Adsorbents Used for the Adsorptive Removal of Highly Hazardous Arsenic from Aqueous Solution: A Review

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Review Article

ABSTRACT

Millions of people worldwide are adversely affected by Arsenic continuing exposure, so providing arsenic-free consumption of water is an immense task for the researchers. The chemistry, content of arsenic-contaminated water as well as adsorption play a big role in arsenic elimination. The mechanism of adsorption technology's elimination of As (V) from the water was simply presented as the elements that govern various adsorption paths. The effects of a variety of adsorbents on As (V) elimination from aquatic were explored in the present research, which classified the materials used as adsorbents based on physical, chemical, and biological processes. When choosing an adsorbent, adsorption capability is an important factor to consider. As a result, developing As (V)

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elimination from aquatic adsorption strategies includes developing environmentally acceptable materials with effectual adsorption abilities, refining the preparation and alteration procedures of recent adsorbents, and boosting renewal effectiveness. After choosing a particular adsorbent for As (V) elimination from water, regional features of arsenic-polluted water, applied viability of the adsorption process, besides suitable environments of respectively material must be extensively reviewed and analyzed. The current study gives an outline of the adsorption technique to remove arsenic from wastewater, as well as the adsorption capacity of various adsorbents.

1. INTRODUCTION

A metallic grey Arsenic is a metalloid, having atomic number 33 and mass number 75. A P-block element and member of Group-15 [pnictogen] in the periodic table, and its arrangement of electron is [Ar] $3d^{10} 4s^2 4p^3$. It covers around 0.00015% of the earth crust, and the 53rd most plentiful element in earth. The important oxidation states of Arsenic (As) are states +V(arsenate), +III (arsenite), 0 (arsenic), and –III (arsine), which existed as an anion with acid behaviours. Arsenic salts, both inorganic and organic, can sometimes be found in foods. Most water-soluble organic arsenic compounds, such as arsenobetaine, are less hazardous than inorganic arsenic [1]. The index of "safely managed drinking water services" in the WHO/UNICEF Combined Guided Programme for Water Supply, a new 2030 Agenda for Sustainable Development, calls for pursuing the inhabitants accessing consumption water that must has permitted value of contamination, chemical pollutants as well as arsenic. The WHO guidelines suggest a perimeter of 10 g/L of arsenic in intake water [2][3]. Arsenic, that is located in the crust of the earth and usually dispersed altogether over the atmosphere in the air, water, and land, causes harm to millions of people across the world. It occurs at high concentrations in nature, groundwater in many countries, on top of Argentina, Bangladesh, Chile, China, India, Mexico, and the United States of America. Fish, shellfish, pig, chicken, dairy products, and grains all contain arsenic [4][5]. In industrial, it's used as an alloying agent, glass pigments, fabrics, paper, metal adhesives, wood preservers, ammunition, as well as the tanning process are all examples. To a lesser extent, it's also used in herbicides, feed additives, and pharmaceuticals. Vomiting, gastrointestinal discomfort, diarrhoea, numbness as well as burning of the limbs, muscle cramping, as well as demise are the instant signs of acute arsenic intoxication in cases of major arsenic absorption.

Pigmentation changes, skin lesions, in addition to firm patch on arms and hands are common signs of long-standing contact to elevated amounts of inorganic arsenic through i water and eating intake. Origins malignancies of the bladder and lungs in addition to skin cancer. Arsenic and arsenic compounds have been characterised being oncogenic to people by the International Agency for Research on Cancer (IARC). Arsenic exposure in gestation and initial infancy has been related to surges in death in Millennials owing to numerous malignancies, heart attacks, lung disease, and renal failure, all of which have negative effects on child health. Arsenic has been demonstrated to have deleterious properties on reasoning growth, IQ, and retrograde amnesia in numerous studies. The most important action in damaged areas is to afford harmless consumption water, food, and irrigating water for food crops to minimize upcoming arsenic hazard. Arsenic levels in intake water possibly reduced using a multiple of means [6-9]. The current study gave an outline of arsenic elimination from water by adsorption procedure, as well as the adsorption capacity of various adsorbents, so as to serve as a link with practical use of adsorption methods to eliminate arsenic by waters.

1.1 Different Technologies are Designed for Said Elimination of Arsenic by Waters

The chemistry and makeup of arsenic-polluted water play a big role in its removal from the water.

1.1.1 Oxidation techniques for the removal of Arsenic

The change of soluble arsenite to arsenate is known as oxidation. Chemicals like chlorine, ozone, as well permanganate, instead, may rapidly oxidize As (III) to As (V). The most often

utilized oxidants in some nations are atmospheric oxygen, hypochlorite, and permanganate. Arsenite oxidation by oxygen is a sluggish procedure that can take several hours or days to finish. [10].

1.1.2 Process of coagulation and flocculation

Coagulation and flocculation are two of the commonest practiced since recognised by means for eliminating arsenic as of water. Positive charge coagulants (like aluminium sulphate ($Al_2(SO_4)_3$) and ferric chloride ($FeCl_3$)) reduce colloids negatively charged, allowing them to collide and then become larger after coagulation. On either end, an anionic flocculant, produces spanning or charge neutralization among the larger particles generated, as a result of which flocs are formed. Throughout those operations, the chemicals convert arsenic in the body into an intractable solid, resulting precipitate. The effectiveness of various coagulants in eliminating arsenic varies with pH. Arsenic removal from water below pH 7.6 is equally effective with $Al_2(SO_4)_3$ and $FeCl_3$ [11-13].

