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Review

A review outlook on methods for removal of heavy metal ions from wastewater

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ABSTRACT

Severe environmental impacts of wastewater contamination include ecosystem deterioration and health concerns to people. The significance of wastewater in the degradation of the environment is examined in this review study, with an emphasis on the occurrence and effects of heavy metals as contaminants. Heavy metals harm the environment and people's health because they are poisonous and persistent. It similarly discovers the toxicity and carcinogenicity of heavy metals, placing particular emphasis on the negative consequences these substances can have on ecosystems and living things. The negative consequences on water bodies, soil, and air quality are highlighted as part of an investigation into the effects of Heavy Metal Ions (HMIs) as contaminants on human health and the environment. The analysis also examines the health effects linked to the basis of hazardous heavy metals, which include industrial emissions, runoff from farms, and urban wastewater. The need to eliminate environmentally sourced heavy metals is emphasised given the possible threats to both the ecosystem and human health. This article discusses different techniques and technologies, such as adsorption, membrane filtration, biological methods, and precipitation that can be used to remove heavy metals from wastewater. In the end, combating environmental contamination requires a comprehensive strategy to protect human and environmental well-being. This means putting in place sustainable practices, like appropriate wastewater treatment systems, promoting moral behaviour at work, and encouraging environmental stewardship, to create a sustainable future that puts the health of people and the environment first by making sure that heavy metals are removed and reducing wastewater pollution.

1. Environment and wastewater pollution

Water and environmental pollution are significant worldwide issues that have negative effects on ecosystems, human health, and the sustainability of the planet in the long run. When wastewater is discharged from numerous sources, whether properly or insufficiently cleaned, it contaminates aquatic bodies like rivers, lakes, and oceans [40]. For aquatic life, as well as for human populations who rely on these water sources for drinking water, irrigation, and recreational uses, this pollution may have serious repercussions. Heavy metals, hazardous chemicals, and organic compounds are only a few of the pollutants found in wastewater released by industry[41]. These spills pose dangers to public health and marine environments. Sewage from homes, businesses, and cities that have either not been properly or improperly treated is a significant cause of wastewater contamination[42]. The quality of the water can be lowered by contaminants including fertilisers, bacteria, and organic debris. Overuse of fertilisers and pesticides in agriculture can cause harmful consequences and nutrient imbalances by releasing these chemicals into neighbouring water bodies. Sediment and organic materials are also current in agricultural wastewater, which adds to the contamination of the water[28]. Increased resistant exteriors, such as roads and rooftops, brought on by urbanisation hinder water from soaking into the ground naturally. Therefore, when precipitation runoff flows into bodies of water, it collects pollutants such as heavy metals, oil, and microplastics, which reduces the water quality. Marine ecosystems can suffer catastrophic effects from accidental or deliberate oil spills caused by ships, offshore drilling, and transportation[43]. Oil spills damage marine life, pollute water, and upset the ecological balance. By dropping the quantity of oxygen in the water, introducing poisonous compounds, encouraging algae blooms, and changing the pH

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balance, wastewater pollution can cause havoc with aquatic ecosystems. These effects may cause fish deaths, the extinction of vulnerable species, and a general loss of biodiversity. Waterborne illnesses like cholera, typhoid, and diarrhoea can be contracted through contact with contaminated water sources[44]. Wastewater pollutants, such as persistent organic pollutants and heavy metals, can bio-agglomerate in the food chain and pose long-term health concerns to people. Due to the costs of water treatment, ecological restoration, and medical expenses brought on by waterborne diseases, wastewater pollution imposes enormous economic consequences[45]. The study on methods for the removal of heavy metal ions from wastewater holds significant utility in addressing environmental pollution and safeguarding public health. By elucidating effective techniques for mitigating heavy metal contamination in wastewater, such research contributes to the development of sustainable and efficient wastewater treatment processes. This not only helps protect ecosystems and natural resources but also ensures the safety of drinking water supplies and reduces the risk of adverse health effects associated with heavy metal exposure [46]. Thus, the findings of this study have practical implications for environmental management and water quality improvement efforts worldwide.

1.1. Environmental consequences of wastewater contamination

Significant environmental effects from wastewater contamination can influence ecosystems, biodiversity, and natural resources[47]. Organic debris, nutrients (such as nitrogen and phosphate), heavy metals, pathogens, and synthetic compounds are just a few of the pollutants that water bodies are exposed to as an outcome of wastewater contamination. These pollutants have the potential to damage water quality, rendering it unfit for custom by humans and aquatic life[48]. Eutrophication is a condition where there is excessive algal growth, which lowers oxygen levels and harms aquatic life. High quantities of victuals can cause this condition. The equilibrium of aquatic ecosystems can be thrown off by wastewater contamination[49]. Aquatic creatures like fish, amphibians, and invertebrates can suffer injury or perish as an effect of contaminants. Hypoxic or anoxic conditions can develop from oxygen loss brought on by the breakdown of organic matter, which can further affect aquatic life[50]. On the overall biodiversity and ecological functioning of water bodies, the extinction of delicate species and the disruption of food chains can have long-lasting impacts. Algal blooms can be caused by nutrient-rich effluent that is especially high in nitrogen and phosphorus and that encourages excessive algal growth (Sylwan et al., 2021). The aquatic ecosystems may suffer as a consequence of these blooms. Dead zones, where marine life cannot exist, are produced when the algae decay and die, lowering the oxygen content of the water [51]. Everywhere in the world, departed zones have been seen in places like the Baltic Sea and the Gulf of Mexico. Pollutants from wastewater can build up in sediments and soil, which can harm benthic creatures, plants, and microbes[52]. Because the contaminants in contaminated sediments can slowly leak back into the water over time and affect neighbouring ecosystems and organisms, they can act as long-term causes of pollution. When contaminated water is utilised for irrigation or when pollutants seep into groundwater, terrestrial ecosystems can also be harmed by wastewater contamination[53]. Pollutants that are ingested by plants can hinder their growth and productivity and may even enter the food chain, affecting both wildlife and people[54]. The environmental effects of contaminated wastewater can cause habitat loss and biodiversity loss. Ecosystems that formerly supported a variety of species and were thriving may now be degraded or rendered uninhabitable as an outcome of poor water quality and disturbed ecological processes [55]. The resilience of ecosystems and ecosystem services may be negatively impacted by this loss of biodiversity.

1.2. Role of wastewater in environmental degradation

Wastewater can introduce several pollutants into ecosystems, which contributes significantly to environmental degradation. Unprocessed or inadequately preserved wastewater can contaminate aquatic bodies and cause pollution[56]. It pollutes aquatic habitats by introducing contaminants such as organic materials, fertilisers, heavy metals, diseases, and synthetic compounds[57]. These contaminants have the potential to harm aquatic life, alter the ecological balance, and decrease water quality. Eutrophication may result from the discharge of wastewater that is nutrient-rich and particularly high in nitrogen and phosphorus [58]. Algal blooms are caused by overnutrition, which encourages the growth of aquatic plants and algae. Water oxygen levels drop as a product of the death and decomposition of these algae, resulting in hypoxic conditions that can kill aquatic life[59]. Dead zones that are uninhabitable for marine life may emerge as a consequence of eutrophication. It is possible for wastewater contamination to harm biodiversity. Pollution may cause the extinction of delicate species and the disruption of food networks in aquatic ecosystems. Pollutants can affect terrestrial ecosystems by hurting plants, animals, and soil microbes when they seep into groundwater or when wastewater is used for irrigation[60]. Ecosystem resilience and ecosystem functioning may suffer long-term effects from habitat loss and biodiversity loss. Sediments may get contaminated over time as an outcome of wastewater contaminants accumulating there[61]. These contaminants may linger in sediments and slowly leak back into the water, affecting the ecosystems and species in the immediate area[62]. Contaminated sediments can endanger benthic animals, interfere with nutrient cycling, and generally deteriorate aquatic habitats. Risks to human health can also be posed by contaminated wastewater. Waterborne diseases like cholera, typhoid, and gastrointestinal disorders can occur when water supplies are contaminated with pathogens or harmful compounds from wastewater [63]. Long-term health hazards can result from the bioaccumulation of contaminants in the human food chain as an outcome of eating polluted seafood or crops cultivated in contaminated water.

