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Review Article

A review on Arsenic remediation from the water by biochar developed from the different waste biomasses

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Abstract

In many nations throughout the world, groundwater is regarded as the main source of drinking water. Clean and safe groundwater is a top concern for water authorities everywhere in order to preserve the sustainability of resources. Groundwater resources are vulnerable to a variety of contamination, with arsenic (As) being a major pollutant in some places as a result of natural or anthropogenic activities. Because of the technical complexity and high expense of conventional As removal treatment systems, it is the goal of many researchers to create methods of groundwater treatment that are successful, environmentally benign and economical. The technical summary is meant to complement the understanding of researchers, scholars, and scientists. Emphasizing the function of biochar as a sorbent and imagining the potential modification to it as decontamination methods, biochar production, characterization and adsorption mechanism of arsenic onto the surface of the biochar/modified biochar.

Keywords: Biochar; arsenic; adsorption; mechanism; modified biochar.

1. Introduction

Arsenic is a metalloid that is occurring naturally that may be found in the earth's crust at the 20th greatest concentration. It is widely recognized for its toxic effects on both human beings and aquatic life and because of its extremely high toxicity to every living creature, there is reason to be concerned about poisoning water sources with arsenic (Genchi et al., 2022). There are four different oxidation states in which As naturally occurs, with As (III) (arsenite) being the most poisonous form (Alka et al., 2021). Mining and metallurgical occupations are the principal anthropogenic sources of arsenic emission to natural waters. This is because of the natural link that arsenic has with minerals that are found in the Earth's crust (Vega-Hernandez et al., 2019; Tapia et al., 2022). Arsenic contamination of water supplies is recognized as a critical environmental issue on a global scale. Certain natural processes, such as dissolution and mineral weathering in the geochemical environment are responsible for their release into the environment. Moreover, some human activities are to blame for the presence of arsenic in surface water supplies (Raju, 2022). Arsenic can cause kidney cancer and damage to the nervous system, especially if it is ingested over a lengthy period of time (Rahman et al., 2021).

Both organic and inorganic forms of arsenic can be found in nature. Arsenite is a more common form under reducing conditions, whereas arsenate can be found in oxidizing conditions. When oxidizing conditions are present, arsenate can be produced. According to Aliaskari and Schafer (2020), various oxidation processes have the potential to convert arsenite into arsenate. The speciation and oxidation state of the element arsenic plays a significant role in determining its hazardous potential. Organic forms of arsenic include dimethyl arsenic acid (DMA), monomethyl arsonic acid (MMA), and arsenobetaine.

Arsenic contamination of surface water caused health problems for a large number of people all over the world, particularly in India, Bangladesh, China and Pakistan (Medunic et al., 2020; Taneja et al., 2023). Ingestion of arsenic-tainted water has been linked to a number of health problems in humans, including pulmonary disease, heart-related disease and an increased risk of cancer in both animals and humans. Among the common diseases linked to arsenic exposure are cardiovascular disease and pulmonary disease (Verma and Singh, 2019). In the present scenario, over one hundred million populations in these countries have been affected by arsenic poisoning (Kabir and Chowdhury, 2017). On our planet, human life cannot exist without access to clean, drinkable water. The presence of hazardous metals such as As^{+3} and As^{+5} can have a negative impact on the quality of drinking water. According to reports, arsenic is a factor that contributes to deaths in more than 70 countries, which results in significant health problems worldwide (Bhatti et al., 2020).

In order to get rid of arsenic from aqueous systems, scientists have turned to a number of different treatment procedures, like precipitation, adsorption, ion exchange and reverse osmosis (Dhana et al., 2020). The process of adsorption stands out among them because it is inexpensive, simple to use, produces lesser byproducts and is widely accessible. The adsorption technique is used to provide a long-lasting, affordable remedy for the reduction of arsenic pollution. Biochar is primarily produced from bio-waste by the process of thermal decomposition at 900°C temperature or less. Bio-waste is waste material that is produced from the agriculture and food sectors. It has received a great deal of interest due to its plentiful raw material sources, economical, larger specific surface area, plenty of surface functional groups and excellent adsorption ability which has many potential applications in As elimination from contaminated water (Amen et al., 2020).

Therefore, reducing environmental deterioration and its negative impacts on human health may only be possible by treating water contaminated with As. It is now an intriguing study subject since multiple findings from studies have been reported that point to the possible suitability of certain adsorbents to remediate water contaminated with As. It will be reviewed how well the biochar that was produced by utilizing organic waste is effectively able to remove As from contaminated water. Because of its properties and feasibility biochar has been used as a substitute for activated carbon in the treatment of water. Though, pristine biochar has significant drawbacks, including a lesser adsorption ability and a narrow range of adsorption (Cheng et al., 2021). To increase the efficiency of biochar several academics concentrate on creating an engineered version of it with more efficacy toward the adsorption of contaminants.

