessary pollutants, such as As, creating the

driving force in NF and RO. Between 85 and 99% of As (V) rejections were observed in NF and RO, and between 61% and 87% of As(III) rejections. [116], removed As with a moderate efficiency of 65% and 53% for As(V) and As(III), respectively, using a charged UF membrane. Additionally, the effectiveness of negatively charged UF membranes for the removal of As was still dependent on the operating circumstances, including pH, As concentration, crossflow velocity, and the presence of other ions or inorganic materials.

The successful treatment of fluids contaminated with As has also been demonstrated using atmospheric pressure thermally regulated membrane processes like Membrane Distillation (MD). MD should be viewed as a method of treating high-quality water that contains detrimental retention rates for heavy metals (HMs) like As and other HMs prevalent in soil water. The expensive treatment facilities resulting from the membrane itself are a typical drawback of employing membrane techniques. Additionally, running expenses are much greater, particularly for RO, NF, and ED approaches that needed high operating pressures. The biggest problem with this technology, to sum up, is membrane fouling.

MF and UF can only retain the particulate fraction of As due to their high pore sizes. The viability of combining traditional methods with membrane separation for As removal, however, has not been thoroughly examined. The combination of coagulation with MF method for As removal was initially reported by [117]. Bench testing was used to identify the ideal operating parameters, which were then used in pilot plant experiments which is hybrid membrane process for As removal. These conditions included pH (6 to 7), membrane pore size (0.2 μm), and coagulant dose (ferric chloride concentration of 7 mg/l) to achieve the greatest As removal effectiveness possible. In these circumstances, filtration flux had no discernible impact on the removal of As until substantial fouling occurred. A similar study that combined MF (mixed esters of cellulose acetate and cellulose nitrate membranes) treatment with ferric chloride and ferric sulphate coagulation showed that, at an ideal pH of 6.2, a hybrid IMF (immersed membrane filtration) process (for both 0.22 and 1.2 μm membranes) could achieve highest As removal efficiency for 7 mg/l and 9 mg/l of ferric sulphate and ferric chloride, respectively. Although it is difficult to understand the reason of removal efficiencies between the two published trials differ, however, the majority of the operational parameters appear to be relatively similar between the two tests, only a minimal removal-efficiency disparity is found.

HVR water purifier is a useful tool for producing pure drinking water is the HVR home water purifier, which uses a membrane distillation method. It can successfully eliminate all nonvolatile pollutants from water, including As. The membrane is made of PTFE

(Polytetrafluoroethylene), which has an 80% porosity and a 0.2 mm thickness. The air gap measures 1 mm in length. Two membranes with a 42 cm by 24 cm surface area are used. Different types of the home water filter were created by HVR. The main advantages of this method are no chemical is required, the As contaminated water's pH doesn't need to be regulated., there is no bacterial development in the membrane that could taint the water and to determine whether the purifier is operating properly, no knowledge is necessary. Therefore, easy to handle and maintenance. This method has some drawbacks too, such as higher start-up expenses compared to chemical methods. Electricity, little tank for storage is necessary. For further treated water, a restart is necessary 40 to 60 minutes after each start.

4.5. Phytoremediation

Using plants and bacteria to purify tainted water, phytoremediation is a plant-based, environmentally benign method of cleaning up As-contaminated locations. The *Pteris vittata* (Chinese brake fern), which has the capacity to hyperaccumulate significant amounts of As in its fronds, was discovered to be resistant to As. Pollutants are taken up by plant roots and transported to their above-ground parts, where they are then removed along with the crops (phytostabilization, phytoextraction, and phytovolatilization). In other plants, the As hyperaccumulation capacity has also been shown. For long-term As remediation, approaches using plants called phytostabilization can also be used in addition to phytoremediation. This approach restricts absorption and prevents As mobilization. The primary advantage of phytostabilization is the reduction in the danger of As transfer across food chains because the vegetative biomass above ground is not polluted with As. A number of sulfate-reducing bacteria as well as other species like *Paenibacillus*, *Pseudomonas*, *Haemophilus*, *Micrococcus*, and *Bacillus* may be used in bioremediation procedures to remove As from contaminated settings. However, creating affordable and widely accessible biosorbents for the removal of As remains a significant issue [118]. The potential of transgenic hyperaccumulators with higher stress tolerance to different pollutants are discussed by [119], together with the significance of nanoparticles in improving phytoremediation technology. In order to clean up contaminated surroundings, a green technology called nanophytoremediation (NP) combines phytoremediation with nanotechnology [120]. The effectiveness of using nanoparticles in conjunction with plants, such as hydrocarbons, pesticides and petroleum, has been shown through nanophytoremediation (NP) [121]. Although it is time consuming,