1.2.3 Membrane filtration process

Membrane filtration is a technology for eliminating arsenic and other toxins from water that can be utilized in the production of drinking water. Membranes are often synthetic materials containing billions of minute opening which operate like obstacles, are selected, blocking the passage of certain water components. Water must be propelled over the membrane as a result of a driving factor, for example, a differential in pressure here between permeate sides. The two primary forms of pressure-driven membrane filtrations are low-pressure membrane processes like microfiltration and ultrafiltration and high-pressure membrane processes like reverse osmosis and nanofiltration [14-15].

1.2.4 Process of adsorption and ion exchange

Sorption process is a solids-based technique as a carrier to eliminate compounds from equally liquid and gaseous solutions. Ingredients are removed as of single component and deposited on the surface of a different component. This system is guided by van der Waals, among adsorbent and adsorbent surface atoms, including forces and electrostatic interactions. By way of a consequence, before using an adsorbent for adsorption, it's vital to define its surface features (e.g., surface area, polarity). Several studies on various sorbents have been undertaken. Activated carbon, coal, red mud, fly ash, chicken feathers, kaolinite, montmorillonite, goethite, zeolites, titanium dioxide, iron hydroxide, zero-valent iron, chitosan, and cation-exchange resins are just few of many examples [16-17].

1.2.5 Nanoparticles are being practised to eliminate arsenic from water

Nanoscience and nanotechnology advancements take lately paved the means for the development of diverse nanoparticles for the analysis of poisoned water. Nanoparticles have aroused environmental interest as potential sorbent of pollutants for example heavy metals and arsenic from aqueous medium due to their huge specific surface area, strong reactivity, as well as excellent selectivity [18-19].

1.2.6 Mechanism of the adsorption of heavy metals by the Nanoparticles

Heavy metal adsorption was already proved to be successful using nanoparticles. Nanoparticles, on the other hand, have low energy barriers because they are frequently present as tiny or ultrafine particles, leading them to combine and acquire a stable state. Aggregation reduces the nanoparticles' free surface area, lowering their adsorption capability and reactivity. Furthermore, the particles' mobility reduces, contributing to a reduction in their effectiveness. Two solutions to the difficulties of aggregation have been published in the literature.

One solution is to impregnate porous materials or surface coatings with nanoparticles. Activated carbon, bentonite, sand, alumina membranes, and ion-exchange resins are just a few of the most commonly utilized host substrates. Surface regulators in a couple of layers has been observed to slow down the reaction rate, regardless of the fact that elimination capacity is enhanced because of the growing numeral of binding spots. As a consequence, the stability-reactivity trade-off must be thoroughly explored. The alternative solution is to design and synthesize micro nano hierarchically ordered adsorbent that is likely balance higher adsorption capacity with nanoparticle stability [18-19].

2. DIFFERENT ADSORBENTS USED AND THEIR CAPACITY FOR THE ELIMINATION OF ARSENIC FROM AQUATIC

Membrane separation, coagulation, precipitation, ion exchange, and adsorption are just a few of the arsenic-removal technologies available. Adsorption is a member of utmost promising machineries for eliminating arsenic from aquatic currently accessible owing to their low cost, high productivity, and ease of application. Several works have employed adsorbents such as nanomaterials, polymers, zeolite, chitosan, granular ferric hydroxide (GFH), and additional substances to extract arsenic [20].

2.1 Use of Different Adsorbents their Adsorption Capacity and Mechanism

An adsorbent's adsorption capacity is an important parameter for evaluating its concert. The outcomes of Arsenic adsorption are affected by pH, temperature, starting Arsenic) content, as well as the existence of supplementary competing ions present in water, as well as the contact time. Electrostatic attraction, ion exchange, and surface complexation are examples of physical and chemical mechanisms that can fix arsenic in water to the adsorbent [21]. Electrostatic attraction, ion exchange, and surface complexation are examples of physical and chemical mechanisms that can bind arsenic in waters to adsorbent materials. Additionally, scientific and technological progress, a number of advanced techniques as well as the mechanics of arsenic elimination from water by adsorption techniques may be studied using sophisticated equipment. X-ray diffraction (XRD), scanning electron microscope (SEM), X-ray absorption spectroscopy (XAS), Fourier transform infrared (FTIR), X-ray photoelectron spectroscopy (XPS), the extended X-ray absorption fine structure (EXAFS), and other techniques have been used to investigate the properties of adsorbents [20-29]. Owing to their high arsenic eliminating efficiency, ecological sensitivity, and availability on Earth. Here some prominent adsorbents will be discussed.

Activated carbons: Activated carbon, a kind of carbide formed by carbonization and activation techniques as of coconut shell, charcoal, lignin, sawdust, rice husk, as well as additional carbonaceous materials, is well-known for its use as adsorptions. The high percentage removal is a term used to describe the ability of a substance to absorb water to a complex porous structure, significant portion groupings and a substantial high surface area [30]. To extract As (V) from water, all active carbon and altered carbon can be employed as adsorbents. One can see some prominent Activated carbons adsorbents in the table 1.