2. Presence of Arsenic in groundwater: the chemical profile, sources and its effect

In natural waterways, the types of arsenic that are most usually found are inorganic arsenate, it is also known as As(V), and arsenite is also known as As(III). As(V) is available in the form of H_2AsO_4 and $HAsO_4$, which are predominates in environments with an oxic pH and reduced oxygen levels, whereas As(III) (neutral H_3AsO_3) predominates in environments with a nearly neutral pH and reduced oxygen levels. Free atomic oxygen (O_2) is present in oxic conditions. However, there may still be bound oxygen present, such as NO_3, in anoxic conditions, which lack free oxygen. In addition, As(III) is more soluble than As(V), and it is approximately sixty times more hazardous (Zhang et al., 2019). Green rust (GR), a redox-active iron phase that typically occurs in anoxic conditions, has the potential to cure As contamination at a previous wood preservation site (Perez et al., 2020). Species of arsenic are always pH dependent. When the pH of the solution is less than 9.2, the majority of As (III) exists as the neutral H_3AsO_3 species, whereas the most abundant species of As (V) are H_2AsO_4 and $HAsO_4$. Chemical oxidants such as hydrogen peroxide (H_2O_2), chloride (Cl), ozone (O_3), persulfate and $KMnO_4$-based systems were normally utilized in order to oxidize aspartic acid (III) to aspartic acid (V) (Hao et al., 2018).

Ferrous rocks, iron pyrites and associated sediments tend to have a small amount of arsenic and the most prevalent mineral possessing As i.e., arsenopyrite is present in rocks developed in oxygen-deficient conditions when As is released into groundwater by the process of desorption. According to Kumar et al. (2020) highly oxidizing and highly reducing conditions favors the pace at which desorption of mineral oxides have happened. The toxicity of As varies because it is present in different oxygen states in the water. When arsenate and arsenite ions coexist and fluctuate in concentration depending on the redox conditions in the groundwater, inorganic composites of arsenic become more prevalent. Arsenite (As(III)) is the most lethal form as it is highly soluble in water, which is followed by organic and inorganic arsenate. Other than the natural source of As, human-generated sources comprise mining, coal burning, smelting, mismanaged domestic waste, and agricultural and industrial operations (Fig.1). Quarrying operations and leachate discharge from mine waste also constitute a serious environmental concern (Verma et al., 2019). Arsenic pollutants make their way to underground freshwater sources, which leads to a decrease in the water's overall quality and makes it unsafe to drink. In prosperous countries, the arsenic is most significant contributor to water contamination in urban areas.
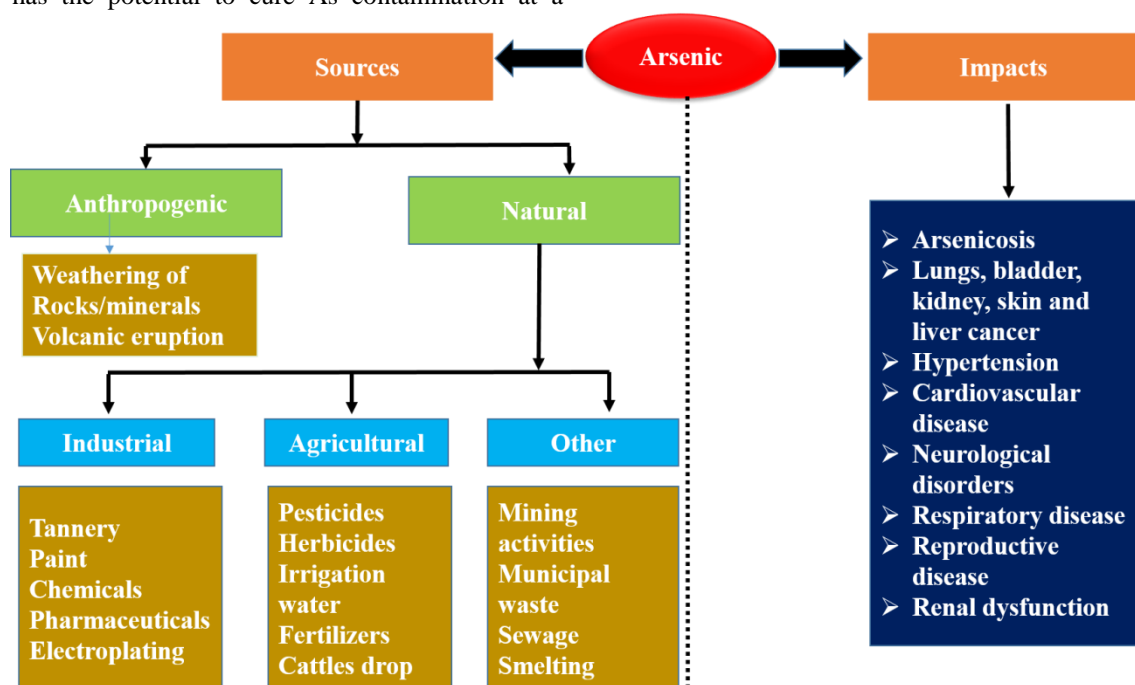

