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Exploring the Potential of Natural Materials in Water Treatment

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ORIGINAL RESEARCH

Abstract— The impending water scarcity crisis due to the growing population, industrialization, and climate change has prompted the need for sustainable and cost-effective water purification methods. Traditional coagulants such as aluminium sulphate and ferric chloride involve unsustainable mining practices and costly sludge disposal. This has led to the exploration of natural coagulants as a more environmentally friendly alternative. A comprehensive literature review was conducted, compiling information from 57 articles on the use of natural coagulants in water treatment. Natural coagulants are seen as advantageous due to their ready availability, affordability, and minimal pollution risks. These materials, which include plant-based materials, minerals, and microorganisms, have shown promising results in water purification processes. Natural coagulants function through an adsorption process involving polymeric bridging or charge neutralization. They have been found to be highly effective in removing pollutants from water. For example, certain fungi species like Aspergillus and Trametes have demonstrated removal efficiencies exceeding 80%, while zeolites have shown impressive removal capacities within a range of 10 to 5000 mg/L concentration. Overall, natural coagulants offer a sustainable and efficient solution for water treatment processes. They are biodegradable, non-toxic, eco-friendly, and generate lower sludge volumes compared to chemical coagulants. By utilizing natural materials for water purification, we can mitigate the environmental impact of conventional coagulants and ensure the availability of clean water for future generations.

Keywords— Natural materials, wastewater treatment, coagulants, aids, removal efficiencies

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1 INTRODUCTION

Water is an essential natural resource that sustains both ecological systems and human life. While the Earth is predominantly covered in water with 71% of its surface, only a small percentage of 2.5% is fresh water (Chen *et al.*, 2022; Li *et al.*, 2021). Increasing global population, expected to surpass nine billion by 2050, will lead to higher water consumption and wastewater generation (Wang *et al.* 2022; Wang *et al.* 2021). This puts pressure on natural water bodies and the self-purification capability of streams and rivers. The worldwide coagulant and flocculants market are anticipated to achieve a value of USD 6.01 billion by 2022, showing a compound annual growth rate of 5.9% (Sun et al. 2022; Li et al., 2021). Coagulation and flocculation play vital roles in water and wastewater treatment processes by aiding in the elimination of impurities and ensuring the provision of clean water suitable for reuse.

These processes are typically used either as pretreatment or post-treatment steps, depending on the type of water being treated (Zhang *et al.* 2022). Coagulation destabilizes suspensions or solutions, while flocculation causes particles to come together and form larger agglomerates for easier separation.

Common coagulants include aluminum and iron, although the use of aluminum in wastewater treatment can have negative health effects (Liu *et al.* 2021). The rise in popularity of natural coagulants, sourced from plants, animals, or microbes, is attributed to their ecological sustainability and potential positive effects on health. These affordable, easy-to-use coagulants are safe for human health, offering a promising alternative to chemical coagulants (Desta & Bote, 2021; Zhang *et al.*, 2021). Research has demonstrated the effectiveness of natural coagulants such as chitosan, gelatin, and Wang *et al.*, 2021). The exploration of new generation coagulants with improved performance and efficiency, including natural options, is ongoing to support sustainable development (Chen *et al.* 2022).

Turbidity is a prevalent water contaminant due to factors like soil erosion, runoff, and high microorganism levels. It degrades water quality, harms fish production, and can lead to various health issues like nausea. The World Health Organization has set 1.0 NTU as the maximum allowable turbidity level for drinking water. To combat this issue, biological, chemical, and physical methods have been utilized to reduce water turbidity. Biological approaches that involve microorganisms are effective in eliminating organic pollutants but are less efficient at removing inorganic matter-related turbidity. Therefore, researchers often combine biological methods with other treatment processes. For instance, combining granular activated

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carbon with a moving-bed biofilm approach has successfully removed 90% of turbidity and 70% of colors from landfill leachate. Similarly, the combination of aerated filter and anoxic filter bed methods has been found to reduce textile industry wastewater turbidity by 94%. However, despite their efficacy, biological methods face challenges such as treatment times, space requirements, and pollution levels.

2. **Natural Materials in Wastewater Treatment: Types and Mechanisms**

2.1. PLANT-BASED MATERIALS

Plant-based materials have shown considerable efficacy in wastewater treatment processes, particularly as coagulants and aids. One of the most commonly used plant-based materials is Moringa oleifera, known for its natural coagulation properties. The seed extracts of Moringa oleifera contain cationic proteins that can bind to negatively charged particles in water, facilitating the formation of floc for easy removal. Studies have demonstrated the high coagulation efficiency of Moringa oleifera in removing turbidity, organic matter, and heavy metals from wastewater. Another plant-based material with promising wastewater treatment potential is chitosan, a biopolymer derived from the exoskeletons of crustaceans. Chitosan exhibits adsorption properties and is capable of efficiently eliminating contaminants like dyes, heavy metals, and organic compounds from water bodies. Its eco-friendly nature and biodegradability make it a sustainable option for wastewater treatment applications.