C. P. Huang, et al [31]. studied the outcome of As (V) elimination by means of activated carbon (AC), pH, carbon type, and total As(V) content all influence the amount of As (V) removed from water by carbon adsorption. Two activated carbons, D-X and D-XI, appeared to be the highly effective of the 15 various kinds of commercial activated carbons examined. At pH 4 to 5, the most As (V) was removed. Lodeiro et al. [32] likened the adsorption abilities of four distinct adsorbents: activated carbons made from sugar beet pulp (BP) using steam activation and with or without Fe or Mn oxidation; Fe activated carbons made from sugar beet pulp (BP) using steam activation and with or without Fe or Mn oxidation; Fe activated carbons made from sugar beet pulp (BP) using steam activation and with or without ($BP-H_2O$, $BP-H_2O-Fe$, $BP-H_2OH_2O_2-Fe$ and $BP-H_2O-MnO_2-Fe$). For processing raw water with a starting As (V) content of 100–1000 g/L and a dose of 0.05 g/100 mL, their BETs were 821 m2/g, 762 m2/g, 858 m2/g, and 741 m2/g, respectively. The adsorption capabilities of these four adsorbents on As (V) were 0.69 mg/g, 2.94 mg/g, 3.25 mg/g, and 16.8 mg/g, respectively, according to the Langmuir equation. George P, et al. [33] used the Iron and Manganese Oxides Modify Activated Carbon Their As(V) adsorption performance was tested. The maximum adsorption capacity (Qmax) of As(V) rose from roughly 4 mg g1 for raw carbon to 11.05 mg g1 after iron impregnation, whereas Mn incorporation boosted the adsorption capacity to 19.35 mg g1 after Mn inclusion. Arsenic adsorption on various carbon organized composites may be effectively created from locally accessible low-cost biomass mixtures, according to Aminul Islam et al. [34], employing an ecologically friendly chemical activation with H_3PO_4 and subsequently pyrolysis. C.L. Chuang, et al. [35] Oat hulls are used to make activated carbon. Initial pH values influenced adsorption efficiency; Adsorption effectiveness is lowered by rising starting pH levels. The primary forms of As(V) at low (e.g., 5) and high (e.g., 9) pH values are H_2AsO_4 and $HAsO_2$ 4, respectively, making H_2AsO_4 a more effective adsorbate than $HAsO_2$ 4. The adsorption isotherms show that as the

initial pH increased from 5 to 8, the adsorption of both the unit layer ability declined from 3.09 to 1.57 mg g1, approaching negative at an initial pH of 9. Hye-jin Hong, et al. [36] using Powdered activated carbon with surfactant modifications. It was feasible to thoroughly cure 0.001 mM arsenate, 0.5 mM chromate, and 0.2 mM ferricyanide using 2 g/L modified PAC. Son Van Dang, et al. [37] using laterite and iron-modified activated carbon have concentrations of 0.48 mg/g and 1.18 mg/g, correspondingly. Lalhmunsiama , et al. [38] using Manganese Coated Activated Carbon and Activated Carbon.The percent clearance of As(III) and As(IV) decreased dramatically as the sorptive pH (i.e., 2.0 to 10.0) as well as quantity (i.e., 1.0 to 10.0 mg/L) increased (V). According to Trishikhi Raychoudhury, et al. [39] the arsenate [As(V)] and arsenite [As(III)] were removed in 92-98 percent and 42-65 percent, respectively, by these AC-Fe composites. The composite with the least amount of iron (1.54 percent) was the most effective in absorbing arsenic. The composite may absorb up to 125 mg As(V)/g Fe and 98.4 mg As(III)/g Fe, according to Langmuir model.

Table 1. Arsenic is removed from wastewater by using various activated carbons as adsorbents

S. No.	Adsorbent	Capacity mg/g	Remarks	Reference
1	Activated Carbon	2.1	Ph determines the amount of As (V) removed from water by carbon adsorption; maximal As(V) removal occurred at pH 4 to 5.	[31]
2	Sugar beet pulp- Activated Carbon.	As (V) - 0.69, 2.94, 3.25, and 16.8.	Steam activation of sugar beet pulp (BP) with or without Fe or Mn oxidation. The adsorption capabilities of As (V) were 0.69 mg/g, 2.94 mg/g, 3.25 mg/g, and 16.8 mg/g, respectively, according to the Langmuir equation.	[32]
3	Iron and Manganese Oxides Altered Enriched Carbon	19.35	Following iron impregnation, the absorbance value (Q max) of As(V) increased from around 4 mg g1 for raw carbon to 11.05 mg g1, while Mn incorporation enhanced the sorption to 19.35 mg g1.	33
4	carbon-based adsorbents with microstructure.	56	After an ecologically friendly chemical activation with H_3PO_4 and later pyrolysis, several carbon structured carbon materials for arsenic adsorption were created from a low-cost biomass combination.	34
5	Oat hulls - activated carbon.	3.09	Starting pH values had an influence on adsorption efficiency, with higher starting pH values reducing adsorption efficiency. When the starting pH was raised from 5 to 8, the unit layer adsorption capacity reduced from 3.09 to 1.57 mg g1, according to the adsorption isotherms.	35