Fig. 1 Sources of Arsenic and its impact on human health

On the other hand, seventy percent of the industrial wastes that are produced in developing countries flushed directly into water bodies without undergoing any sort of treatment and ninety percent of the wastewater that is produced in these countries is discharged into rivers, lakes, and coastal areas. This scenario is made much more precarious as a result of the

proliferation of highly polluting enterprises in developing nations (Wong et al., 2018). Arsenic is placed in Group I of human carcinogens by the International Agency for Research on Cancer (IARC), and drinking water that contains arsenic can cause a person to develop persistent health issues if they are exposed to it. Chronic health issues are caused by As comprise cancer in the kidney, liver, skin,, bladder defects in the nervous system and cardiovascular diseases. Chronic health problems are caused by arsenic include discoloration of the skin and cardiovascular diseases (Goren and Kobya, 2021).

3. Technologies for arsenic removal

When wastewater is not appropriately treated then the presence of heavy metals poses a significant risk to human health; hence, the removal of these contaminants is of the utmost significance. The vast majority of techniques for removing As are effective when the element is in its pentavalent state, primarily in the forms of the oxyanions H_2AsO_4 and $HAsO_4$ (pH 2–12). The trivalent form is neutral (H_3AsO_3) up to at pH of 9.2 but has a reduced capacity to be eliminated from the environment. Both physicochemical (oxidation, flocculation, membrane separation, ion exchange, adsorption, electrocoagulation, etc.) and biological (bioreactors equipped with membranes, activated sludge process, etc.) methods are employed for the treatment of contaminated water. For heavy metal removal, the best-reported methods are adsorption, membrane filtration, ion exchange, coagulation/flocculation and oxidation. As it was reported by Siddiqi et al. (2022), 80 to 100 % of arsenic was removed from water using these methods.

3.1. Oxidation

Though oxidation is not a removal technique in and of itself, it may considerably increase the effectiveness of several methods used to remove As from water. A study directed by Zhenga et al. (2020) discovered that the technique for As(III) oxidation coupled with adsorption of the generated As(V) and it employing metal binary oxides as adsorbents that have been very for treating As from groundwater. Arsenite must be processed with the process of oxidation in order to get oxidized into the pentavalent form of As since the majority of typical treatment methods are capable of eliminating pentavalent As than that of trivalent As. Some of the As(III) oxidizing agents include H_2O_2, permanganate, ozone, chlorine, oxygen, etc.

3.2. Electrocoagulation

Heavy metals, organic pollutants, suspended particles, microbes may all are being removed from water using the method of electrocoagulation, which is extensively used as a cleaning strategy. Electrocoagulation with electrodes of iron that had an effective surface area was utilized for removing As(V) ions from municipal tap water (Das and Nandi, 2021). The presence of both arsenic and anions in groundwater is extremely dangerous to human health, and the combined impacts of these two contaminants have a substantial negative impact on the effectiveness of water treatment. With the application of low electro-charge loading 65% of As removal was observed while a higher level of As removal was achieved on applying high electro-charge loading in the electrocoagulation technique in a study conducted by Dutta et al. (2021).

3.3. Electrochemical method

Considering its advantages over conventional approaches, like in-situ oxidation, reduced sludge generation, and higher efficiency at lower costs, electrochemical approaches are receiving more research attention in the past few decades for arsenic removal. This is due to the fact that electrochemical methods are more efficient than conventional techniques. Both arsenate and arsenite are able to be extracted from an aqueous solution by the use of electrochemical techniques (Syam Babu, 2021).