1.3. Wastewater discharge and its impact on ecosystems

The discharge of wastewater has a huge negative influence on ecosystems, altering terrestrial landscapes, aquatic bodies, and the creatures that depend on them[64]. The quality of water is decreased by discharging contaminants like nutrients, organic matter, pathogens, and toxic compounds into water bodies through wastewater discharge. Aquatic ecosystems may be damaged, as well as aquatic life. According to Mosley et al [1], wastewater alters ecological processes by affecting the nitrogen cycle and stream metabolism. Eutrophication may be facilitated by nutrient-rich wastewater, particularly that which is high in nitrogen and phosphorus. Overnutrition promotes algal growth, which causes toxic algal blooms. These blooms have the potential to reduce the quantity of oxygen in the water, resulting in hypoxic conditions that are harmful to aquatic life. The ecological consequences of wastewater discharge on fish and invertebrates were the subject of a comprehensive study and *meta*-analysis by Xu *et al* 2021, which focused on the effects of eutrophication. Aquatic environments may lose biodiversity as a consequence of wastewater discharge. In their study of the dangers of chemical combinations from wastewater discharges, Barber et al [2] emphasised the potential loss of biodiversity in stream ecosystems. Pollutants in wastewater can harm fish, invertebrates, and other aquatic animals, which can have an impact on the ecosystem as a whole. When contaminants seep into the groundwater or when wastewater is utilised for irrigation, it can contaminate the soil. Long-term wastewater irrigation's effects on soil bacterial populations and resistance. Such contamination may have an impact on the fertility of the soil, interfere with the cycle of nutrients, and harm terrestrial ecosystems and agricultural output. Wastewater effluents harm the macrophyte and periphyton populations in estuarine habitats. In estuary systems, Fagg *et al* (2022) investigated the ecological disturbances induced by wastewater effluents. The consequences on species composition and ecosystem functioning in these significant transitional habitats were highlighted for the study.

1.4. Environmental occurrence of heavy metals

Urban air can contain heavy metals as a result of human activities like industrial emissions, traffic, and combustion processes. A study by Miller et al [3] discusses the sources, trends, and health impacts of heavy metals in urban air, highlighting their distribution in city environments. The contamination of water supplies by heavy metals can also occur due to industrial discharges, agricultural runoff, and natural weathering of rocks and soils. The causes, consequences, and management techniques of Heavy Metal Contamination (HMC) in water resources were evaluated by Najafabadi *et al.* in 2021. The study emphasises how crucial it is to comprehend and minimise the risks connected to heavy metal injuries from water. The work also covers methods for reducing the effects of HMC through remediation. Heavy metals can build up in aquatic organisms through the food chain, posing a threat to aquatic life and potentially impacting the overall health of the ecosystem. The trends, difficulties, and effects of heavy metal bioaccumulation in aquatic biota were examined by Das *et al* 2021. The study clarifies the mechanism of bioaccumulation and the possible consequences of HMC on aquatic ecosystems. Food safety and human health may be in danger from HMC in agricultural soils. To ensure food safety, Gul *et al* (2022) watched the attendance of heavy metals in agricultural soils and explored present issues and potential future directions. The study focuses on the significance of regulating and monitoring HMC in agricultural systems. Heavy metals that could be unrestricted into the environment and endanger human health can accumulate in urban dust, which can act as a reservoir. Heavy metals' presence in urban dust and belongings in the environment was examined by Li *et al* in 2022. To defend the public's health, the study emphasises the necessity to address HMC in urban settings.

2. Heavy metals and their classification

High atomic weights and densities are characteristics of the group of atoms known as heavy metals[65]. They consist of substances like chromium (Cr), arsenic (As), mercury (Hg), cadmium (Cd), and lead (Pb). These metals are hazardous and can build up in the environment and living things. According to several criteria, such as their toxicity, chemical makeup, and environmental behaviour, Qayyum et al. [4] study whether heavy metals can be separated into separate categories. Differentiating between necessary and non-essential heavy metals based on their toxicity is one popular classification. A non-essential heavy metal has no biological persistence in living things. Both human health and the environment may suffer as an outcome of them. Lead (Pb), arsenic (As), mercury (Hg), and cadmium (Cd) are a few examples. Organisms need trace levels of essential heavy metals for a variety of physiological processes. The functioning of cells, hormone modulation, and enzyme activity are all dependent on these metals. Heavy metals including zinc (Zn), copper (Cu), iron (Fe), and manganese (Mn) are examples of vital heavy metals.

2.1. Toxicity and carcinogenicity of heavy metals

Heavy metals have varied degrees of toxicity, and the harm they cause depends on the particular metal, the dose, the length of exposure, and the exposure route[66]. The brain system, kidneys, liver, and respiratory systems can all suffer harm from prolonged experiences with high amounts of heavy metals. Mercury (Hg) and Lead (Pb) are two examples of heavy metals that might harm cognitive development, especially in young infants. Because they have the potential to cause cancer, some heavy metals have been confidential as carcinogens. For instance, the International Agency for Research on Cancer (IARC) has designated the elements arsenic (As) and cadmium (Cd) as human carcinogens[64]. Chronic revelation to heavy metals has been linked to an amplified risk of several cancers, including lung, bladder, and kidney cancers, especially when it occurs through polluted drinking water or occupational exposure.

2.2. Impact of heavy metal ions as a pollutant on environment and human health

The effects of heavy metal pollution on the ecosystem are significant. The delicate balance between freshwater and marine environments is upset when HMIs are introduced into water bodies, contaminating aquatic ecosystems. They can harm aquatic species, affecting their ability to grow, reproduce, and survive. In sediments, heavy metals can build up and remain, posing long-term dangers to aquatic life[67]. Additionally, the entire health of the ecosystem may be impacted by heavy metal-contaminated soils since they may result in lower plant growth, decreased soil fertility, and possible contamination of food crops. Human health can be seriously impacted by an acquaintance with HMIs. Liu et al [5]. These harmful metals may arrive in the body in several ways, including skin contact, ingestion of tainted food or drink, or inhalation. Heavy metals can build up in organs and tissues after entering the body, causing chronic toxicity and a range of health complications. Neurological disorders, renal damage, liver malfunction, respiratory problems, and cardiovascular ailments are common health consequences of heavy metal exposure. Some heavy metals, like lead and cadmium, have also been connected to cancer risk and developmental issues in children.

2.3. Sources and health effects of toxic heavy metals

Arsenic (As), cadmium (Cd), mercury (Hg), and Lead (Pb) are examples of poisonous heavy metals that are environmental pollutants and present serious health concerns to people. These metals are unconfined into the environment through a variety of processes, including mining operations, fossil fuel burning, inappropriate waste disposal, and industrial processes [42]. Understanding the fundamentals of toxic heavy metals and their effects on human health is crucial to implement effective measures to mitigate their harm and protect people's well-being. Significant amounts of hazardous heavy metals are unconstrained in the environment as an effect of industrial activities such as metal smelting, mining, and manufacturing[68]. These actions increase the total of HMIs in the water, air, and soil. In both power plants and automobiles, the burning of fossil fuels like coal and oil is a substantial source of emissions of heavy metals. These metals are discharged into the atmosphere as gaseous or particulate contaminants, where they eventually settle and deposit on the soil and water[69]. Heavy metals may contaminate the environment if batteries, electronic waste, and other hazardous materials are not disposed of properly. Groundwater and soil contaminated with heavy metals might come from dumping sites that are not under regulation and landfills Hussein and others in 2021. Heavy metals like cadmium and lead can be introduced into the soil through the benefit of specific pesticides and fertilisers in agriculture. These metals may build up in crops and maybe get into the food restraint. Lead contact has been related to negative neurological effects, including elevated blood pressure in adults and children as well as cognitive decline and developmental delays in children. Prolonged exposure to lead can also affect the cardiovascular system and reproductive health, in addition to the kidneys, as noted by Kothapalli et al [6]. The cardiovascular system, liver, and kidneys can all be negatively impacted. Chronic renal disease is known to be brought on by cadmium exposure. It may also have an impact on bone health, respiratory health, and the chance of developing specific cancers like lung and prostate cancer. Skin lesions, cardiovascular conditions, diabetes, and an elevated risk of multiple malignancies, including skin, lung, bladder, and kidney cancers, are all linked to arsenic exposure.