however, certain research show how well nanomaterials can be used to enhance phytoremediation systems [122]. Numerous nanoparticles may promote plant growth and development, according to recent studies. Studies on the effects of As nanomaterial-assisted phytoremediation are still lacking, nevertheless [123]. Long-term studies are also necessary to investigate the effects, workings, and security of nanomaterials on plant health and soil fertility.

4.6 Electrokinetic method

The electrokinetic method is an in-situ, cutting-edge, and efficient method for removing free contaminants from soil [124]. With the use of electrophoresis, electromigration, water electrolysis, and electroosmotic flow, this method removes pollutants from the soil by directing their movement and conveyance inside an electrical field [125]. Arsenic removal by electrokinetics has also been researched [126]. Due to the difficulty of treating As in its dissolved state and the fact that it makes risky heavy metals more mobile, this method is limited in its ability to remove As. However, by incorporating or combining other methods, it becomes more effective and efficient, more ecologically friendly, and an economically feasible option [124]. Arsenic removal is accomplished, using Permeable Reactive Barrier (EK-PRB) in conjunction with Electrokinetic Technology, which has the action of a chelating agent [125]. In order to increase the efficiency of soil As remediation without raising expenses, substantial research has been done on the combination of PRB and EK remediation [127].

4.7 Iron/manganese removal methods

Iron/manganese removal techniques are known to be effective for the removal of As because arsenic, especially As(V), is easily adsorbed onto iron hydroxide. According to one study, As(V) levels dropped from 200 $\mu\text{g/L}$ to less than 5 $\mu\text{g/L}$. The filtration procedure, which typically uses a granular media, removes the insoluble form of iron (ferric) that was created during the oxidation step. Because air oxidation typically fails to convert As(III) to As(V), source waters containing As(III) may need to be treated with chlorine or another oxidant. The filtration media is backwashed to create a liquid residual (backwash water) once it has reached its capacity to filter. Another popular technique for removing iron and manganese from water is the use of potassium permanganate in combination with a manganese greensand filter. To oxidize As(III) to As(V) and the iron and manganese that are subsequently adsorbed on the greensand, potassium permanganate can be injected constantly ahead of the filter. The manganese greensand is also renewed by

potassium permanganate [128]. As an alternative, the greensand bed might be intermittently activated with permanganate to provide an active manganese dioxide layer. The capacity for As removal depends on the proportion of iron in the source water since the As removal process involves adsorption onto the iron. Periodic backwashing is also necessary for the greensand filters to get rid of extra solids.

4.8 Biological method

As(III) and As(V) are interconverted through oxidation and reduction processes. By oxidation and reduction reactions, bacteria play a significant part in the geochemical cycling of As. They also establish the concentration and mobility of As in groundwater [30]. Dissimilatory arsenate-reducing bacteria, also known as arsenate respiring bacteria (ARD), include *Geospirillum arsenophilus*, *Desulfotomaculum auripigmentum* and *Crysiogenes arsenatis*. When these bacteria breathe, arsenate serves as the terminal electron acceptor. The majority of the As removal techniques are unable to remove neutral As(III) molecules [129]. So, in those As removal methods, oxidation is a pretreatment technique. Chemical reagents like ozone, hydrogen peroxide, chlorine, and potassium permanganate are utilized in the chemical oxidation of As(III) to As(V), however, hazardous by-products can occasionally be produced during chemical oxidation. The treated water is not fit for drinking until these by-products are eliminated by some techniques and the expense of the treatment process will go up as a result. Thus, utilizing microorganisms to biologically oxidize As(III) is an option.