Various researchers have explored the effectiveness of plant-based coagulants in water treatment. Pang *et al.* (2021) showed that okra seeds can effectively remove turbidity from water, with removal efficiencies ranging from 80% to 95%. Pine bark extract has been identified as a promising natural coagulant for wastewater treatment due to its high removal efficiency for turbidity and suspended solids (Zheng *et al.*, 2021; Wang *et al*., 2021). Studies have indicated that banana peel extract can significantly decrease COD levels in wastewater, with removal efficiencies exceeding 60% (Wang *et al.*, 2021). Okra mucilage has demonstrated effectiveness in removing heavy metals from wastewater, with removal efficiencies of up to 90% reported in Lin *et al.* (2021). The utilization of Moringa oleifera seed extract has been successful in reducing microbial contamination in water, showcasing its potential for improving water quality for drinking purposes (Wu *et al.*, 2021). Research has shown that acorn extract can efficiently eliminate organic matter from wastewater, with removal efficiencies of over 80% documented in certain studies. Banana peel powder has been effectively used as a bio-sorbent to remove various pollutants from wastewater by demonstrating significant adsorption capacities for heavy metals and organic compounds. Wu *et al.* (2021) have demonstrated the effectiveness of using Moringa seed extract in conjunction with other natural coagulants to enhance the removal efficiency of contaminants in water. Banana peel extract has been explored for its potential in mitigating the environmental impact of textile wastewater by efficiently removing dyes and organic compounds (Ren *et al.*, 2020). Ren *et al*. (2020), Wu *et al.* (2021), Lin *et al.* (2021), and Huang et al. (2021) have conducted studies on the application of acorn extract in treating industrial wastewater, demonstrating its effectiveness in reducing contaminants and improving water quality. Banana peel extract has shown promise in eliminating pharmaceutical residues from wastewater, addressing emerging contaminants that pose risks to aquatic ecosystems (Cui *et al.*, 2021).

2.2. MINERALS

Minerals such as zeolites and iron oxide play significant roles in wastewater treatment by serving as effective coagulants and aids due to their ion exchange properties and adsorption capacities. Zeolites, which are natural aluminosilicate minerals, have been recognized for their capacity to eliminate heavy metals, ammonia, and nutrients from water due to their high removal rates and ability to be regenerated. This makes them a cost-efficient choice for treating wastewater. Similarly, iron oxide, another mineral commonly utilized in wastewater treatment, acts as an efficient coagulant for the removal of phosphate, arsenic, and organic pollutants due to its superior adsorption capabilities and photochemical reactivity. The sustainable and recyclable properties of iron oxide make it a promising material for environmentally friendly wastewater treatment processes.

Zeolites stand out for their unique porous structure and high adsorption capacity, making them effective in the removal of heavy metals and pollutants from water. Various studies have explored the efficiency of both natural and modified zeolites in water treatment, highlighting their versatility and effectiveness in wastewater treatment processes. This review aims to assess the literature on the use of zeolites for removing heavy metals and pollutants from water, emphasizing the significance of surface modification in enhancing their adsorption capacity and overall performance.

Numerous researchers have examined the efficacy of zeolites in removing contaminants from water, illustrating their high efficiency and selectivity in pollutant removal. Studies have demonstrated the potential of zeolites in efficiently removing heavy metals, nutrients, and cationic pollutants from water

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through various surface modifications and applications of advanced materials. Zeolites have shown promise in adsorbing pollutants from water, with positive kinetics, isotherms, and thermodynamics supporting their effectiveness in wastewater treatment solutions. Therefore, zeolites offer great potential in effectively removing heavy metals, nutrients, and pollutants from water, thanks to their unique properties and high adsorption capacity. The application of surface modification techniques further enhances the efficiency of zeolites in water treatment, making them valuable materials for sustainable and impactful water treatment solutions. Continued research is essential to fully explore the capabilities of zeolites in water treatment and optimize their performance to address diverse challenges in water quality management.

There is a detailed summary of the elimination of heavy metals using various zeolites, including the experimental settings and adsorption and kinetic models, Alvarez-Ayuso *et al.* (2020). It presents information on the type of metal ion, the specific zeolite employed, as well as experimental variables like temperature, duration of contact, metal concentration, solution-to-zeolite ratio, and pH. Additionally, the metal sorption capacity in milligrams per gram. Additionally, Iyere-Okojie *et al.* (2021) includes the isotherm and kinetic models used for each experiment, providing a detailed insight into the removal efficiency of each zeolite for different heavy metal ions.

The data presented in the table 1 showcases the diverse capabilities of zeolites in removing heavy metals such as Pb2+, Cd2+, Cr3+, Ni2+, Zn2+, Cu2+, and Mn2+ from water sources under varying experimental conditions. Different zeolites exhibit varying adsorption capacities and efficiencies for different metal ions, emphasizing the importance of selecting the appropriate zeolite based on the target heavy metal pollutant. The use of Langmuir, Freundlich, and Pseudo-second-order kinetic models helps in understanding the adsorption behavior and mechanisms involved in the removal of heavy metals by zeolites.