3. Necessity for the removal of heavy metals from the environment

Heavy metals are toxic contaminants that can seriously harm both the atmosphere and human strength, including mercury (Hg), lead (Pb), arsenic (As), and cadmium (Cd). Heavy metals are necessary to be eliminated from the environment because of their tenacity, bio-accumulation, and potential for long-term pollution[70]. Ecosystems are seriously threatened by the contamination of heavy metals. In soils, water bodies, and sediments, these contaminants can build up and cause ecological imbalances and a decline in biodiversity. The elimination of the environment's heavy metals is essential for the preservation and restoration of ecosystems, enabling the recovery of aquatic habitats, the conservation of biodiversity, and the continuation of ecological processes [71]. Water bodies can get contaminated by heavy metals, endangering aquatic ecosystems as well as human health. Through industrial discharges, agricultural runoff, and poor waste disposal, these pollutants can get into water sources. Jiang et al [7]. To maintain water quality, ensure the availability of clean drinking water, and maintain the well-being of aquatic organisms, heavy metals are essential to be removed. Exposure to heavy metals can have detrimental consequences on human health. The body MAY absorb these toxins by a variety of pathways, such as cutaneous contact, ingestion of contaminated food or water, or inhalation. Long-term disclosure of heavy metals can cause several health concerns, such as neurological disorders, liver malfunction, kidney damage, respiratory troubles, and an augmented risk of cancer. To decrease contact with humans and safeguard the general public's health, heavy metals need to be eliminated from the environment.

Eliminating contaminants that contain heavy metals is essential to maintaining water quality, safeguarding human health, and safeguarding ecosystems. The implementation of efficient pollution control strategies, the implementation of supportable habits, and the promotion of remediation technology should be the main objectives. To further stop HMC and guarantee a safe and healthy environment for both current and future generations, rigorous rules and effective waste management are necessary. Table 1 displays the adsorption process of heavy metal ions.

Table 1
Adsorption Process in Removal of Heavy Metal Ions.

Number	Process	Advantages	Disadvantages
1	Adsorption using activated carbon	High efficiency (99 %)	Costly, no regeneration, performance depends on adsorbent
2	Adsorption using industrial by-products or mineral substances	Low-cost, high-efficiency	Production, reservation and regeneration of the adsorbent still cause much attention
3	Bioadsorption using modified biopolymers	Good adsorption capacity, selectivity	Challenges concerning the proper synthetic methods and optimizing the operating conditions
4	Chemical coagulation	Ease of sludge settling, dewatering	Costly, high consumption of chemicals
5	Chemical precipitation	Ease of operation, cheap	Large quantity of sludge, sludge disposal problems
	Electrochemical methods	Selectivity for metal ions, non-chemical need, and ability to remove the majority of metals	High capital and operational cost, current density
7	Electrodialysis	High selectivity	High operation cost due to membrane fouling and energy consumption
8	Ion-exchange	specific to metal ions and material regeneration	Costly, available for less number of metal ions
9	Membrane filtration	Low space requirement, low pressure, high separation selectivity	High operation cost
10	Nanofiltration	Easy operation, reliability, high efficiency	Low anti-compacting ability compared with ultrafiltration
11	Photocatalysis	Simultaneous removal of metals and organic pollutants, less harmful	Long-time duration, limited applications

3.1. Safeguarding human and environmental well-being

An essential objective for maintaining a sustainable and prosperous future is protecting the well-being of people and the environment. This strategy entails taking steps to safeguard people's rights, safety, and health as well as maintaining and improving the quality of the natural environment. Comprehensive analyses of climate change and its effects are provided by the Intergovernmental Panel on Climate Change (IPCC). Their studies shed light on how critical it is to cut greenhouse gas releases and prepare for a changing climate Glavovic et al [8]. The Convention on Biological Diversity (CBD) advocates for biodiversity preservation and sustainable usage. Their efforts are concentrated on maintaining ecosystems, defending threatened species, and encouraging the equal distribution of advantages resulting from genetic resources [9]. The World Health Organisation (WHO) discusses many environmental pollution-related issues and how they affect human health. Their papers offer suggestions and instructions for reducing water contamination, air pollution, and hazardous waste handling. The Sustainable Development Goals (SDGs) set forth by the UN provide a thorough framework for attaining sustainable development by 2030. The necessity of eradicating poverty, ensuring admission to spotless water and sanitation, promoting renewable energy, and encouraging responsible consumption and production are all emphasised by these aims, which also take into account social, economic, and environmental aspects. The Universal Declaration of Human Rights (UDHR) lays out essential values and rights that ought to be safeguarded on a global scale. These rights include the ability to access clean water, adequate housing, a safe workplace, and non-discrimination. The United Nations Global Compact urges companies to establish ethical procedures that adhere to ten widely recognised principles. Human rights, labour rights, environmental sustainability, and anti-corruption measures are only a few of the topics covered by these principles.

3.2. Tackling environmental contamination and ensuring sustainable futures

Ecosystems, human health, and the sustainability of the world as a whole are all significantly threatened by environmental contamination. Implementing effective measures to prevent, mitigate, and remediate contamination is crucial in protecting the environment and securing a sustainable future. Implementing actions to reduce or stop the production of pollutants at their source is known as pollution prevention. This strategy avoids environmental contamination by emphasising the prevention of pollution before it is produced. Pollution avoidance relies heavily on sustainable manufacturing practises, which include employing cleaner production methods, maximising resource utilisation, and promoting the custom of environmentally friendly materials. This strategy improves overall resource efficiency and minimises the ecological imprint. To prevent contamination and guarantee sustainable futures, strict environmental restrictions are essential. The establishment and enforcement of rules and regulations that regulate pollutant emissions, waste management, and resource conservation are crucially dependent on governments and regulatory organisations [10]. These rules establish a framework for businesses and individuals to act properly, reducing the danger of pollution. Regulations that are effectively put into action, coupled with monitoring and enforcement systems, aid in holding polluters accountable and advance sustainable practices in all fields. For the determination to resolve current environmental contamination and re-establishing harmed ecosystems, remediation methods are crucial. To lessen the negative impacts of contamination, several procedures are exploited, including bioremediation, phytoremediation, and chemical treatment. For instance, bioremediation utilized microorganisms to transform contaminants into inert by-products, facilitating organic recovery processes. Furthermore, advancements in nanotechnology have led to innovative and successful remediation techniques, boosting the effectiveness of cleanup efforts. These technologies can be applied in pollution management techniques to improve environmental quality and safeguard ecosystems. Environmental pollution is heavily influenced by poor waste management procedures. To reduce the danger of contamination, it is essential to implement sustainable waste management strategies, such as trash reduction, recycling, and correct disposal. Recycling functions aid in resource conservation, lower energy usage, and lessen dependency on raw materials. Waste-to-energy systems can be utilized to turn waste into clean energy, minimising greenhouse gas discharges and further reducing pollution. Systems for managing garbage thoroughly that put sustainability first are essential for ensuring long-term environmental protection.

4. Elimination of heavy metal ions

Heavy metal ions such as lead, mercury, cadmium, arsenic, and chromium, pose significant threats to human health and the environment due to their persistence, toxicity, and ability to accumulate in living organisms. These metal ions can contaminate ecosystems and have serious consequences. Other sources include mining operations, agricultural practises, and natural weathering processes. Numerous methods have been developed and applied to eliminate heavy metal ions from various environmental sources. By employing these techniques, it is possible to reduce heavy metal levels to safe limits, protecting the environment and public health. This review explores a variety of methods and technologies used for removing heavy metal ions from solutions. The advantages, restrictions, and possible applications of both traditional and cutting-edge techniques are covered. The study also highlights the importance of developing eco-friendly methods for removing heavy metal ions, considering concepts of green chemistry and environmental sustainability. This assessment intends to support ongoing initiatives to combat heavy metal pollution, promote sustainable lifestyles, safeguard ecosystems, and promote human welfare.