S. No.	Adsorbent	Capacity mg/g	Remarks	Reference
6	Powdered activated carbon with surfactant modifications	6.52	Using 2 g/L modified PAC, it is possible to thoroughly cure 0.001 mM arsenate, 0.5 mM chromate, and 0.2 mM ferricyanide.	36
7	Iron-modified activated carbon and laterite	0.48 and 1.18, respectively.	Laterite and iron-modified activated carbon have adsorption capacities of 0.48 mg/g and 1.18 mg/g, respectively, for removing arsenic from synthetic groundwater.	37
8	Manganese Coated Activated Carbon.	1.37, 1.39. 1.55 and 1.50 in the case of AC-R, AC-N, MCAC-R and MCAC-N, respectively.	As the sportive pH (i.e., 2.0 to 10.0) and concentration (i.e., 1.0 to 10.0 mg/L) increased, the removal of As(III) and As(IV) reduced considerably (V).	38
9	AC-Fe composites.	125 for As(V) and 98.4 for As(III)	The arsenate [As(V)] and arsenite [As (III)] were removed in 92-98 percent and 42-65 percent, respectively, by these AC-Fe composites. The composite with the least amount of iron (1.54 percent) was the most effective in absorbing arsenic. The composite may absorb up to 125 mg As(V)/g Fe and 98.4 mg As(III)/g Fe.	39

Polymers: A variety of polymer-based adsorbents were used for heavy metal adsorption from water that has been tainted in the past because of the availability of diverse functional groups. Pure polymers, on the other hand, have a number of disadvantages, including limited stability and the separation of adsorbents from wastewater during adsorption handling, particularly when powdered. If the used adsorbent can be efficiently improved, It's possible to rejuvenate and reused, which saves money [40]. One can see some important polymer-based adsorbents in the Table- 2.

Hatice Bekta et al. [41] developed cryogel technologies as an active adsorbent for elimination of arsenic species by coupling cryogels' remarkable mechanical capabilities and macroporous architectures with ion-imprinting technology's excellent selectivity. At a starting amount of arsenic10 ppm, the sorption efficiency of ion imprinted cryogels was predicted to be 372.5 g/g polymer at pH 8.0. As a consequence of the cryogel-based ambient water investigation.

The IIP elimination rate was calculated to be 94.8 percent. Sadia Saif and colleagues [42] The environmentally friendly synthesis of iron–oxide nanoparticles (IONPs) and their stabilization with polymers, such as chitosan (C) and polyvinyl alcohol (PVA)–alginate (PA), as well as future research into arsenic (V) elimination from aqueous solutions. IONPs with a mean size of less than 100 nm were made utilizing an aqueous leaf extract of Terminalia chebula in a green synthesis technique. The maximum monolayer saturation adsorption capacity for IONPs was 28.57 mg/g, as determined by the Langmuir adsorption isotherm. The Freundlich model best fit As(V) adsorption by polymer-supported IONPs, with maximum adsorption capacities of 34.4 mg/g and 40.3 mg/g for chitosan- and PVA–alginate-supported IONPs, correspondingly. The Hybrid inorganic/organic polymer was used by Carmen M. Iesan et colleagues [43]. In fixed-bed column operation, the hybrid adsorbent HFO/SBA shown excellent adsorptive characteristics toward As(V) and As(III) oxyanions seen in water sources. The