Furthermore, Adamiak *et al.* (2021) also highlights the effectiveness of surface modification or activation of zeolites in enhancing their adsorption capacities for specific heavy metal ions, as observed in the experiments utilizing activated clinoptilolite + mordenite for Mn2+ removal. In summary, the table offers insightful data on the adsorption capacities of different zeolites towards various heavy metal ions. This contributes to enhancing the efficiency of zeolite-based water treatment methods and fostering the creation of sustainable solutions to address heavy metal pollution in wastewater.

Zeolites have been extensively researched and utilized for their ability to remove ammonium from water, thanks to their generous specific surface area, porous structure, and ion exchange capacity.

In the table 1 provided, various types of zeolites such as clinoptilolite, analcime, chabazite, and NaY among others have been investigated for their ability to sorb ammonium under different experimental conditions.

The effectiveness of zeolites in removing ammonium is influenced by several experimental variables, including temperature, contact time, initial ammonium concentration, solid-to-liquid ratio, and pH levels.

For example, the sorption capacity of ammonium by clinoptilolite was found to be 4.3 mg·L-1 at 25°C and a contact time of 12 hours in one study.

Various isotherm and kinetic models have been utilized to explain the sorption process and mechanism of ammonium ions onto zeolites. The Langmuir and Freundlich isotherm models are frequently used to study the equilibrium data and ascertain the maximum sorption capacity and affinity of zeolites for ammonium. The pseudo-first-order and pseudo-second-order kinetic models are commonly employed to analyze the rate of sorption and the underlying mechanism.

Overall, the studies mentioned in the table indicate that zeolites have great potential for removing ammonium from water through adsorption processes. Further research is needed to optimize the experimental conditions and develop efficient adsorption models for better understanding and application of zeolites in water treatment processes.

Table 1: Zeolites used in ammonium removal, along with experimental conditions and adsorption and kinetic models (Choudhary *et al.* 2020)

Metal ion	Zeolite	(°C)	Contact time (h)	Metal concentration (mg·L^{-1})	S/L ratio (g·L^{-1})	pH	Metal sorption (mg·g^{-1})	Isotherm model	Kinetic model	References

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Pb^{2+}	A	25	5	50-800	1	4	100.0	Langmuir	Pseudo-second-order	Adamiak *et al.* 2021
	A	25	0.5	100-400	—	7.5	182.0	Langmuir	—	Adamiak *et al.* 2021
	X	25	0.5	100-400	—	7.5	213.0			Adamiak *et al.* 2021
	Clinoptilolite	70	24	200-2000	10	4.5	78.7	—	—	Adamiak *et al.* 2021
	Na-clinoptilolite	70	24	200-2000	10	4.5	91.2	—	—	Adamiak *et al.* 2021
	Faujasite	25	1	70-400	2.5	4.5	25.9	Langmuir	Pseudo-second-order	
	Y	26	1	100	1	6	454.5	Langmuir	Pseudo-second-order	Al-Ghouti *et al.* 2020
	Clinoptilolite	20	6	103.8	100	3	51.6	Langmuir	—	Al-Ghouti *et al.* 2020
	HDTMA-Y	25	24	1000.0	4	5	76.0	Langmuir	Pseudo-second-order	Al-Ghouti *et al.* 2020
Cd^{2+}	A	25	5	50-800	1	4	56.5	Langmuir	Pseudo-second-order	Alvarez-Ayuso *et al.*, 2020
	NaP1	22	6	10-200	2.5	6	50.8	Langmuir	—	Al-Ghouti *et al.* 2020
	A	25	0.5	100-400	—	7.5	71.0	Langmuir	—	Alvarez-Ayuso *et al.*, 2020
	X	25	0.5	100-400	—	7.5	92.0			Al-Ghouti *et al.* 2020
	Clinoptilolite	22	6	10-200	10	6	4.6	Langmuir	—	Al-Ghouti *et al.* 2020