3.4. Arsenic elimination by Adsorption

Adsorption technology has been used most frequently to remove heavy metals from wastewater out of the many different methods that may be used to treat wastewater. This is owing to its adaptable design, simple operation and low cost (Madan et al., 2021). Granular media is typically used in the adsorption process, which is a technique for arsenic removal from water through a purposeful process. Granular adsorbents have qualities such as a high specific surface area, spherical form, elevated adsorption capacity and least secondary waste generation. All properties of adsorbents make the adsorptive technique a more proper choice. The pollutant adheres to the exposed adsorbent surface during the removal process. The adsorbent's surface characteristics and solutions' initial characteristics strongly influence the degree of adherence. A crucial component of efficient removal is the porous structure of the surface of the adsorbent (Wang et al., 2022). Efficient decontamination depends on the surface properties of adsorbents, where immobilization and trapping of pollutants occurred due to the electrostatic attraction, or strong van der Waals forces. Few other experimental factors like solutions pH, co-existing ions, As oxidative species and particle size of the biochar extremely influence the adsorption of arsenic in an aqueous medium. Additionally, adsorbents dose, contact time of adsorbent with adsorbate and initial adsorbate concentration, etc. According to several reports, it was revealed that the pH of the solution is one of the major deciding factors that affect the adsorption process. It was reported that a pH value below pH_{ZPC} of the adsorbent favors the high adsorption rate of As(V) (Vaddi et al., 2023).

When it comes to elimination via the adsorption process, arsenite (As (III)) as well as arsenate (As (V)) both can be removed efficiently from water. Integration of pre-oxidation from As(III) to As(V), while simultaneously performing in-situ adsorption of newly created As(V) would be highly desirable (Pervez et al., 2021). Because of ease implementation and requirement of limited space, adsorption is one of the most successful techniques for removing As (arsenic). The removal of As using a variety of media, including carbons that have been impregnated with iron (Fe), has been the subject of substantial research. Because of highly toxic and carcinogenic nature of arsenic (As), it is imperative that it should be removed as effectively as possible from drinking water.

The effectiveness of the adsorption media may be differentiated according to their certain properties such as pore size, specific surface area, adsorption capacity to adsorb adsorbate to withstand clumping or aggregation in solution and thermal stability. Initially, the rate of adsorption enhances with the rise in the adsorbent dose because of the more unoccupied active binding sites and after a certain time the adsorption rate reaches an equilibrium level, mostly because of the monolayer formation over the adsorbent surface and filling the pores of

adsorbent by adsorbate (As) (Yusof et al., 2020). Thus, choosing the best amount of adsorbent dose is still a crucial experimental constraint. Fly ash, natural minerals (clay/bentonite, zeolite), activated carbon, oxides, biochar materials, etc. have all been found very efficient in adsorbing As from contaminated water with up to 150 mg/g of adsorption capacity as reported by Hao et al. (2018). Some natural adsorbents are made naturally by grinding the organic dry waste (corn cob, eggshell, waste tea granules, fruit peel, etc.) into powder are reported to adsorb As(III) as well as As(V) efficiently from an aqueous solution (Shakoor et al., 2019). In contrast to conventional available materials applied for As removal, biochar has become known as a feasible and effective material that is inexpensive, has a wide availability of raw material, easy to use, and produces minimal secondary waste. Researchers are interested in using biochar as an adsorbent because of its carbon-richness, fine-grained, porous, availability of various surface functional groups, and contains mineral components. Moreover, the use of biochar as an adsorbent is cost-effective, highly efficient and safe for the environment. Biochar is an innovative, carbon-rich adsorbent that is often made from agricultural wastes, wood and various other waste materials in oxygen-limited settings (Verma and Singh, 2022). It has the potential to be used in a variety of applications. Biochar is characterized by a larger specific surface area, a porous structure, a net negative charge, an abundance various functional groups (such as phenolic, amide, hydroxyl, carboxylic and phenolic groups), and mineral components. Biochar also possesses a net negative charge on its surface. Although its sorption capacity is often modest compared to modified biochar like metal oxide-impregnated BC, biochar can potentially remove arsenic from water. This ability is referred to as biochar's sorption capacity. The usage of biochar is receiving greater interest because of its possible benefits for the environment.

3.4.1. Adsorption of arsenic via biochar

Biochar is used as an adsorbent for the removal of water contaminants in an environmentally friendly way. A diverse raw material type which comprises waste from industries, sewage waste, waste from agri-farms, etc. are viable options for biochar production and are extensively used for the As removal from water. According to Bakshi et al. (2018), creating biochar from agricultural waste products can have several significant benefits, including the ability to purify contaminated water at low cost, improve the fertility of the soil, and also serves as an alternate source of energy. Biochar shows the superior capacity to remove As from contaminated water. Many different types of waste biomasses were utilized for biochar synthesis and have also been applied for As(III) as well as As(V) removal, including waste dry leaves of timber plant (Tectona), perilla leaves waste, wood from an oak tree, the outer shell of chestnut, maize straw, etc. (Verma and Singh, 2019; Niazi et al., 2018a; He et al., 2018). A comparatively large volume of ash was produced with higher pyrolysis temperatures that may result in a concurrent rise in pH. It was observed that biochar produced at higher pyrolytic temperature have a good capability to adsorb As very efficiently because of its higher specific surface area and porous structure. In various studies, it was reported that the specific surface area of biochar was increased with an increasing pyrolytic temperature.