goal of this research is to assess the performance of a hybrid inorganic/organic polymer material based on hydrated ferric oxide (HFO) in the adsorption of arsenic oxyanions from polluted drinking water. Nano-alumina distributed in chitosan-grafted polyacrylamide was used by Suparna Saha et al. [44]. The removal capability of an arsenic adsorbent made up of alumina nanoparticles distributed in a polymer matrix was investigated. This newly synthesized adsorbent was shown to have a high loading capacity (6.56 mg/g). The elimination was discovered to be pH dependant, with the highest removal occurring at pH 7.2 and an equilibrium time of 6 hours. Using Hybrid Polymer Containing Manganese Oxides, Daniel Ocinski et al [45] investigated the oxidative and sorptive characteristics of a MnO_2 loaded hybrid polymer ([P]-SO_2NH_2#MnO_2) toward arsenic species in water. Batch tests revealed that the hybrid polymer had a very strong oxidizing capacity toward arsenite in the pH range of 2.0–12.0, even up to 75 mg g21, and a comparatively poor sorption capacity toward As(III) and As (V). By loading nanosized sol–gel-derived TiO_2–SiO_2 onto a porous PAN polymer for increased arsenite [As(III)] and arsenate [As(V)] species removal from aqueous environments, A. Nilchi et al [46] developed a new hybrid adsorbent, titania–silica binary oxide (TiO_2–SiO_2)–polyacrylonitrile (PAN). M. Sadani et al. [47] created a novel magnetic ion imprinted polymer, a new adsorbent having adsorption on the surface and regenerate capability, for arsenic (As+5) effluent adsorption. To estimate the combined effect of independent input elements and dependent output response, the response surface methodology utilizing R software was chosen. Hiroyuki Hoshina et al. [48] used nonwoven cotton fabric as a trunk polymer to create a fibrous adsorbent for arsenic (As) removal. Radiation-induced graft polymerization was used to introduce 2-hydroxyethyl methacrylate phosphoric acid monomer, which is constituted of phosphoric acid mono (50%) and di (50%) ethyl methacrylate ester, onto nonwoven cotton fibers. Poly (layered double hydroxides) [poly (LDHs)] beads as an adsorbent for arsenate removal from aqueous solution are investigated by Ho Nguyen Nhat Ha et al [49]. Immobilizing LDHs into spherical alginate/polyvinyl alcohol (PVA)-glutaraldehyde beads produced the poly (LDHs) beads (spherical polymer beads). Poly (LDHs), a hybrid sorbent, was created to meet the demand for a cost-effective, reusable, and easy-to-separate material from effluent water. Hybrid anion exchange resins coated with hydrous zirconium oxide nanoparticles were used by Surapol Padungthon et al [50]. In the literature, HAIX–Zr is the first highly selective and regenerable arsenic hybrid sorbent based on HZOs and the Donnan membrane principle. Because the Donnan effect facilitates transport of anions, such as As(V), into the polymer phase due to its large concentration of fixed positive charges, polymeric anion exchange resins provide the best support for zirconium oxide. HZO nanoparticles are easily impregnated into anion exchange resins and are safe to use afterward. EGDMA polymer demonstrated excellent adsorption capacities and kinetics for As(V) in aqueous solutions via molecular imprinting. Nano MIP outperformed commercially available iron/aluminum oxides and activated carbon-based adsorbents in terms of adsorption. A potential technology operation with a cheap cost and minimal by-product generation. Using a synergistic method of molecular imprinting and metal–organic ligand chemistry, a novel polymer-based nano-adsorbent for As(V) has been developed [51]. N,N'-Dimethylaminopropyl acrylamide, methyl chloride quaternary (DMAPAAQ) loaded with iron hydroxide (DMAPAAQ + FeOOH) was used, as well as a non-ionic polymer gel composite, N,N'-Dimethylacrylamide (DMAA) loaded with iron hydroxide (DMAA + FeOOH). Under natural conditions, DMAPAAQ + FeOOH had a better As removal efficiency while being environmentally beneficial [52]. This co-imprinted polymer MICIP was found to be effective for the selective separation of combined Cr(III) and arsenate ions in solutions in an adsorption study[53]. ArsenXnp is a hybrid sorbent made up of hydrous iron oxide nanoparticles dispersed throughout a porous polymeric bead. This involves combining ion exchange resins' superior handling, flow properties, and attrition resistance with hydrous iron oxides' well-documented arsenic affinity [54]. A new stimuli-responsive composite based on poly(4-vinylpyridine) (PVP) brushes end-grafted to montmorillonite clay (GPC) was designed as a bioremediation sorbate for extraction and purification of contaminants from water [55]. As promising adsorbents for arsenic removal, iron-aluminium double hydrous oxides were produced and integrated into cryogels. According to adsorption investigations, the Fe-Al-Cryo can adsorb As(III) from a realistic smelting wastewater solution without experiencing considerable competition from other ions [56]. Different polymer content Fe_3O_4/PANI nanocomposite composites were effectively

produced. Because PANI is highly insoluble in solvents and stable in settings with O_2 and H_2O, the physical and chemical characteristics of Fe_3O_4/PANI are stable, resulting in better arsenic adsorption capacities in aqueous medium [57]. Cement gelation of arsenic waste material is an effective way to limit arsenic leachability. Due to the production of calcite, which plugs the pores of the solidified sample and precipitates the creation of calcium arsenite, arsenic waste consolidated/stabilized with cement, fly ash, and Ca $(OH)_2$ [58]. During an intermediary phase of the synthesis, suspension polymerization was employed to integrate Al and Fe into polymeric beads. The fluoride (100 mg/g) and arsenic(V) (40 mg/g) loadings of the Al- and Fe-doped, activated micron (0.8 mm) and nano (100 nm) sized porous adsorbents generated were shown to be significant [59].

Table 2. Arsenic is removed from wastewater by using various polymers as adsorbents

S. No.	Adsorbent	Capacity mg/g	Remarks	Reference
1	Ion-imprinted cryogens	0.372	At an initial arsenic concentration of 10 ppm, the highest adsorption capacity of ion-imprinted cryogels was predicted to be 372.5 g/g polymer at pH 8.0.	[41]
2	Iron–Oxide Nanoparticle Polymeric Nanocomposites	IONPs (28.27), IONPs–C (34.4), IONPs–PA (40.3)	Has highest monolayer saturation adsorption capacity.	[42]
3	Hybrid inorganic/organic polymer	15.26	In fixed-bed column operation, the combination adsorbent HFO/SBA has demonstrated excellent adsorptive characteristics towards As(V) and As (III).	[43]
4	In chitosan-grafted polyacrylamide, nano-alumina is dispersed.	6.56	Alumina nanoparticles distributed in a polymer matrix were used to create an arsenic adsorbent.	[44]
5	Hybrid Polymer Containing Manganese Oxides	1.59 for As(III) and 0.87 for As(V)	Batch tests revealed that the composite polymer had a high oxidizing capacity.	[45]
6	Polyacrylonitrile Polymer with Titania–Silica Binary Oxide Nanoparticles	35.21 for As(V) and 29.23 for As(III)	A new hybrid adsorbent, titania–silica binary oxide (TiO_2–SiO_2)–polyacrylonitrile (PAN), has indeed been developed by unloading nanosized sol–gel-derived TiO_2–SiO_2 onto a porous PAN polymer.	[46]
7	Polymer imprinted with nanomagnetic ions	104.7	A new adsorbent with specific adsorption and regenerate capability has been used for arsenic (As+5) effluent adsorption.	[47]
8	Polymer for the trunk. Phosphoric acid monomer 2-hydroxyethyl	7.49	Nonwoven cotton fabric was used to create a fibrous adsorbent for the elimination of arsenic (As).	[48]