	Clinoptilolite	70	24	110-1100	10	4.5	13.5	—	—	Al-Ghouti *et al.* 2020
	Scolecite	55	24	10-5000	16	6	100.0	Freundlich	Pseudo-second-order	Alvarez-Ayuso *et al.*, 2020
	Na-clinoptilolite	70	24	110-1100	10	4.5	23.6	—	—	Al-Ghouti *et al.* 2020
	Clinoptilolite	20	6	81.5	100	3	7.3	Langmuir	—	Iyere-Okojie *et al.* 2021
	A	30	—	50-1000	3	8	736.4	Langmuir	Pseudo-second-order	Al-Ghouti *et al.* 2020
	X	30	—	50-1000	3	8	684.4			
	X	30	2.5	10-160	1	7	38.3	Langmuir	Pseudo-second-order	Iyere-Okojie *et al.* 2021
Cr^{3+}	NaP1	22	6	10-200	2.5	4	43.6	Langmuir	—	Iyere-Okojie *et al.*2021
	A+X	25	24	500	5	—	71.1	—	—	Alvarez-Ayuso *et al.*, 2020
	A	25	4	50-300	1	4	41.6	Langmuir	Pseudo-second-order	Zhang *et al.* 2021
	Clinoptilolite	22	6	10-200	10	4	4.1	Langmuir	—	Singh *et al.* 2020
	Mordenite	25	24	500	5	—	3.6	—	—	Singh *et al.* 2020
	Scolecite	55	24	10-5000	16	6	106.4	Freundlich	Pseudo-second-order	Reza *et al.* 2021
	X	30	2	10-160	1	7	62.1	Langmuir	Pseudo-	Reza *et al.* 2021

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									second-order	
Ni^{2+}	A	25	5	50-800	1	4	41.2	Langmuir	Pseudo-second-order	Reza *et al.* 2021
	A	25	4	50-300	1	4	9.0	Langmuir	Pseudo-second-order	Zhang *et al.* 2021
	NaP1	22	6	10-200	2.5	6	20.1	Langmuir	—	Singh *et al.* 2020
	A	25	1	100-400	—	7.5	24.7	Langmuir	—	Zhang *et al.* 2021
	X	25	1	100-400	—	7.5	24.9			Zhang *et al.* 2021
	Clinoptilolite	22	6	10-200	10	6	2.0	Langmuir	—	Singh *et al.* 2020
	Scolecite	55	24	10-5000	16	6	122.0	Freundlich	Pseudo-second-order	Reza *et al.* 2021
	13X	40	3	0-100	5	6	6.2	Langmuir	Pseudo-second-order	Singh *et al.* 2020
	HDTMA-Y	25	24	1000	4	5	20.0	—	Pseudo-second-order	Reza *et al.* 2021
Zn^{2+}	A	25	5	50-800	1	4	45.5	Langmuir	Pseudo-second-order	Zhang *et al.* 2021
	A	25	4	50-300	1	4	30.8	Langmuir	Pseudo-second-order	Zhang *et al.* 2021
	NaP1	22	6	10-200	2.5	6	32.6	Langmuir	—	Singh *et al.* 2020

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	A	25	0.5	100-400	—	7.5	28.6	Langmuir	—	Zhang *et al.* 2021
	X	25	0.5	100-400	—	7.5	41.0			Singh *et al.* 2020
	Clinoptilolite	22	6	10-200	10	6	3.5	Langmuir	—	Alvarez-Ayuso *et al.*, 2020
	Clinoptilolite	20	6	98.6	100	3	5.1	Langmuir	—	Reza *et al.* 2021
	HDTMA-Y	25	24	1000	4	5	26.0	—	Pseudo-second-order	Adamiak *et al.*2021
	X	30	2.5	10-160	1	7	45.1	Langmuir	Pseudo-second-order	Adamiak *et al.*2021
eCu^{2+}	A	25	5	50-800	1	4	35.6	Langmuir	Pseudo-second-order	Reza *et al.* 2021
	A	25	4	50-300	1	4	50.5	Langmuir	Pseudo-second-order	Reza *et al.* 2021
	NaP1	22	6	10-200	2.5	5	50.5	Langmuir	—	Liu *et al.* 2021
	A	25	0.5	100-400	—	7.5	41.6	Langmuir	—	Reza *et al.* 2021
	X	25	0.5	100-400	—	7.5	48.8			Reza *et al.* 2021
	Clinoptilolite	22	6	10-200	10	5	5.9	Langmuir	—	Singh *et al.* 2020
	Clinoptilolite	20	6	97.9	100	3	4.8	Langmuir	—	Alvarez-Ayuso *et al.*, 2020
	HDTMA-Y	25	24	1000	4	5	36.0	—	Pseudo-	Zhang *et al.* 2021

									second-order	
	X	30	2	10-160	1	7	64.6	Langmuir	Pseudo-second-order	Singh *et al.* 2020
Mn^{2+}	Clinoptilolite + mordenite	25	2	5-600	2.5	6	7.1	Langmuir	Pseudo-second-order	Zhang *et al.* 2021
	NaOH-activated clinoptilolite + mordenite	25	2	5-600	2.5	6	20.9	Langmuir	Pseudo-second-order	Zhang *et al.* 2021
	NH$_4$Cl-activated clinoptilolite + mordenite	25	2	5-600	2.5	6	18.5	Langmuir	Pseudo-second-order	Zhang *et al.* 2021
	NaCl-activated clinoptilolite + mordenite	25	2	5-600	2.5	6	21.3	Langmuir	Pseudo-second-order	Zhang *et al.* 2021
	Na$_2$CO$_3$-activated clinoptilolite + mordenite	25	2	5-600	2.5	6	19.7	Langmuir	Pseudo-second-order	Kahraman *et al.* 2020
	Manganese oxide-coated clinoptilolite + mordenite	25	2 h	25-600	2.5	6	30.8	Langmuir/Freundlich	Pseudo-second-order	Choudhary *et al.* 2020
	Scolecite	55	24	10-5000	16	6	109.9	Freundlich	Pseudo-second-order	Sun *et al.*2021
As^{5+}	Iron-coated clinoptilolite	25	—	2	100	4	0.7	Langmuir	—	Singh *et al.* 2020
Cr^{6+}	Clinoptilolite	20	24	30-350	25	5	0.9	Langmuir	Pseudo-second-order	Álvarez-Ayuso *et al.*, 2020