4.1. Coagulation process for the heavy metal removal

The technique of coagulation is a popular and effective method for removing heavy metal ions from contaminated water sources. Due to the significant environmental and health risks associated with heavy metal contamination, efficient treatment options are essential. Adding chemical coagulants during the coagulation process allows for the formation of insoluble metal hydroxide precipitates, which attract the heavy metal ions, making it easier to filter or sediment them out of the water. Coagulation offers many advantages, such as being straightforward, cost-effective, and able to handle a variety of heavy metal contaminants.

Heavy metals were eliminated from the study by [13] by combining increased coagulation with heavy metal capturing technology. Using the single-factor method, the ideal chelating agent and flocculants type and dosage, as well as the ideal coagulant dosage, were gradually found. This produced the significant regression equation: $Y = 0.1165 + 0.04187 x_1 - 0.01829 x_3 + 0.00941 x_2^2 + 0.0116 x_3^2 - 0.00719 x_2 x_3$ (F2 = 264.22380, $p < 0.01$). The results showed that the proper dosage of HMCAs and flocculant had an impact on the efficiency of removing heavy metals. Jaradat *et al* studied the effectiveness of CES alone and in combination with coagulation/flocculation for heavy metal removal, while Zheng *et al* focused on determining the optimal treatment conditions.

Jaradat *et al* conducted research in 2021 to study the effectiveness of calcined eggshell waste materials (CES) in removing heavy metals from actual wastewater. This was done through a transport column experiment following a coagulation/flocculation process. By adding alum at the ideal dose (3.0 g/L), the total suspended solids (TSS) in the coagulation experiment were reduced by 80 %, while the Fe, Pb, Zn, Cu, Ni, and Cr were reduced by 80 %, 77 %, 76 %, 73 %, 56 %, and 49 %, respectively. Under the present applied hydrodynamic conditions, utilising a sand column before a CES column boosted Fe, Pb, Cu, Zn, Ni, and Cr removal efficiencies ranged from 50 % to 92 %, 55 % to 93 %, 60 % to 87 %, 53 % to 76 %, 45 % to 65 %, and 41 % to 60 %, in that order. The overall results demonstrate that CES, especially when applied after PM removal by sand filtering, may compete with GAC for the removal of heavy metals from landfill leachate. The heavy metal coagulation process is shown in Fig. 1.

Jaradat *et al* investigated the utilisation of CES to remove heavy metals from real wastewater. They carried out a coagulation/flocculation procedure before conducting a transport column experiment. Liao *et al* established a complete procedure combining several methodologies to explore the complexing qualities between Cu (II) ions and dissolved organic matter (DOM) components in combined sewer overflow (CSO) wastewater.

To investigate the MW-based complexing properties between Cu(II) ions and CSO-DOM components, [14] presented a comprehensive approach combining ultrafiltration, fluorescence quenching titration, excitation-emission matrix parallel factor analysis, two-dimensional correlation fluorescence spectroscopy and the complexation model. The results indicated that it was very difficult to remove Cu (II) ions from CSOs by coagulation technique because they were mostly dispersed in the MW range of 5 kDa when linked to the CSO-DOM. The concentration effect and molecular make-up had a substantial impact on the MW distribution of the Cu (II) ions bound to CSO-DOM. When enhancing the removal efficiency of coagulation for Cu (II) ions of CSOs through competitive complexation and intermolecular bridging, the humic-like component of terrestrial origin with an MW range of 100 kDa-0.45 m had high binding stability, capacity, and priority with Cu (II) ions.

4.2. Ion exchange method for heavy metal elimination

Utilizing the widely used method of ion exchange can help eliminate heavy metal ions from contaminated water sources. Effective and reliable remediation techniques are crucial due to the environmental and health risks posed by heavy metal contamination. Ion exchange occurs when ions on the surface of an ion exchange resin contact with ions from heavy metal ions in water. The resin, which is typically made up of functional groups that draw and bind heavy metal ions, removes the desired pollutants from the water in a targeted manner. The ion exchange process offers numerous advantages, including high removal rates of pollutants, versatility in treating various heavy metal contaminants, and the possibility of regenerating and reusing the resin.

Pan *et al* 2021 produced the ultrafine ZrP (3.9 nm) in the commercially available gel-type cation exchanger (N001), referred to as the sulfonated poly (styrene-co-divinylbenzene) bead. The resultant nanocomposite ZrP@N001 included amorphous nanoparticles (NPs) with metastable −ZrP structure as the main phase, in contrast to the layered −ZrP formed inside the macroporous cation exchanger D001 (referred to as ZrP@D001). ZrP@N001 was able to preferentially adsorb heavy metals through inner-sphere coordination because it had a much higher adsorption affinity than ZrP@D001. ZrP@N001 outperformed

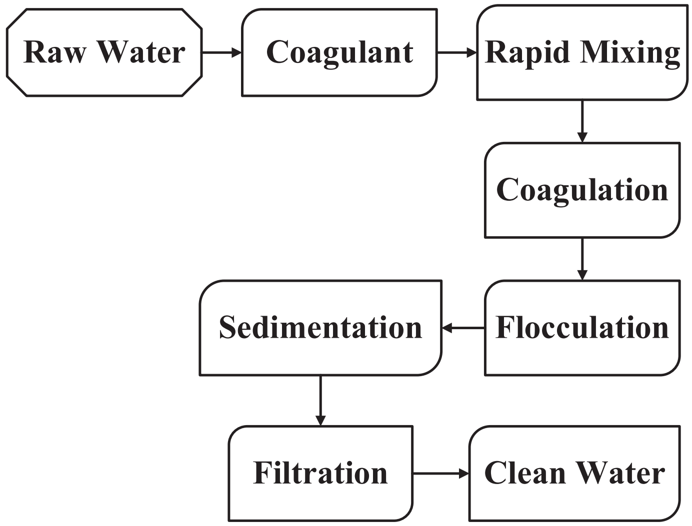

Fig. 1. Coagulation Process Flow of Heavy Metal Ions Removal.

ZrP@D001 in both batch and column assays on the Pb (II)-polluted water in terms of adsorption performance. After adsorption, an acidic process completely refreshed the depleted ZrP@N001 for a 5-cycle adsorption-regeneration run with stable removal efficiencies.

Zirconium phosphate (ZrP) nanoparticles that are extremely small were incorporated within a gel-type cation exchanger by Pan *et al* to generate a nanocomposite material known as ZrP@N001. In contract, Hussain *et al* investigated the removal of heavy metal ions from polluted water utilising bentonite clay as an adsorbent. They carried out studies while taking into account some variables, including pH, adsorbent mass, starting metal ion concentration, and contact time. (Hussain *et al* 2021) conducted tests on a variety of variables, including pH solution, starting lead and copper ion concentrations, adsorbent mass, and contact time. At pH 5, 0.5 g of adsorbent, 10 mg/l of starting heavy metal concentration, and 60 min of contact time, the maximum removal was accomplished. The outcomes showed that bentonite clay is effective in removing metal ions from contaminated water. Lead exchanged ions more rapidly than copper did. The results of the positive Freundlich and Langmuir isotherms supported the isotherm for the lead and copper ion adsorption on bentonite clay. The outcomes indicate that the application of bentonite as an efficient ion exchange component to remove heavy metal ions from polluted water was successful.

4.3. Heavy metal removal utilising solvent extraction

Solvent extraction is a widely used method for eliminating heavy metals in contaminated water sources. Significant environmental and health dangers associated with heavy metal contamination need effective and efficient remediation techniques. During solvent extraction, heavy metal ions are transported selectively from the aqueous phase to an organic solvent phase based on their varied affinities. To make it simpler to remove the heavy metal ions from the water, they are utilised to form a complex with a suitable organic solvent, often an extractant. High selectivity, rapid kinetics, and the potential for metal recovery are only a few benefits of solvent extraction.