S. No.	Adsorbent	Capacity mg/g	Remarks	Reference
	methacrylate			
9	Double hydroxides are coated and inserted in spherical polymer beads.	21.67	As an adsorbent for arsenate removal, poly (layered double hydroxides) [poly (LDHs)] beads were used. Poly (LDHs) is a cost-effective, dependable, and reusable hybrid sorbent that is easy to separate from wastewater sample.	[49]
10	Hybrid anion exchange polymers were impregnated with hydrous zirconium oxide nanoparticles.	20	HAIX–Zr is the first highly selective and regenerable hybrid sorbent for arsenic.	[50]
11	Molecularly imprinted nanoparticles	49	A novel As (V) nano adsorbent based on polymers. Adsorption is by far the most promising technology because of its low cost and low by-product generation.	[51]
12	Polymer Gel Composites	123.4	N,N'-Dimethylaminopropyl acrylamide, methyl chloride quaternary (DMAPAAQ) loaded with iron hydroxide (DMAPAAQ + FeOOH), and a non-ionic polymer gel composite demonstrated improved As extraction efficiency under natural conditions while staying ecologically benign.	[52]
13	As(V)-Cr (III) Co-Imprinted Polymer	12.0	The efficient isolation of mixed Cr (III) and arsenate ions in solutions was made possible by the adsorption of this co-imprinted polymer MICIP.	[53]
14	ArsenXnp	8.17	ArsenXnp is a hybrid sorbent made up of hydrous iron oxide nanoparticles dispersed throughout one highly porous bead.	[54]
15	Grafted Polymer-Clay	17.23	A stimuli-responsive composite made up of poly(4-vinylpyridine) (PVP) brushes end-grafted to montmorillonite clay (GPC) as a sorbent.	[55]
16	Cryogels containing iron-aluminum double hydrous oxides implanted in them.	24.6	As promising adsorbents for removing heavy metals, iron-aluminum double hydrous oxides Fe-Al-Cryo were produced.	[56]

S. No.	Adsorbent	Capacity mg/g	Remarks	Reference
17	Fe_3O_4/Polyaniline Nanomaterial	50.0	Different polymer content Fe_3O_4/PANI nanocomposite composites Fe_3O_4/PANI is a stable compound that improves arsenic adsorption in aqueous systems.	[57]
18	polymeric materials	125	Cement, fly ash, and $Ca(OH)_2$ were used to solidify and stabilize arsenic waste. This occurred as a result of the creation of cement, which functions as a binder.	[58]
19	Multi-functional polymeric Adsorbents	40	Suspension polymerization was used to integrate Al and Fe into polymeric beads during an intermediate step of the synthesis.	[59]

3. NANOMATERIALS

Traditional adsorption materials have a wider specific surface area, whereas nanomaterials have a narrow size distribution and a better adsorption ability [27]. Mesoporous materials have pore widths fluctuating as of 2 to 50 nanometres, a vast volume of surface, a well-organized porous structure, and an adsorption ability [28]. Biological adsorbents comprise plants, microorganisms, and biomaterials, that has ability to absorb, convert, and degrade As (V) in water by a range of physical, chemical, and biological processes. Biological adsorbents have a lot of use potential because of their highly efficient, low price, and low secondary pollution [29]. One can see various nanomaterials as adsorbents in the Table 3.

Hasmukh A. Patel et al. [60] created a magnetized nanocrystalline barium hexaferrite that is absorbent. BHF nanoparticles have a higher arsenic capacity and can be handled more easily than magnetite nanoparticles. Once the elimination of arsenic by magnetic nanoparticles is transferred to the field, this behaviour proved effective [60]. CFF, a new composite material made from iron and iron oxide, was created using a simple two-step reduction procedure. CFF is an adsorbent that has a high adsorption capacity and a fast extraction efficiency, as well as a significant oxidation capability for As [61]. The manufacture of a simple copper oxide nanoparticle (CuO NPs) utilizing Phyllanthus emblica leaf extract as fuel has been proven, as P. emblica is a locally plentiful plant. CuO NPs were produced and employed as an absorbent to extract As(V) from water [62]. Mike O et al. [63] achieved bifunctional magnetic nanoparticles by covalently coupling an imine ligand, 4-[(E)-phenyl methylidene] amino benzoic acid (Maph-COOH), with amine modified magnetic nanoparticles (MNP-NH2) in batch adsorption experiments for the uptake of Zn (II) and As (III) from aqueous solutions.