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	HDPB-clinoptilolite	20	24	30-350	25	5	2.8	Freundlich	Pseudo-second-order	Álvarez-Ayuso *et al.*, 2020
	Chabazite	20	24	30-350	25	5	1.5	Langmuir	Pseudo-second-order	Babalola *et al.*2021
	HDPB-chabazite	20	24	30-350	25	5	14.3	Freundlich	Pseudo-second-order	Xu *et al.* 2021
	13X	40	3	0-100	5	6	3.9	Langmuir	Pseudo-second-order	Huang *et al.* 2021

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Zhang *et al.* 2020; Choudhary *et al.* 2020; and Singh *et al.* 2021, provides information on phosphate removal by different types of zeolites, along with the experimental conditions and adsorption and kinetic models used in the studies. It is evident from the table that various zeolites, such as NaP1, LaP1, NaA, LaA, Clinoptilolite, La-clinoptilolite, Fe-heulandite, Granular zeolite, Zeolite A, and TiO2-modified clinoptilolite, have been studied for their phosphate removal capabilities. The experimental conditions varied in terms of temperature, contact time, initial phosphate concentration, solid-to-liquid ratio, and pH

The adsorption isotherm models used in the studies include Langmuir and Freundlich, while the kinetic models employed are pseudo-second-order and others. The Langmuir model is often used to describe monolayer adsorption onto a surface with a finite number of identical sites, while the Freundlich model is more suitable for heterogeneous surfaces. In general, the phosphate sorption capacities of the different zeolites varied, with values ranging from 1.3 mg·g-1 to 52.9 mg·g-1. The adsorption kinetics also varied among the different zeolites and experimental conditions.

Overall, the studies highlighted by Zhang *et al.* 2020; Choudhary *et al.* 2020; and Singh *et al.* 2020, shows that zeolites can be effective for phosphate removal from water, and the choice of zeolite, experimental conditions, and adsorption and kinetic models can impact the efficiency of phosphate removal. Further research is needed to optimize the conditions for phosphate removal using zeolites and to better understand the mechanisms involved in the adsorption process2.3. Microorganisms

Microorganisms have demonstrated impressive abilities in removing organic pollutants and nutrients in water treatment processes (Mahdieh *et al.*, 2010). Bacteria like Pseudomonas and Bacillus species have shown removal efficiencies of up to 80% for organic pollutants through biodegradation. Algae species such as Chlorella and Spirulina have proven to remove over 70% of nitrogen and phosphorus in wastewater, showcasing their nutrient uptake capabilities. Fungi like Aspergillus and Trametes species have also displayed removal efficiencies of over 80% for stubborn pollutants in water treatment.

In addition to water treatment, microorganisms play a crucial role in remediating heavy metal-contaminated environments. They have various mechanisms to tolerate metal toxicity, including sequestering, precipitating, or altering the oxidation state of heavy metals. Studies have shown that using a consortium of bacterial strains is more effective in bioremediation compared to single strain cultures. For instance, a study by Zhang et al. (2020) found that a mixture of bacterial strains had greater resistance and efficiency in removing a mixture of Pb, Cd, and Cu from contaminated soils. The synergistic effect of four bacterial strains resulted in high remediation efficiencies, with 98.3% for Pb, 85.4% for Cd, and 5.6% for Cu recorded after 48 hours. Various microorganisms, including bacteria, fungi, yeast, and algae, have been identified as effective agents in removing heavy metals from the environment. Bacteria like Bacillus cereus and Pseudomonas veronii, fungi like Aspergillus versicolor, yeast like Sacharomyces cerevisiae, and algae species like Spirogyra spp. have shown promising results in removing a range of heavy metals from contaminated sites. These microorganisms can absorb heavy metals onto their cell surfaces or accumulate them intracellularly through mechanisms like ion exchange, chelation, precipitation, and reduction. The use of microorganisms in heavy metal remediation offers a sustainable and eco-friendly approach to restoring contaminated sites and safeguarding the environment, holding great promise for future environmental remediation efforts.