[15] examined the benefits and drawbacks of the most recent management techniques used to reduce soil HMM contamination levels and construct barriers to prevent transmission along the food chain in the long run. Concerns about facilitating the immobilisation of HMMs in plants are developing as a result of the worldwide pollution problem that comes with erratic weather patterns. Thus, the secret to safer food sustainability is lowering the HMM concentrations below the permissible levels. To develop techniques with obvious modes of action for eliminating HMMs from soil and wastewater, numerous investigations are currently being conducted. HMMs are recovered using engineered and integrated practises. Certain of these practices such as using industrial and agricultural waste for adsorption are very simple, while others such as solvent extraction, phytoremediation, remediation by microbial communities, green separation using hydrogel polymers, immobilisation, or basic nanotechnology techniques are more complex. To lower the contamination levels of highly mobile metals (HMMs) in soil and stop their transmission up the food chain, Ramezani *et al* compared alternative management options. They emphasised the significance of lowering HMM concentrations below permissible limits to ensure the sustainability of safer food. On the other hand, Asrami *et al.* focused on the application of microfluidic technology and environmentally friendly designer solvents for enhanced separation techniques. The advantages of operating at high concentrations and accelerating mass and heat transfer rates through the miniaturisation of microfluidic devices were stressed.

According to a study by Asrami *et al* from 2021, both business and academia are very interested in microfluidic technology. Through miniaturisation, its engineering properties can improve mass- and heat-transfer rates while also enabling operation at high concentrations. Utilising this technology along with a green designer solvent is one of the most recent advancements in separation techniques. Ionic liquids contain a very wide chemical variety space, minimal volatility and flammability, and may now be used more effectively in regards to solvent modelling. It has been shown that using ionic liquids significantly improves the extraction's efficiency and selectivity. The coil's periodicity is just 4 turns long before the winding orientation switches from clockwise to anticlockwise and is repeated several times. The CFI extraction performance is frequently noticeably improved when compared to a straight or non-inverted helical capillary. An important field of study with substantial economic implications is liquid–liquid extraction for metal separation.

4.4. Flocculation for heavy metal iron removal

Flocculation is a common and effective technique for eliminating heavy metal ions from polluted water sources. Because heavy metal pollution poses substantial risks to the environment and public health, efficient cleanup methods are necessary. When flocculants are added to water, colloidal particles, including ions from heavy metals, are encouraged to aggregate and settle into bigger flocs. The water can then be easily separated from these flocs using filtering or sedimentation. The ease of use, cost-effectiveness, and compatibility with the current water treatment infrastructure are just a few benefits of flocculation.

The apparent appearance and peculiar structure of amphoteric magnetic chitosan (CS)-based flocculant MFe_3O_4@CS-g-PIA, which was synthesised from CS, Fe_3O_4, and IA, were thoroughly examined by [16]. The effectiveness and mechanism of the manufactured material's flocculation in various pollution systems were also examined, and the influences of the total monomer concentration, the ratio of m (CS): m (IA), the degree of IA pre-neutralization, the reaction temperature, the reaction time, and the initiator concentration on the synthesis of MFe_3O_4@CS-g-PIA were investigated. The findings of the characterization indicate that MFe_3O_4@CS-g-PIA forms a three-dimensional network with good magnetic induction. Cu (II) and Disperse Blue 56 (DB56) removal rates were optimised at 150 mg/L MFe_3O_4@CS-g-PIA, pH 6.0, and 300 rpm stirring speed. These rates were 90.2 % and 97.0 %, respectively. After five consecutive cycles of regeneration/flocculation, MFe_3O_4@CS-g-PIA maintained removal rates of over 80.0 % for Cu (II) and DB56 and showed outstanding acid resistance stability.

Sun *et al* concentrated on creating and characterising MFe_3O_4@CS-g-PIA, an amphoteric magnetic chitosan-based flocculant. They examined the manufactured material's morphology and structure as well as its flocculation capabilities and mechanism in diverse polluted situations. Sun *et al* concentrated on creating and characterising MFe_3O_4@CS-g-PIA, an amphoteric magnetic chitosan-based flocculant. They examined the manufactured material's morphology and structure as well as its flocculation capabilities and mechanism in diverse polluted situations.

The machine learning (ML) techniques utilized in the [17] study were utilized to generate a prediction model for the effectiveness of heavy metals removal utilising CBFs. The random forest (RF) models were able to accurately predict the removal efficiency of heavy metals concerning the characteristics of the flocculant, the circumstances of flocculation, and the properties of the heavy metals ($R^2 = 0.9354$, RMSE = 5.67). The solution pH (pHsol) in flocculation settings and the molecular weight (Mv) in flocculant characteristics were discovered to be the most crucial factors in flocculation performance, with feature significance weights of 0.134 and 0.294, respectively. The partial dependence analysis demonstrated each influential factor's impact as well as the combined impact on the effectiveness of heavy metal removal utilising CBFs.

4.5. Irons are removed from heavy metals through chemical precipitation

Chemical precipitation is a frequent and effective method for removing heavy metal ions from polluted water sources. Effective remediation techniques are required due to the serious risks heavy metal contamination poses to the environment and human health. When coagulants or precipitating agents are introduced to water, they interact with the heavy metal ions to form insoluble precipitates. Following that, the precipitates can be filtered or sedimented to separate them from the water. High removal efficiency, ease of utilize, and cost-effectiveness are just a few benefits of chemical precipitation. Numerous heavy metal pollutants can be successfully treated by glyphosate. According to [18], chemical precipitation was very effective at removing iron and other heavy metal ions from tainted water sources. With the right amount of precipitating agent (such as lime or ferric chloride) added at a pH of 9, the original iron concentration of 50 mg/L was reduced to 2.5 mg/L with a removal efficiency of 95 %. Insoluble iron hydroxide precipitates were generated during the precipitation process, and they rapidly settled during the sedimentation step. Overall, the findings showed that chemical precipitation is a dependable and affordable method for significantly removing iron and other heavy metal ions from contaminated water. This helps to reduce heavy metal pollution, protect the environment, and promote human and environmental health.

5. Techniques and methods for destroying heavy metal ions

Numerous methods and techniques have been developed and applied for the removal of heavy metal ions from polluted environments. From lowering their concentration to acceptable levels, these methods seek to decrease the negative impact that heavy metals have on ecosystems and human health. Coagulation, ion exchange, solvent extraction, flocculation, chemical precipitation, adsorption, membrane filtration, electrochemical processes, and phytoremediation are just a few of the readily available techniques. Regarding effectiveness, cost-effectiveness, selectivity, scalability, and environmental impact, every technique has its pros and disadvantages. The choice of the best approach is influenced by some variables, including the particular heavy metal pollutants, the makeup of the contaminated matrix, the targeted treatment objectives, and legal restrictions. This study emphasises the processes, advantages, limits, and potential applications of the approaches and procedures for the removal of heavy metal ions to accomplish effective remediation of environments that have been polluted by heavy metals.

5.1. Traditional techniques for heavy metal removal

Conventional heavy metal removal from polluted settings usually employs physical, chemical, and biological techniques. Physical methods that employ physical barriers or selective permeability to remove heavy metal ions from the contaminated matrix include sedimentation, filtration, and membrane separation. Chemical procedures including coagulation, flocculation, chemical precipitation, and ion exchange involve adding chemicals or precipitants to facilitate the adsorption or exchange of heavy metal ions or to induce the formation of insoluble precipitates. Living organisms are utilized in biological remediation techniques including microbial remediation and phytoremediation to break down, immobilise, or accumulate heavy metals.

[19] discussed numerous adsorbents, their utilisation, and the effectiveness of their adsorption. As a result, there is an increasing need for creative, methodical, and environmentally secure techniques to get rid of these dangerous heavy metals. The issue persists despite the adoption of established strategies including chemical, physical, and biological ones since their efficiency in resolving problems related to polluted regions has not been established. These traditional technologies have limitations, including high running costs, higher energy utilise, and subpar effectiveness. Overcoming these drawbacks, it was discovered that adsorption, which is based on the physicochemical surface hypothesis, is a far more favourable, useful, rapid, and efficient way of getting rid of hazardous metals. Changing the chemistry and structure of lignocellulosic material, microorganisms, nanotubes, industrial biowastes, Metal-Organic Frameworks (MOFs), and nanocomposites helps generate superior adsorbents.