Table 1 A detailed study on the removal of arsenic using various pristine biochar

Adsorbent	Temperature (°C)	Arsenic species	Initial concentration (mg/L)	Dose (g/L)	Adsorption capacity (mg/g)	References
Oak bark biochar	400	As(III)	0.01-0.1	10	3.0	Amen et al. (2020)
Rice husk char	300	As(V)	0.90	8	0.25	Agrafoti et al. (2014)
Corn stem char	750	As(III)	50	1	2.89	Lin et al. (2017)
Oakwood biochar	400-450	As(III)	0.01-0.1	10	4	Niazi et al. (2018b)
Perilla leaf char	300	As(III)	0.05-7.0	1	4.7	Niazi et al. (2018a)
Perilla leaf char	300	As(V)	0.05-7.0	1	3.8	Niazi et al. (2018a)
Tectona leaf char	800	As(III)	0.5-2.5	4	0.66	Verma and Singh (2019)
Tectona leaf char	800	As(V)	0.5-2.5	2	1.3	Verma and Singh (2019)
Lagerstroemia leaf char	800	As(III)	0.5-2.5	4	0.45	Verma and Singh (2019)

Table 2 A detailed study on the removal of arsenic using various modified biochar

Adsorbent	Temperature (°C)	Arsenic species	Initial concentration (mg/L)	Dose (g/L)	Adsorption capacity (mg/g)	Reference
Magnetic pea peel	500	As(III)	0.5-2.5	3	0.73	Sahu et al. (2022)
	600	As(V)	0.5-2.5	2.5	0.49	Sahu et al. (2022)
Magnetic pea peel	500	As(III)	0.5-2.5	3	1.33	Sahu et al. (2022)
	600	As(V)	0.5-2.5	2.5	0.80	Sahu et al. (2022)
MnO modified pine wood	NA	As(V)	NA	NA	10	Wang et al. (2015)
Magnetic *Citrus limetta* peel biochar	500	As(III)	0.5-2.5	3	0.61	Verma et al. (2019)
Magnetic *Citrus limetta* pulp biochar	500	As(III)	0.5-2.5	3	0.19	Verma et al. (2019)
Mn-oxide pine-wood biochar	600	As(V)	20	2.5	0.43	Wang et al. (2015)
KOH treated MSW	NA	As(III)	50	5	31	Jin et al. (2014)
Hydro gel rice husk	300	As(V)	1-150	0.167-16.7	28	Sanyang et al. (2016)

Shaheen et al. (2019) observed that biochar developed using oak bark has a significantly higher adsorption capacity in eliminating trivalent As (AsIII) from water. As(V) was adsorbed using biochar derived from rice husk, sewage sludge and solid organic waste and it was found that maximum adsorption was achieved with biochar developed from sewage sludge (0.068 mg/g) (Agrafoti et al., 2014). The As(III) and As(V) removal from contaminated well water was found to be 81% and 84% at pH 6 and 7, respectively, through biochar prepared by oak wood (Niazi et al., 2018b). It requires very low temperatures to make pristine biochar and it has been used to decontaminate the water with a low level of contamination. It was reported in several studies that pristine biochar consists of negative surface charge due to which the efficiency of As(III) and As(V) removal was quite low (Asere et al., 2019). As a result, research focused on altering the surface of biochar, ideally utilizing positively charged species, in order to significantly remove As from contaminated water. Table 1 and Table 2 represents the adsorption capacity of pristine biochar and modified biochar, respectively for the As removal from the contaminated water.