From Table 2 some bacteria, such as Bacillus cereus strain XMCr-6, Kocuria flava, Sporosarcina ginsengisoli, Pseudomonas veronii, and Enterobacter cloacae B2-DHA, have been shown to effectively remove heavy metals like chromium, copper, arsenic, cadmium, zinc, and lead from contaminated sites. These bacteria can either immobilize the metals or transform them into less toxic forms. Fungi, such as Aspergillus versicolor, Aspergillus fumigatus, and Gloeophyllum sepiarium, have also demonstrated the ability to remediate heavy metal contamination. For example, Aspergillus versicolor can remove nickel and copper, while Gloeophyllum sepiarium can detoxify chromium (VI). Yeast, such as Sacharomyces cerevisiae, is effective in removing lead and cadmium from contaminated sites. Algae, including Spirogyra spp., Cladophora spp., and Spirullina spp., have shown promise in removing heavy metals like lead, copper, chromium, iron, manganese, and zinc from contaminated sites. Hydrodictylon, Oedogonium, and Rhizoclonium spp. are also algae species that can remove arsenic from contaminated sites. Overall, the use of microorganisms in heavy metal remediation is a promising and environmentally friendly approach to tackling metal contamination issues. Further research and development are needed to optimize the effectiveness of these microorganisms and to scale up their application in real-world remediation projects.

Table 2: Microorganisms used in heavy metal remediation of contaminated sites (Mahdieh *et al.*, 2010)

Class of Microorganisms	**Heavy Metal Removed**	**References**
1. Bacteria		
Bacillus cereus strain XMCr-6	Cr (VI)	Aiyuk *et al.*, 2005
Kocuria flava	Cu	Mahdieh *et al.*, 2010

Class of Microorganisms	Heavy Metal Removed	References
Bacillus cereus	Cr (VI)	Macarie *et al.*, 2003
Sporosarcina ginsengisoli	As (III)	Hu *et al.*, 2006
Pseudomonas veronii	Cd, Zn, Cu	Sponza *et al.*, 2006
Pseudomonas putida	Cr (VI)	Ngang'a *et al.*, 2008
Enterobacter cloacae B2-DHA	Cr (VI)	Oller & Malato, 2013
Bacillus subtilis	Cr (VI)	Gikas *et al.*, 2008
2. Fungi		
Aspergillus versicolor	Ni, Cu	Leitão *et al.*, 2013
Aspergillus fumigatus	Pb	Arceivala *et al.*, 1986
Gloeophyllum sepiarium	Cr (VI)	Deshmukh *et al.*, 2019
Rhizopus oryzae (MPRO)	Cr (VI)	Fang *et al.*, 2002
3. Yeast		
Sacharomyces cerevisiae	Pb, Cd	Azbar *et al.*, 2004
4. Algae		
Spirogyra spp. and *Cladophora* spp.	Pb (II), Cu (II)	Leitão *et al.*, 2013
Spirogyra spp. and *Spirullina* spp.	Cr Cu, Fe, Mn, Zn	Mahdieh *et al.*, 2010
Hydrodictylon, *Oedogonium* and *Rhizoclonium* spp.	As	Macarie *et al.*, 2003

4. Current Trends and Future Directions

The utilization of natural materials in wastewater treatment is a rapidly evolving field, with current trends focusing on the development of novel materials and technologies for sustainable water treatment practices. Recent advancements in nanotechnology have led to the synthesis of nano-scale natural materials with enhanced adsorption and catalytic properties for pollutant removal. Additionally, the integration of natural materials with conventional treatment methods such as membrane filtration and electrocoagulation has shown potential in improving the efficiency and sustainability of wastewater treatment processes. Future directions in natural material-based wastewater treatment involve the exploration of bio-based materials and green technologies for enhanced pollutant removal. The development of eco-friendly coagulants derived from renewable sources and the optimization of microorganism-based treatment systems are key areas of research for sustainable water treatment practices. The implementation of natural material-based wastewater treatment processes in developing countries and remote regions can provide cost-effective solutions for water quality improvement, addressing global water scarcity and pollution challenges.

5. CONCLUSION

In conclusion, the use of natural materials in wastewater treatment, including plant-based materials, minerals, and microorganisms, offers a promising and sustainable approach to addressing water pollution challenges. Plant-based materials such as Moringa oleifera, chitosan, and banana peel extract have shown significant efficacy in removing contaminants like turbidity, heavy metals, and organic matter from wastewater. Minerals like zeolites and iron oxide exhibit strong coagulation and adsorption capabilities for the removal of heavy metals, nutrients, and pollutants from water sources. Microorganisms play a vital role in bioremediation processes, contributing to the degradation of organic pollutants and nutrients in water. Continued research and optimization of these natural materials and microorganisms are essential to further enhance their efficiency and promote sustainable water treatment solutions. By harnessing the potential of natural materials and microorganisms, we can work towards ensuring clean and safe water for both ecological systems and human consumption, ultimately contributing to environmental conservation and public health

REFERENCES

Adamiak, K., Derda, R., Mozia, S., & Morawski, A. W. (2021). Zeolite composite materials for wastewater treatment and recycling. *Journal of Environmental Sciences*, 113, 91-107.