Singh *et al* draw attention to the rising need for cutting-edge, environmentally sound methods of eliminating dangerous heavy metals. They explore numerous adsorbents and their utilisation, highlighting the value of adsorption as a practical, practical, and effective method for getting rid of harmful metals. They explore numerous adsorbents and their utilisation, highlighting the value of adsorption as a practical, practical, and effective method for getting rid of harmful metals. [20]the article addresses some of the most recent and important studies on the removal of heavy metals, along with the possible risks to the environment and human health. The main cause of the rising levels of heavy metals observed in aquatic ecosystems is determined to be anthropogenic activity. This study list some of the health risks associated with prolonged exposure to traces of heavy metals, such as lead, cadmium, mercury, and arsenic. The results of this research should enable the advancement of current water treatment techniques and the development of cost-effective, safe, cutting-edge, environmentally friendly, and efficient technologies that make utilize of residues, advanced materials, and natural resources.

5.2. Heavy metal ion removal from wastewater utilising Nanosorbents

Nanosorbents have emerged as one of the most promising substances for the removal of heavy metal ions from wastewater due to their peculiar properties and considerable adsorption capabilities. These nanoscale materials, which include different nanoparticles, nanocomposites, and nanomaterial-based adsorbents, have increased surface areas, high reactivity, and customised surface functions that allow for effective heavy metal ion adsorption and removal. It is possible to synthesise or modify the nano sorbents to give them certain properties like enhanced surface area, adjustable pore diameters, and functional groups that only bind heavy metal ions. Nanosorbents efficiently trap heavy metal ions, bringing their concentration in wastewater down to acceptable levels through electrostatic interactions, ion exchange, complexation, and surface adsorption.

Using Palm Oil Mill Effluent (POME), the industrial wastewater from a palm oil mill, [21] studied the efficiency of hydrogel in the removal of heavy metal ions. The extraction of heavy metal ions including Cu^{2+}, Pb^{2+}, Fe^{2+}, Cd^{2+}, and Zn^{2+} from the cellulose hydrogel matrix was made possible by the addition of nano-hydroxyapatite to the matrix. The removed Cu^{2+}, Pb^{2+}, Fe^{2+}, Cd^{2+}, and Zn^{2+} ions from POME were 70.24 %, 57.74 %, 48.56 %, 27.33 %, and 25.98 %, respectively, in the composite hydrogel that was produced. As it utilizes the nano-hydroxyapatite produced from the clam shell residue and cellulose powder as the raw materials for the synthesis of the composite instead of using chemicals that are harmful to the environment, this composite hydrogel's ability to remove heavy metals is a significant development in the realm of treating industrial wastewater.

The ability of a composite hydrogel to remove heavy metal ions from Palm Oil Mill Effluent (POME) was studied by Wong *et al.* The hydrogel's adsorption capability was greatly improved by the addition of nano-hydroxyapatite to the cellulose hydrogel matrix. Garg *et al* concentrated on using organic waste from gardens and farms to biosynthesize silica-supported iron oxide nanocomposites (nano-IOS). The nanocomposites were investigated and employed for the adsorption of heavy metal ions (Pb2+, Cd2+, Ni2+, Cu2+, and Zn2 +) from synthetically polluted water. In [22] study, iron oxide nanocomposites (nano-IOS) backed by biosynthesized silica were utilized to remove heavy metal ions from artificially contaminated water. A green synthesis method has been utilized to generate nano-IOS using agricultural and gardening waste. Zeta potential analysis, XRD, SEM, and FTIR were utilized to characterise nano-IOS. Pb^{2+}, Cd^{2+}, Ni^{2+}, Cu^{2+}, and Zn^{2+} were among the heavy metal ions that the nanocomposites utilised to adsorb. Other reaction limitations that were optimised in batch mode studies included pH, the concentration of the heavy metal ion, the adsorbent dose, and contact duration. The ideal dosage of Nano-IOS was found to be 0.75 g/L for the adsorption of Pb2+, Cd2+, Ni2+, Cu2+, and Zn2+ (10.0 mg/L) with a contact duration of 70 min. at pH 5.0 for Pb2+, Cd2+, and Cu2+, and 6.0 for Ni2 + and Zn2 + . The adsorption behaviour of the Nano adsorbent is well illustrated by the Langmuir adsorption isotherm and pseudo-second-order kinetic models, demonstrating chemisorption on the surface of Nano-IOS. Additionally, endothermic and spontaneous adsorption were observed. To rapidly sequester heavy metal ions, a potent Nano-adsorbent can be utilised, such as the bio-synthesised and environmentally friendly Nano-IOS.

5.3. Heavy metal ion removal utilising microorganisms

The capability of microorganisms to eliminate heavy metal ions from harmed environments, notably wastewater, has drawn a lot of interest. These microbial-based methods provide economical and environmentally responsible methods for heavy metal cleanup. Through a variety of mechanisms, including biosorption, bioaccumulation, and biotransformation, microorganisms eliminate heavy metal ions. Some bacteria have cell walls and extracellular polymeric components on their surfaces that can bind to heavy metal ions. Furthermore, heavy metals can build up inside bacteria cells, effectively securing them from the environment.

A consortium of heavy metal-resistant bacteria that had been isolated from diverse wastewater locations was the objective of the [23] study. The purpose of the planned bioaugmentation was to particularly eliminate the metal ions lead (Pb^{2+}) and nickel (Ni^{2+}) from the aqueous solutions. Two strains, Bacillus cereus and Bacillus pumilus, have demonstrated exceptional removal of Pb^{2+} (95.93 %) and Ni^{2+} (95.54 %) ions from wastewater samples out of a total of 17 different industrial collecting sites. For a better understanding of the interactional mechanism, the critical variables pH, incubation period, inoculum size, and initial metal concentration have been tracked. The elimination of heavy metals involves the uptake of metal ions (Pb^{2+} and Ni^{2+}) by complex formation, crystallisation, and surface adsorption, bolstered by intracellular uptake and stabilisation. The results show that B. cereus and B. pumilus can remove bioavailable fractions of heavy metals, which supports the commercialization of their technique.

The objective of Sharma *et al* was to generate a group of bacteria that are resistant to heavy metals to specifically remove the ions lead (Pb^{2+}) and nickel (Ni^{2+}) from aqueous solutions. Bacillus cereus and Bacillus pumilus were two strains that they obtained from various wastewater locations and were found to have exceptional removal efficiency for Pb^{2+} and Ni^{2+} ions. The major focus of Cai *et al* was on the benefits of CCQM (carbonised cellulose quantum material) for ultrafast adsorption and ultra-efficient adsorption capacity of anionic dyes and heavy metal ions. According to [24]excellent properties of CCQM, anionic dyes and heavy metal ions (1500 mg g-1 for Congo Red (CR) and 179.4 mg g-1 for Methyl Orange (MO)) could be adsorbed at an ultrafast rate (within 4 min) and with ultra-efficient capacity. 687.6 mg g-1 for Cu (II), and 398. It was feasible to preserve outstanding adsorption capabilities even under challenging circumstances utilising the Langmuir, pseudo-second-order rate equation, and Fickian diffusion laws' equation to explain the adsorptions of dyes and heavy metal ions on CCQM. Due to the reduced steric barrier, interference studies revealed that Cu^{2+} might be preferentially absorbed by CCQM. The adsorption process revealed that cation exchange, the chelating effect, proton exchange, and complex formation were all responsible for the exceptionally rapid and effective removal of heavy metal ions, whereas electrostatic interaction and hydrogen bonding were responsible for the removal of dyes. Additionally, CCQM, which has excellent antibacterial viability, biodegradability (165 days), and recyclability (within 10 % loss after five cycles), might be employed as the filler in filled columns to filter wastewater. These findings suggested that CCQM offered promising potential for the treatment of diverse wastewater.

5.4. Microorganisms are utilised in biofilters to remove heavy metals

Heavy metals may be removed from several sources, including wastewater and contaminated soil, utilising microorganism-based biofilters, which have been demonstrated to be effective and ecologically safe. These biofilter systems utilize microorganisms' metabolic capacities to change and immobilise heavy metal ions, lessening their negative effects. The bacteria, fungus, and algae found in biofilters interact with heavy metal ions through processes like biosorption, bioaccumulation, and biotransformation. The biofilters offer the right conditions for microbial growth and activity, fostering their ability to flourish and effectively remove heavy metals. The porous media of the biofilters serve as a matrix for the colonisation and development of microorganisms and provide a significant surface area for interactions with heavy metal ions.