A. Goswami et al. [64] utilized thermal refluxing to make copper (II) oxide nanoparticles, which they seen as a method for removing arsenic from water. Jing Wang et al [65] used a template technique to create magnetic nanoparticles Fe_3O_4@Zr (OH)4-impregnated chitosan beads as an excellent adsorbent for treatment of waste water. A simple precipitation procedure was used to make hydrous ceric oxide nanoparticles, which displayed excellent arsenic removal on both As(III) and As(V) species[66]. Nanocomposite based on carbon nanotubes (CeO_2-CNTs) has been produced; tests suggest that CeO_2-CNTs have substantially greater zeta potentials than oxidized CNTs, and can be expected to reduce repulsion between its particles and negatively charged compounds, hence enhancing their removal from water [67]. A polymer-based nano-adsorbent for As was made to use a cost-effective polymethacrylate imprinted with fluorescein and As(V) complex (V). During polymerization, As(V) in the polymer matrices was eliminated, resulting in cavities with a greater affinity for As (V) [68] .The arsenic removal ability of calcine FeHT (CFeHT) was investigated [69], and the surface area of the adsorbent obtained at 450 C in 90 minutes was determined to be 172.93 m2 /g as a

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consequence of the calcination studies. Sadia Saif et al [70] used a solution combustion approach to synthesize green CuO NPs from P. emblica leaves extract. The speedy, simple single-step "green" biosynthesis of CuO NPs has an eco-friendly procedure, and this method can be used for environmental cleaning. Using a simple and low-cost polymerization process, a new composite adsorbent based on magnetic polyaniline and strontium–titanium (MP-SrTiO$_3$) nanoparticles for efficiently absorbing arsenic (III) ions from aqueous samples was produced [71]. As evaluated to other commercially available sorbents, a new goethite/silica nanocomposite [72] was shown to be an excellent adsorbent of As (V).

Table 3. Arsenic is removed from wastewater by using various nanomaterials as adsorbents

S. No.	Adsorbent	Capacity mg/g	Remarks	Reference
1	Magnetic nanocrystalline barium Hexaferrite	2.27	BHF nanoparticles have a higher arsenic capacity and can be treated more easily than magnetite nanoparticles.	[60]
2	Cu-Doped Fe@Fe$_2$O$_3$ core–shell nanoparticle	67.3	CFF is an adsorbent that has a strong affinity and a fast removal rate, as well as a high oxidation ability for Just as.	[61]
3	copper oxide nanoparticles	1.17	The use of Phyllanthus emblica leaf extract as a fuel has been proved, as P. emblica is a locally plentiful plant. CuO NPs were produced and employed as an absorbent to extract As (V) from water.	[62]
4	Imine Functionalized Magnetic Nanoparticles.	50.08, 46.71, 47.17 and 57. 60 at 20, 30, 40 and 45°C	4-[(E)-phenyl methylidene] amino benzoic acid (Maph-COOH) was mixed with amine modified magnetic nanoparticles to ingest Zn (II) and As (III) from aqueous solutions (MNP-NH2).	[63]
5	Fe$_3$O$_4$ nanoparticles	16.56 for As (V), and 46.06 for As (III).	Obtaining superparamagnetic high-surface area Fe$_3$O$_4$ nanoparticles using a simple, ecologically safe hydrothermal technique. The produced Fe$_3$O$_4$ nanoparticles were shown to be very effective at removing heavy metal arsenic ions from water.	[64]
6	Copper (II) oxide nanoparticles.	1.09	Thermal refluxing produces copper (II) oxide nanoparticles, that are used as an adsorbing arsenic from water.	[65]
7	Magnetic nanoparticles impregnated chitosan beads.	35.7 for As (V), and 35.3 for As (III)	This was created with the help of a template and could be an arsenic adsorbent.	[66]
8	Hydrous cerium	171.88 for As (III)	On both As(III) and As(V)	[67]

	oxide Nanoparticles.	and 107.10 for As(V).	species, shown outstanding arsenic removal capability.	
9	Carbon nanotubes support ceria nanoparticles.	81.9	CeO_2-CNTs have a substantially higher zeta potential than oxidized CNTs, allowing them to remove these compounds from water more efficiently.	[68]
10	Molecularly imprinted nanoparticles.	49.4	Using cost-effective polymethacrylate imprinted with fluorescein and As(V) complex, a polymer-based nano-adsorbent for As (V) was created.	[69]
11	calcined modified hydrotalcite.	597.38	The ability of calcine FeHT (CFeHT) to remove arsenic was investigated.	[70]
12	Phyllanthus emblica Leaf Produces CuO Nanoparticles	1.17	"green" biosynthesis of CuO NPs an ecofriendly.	[71]
13	Polyaniline-doped strontium–titanium nanocomposite with magnetic properties.	67.11	A new nanocomposite adsorbent based on magnetic polyaniline and strontium–titanium (MP-SrTiO3) nanoparticles simply eliminates arsenic (III) ions from aqueous systems.	[73]
14	Goethite/silica Nanocomposite.	17.64	The effectiveness of a novel goethite/silica nanocomposite as an adsorbent for As elimination has been proven (V).	[74]