4.9 Useful inexpensive technologies

According to the [130], people in small towns and rural areas as well as those living in low and lower middle-income nations are inclined to adopt cheaper and simple As removal technology. In several As contaminated nations in the South and East Asian areas, a number of technologies have been documented for rural community and individual level applications. For the in-house and community-level implementations of these technologies, the stated average cost for producing 1 m^3 of water was US\$ 0.24–2.39 and US\$ 0.054–3.72, respectively [131]. However, the low-cost methods currently in use are unable to lower As to below the WHO-recommended level of 10 $\mu\text{g/L}$. As a result, people in countries with heavy As contamination frequently drink water that contains more As than 10 $\mu\text{g/L}$.

Arsenic was discovered to be successfully removed from the hand tube well-sourced drinking water by sorptive filtration through iron-coated sand. From an initial concentration of 226 $\mu\text{g/L}$, As was decreased to

below 15 µg/L. Prior to filter media regeneration, about 2.5 m³ of water may be filtered. After being regenerated up to five times, the filter displayed constant performance. The primary drawback of this method is the speedy clogging of the sand filter bed. The method needs pretreatment to get rid of extra iron. Monitoring for the As breakpoint and routine filter media regeneration are also necessary. For the purpose of removing extra iron, pretreatment is necessary. Additionally, regular filter media regeneration and monitoring to identify the As breakpoint are needed. In addition, it takes time and money to prepare iron-coated sand [132]. It should be emphasized that people in rural regions favored technology based on coagulation using ferric chloride because it was less expensive, easier to maintain, and easier to build in a home.

From initial concentrations of 375–640 µg/L, the bucket treatment unit (BTU) (Figure 7) reduced As to 20–37 µg/L. The method is simple, and the entire price varies between US\$1.64 and \$1.68 per cubic meter of water. The initial capital expenditure will be in the range of US\$ 6–8, while annual operating and maintenance expenses would be around US\$25. A single family's daily basic needs can be met with the water production rate of approximately 0.48 m³/day [91].

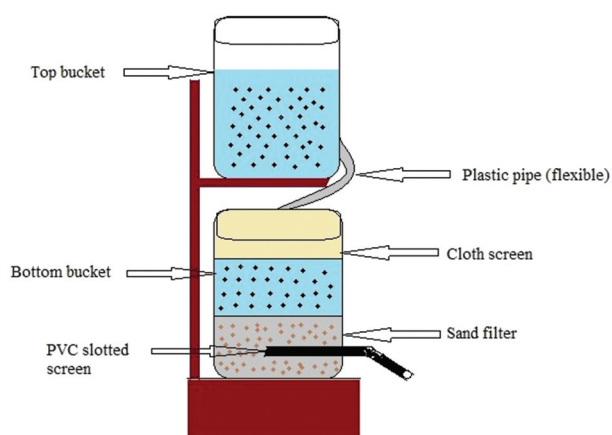


Figure 7. Bucket treatment unit.

A different technology called the Stevens Institute Technology (SIT) uses a similar methodology to BTU and was able to lower As to below 50 µg/L in 80–95% of the water samples.

In rural areas, a few other filtration systems are also in use. Sono 3-Kolshi filter, Shapla Filter, Shafi Filter, Homemade Garnet Filter are a few of these (Table 5). Initial values frequently reach 100 µg/L in several of the region's As contaminated sites in under developed countries [133]. Though, utilizing these methods can considerably increase the water's quality [91]. However, these methods did not work to bring As levels down to below the WHO guideline values of 10 µg/L.

In the fill and draw unit, a locally developed technology (Table 5), water is combined with an oxidant and a coagulant, agitated for 30 seconds at 60 rpm, and then allowed to settle overnight. For floc formation, a sloppy water tank's hydraulic gradient is used. This method lowers As to below the Bangladeshi local limit of 50 µg/L. A unit with a 0.6 m³ capacity may accommodate 15 households [91,136].

Another method to lower As in drinking water is the tube well-attached As removal device. With this method, 300 µg/L of original As content was reduced by up to 90% [137]. This approach involves attaching a coagulation, flocculation, and upflow filtering equipment to a tube well. Although the use of chemicals makes this process more expensive than some comparable procedures, its simplicity of use and high eradication rate make it popular in rural regions.