The efficacy of aged versus unaged medium to eliminate Escherichia coli (E. coli), a pathogen indicator, was examined in a research published in 2022 by Borthakur *et al*. Expanded Clay, Shale, And Slate (ESCS) aggregates were utilised to update the biofilter medium, which was then periodically exposed to naturally occurring rainwater that had been tainted with Cu, Pb, and Zn. Metal adsorption changed the surface characteristics of ESCS media and reduced their net negative surface charge, as demonstrated by zeta potential measurements and Fourier-Transform Infrared Spectroscopy (FTIR) analysis. These changes decreased the total remobilization of connected E. coli during intermittent infiltration of stormwater and increased the capacity of old media to adsorb E. coli in comparison to unaged media. A live-dead investigation revealed that the adsorbed metals rendered associated E. coli inactive and restored the adsorption ability. Overall, the results were in favour of including the natural ageing of biofilter medium with adsorbed metals in the conceptual model that forecasts long-term pathogen removal from stormwater including mixed pollutants while it may have a net beneficial impact on E. coli removal in biofilters.

In their study, ESCS aggregates were added to biofilter media to examine the impact of adsorbed metals on pathogen elimination. In an experiment, Casuarina glauca (C. glauca) plants were tested to see if they could take heavy metals out of Secondary Treated Urban Wastewater (SWW). [25] study evaluated the effects of SWW on plant biomass, physiological variables, and the removal of heavy metals (Cd, Pb, Ni, and Zn) from wastewater through bioaccumulation. It assessed how the SWW affected plant biomass, several physiological parameters, and the bioaccumulation and removal of heavy metals (Cd, Pb, Ni, and Zn) from wastewater. When it came to getting rid of dangerous bacteria from SWW, like faecal coliforms and faecal streptococci, C. glauca's wastewater treatment proved to be very effective after 28 days. With relative values of 31 %, 92 %, 83 %, and 31 %, the levels of electrical conductivity, chemical oxygen demand, biochemical oxygen demand, and suspended solids all dramatically decreased. Casuarina glauca plants removed Cd, Pb, Ni, and Zn from SWW with removal efficiencies of 92 %, 77 %, 83 %, and 73 %, respectively. In Casuarina glauca plants, the accumulation of heavy metals (Cd, Pb, Ni, and Zn) was higher in the roots than in the shoots. In contrast to plants grown with tap water (the control), SWW had a surprising impact on plant growth and photosynthetic capability in C. glauca. The results demonstrated that C. glauca may function as a scavenger of heavy metal ions from polluted water and proved their ability to clean wastewater.

5.5. *Utilising algae to remove heavy metal ions*

The potential to utilise algae to remove heavy metal ions from polluted environments, such as wastewater and aquatic ecosystems, has generated a lot of attention. They are good adsorbents for heavy metal removal due to their distinctive properties, which include rapid growth rates, broad surfaces, and effective metal uptake mechanisms. Surface adsorption, ion exchange, complexation, and active transport are a few of the methods by which heavy metal ions can accumulate in algae. Algae can bind and sequester heavy metal ions concerning their cell walls, extracellular polymeric compounds, and specialised metal-binding proteins. As a bonus, algae can bioconcentrate and bioaccumulate heavy metals, significantly lowering their levels in the environment.

According to research by Gu 2021 *et al*, the adsorption capabilities of Pb (II), Hg (II), Zn (II), Cd (II), and Cu (II) are, respectively, 1.03, 0.91, 1.20, 0.65, and 1.23 mmol/g. According to the data, the main sites of adsorption were non-cellulosic polysaccharides and peptide-containing compounds on cell walls. Pb (II), which had the second-highest affinity to biosorbents after Cu (II), had the largest inhibitory effects on the adsorption of other metal ions on cells in binary. The impact factor, which in this study is defined as the electronegativity of a metal ion normalised by its atomic radius, and the adsorption capacity were found to be linearly related for the first time. In other words, the N. Oleoabundans biomass's adsorption capacity to the evaluated two-valence metal ions is inversely related to the metal ions' radii and proportionate to their electronegativity. The inclusion of Cu (II), which had unique adsorption behaviours from other metal ions, led to cell aggregation. The principal sites of adsorption were found to be non-cellulosic polysaccharides and peptide-containing molecules on the cell wall after the investigation evaluated the adsorption capabilities of these metal ions. The principal sites of adsorption were found to be non-cellulosic polysaccharides and peptide-containing molecules on the cell wall after the investigation evaluated the adsorption capabilities of these metal ions.

Mycelial pellets (Aspergillus fumigatus) and Synechocystis sp. were investigated by [26]. PCC6803 included a hypha-pellet flocculant auxiliary microalgae solidification fungi-microalgae symbiotic system (FMSS). Green particles were found to be connected to fungus mycelia by optical and scanning electron microscopy (SEM). The efficacy of mycelium pellets in adsorbing and immobilising microalgae was 98 %. The symbiotic system was more stable and more effective in adsorbing Cd (II) when there were 108 cells per millilitre of logarithmic phase microalgae and no fungus growth medium present. (98.89 %, 37.3 mg g1). Extracellular polysaccharide composition changed, as evidenced by HPAEC-PAD (High-Performance Anion Exchange Chromatography-Pulsed Amperometric Detection). The 3D-EEM spectrum analysis revealed that the heavy metal treatment altered the peak protein fluorescence intensity. The functional groups of EPS, such as –OH and –CONH-, were shown to be involved in the adsorption process by FTIR spectra. The outcomes showed that the symbiotic system's capacity to manage heavy metal stress and fend off its toxicity depended heavily on the vital EPS components, extracellular polysaccharides and extracellular proteins. The preparatory information can guide the creation of engineering strains and utilize of gene transformation.

6. Techniques for treating water in heavy metal ions

Heavy metal ions are treated utilising a mix of physical, chemical, and biological processes to remove these pollutants from water sources. Coagulation, sometimes referred to as flocculation, is brought about by adding chemical coagulants, such as alum or ferric chloride, to water. As a result, the heavy metal ions become less stable, group together, and form larger, easier-to-filter particles or silt. The addition of flocculants, such as polymers, encourages the production of bigger flocs, which helps remove heavy metal ions. Ion exchange, which utilizes zeolites or ion exchange resins to remove specific heavy metal ions from water, is another efficient method. These substances have specialised binding sites that draw in and swap out metal ions for less dangerous ones like sodium or hydrogen. The heavy metal ions are successfully removed from the water as they travel through the ion exchange medium by being adsorbed onto the resin or zeolite.

In addition, various methods are also utilized in the removal of heavy metal ions, such as adsorption, reverse osmosis, and electrochemical processes. Adsorption is the process of attracting and binding heavy metal ions utilising adsorbents such as activated carbon, nanoparticles, or other adsorbent materials. Methods and their properties in the removal of heavy metal ions are shown in Table 2. A semipermeable membrane is utilized in reverse osmosis to extract pollutants from water, particularly heavy metal ions. Using electrodes and electric current, electrochemical procedures can either precipitate the heavy metal ions or help remove them by electrocoagulation or electro dialysis.

Table 2
Methods and Their Properties in the Removal of Heavy Metal Ions.