3.4.2. Adsorption of arsenic by modified biochar

Modified biochar has attracted a lot of attention due to its exceptional ability to decontaminate As contaminated water. Recently conducted research studies produced biochar composites via different pyrolysis techniques, chemical and physical modification to efficiently remove As from contaminated water. Meanwhile, the pristine biochar has a negative surface charge that results in decreased adsorption of As because there is static interference among the As oxyanions and biochar negative surface that makes adsorption of As difficult. In order to increase the efficiency of removing As biochar needs to be modified (Liu et al., 2023). For instance, the modification of biochar with metal salts/oxides imparts a positive charge to its surface. Furthermore, despite pristine biochar's high surface area, a large number of functional groups, high porosity and its potential for adoption are constrained (Sahu and Shukla, 2022). Conversely, by altering the physical and chemical characteristics, it is possible to increase adsorption efficiency as well as its capacity of As. For instance, compared to unmodified biochar, rice straw biochar modified with iron had a much higher adsorption rate for As(V) i.e., 26.9 mg/g (Rahman et al., 2021). Adsorption kinetics was used to analyze the performance of biochar in its adoption of As and the mechanisms involved (V). Initially, the adsorption rose in proportion to the length of time the two substances were in touch with one another, but after 24 hours, they appeared to have reached an equilibrium state. In comparison, the amount of time it took for any of the modified biochar to achieve equilibrium was less than eight hours, which suggests that the addition of iron/aluminum or iron/aluminum/zinc to biochar can considerably improve its ability to adsorb arsenic (V) (Sun et al., 2022). In order to remove arsenic from an aqueous solution, biochar that was produced through the co-pyrolysis of sewage sludge and nano-zero-valent iron was utilized (Liu et al., 2021).

As compared to pentavalent As, trivalent As is highly mobile and combines some redox chemical substances (nitrate, MnOOH, FeO(OH), MnO_2, etc.) to the surface of biochar. Biochar treated with oxides of iron trap As(V) very effectively as suggested by Srivastav et al. (2021). Removal of As(V) was investigated in presence of multiple ions using biochar in combination with zero-valent iron that was pyrolyzed at high pyrolysis temperature (900°C) at neutral pH (Bakshi et al., 2018). In a study, it was observed that using biochar modified with iron and manganese oxides effectively eliminates As from water with 8.80 mg/g of adsorption capacity (Lin et al., 2020). Verma and Singh (2023) reported that waste biomass of *Tectona* and *Lagerstroemia* were utilized for synthesizing biochar pretreated with iron salt ($FeCl_3$) has a great adsorption ability in removing both the species of As (III) and As (V). Biomass of waste vegetables (Radish leaves and Jackfruit peel) were successfully impregnated with $FeCl_3$ and were found to be efficient for As(III) and As(V) removal from an aqueous solution as well as from the groundwater (Verma et al., 2022).

Three types of biochar from cotton stalk waste biomass: pristine cotton stalk biochar, H_3PO_4 and KOH treated biochar were prepared and investigated for their adoption potential for As (V) removal. In this instance, biochar modified by KOH exhibits higher adsorption efficiency and capacity than that of unmodified biochar and H_3PO_4-treated biochar (Hussain et al., 2020). Sludge biochar was developed in combination with iron salt at 700°C temperature and shows greater immobilization of As (V) with 90 mg/g adsorption capacity (Yu et al., 2020).

4. Methods of biochar synthesis
Biochar can be produced by using various processes like pyrolysis, gasification and hydrothermal carbonization.

4.1. Pyrolysis
In the process of pyrolysis, the organic biomass thermally decomposed under an oxygen-free environment between 300-900°C temperatures. The components of biomass i.e., hemicellulose, lignin and cellulose each go through a different set of reactions while thermally degraded, resulting in the formation of gaseous (syngas), solid (char) and liquid (bio-oil) components. Some of the constraints that affect the pyrolysis product such as residence time, heating rate and temperature reaction (Cha et al., 2016).

4.2. Gasification
In the process of gasification, the carbon-containing organic biomass is gasified at temperatures 700-1000°C using a variety of gasifying mediators like oxygen, air, CO_2, a mixture of gases and steam, resulting in the production of gaseous products. The gasification process leads to the formation of various gaseous products (CO, CO_2, H_2, N_2, etc.), liquid (oil and tar) and solid (ash and char) products. The concentration of carbon in biochar formed by the gasification process directly influences its quality. Biochar produced through gasification generates low biochar yield around 5-10%, and generates around 15-20% gaseous products because this process is intended to produce gaseous products (Del Grasso et al., 2022).

4.3. Hydrothermal carbonization
A higher percentage of yield was achieved with gasification and pyrolysis in which the biomass used contains less moisture with little energy loss. However, some organic biomass contains higher moisture content, therefore, an independent drying procedure is needed to produce biochar with high yield while using less energy during the whole process. Biomass and water are combined in a closed reactor and for a certain amount of time, the temperature was increased to stabilize the process. Additionally, more pressure is required to keep water in a liquid state higher than 100 degrees. The primary byproduct of the hydrothermal process are char (250°C), gaseous products (>400°C) and bio-oil (250°C to 400°C) (Rajagopal et al., 2022).