The filter medium for low-cost technologies frequently need frequent cleaning and/or replacement, whereas chemicals and filters are usually required. Additionally, these technologies frequently result in toxic metal-laden sludge that needs to be safely disposed of. The under developed and economically poor nations typically employ coagulation-assisted adsorption and iron coating-assisted adsorption procedures among them [138].

Table 5. A summary of various low cost As removal methods.

Methods	Positive	Negative	References
Stevens Institute Technology (SIT)	In 80 to 95% of samples, lower As concentrations to 0.05 mg/L.	For better performance, the filter needs to be washed frequently.	136
BTU	60% of As removal using a basic, low-cost technology and a production rate of 20 L/h	Ineffective removal brought on by incorrect mixing and fluctuating groundwater pH	91
Sono 3-Kolshi filter	As removal of 90–95% at a rate of 20–30 L/h	Unit must be replaced after three to five years if it can't reduce noise to a certain level.	91
The Shafi filters	Chemical not required.	Low production rate and unable to drop below desired levels	91, 136
Apyron As treatment unit	Simple and efficient	Regular cleaning of media is required.	91, 136
Garnet homemade filter	Chemical not required.	Low production rate	134, 136
Arsenic removal unit attached to tube-well	90% reduction efficiency for 300 g/L of original As	Hazardous sludge handling and chemical expense	138
Fill and draw units	Simple to handle	Unable to drop below desired levels	91, 134, 136
Shapla filter [Iron-coated sand and brick chips]	Arsenic elimination of 80–90% in a single procedure	Frequent cleaning required	134
Manual flocculation followed by sedimentation	There is no need to add chemicals after the original expense of the container.	Unable to decrease below expected level	135

4.10 Latest technologies

Global researchers are working hard to find novel and affordable techniques for removing As in light of the USEPA's lowering of the drinking water regulations. This paper will discuss about cutting-edge new technology called a polymeric ligand exchanger (PLE). A polymeric ligand exchanger typically comprises of (a) a cross-linked hosting resin and (b) immobilized transition metal ions, such as copper and iron, to the functional groups of the hosting resin. Since the polymeric ligand exchanger contains transition metals as a terminal functional group, ion exchange involves electrostatic interactions between the fixed metal ions and the target anion as well as Lewis acid-base (LAB) interactions (metal-ligand complexation). Accordingly, in a PLE, the selectivity of different anions is controlled by the strength of the ligand, whereas in a traditional ion exchanger, it is controlled by the anion's basicity. As a result, even when competing common ions like sulfate and chloride, which are considerably weaker ligands, are present, the PLE may still take up stronger ligands like arsenate and phosphate. In this method, resin must be able to absorb a lot of metal and it should be able to firmly hold the metal ion, ensuring that there is little metal leakage throughout the ligand exchange process [129]. By using this technique, neutral arsenite molecules cannot be isolated. As a result, this method is combined with an oxidation phase as a pretreatment to transform As(III) into As(V) in order to achieve the highest As removal efficiency. For this purpose, strong cation-exchange resins, biopolymer gels, or chelating resins, such as polystyrene or polyglycidyl methacrylate-based chelating resins such as sulphonic acid and iminodiacetic (IDA) resins, polyhydroxamic (PHA), and lysinediacetic (LDA) resins, are preferred. The chelating group attached to the polymer is not hydrolyzed in acidic or basic conditions, making them insoluble, non-toxic, and chemically resistant.

A literature search finds that iron loaded resins have been used most frequently to separate As. Yoshida and Ueno have reported one of the initial works. They employed Uniselec UR-10, a commercially available resin with iron loading and *o*-hydroxy-benzyl-nitrilodiacetic groups, to separate groundwater from As(III) and As(V). They stated that while As(III) was adsorbed at pH 8.5, arsenate was adsorbed between pH 3.6 and 5.5 [129]. The main disadvantage of iron-laden resins is that (a) the amount of Fe³⁺ loaded was minimal because ferric ions have weak Lewis acids, and (b) the loaded iron was virtually entirely eliminated from the host resin during regeneration, necessitating the reloading of iron(III) after each cycle of operation.