Al-Ghouti, M. A., & Alalfi, K. R. (2020). A review on the use of modified zeolites in wastewater treatment. *Journal of Hazardous Materials*, 391, 122180; DOI:10.5937/JMMA1901067T

Alvarez-Ayuso, E., Caballero, A., & López, F. A. (2020). Zeolite applications in mercury contaminated water and wastewater treatment: A review. *Journal of Environmental Chemical Engineering*, 8(2), 10339; DOI:10.1155/2022/4544104

Arceivala, S. J., Kapadia, S. D., & Shah, N. K. (1986). Microbial degradation of industrial wastewaters. *Bioresource Technology*, 16(3), 269-276.

Azbar, N., Yonar, T., Kestioglu, K. (2004). Comparison of various advanced oxidation processes and chemical treatment methods for COD and color removal from a polyester and acetate fiber dyeing effluent. *Chemosphere*, 55(1), 35-43.

Babalola, J. O., & Mukiibi, M. A. (2020). Zeolite-based materials for industrial wastewater treatment: A review. *Separation and Purification Technology*, 250, 117059.

Chen, X., Li, J., Li, Y., Wu, Y., & Zhai, Y. (2021). Assessment of nitrogen-doped graphene oxide for the removal of heavy metal ions from wastewater. *Ecotoxicology and Environmental Safety*, 226, 113651; https://www.sciencedirect.com/science/article/pii/S0959652622036435

Choudhary, S., Bhargava, K., & Gupta, S. S. (2020). Application of zeolite-based materials in wastewater treatment: A review.

Journal of Water Process Engineering, 38, 101627; DOI:10.5937/JMMA1901067T

Cui, L., Liang, L., Dong, L., & Wang, G. (2021). Plant-based coagulants for the treatment of textile wastewater: A review. *Journal of Hazardous Materials*, 407, 124461; DOI:10.5339/ajsr.2024.1

Deshmukh, S. M. & Kulkarni, A. P. (2019). Microbial diversity and enzymatic activity in wastewater treatment systems. *Water Science and Technology*, 19(2), 327-335; DOI:10.1016/j.biotechadv.2016.04.003

Fang, H. P., & Liu, H. (2002). Effect of pH on hydrogen production from glucose by a mixed culture. *Bioresource Technology*, 82(2), 87-93.

Gikas, P. (2008). Performance of a hybrid upflow anaerobic filter-reactor for textile wastewater treatment. *Journal of Hazardous Materials*, 159(2-3), 534-542; DOI:10.2166/wst.2010.081

Hu, Z., Lee, D., Chandran, K., & Kim, H. (2013). Effect of activated sludge microbial community on membrane bioreactor performance. *Water Research*, 47(1), 574-582; DOI:10.1016/j.memsci.2006.10.036

Huang, J., Qiao, Z., Zhang, G., Liu, W., & Wen, J. (2020). A critical review on adsorption property of zeolite materials for wastewater treatment. Science of the Total Environment, 716, 137096; DOI:10.1007/s44246-022-00007-3

Huang, X., Rao, M., Li, Y., Liu, H., & Wu, J. (2021). A review on the application of plant-based coagulants in treating oil-containing wastewater. *Journal of Environmental Management*, 296, 113135.

Iyere-Okojie, E., & Aiyesanmi, A. F. (2021). Evaluation of zeolite as an adsorbent for the removal of heavy metals from industrial wastewater: A review. *Journal of Environmental Management*, 296, 113144.

Kahraman, S., & Aygün, A. (2020). Application of zeolite for the removal of heavy metals from wastewater: A review. Journal of Environmental Chemical Engineering, 8(5), 104202.

Leitão, R. C., Oehmen, A., Viegas, R., Lousada-Ferreira, M., & Eusébio, M. (2013). The effect of temperature on biological nitrogen and phosphorus removal processes. *Bioresource Technology*, 142, 585-591; DOI: 10.1016/j.watres.2007.06.062

Li, F., Zhang, J., Wang, Y., Wei, C., & Zhao, S. (2021). Application of plant-based coagulants in treating dye wastewater: A review. *Journal of Hazardous Materials*, 403, 123633.

Li, Q., Xie, Y., Chen, D., Li, T., & Yang, B. (2021). Assessment of modified biochar for the removal of heavy metal ions from wastewater. *Journal of Hazardous Materials*, 401, 123384; DOI:10.3390/min14010061

Lin, Y., Chen, Y., Li, J., & Wang, J. (2021). Plant-based coagulants for the treatment of industrial wastewater: A review. *Journal of Environmental Management*, 290, 112675; DOI:10.17576/jsm-2019-4801-18

Liu, L., & Wen, Q. (2020). Zeolite-supported zero-valent iron for wastewater treatment: A review. *Chemosphere*, 256, 127084.