5. Characterization of biochar
5.1. Scanning electron microscope (SEM) and energy dispersive x-ray spectroscopy (EDX)
SEM is used to identify the surface morphology and structure of the biochar. Images of SEM provide a precise overview of the spatial arrangement of meso and microporous structures as well as the pore organization in biochar surface. SEM may be used to anticipate the structural changes before and after the adsorption process. SEM equipped with EDX is used to analyze the biochar's elemental composition. Various elements (oxygen, carbon, iron, nitrogen, magnesium etc.) are identified on the biochar surface after analyzing it using EDX.

5.2. Fourier transform infrared spectroscopy (FTIR)
Carboxylic group (COOH), amine, hydroxyl, amide, and other aromatic groups are the crucial surface functional groups of biochar that improve its adsorption capacity. The organic biomasses were used for the preparation of biochar and the pyrolysis temperature are the two key determinants of functional groups found on biochar surfaces. Additionally, there currently is a possibility that the number of biochar functional groups decreases as other characteristics like surface area, pH, and porosity increase. FTIR is used to characterize the functional group of biochar surface. Functional groups present on the surface of biochar synthesized at different temperatures varied considerably (Li et al., 2017).

5.3. X-Ray Diffractometer
A widely applicable method for figuring out the amorphous and crystalline structure of biochar is XRD. A mirror, radiation source and a monochromator are the main part of the computational XRD setup. The generated peak of XRD is similar to the produced crystalline structure and it is similar to prove the crystallographic structure of the material.

6. Possible mechanism of As adsorption on biochar
Electrostatic attraction, redox reaction, surface complex-formation, precipitation, ion exchange, surface adsorption, and chemical interaction that occurs between the functional groups of adsorbent and metal ion are some of the mechanisms currently known for the adsorption of As onto the biochar (Fig. 2). As is highly attracted by a number of functional groups present on biochar surfaces, primarily –COOH, -OH, -SH, etc. through ion exchange, electrostatic attraction and complex formation. In order to eliminate the arsenic, the process of surface adsorption entails that As ions are diffused into the porous structure of engineered biochar (Amen et al., 2020). According to the available literature modified biochar has a greater affinity towards arsenic adsorption than that unmodified biochar because of its porous surface. Modified biochar can retain more As due to its functional groups and higher specific surface area. Adsorption through electrostatic attraction, pH_{ZPC} of biochar and solution pH has a very significant impact. The solution pH has a major effect on the various species of As. Therefore, the As removal mechanism is highly directed by the initial pH of the solution. The charge on the biochar surface (positive or negative) varies at several pH ranges. The pH of the solution at which the adsorbent has a neutral surface charge is the point of zero charges or pH_{ZPC}. According to Herath et al. (2016) at greater pH_{ZPC} value the adsorbent surface definitely has a negative charge and due to this point of zero charge is regarded as an important determinant in the elimination of pollutants including As through the process of adsorption. During the process of complexation, the D orbital of arsenic interacts with the oxygenated surface functional groups present on the surface of biochar and forms polyatomic structures, and as the biochar surface has been modified with metal oxides it consists abundance of oxygenated functional groups that results in improved removal of As via the process of complexation. According to Wang et al. (2017), chemical reduction was