According to several researches, compared to iron-loaded resins, copper-loaded resins exhibit a strong and focused attraction for arsenate. Because copper (II) is

a much stronger Lewis acid than iron(III), according to Irving and Williams' order. Additionally, copper is seen to have a far higher metal loading capacity than iron.

5. Discussion and conclusion

In several regions of the world, elevated amounts of As in drinking water have been documented. Consequently, supplying clean and safe drinking water is the biggest worldwide challenge of the twenty-first century. Therefore, it's critical to develop new technologies and materials to keep up with the rapidly expanding demand. Based on the current situation, it appears that the only practical way to reduce the risk to public health is to remove As from contaminated water. Different methods are being used to do this. It is challenging to choose the optimal procedure because each one has pros and cons, and their byproducts may also provide a risk for secondary As pollution. As a result, new technologies with the capability of new hybrid methodologies are required to combat the threat of As in future. More environmentally friendly and sustainable chemicals must therefore be used in their place. Other crucial factors to take into account while choosing a sustainable technology include the system's flexibility, simplicity, and ease of maintenance. Ion exchange, membrane process, adsorption, or chemical precipitation are the different process types that make up the majority of As treatments, however, due to exchange competition with other anions present in groundwater, ion-exchange techniques' capacity to extract As is severely constrained. Arsenic may be removed from groundwater using membrane techniques, although they are expensive. In order to find affordable, successful methods, adsorption and chemical precipitation methods are being investigated.

Although there has been great progress in the development of advanced technology for As removal, the majority of these solutions are expensive and frequently out of the reach of many As affected populations [139]. Low-cost devices that could help the underprivileged communities lessen their exposure to As contaminated drinking water are desperately needed. Furthermore, unless low-cost technologies are reliable enough to be used by rural people, they could not be warmly received. The possibility of media regeneration might increase people's desire to use these technologies. To solve these difficulties, additional research is required. For example, at a relatively modest cost, EC has been shown to have good performance in lowering As to below the WHO guideline value. The modest solar power system can be used to address the main problem, which was the power source. Additionally, this may raise total costs. Future research is required to determine the overall cost of

this system with the solar power system and to better understand its performance. Arsenic was lowered to under 5 µg/L at pH 7.6 by using high-temperature based iron oxide-coated sand in filters [140]. The primary issue was a sudden decrease of capacity brought on by the removal of filter materials, fouling, and pore space blockage. The use of alternative base materials, such as fiber glass and cellulose fiber from agricultural waste, has significantly increased the adsorptive surface area, which is predicted to improve the effectiveness of the As removal process [141]. Future research is required in this area.

In order to reduce As to below the WHO recommendation value, carbon nanotube (CNT)-based point of use (PoU) technology (such as filters) has demonstrated good efficacy [142]. However, making CNT was expensive, and there was a chance that CNT might be harmful to human health [131]. Therefore, future investigation is required to lower the cost of CNT-based technology and the product water's toxicity to human health.

This has long been understood that nanotechnology has enormous promise for developing water treatment and enhancing water quality. Nanomaterials are useful for numerous applications including membrane separation processes and adsorption because of their enormous surface areas and high adsorption capabilities. Additionally, to improve their ability to remove contaminants, nanomaterials can be functionalized with a variety of chemical groups utilizing various methods of modification. Although some authors discuss the expense of manufacturing nanoparticles, the emphasis is primarily on cost-effective methods for purifying water that may be accomplished with less expensive materials. On a laboratory scale, nanoparticles for water purification produced encouraging results, but it appears that there are several obstacles, for instance, cost effectiveness to be taken into account before applying them at full scale.

This study focused on various As decontamination technologies as well as low-cost technology to examine As removal methods for drinking water. For further advancements, several low-cost technologies were identified. Future study should be done on the alternative generation of activated alumina, which has the potential to lower costs. Due to the use of inexpensive materials and agricultural products, biotechnologies are probably accessible at low cost. The efficacy of the As adsorption can be improved by impregnating the bio-based products with iron and activated alumina. Future investigation in these areas is necessary. Because low-income populations are typically uneducated, the intricacy of new technology is likely to discourage them from adopting them, even if these technologies are provided through government or other agency-sponsored initiatives.

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