4. LOW-COST AND OTHER ADSORBENTS MATERIAL

In recent years, clays, biomass, agricultural, and industrial residuals have all been employed to generate low-cost adsorbents. Clay, which belongs to the aluminium silicate minerals family, metals, metal oxides, and metal hydroxides, has a tiny quantity of iron, magnesium, as well as other elements, leading in the formation of tiny particles, a large surface area with a large specific, excellent adsorption, and ion exchange recital, ion exchange recital. Kaolinite, montmorillonite, and illite, as clay minerals, may effectively absorb As(V) from water. Natural iron ores (goethite, hematite, and so on) and manganese ores (sodium manganese, manganese potassium, and so on) similarly exhibit high adsorption capabilities for As(V) elimination from aquatic [26-29]. Grafted Vietnamese manganese oxide ore (Fea -VMO and Zra -VMO) grafted Vietnamese manganese oxide ore (Fea -VMO and Zra -VMO), the dried or calcined beads were examined in this work [75], which employed alginate and polyvinyl alcohol to create beads containing alum sludge from a water treatment facility. A biochar/iron oxide composite, MBC, was prepared with magnetite primary nanoparticles used as for the elimination of As (III) polluted aquatic and waste waters containing several coexisting contaminants [76]. Denim fiber scraps were seen as a low-cost sportive option to eliminate Pb, Cd, Zn, and arsenic among heavy metals that may be extracted from aqueous media. According to the outcomes, such discarded fabric was a good sorbent for removing several ions of heavy metal, outperforming other synthetic and biological sorbents such as activated carbons and zeolite [77].

Table 4. Arsenic is removed from wastewater by using various Low-cost and other adsorbents material

S. No.	Adsorbent	Capacity mg/g	Remarks	Reference
1	Modified manganese oxide ore.	1.94 for Zra-VMO and 2.19 for Fea-VMO	To eliminate arsenic (As) from water supply, a Vietnamese manganese oxide ore grafted with iron (Fe) and zirconium (Zr) was used (Fea -VMO and Zra -VMO).	[74]
2	Alum sludge-containing calcined alginate bead.	18.49, 21.20 and 15.15 for A-A, A-A-P and S-A-P, respectively	Using alum sludge from a water treatment facility to remove As, alginate and polyvinyl alcohol were utilized to make beads.	[75]
3	Magnetite precipitated onto Douglas fir biochar.	5.06	MBC, a biochar/iron oxide composite made of magnetite main nanoparticles, was applied to eliminate As (III) from contaminated water and waste fluids that also included other pollutants.	[76]
4	Denim fiber scraps.	Raw denim fiber scraps (1.96) and Pb^{2+}-loaded denim scraps (3.3)	Reduced sorbent for extracting heavy metals such as arsenic from aqueous systems, as well as an effective sorbent for removing these toxic metal ions.	[77]

5. DISCUSSION AND DIFFICULTIES

The chemistry and content of arsenic-contaminated water play a big role in arsenic elimination. As compared to coagulation or membrane technologies for removing arsenic (V), adsorption yields no chemical sludge or saturated water that needs to be treated further. Moreover, since an adsorbent's adsorption capability is restricted, as well as the influence of elimination of arsenic is simply persuaded because of the competitiveness co - occurring ions in the water, utilizing adsorption innovation to handle Arsenic (V)- polluted water by means of a complicated ion concentration is not advantageous, and the expenses will massively boosted resulting in supplementary well before course involved. Extraction of adsorbents with water has been cited as a major challenge in purification of water supply. Adsorption system is typically used to treat water having lower arsenic content (V) as well as a straightforward melody. Adsorbing substances must be employed in diverse practical purposes, and a thorough evaluation of adsorption abilities and economic viability must be performed. The trend of sustainable development is followed by adsorbents that are reused following chemical regeneration. Research of environmentally friendly materials with increased performance, as well as approaches to boost regeneration capacity, are among the potential development prospects., optimizing synthesis and modification means, and trying to lower total price in promoting the commercialization of this technology. Transforming powder adsorbents to granular forms, loading metal ions or bacteria on adsorbents, fixing nano or highly porous particulate on sorbent with a low price or large volume, adding magnetic components, using microbial and algae symbionts as adsorbents, and chemically modifying biological adsorption materials can all improve adsorption behaviour significantly.

6. CONCLUSION

Arsenic poisoning affects millions of people around the world, thus producing arsenic-free drinking water is a significant challenge for the scientific community. Inorganic arsenic, which is extremely dangerous, is found in high concentrations in the groundwater of various countries. The chemistry and makeup of arsenic-

contaminated water play a big role in its elimination. It's critical to select a technology after conducting an extensive research examination of the nature of the water and the situations under which alternative methods can be used. The adsorption method cleans water with low As (V) levels and straightforward chemistry. It's vital to weigh the benefits and downsides of distinctly adsorbents for its elimination when choosing a practicable substance for As (V)- polluted purification of waters. The method is used to be additional research in the exploration of effective and ecologically suitable adsorption components, broad chemical and biological processes are used, and improvement of renewal means to maximize the preparations and alteration of adsorbents.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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