recognized as one of the primary mechanisms for arsenite removal through Fe/Ag biochar composite. According to the work done by Wongrod et al. (2019) the biochar oxidizes As(III), but oxidation of As(III) through biochar is just a tiny component of the overall process and most of the As(III) was adsorbed onto the biochar modified with KOH in the form of As(III). Consequently, the oxidization of As (III) to As (V) and then removing it by adsorption using biochar/modified.
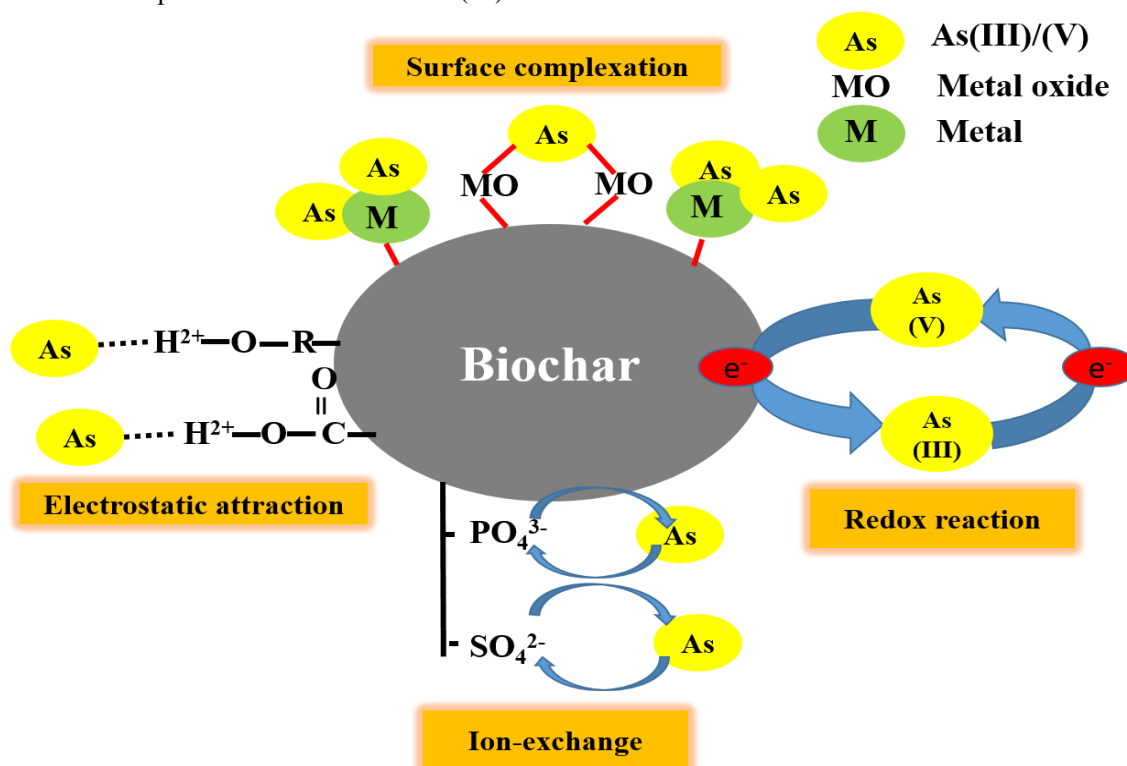

Fig. 2. Possible mechanism of arsenic adsorption using biochar as an adsorbent

7. Conclusions and future recommendations

Arsenic-contaminated groundwater is a major concern on a global scale because of its toxicity and carcinogenicity for human health. As a class-1 carcinogen, it possess a serious risk to people through a number of exposure pathways. Arsenic's environmental destiny is influenced by a variety of factors, including its primary source, pH, and microbial activity. Thus, it is vital to comprehend the biogeochemical change of arsenic components. There is currently no treatment technique that is universally accepted, however, the use of a variety of adsorbents as a passive treatment alternative is a growing trend. With a high adsorption capacity and cost-effectiveness, biochar seems to be an appealing treatment option for treating water contaminated with As. The feedstocks are utilized for preparation of biochar and the temperature of pyrolysis have an impact on the characteristics of biochar, but especially their adsorption efficiency may be significantly increased by altering the functional groups or other properties by its modification. The use of biochar for arsenic cleanup has shown encouraging results in literature studied. It is important to note that modification and condition adjustments of biochar can improve its effectiveness for the remediation of As. Consequently, it is essential to investigate the possibility of tailoring biochar to increase its efficacy as a remediation technique. Early studies on As remediation using biochar have yielded encouraging results, suggesting that this technique may be an attractive and viable approach for treating arsenic contamination in groundwater.

Biochar has come into sight as a novel and great potential material to combat water pollution in a sustainable form. It has been widely used for the management of pollution as well as for mitigating climate change. Biochar is an environmentally friendly material that might significantly improve the circular economy by promoting the long-term conservation of resources. Studying these specific facts in order to set up and characterize biochar in an approach that guarantees the necessary final product is not only very effective as well as customized for the required purpose but also financially feasible for application on a wider scale. In the future, the development directions that need to be pursued in order to encourage the commercialization of this technology include the creation of environmentally friendly materials that achieve more efficient performance, the investigation of methods that enhance regeneration capacity, the optimization of synthesis and modification methods, and the pursuit of a reduction in the overall cost. For optimal biomass valorization, it is advised that for the production of pristine biochar/modified biochar would be linked with the generation of biofuels (liquid and gaseous). Since producing biochar requires a lot of handling and machinery, which raises the cost of production, it is necessary to assess its feasibility in terms of technical aspects as well as energy balance. There isn't much research available that provides a complete cost-benefit analysis of synthesizing biochar and its usage in the arsenic treatment of contaminated water.

Conflict of interest
There is no conflict of interest among the authors

Contribution of authors
Lata Verma: Writing original draft, conceptualization and formal analysis **Nishu Kanaujia:** Writing work, **Jiwan Singh:** Provided supervision and validated the manuscript.

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