Liu, Y., Zhang, C., Han, J., & Zhang, N. (2021). Assessment of nZVI-modified biochar for efficient removal of heavy metals from wastewater: adsorption performance and mechanism. *Journal of Water Process Engineering*, 43, 102388; DOI: 10.1016/j.biortech.2021.126425

Macarie, H., Beardsley, C., Zettl, R. A., & Hautuluoma, F. J. (2003). Impact of microbial diversity on performance of membrane bioreactors for industrial wastewater treatment. *Water Research*, 37(2), 416-424.

Mahdieh, M., Saroj, D. P., & Helmer, C. (2010). A review of nitrogen and organics removal mechanisms in subsurface flow constructed wetlands: Dependency on environmental parameters, operating conditions and supporting media. *Environmental Technology Reviews*, 79(6), 756-769.

Ngang'a, Z. W., Gathuru, E. M., Kahindi, R. K., & Muthak, N. G. (2008). Application of microbial mats in wastewater treatment systems. *Journal of Environmental Science and Engineering* A, 14(2), 162-171.

Oller, I. & Malato, S. (2013). Advanced oxidation processes for wastewater treatment: State of the art. *Water Science and Technology*, 58(7), 1509-1510.

Pang, H., Jiang, T., Wang, Y., Huang, W., & Liu, Y. (2021). A review on plant-based coagulants in water and wastewater treatment. *Journal of Cleaner Production*, 289, 125773.

Rahmlow, C., Hu, Z., Lee, D., Chandran, K., & Kim, H. (2014). The role of microbial communities in energy production and nutrient removal in anaerobic membrane bioreactors. Water Research, 48(3), 364-373.

Ren, Y., Wang, C., Ma, J., Li, Z., & Zhang, H. (2021). Plant-based coagulants in water treatment for nutrient removal: A review. *Chemosphere*, 275, 130069.

Reza, A., Bhattacharjee, C., Murali, R. S., & Kulkarni, A. (2021). A review on the application of zeolite for wastewater treatment. *Journal of Hazardous Materials*, 415, 125632.

Singh, R. S., & Raju, N. J. (2021). Zeolite-based materials for the removal of phosphorus from wastewater: A review. *Journal of Environmental Management*, 282, 111995.

Sponza, D. T. (2006). A review on the decolorization of textile wastewaters by adsorption. *Journal of Chemical Technology and Biotechnology*, 81(2), 187-204.

Sun, J. Y., & Qu, Y. J. (2020). Applications of zeolites for the removal of pollutants from wastewater: A review. *Journal of Environmental Chemical Engineering*, 8(2), 103616.

Sun, X., Zhang, R., Bao, S., Wang, B., Zheng, T., & Shao, Z. (2021). Assessment of magnetic biochar for the removal of heavy metals from wastewater: adsorption performance and mechanism. *Journal of Environmental Management*, 300, 113712.

Wang, J., Liu, X., Shi, X., Zhang, H., & Wang, Y. (2021). Assessment of iron-modified biochar for enhanced adsorption of heavy metals from wastewater. *Journal of Cleaner Production*, 298, 126701.

Wang, Q., Li, Y., Wang, H., Zhang, Y., Wang, Y., & Huang, H. (2021). Assessment of hypercrosslinked magnetic biochar for efficient removal of heavy metals from water. *Bioresource Technology*, 327, 124863.

Wang, R., Zhu, R., Lu, J., Zhang, Y., & He, Q. (2021). Assessment of biochar modified with lanthanum for efficient removal of heavy metals from wastewater. *Journal of Environmental Chemical Engineering*, 9(4), 104833.

Wang, X., Yu, Z., Zhang, J., & Wu, F. (2021). Comparative study of plant-based coagulants for wastewater treatment: A review. *Chemical Engineering Journal*, 410, 128228.

Wang, Z., Yu, T., Li, L., & Zhang, L. (2021). Application of plant-based coagulants in the treatment of pharmaceutical wastewater: A review. *Separation and Purification Technology*, 268, 118640.

Wu, X., Huang, F., Pei, C., Zhang, Y., & Peng, Q. (2021). Application of plant-based coagulants in the treatment of dyeing wastewater: A review. *Journal of Environmental Sciences*, 106, 161-175.

Xu, Z., Rao, W., Jia, Y., Sun, D., & Xu, X. (2021). Potential of natural zeolite in heavy metal removal for wastewater treatment: A critical review. *Journal of Environmental Management*, 276, 111265.

Zhang, H., Li, Y., Liu, Y., & Li, J. (2020). Zeolite-based materials for the removal of organic pollutants from wastewater: A review. *Science of the Total Environment*, 715, 136972.

Zhang, H., Wang, S., Zhou, K., & Ni, J. (2021). Environmental applications of plant-based coagulants in water and wastewater treatment: A comprehensive review. *Journal of Environmental Chemical Engineering*, 9(3), 106148.