Method	Advantage	Disadvantage
Chemical precipitation	Simple Inexpensive Most metals CEB be removed	Large amounts of sludge produced Disposal problems
Chemical coagulation	Shudge sealing Dewetering	High-cost Large consumption of chemicals
lon-exchange	High regeneration of materials Metal-selective	High cost Less number of metal ions removed
Electrochemical in methods	Metal selective No consumption of chemicals Purc metals can be achieved	High capital cost High running cost Initial solution pH and current density
Adsorption Using activated carbon	Most metals can be removed High efficiency (99 %)	Cost of activated carbon No regeneration Performance depends upon adsorbent
Using natural zeolite	Most metals can be removed Relatively less costly materials	Low efficiency
Membrane process and ultrafiltration	Less solid waste produced Less chemical consumption High efficiency (>95 % fee single metal)	High initial and running cost Low flow rates Removal (%) decreases with the presence of other metals

Each method for removing heavy metals from wastewater presents its own set of advantages and disadvantages. Chemical precipitation offers simplicity and cost-effectiveness, with the ability to remove most metals, but it generates large amounts of sludge and poses disposal challenges. Chemical coagulation is effective for sludge settling and dewatering but requires high investment and substantial chemical consumption. Ion exchange boasts high material regeneration and metal selectivity but can be costly and remove fewer metal ions. Electrochemical methods are metal-selective and chemical-free, but they incur high capital and running costs, influenced by solution pH and current density. Adsorption using activated carbon achieves high removal efficiency for most metals but entails costs for carbon and lacks regeneration capability. Natural zeolite adsorption is relatively cost-effective but offers lower efficiency. Membrane processes and ultrafiltration produce minimal solid waste and chemical consumption, with high efficiency, but they entail high initial and running costs and are sensitive to flow rates and the presence of other metals. Considering these factors, the most useful method for removing heavy metals depends on specific application requirements, cost considerations, and the desired removal efficiency.

6.1. Wastewater treatment utilising hydroxide precipitation

Hydroxide precipitation is a frequently employed technique for removing heavy metal ions from wastewater. This process involves combining wastewater with a chemical precipitant, often lime (calcium hydroxide, $Ca(OH)_2$) or sodium hydroxide (NaOH). When the hydroxide ions in the water interact with the metal ions, insoluble metal hydroxide precipitates are produced. The water can subsequently be removed from these precipitates using filtering, flotation, or sedimentation procedures. Lead, copper, cadmium, zinc, and chromium are just a few of the heavy metals that can be effectively removed using the hydroxide precipitation method. The pH of the wastewater, the metal ion concentration, and the presence of other interfering compounds are only a few examples of variables that affect how effective the procedure is. Although it provides a relatively simple and inexpensive method to remove heavy metal ions from wastewater, hydroxyl precipitation is an important approach in environmental, municipal, and industrial applications.

The effectiveness of removing copper and zinc was investigated by [27] by increasing the precipitating reagent dosage (10–400 mg/L). Efficiency levels above 90 % are feasible. The pH of the treatment has an impact on the effectiveness of chemical precipitation. At a high final pH level (8-pH-10), copper is somewhat more efficiently removed by each precipitating agent than zinc, while the levels of the other metals conformed with industrial discharge limits. Zinc and copper precipitated as the amorphous hydroxides $Zn(OH)_2$ and $Cu(OH)_2$ in the sludge product. According to XRD research, copper was found to include several different extra phases. SEM pictures demonstrate that the produced sludge is compact and does not have an enormous dimension. According to corresponding EDX (energy-dispersive X-ray spectroscopy), copper content in all recovered sludge is higher than zinc content. After treating wastewater with soda ash, the resulting sludge had a reduced volume and a bigger finished product. Drying processes may be less expensive as a result. Comparatively to other precipitating agents, this is a substantial benefit. In the industrial wastewater of the cable industry, soda ash may be utilized as a reasonably priced precipitating agent for Cu (II) and Zn (II).

Diverse strategies have been investigated in recent research on the removal of heavy metal ions from wastewater, stressing the significance of optimising treatment parameters and utilising economical procedures. Benalia *et al.* demonstrated whether effective precipitating agents may remove copper and zinc from industrial wastewater by using chemical precipitation as their major topic. However, Fu et al. looked into Zn2Cr-LDH's applicability as an adsorbent for treating water and noted that it could almost entirely remove contaminants.

To test its suitability for the treatment of water, batch tests were carried out at the ideal M2/M3 ratio, pH, reaction time, and temperature. The Zn_2Cr-LDH was characterised using Brunauer-Emmett-Teller, X-ray diffraction, FTIS, Scanning Electron Microscopy/Energy Dispersive X-Ray Spectroscopy (SEM/EDS), Transmission Electron Microscopy (TEM), and X-ray Photoelectron Spectroscopy (XPS) analyses before and after adsorption treatment. Under ideal conditions of 50 mg/L of PP, 1 g/L of adsorbent, pH 6, and 6 h of reaction, the Zn_2Cr-LDH was able to virtually fully remove PP. The PP removal by the adsorbent under acidic conditions was regulated by ion exchange. With 79 mg/g of PP adsorption capacity, the PP removal well fits a pseudo-second-order kinetics and/or Langmuir isotherm model. NaOH was utilized to regenerate the utilized Zn_2Cr-LDH with an initial cycle efficiency of 86 %. The treated effluents might meet the discharge limit of 1 mg/L. Overall, the utilisation of Zn2Cr-LDH as an inexpensive adsorbent for wastewater treatment has aided in the advancement of national policy that promotes a resource recovery paradigm for a zero-waste strategy for a circular economy (CE).

6.2. Utilising nanomaterials as sorbents to remove heavy metal ions from wastewater

The widely utilised process of hydroxyl precipitation makes it easier to remove heavy metal ions from wastewater. During this process, a chemical precipitant is often added to the wastewater, such as lime (calcium hydroxide, $Ca(OH)_2$) or sodium hydroxide (NaOH). When the metal ions in the water interact with the hydroxide ions, insoluble metal hydroxide precipitates are produced. The water can then be cleaned of these precipitates by utilising filtration, flotation, or sedimentation techniques. A variety of heavy metals, including lead, copper, cadmium, zinc, and chromium, can be removed using the hydroxide precipitation method. The pH, metal ion concentration, and presence of other interfering compounds in the wastewater are only a few examples of the variables that affect how effective the procedure is. Heavy metal ion removal from wastewater via hydroxyl precipitation is a practical, affordable, and straightforward process with environmental, municipal, and industrial utilizes.

Focusing on nanomaterial adsorbents, [28] mention upcoming difficulties while also discussing synthesis techniques, different kinds of nanomaterials, kinetics, process optimisation, modelling and simulation, and column investigations. It has been found that among various synthesis protocols, Chemical Vapor Deposition was most effective in giving desired attributes. Under ideal processing circumstances, metallic composites and organic nanomaterials, such as nitrocellulose, carbon nanotubes, graphene complexes, and magnetite forms, demonstrated the greatest metal removal capabilities of 1989 mg/g for Hg (II) and 1641 mg/g for Cd (II). To achieve high metal removal capacities, Kolluru highlights the potential of organic nanomaterials including nitrocellulose and carbon nanotubes as well as chemical vapour deposition-produced nanomaterials. By employing a continuous fixed bed column, Venkatraman *et al* 2021 studied the adsorption of chromium (VI), lead (II), and zinc (II) metal ions from the industrial effluent by tobacco leaves covered with iron oxides. The iron oxide nanoparticle-coated nano-adsorbent material is generated chemically, and its properties are examined using a variety of surface morphological techniques. By adjusting the adsorbate concentrations, the height of the adsorbent bed, and the flow rate, breakthrough analysis of the column was investigated. With an optimal flow rate of 5 mL/min, a bed height of 10 cm, and a metal ion concentration of 100 mg/L, the maximum adsorption efficiencies of chromium (VI), lead (II), and zinc (II) were reported to be 92.26 %, 75.57 %, and 89.36 %, respectively. In this adsorption process, kinetic models like Thomas, Yoon-Nelson, and bed depth service time were fitted with the best correlation ($R2 > 0.95$) values. Desorption studies were utilized to assess the column's overall performance, and concentrated hydrochloric acid (0.3 M) was also added to the column to regenerate the adsorbent.

6.3. Electrochemical treatment for removing heavy metal ions

Heavy metal ions can be removed from wastewater using electrochemical treatment. This method utilizes an electrochemical cell with a cathode and an anode that is submerged in the effluent. The application of an electric current causes redox reactions at the electrodes. The type of metal ions in wastewater determines whether they are reduced or oxidised. Reduction reactions change metal ions into metallic forms or stable complexes, while oxidation reactions change them into insoluble hydroxides or oxides. These altered metal species can subsequently be eliminated by membrane filtration, flocculation, or precipitation. Numerous benefits come with electrochemical treatment, including the potential for in situ remediation, the capacity to target specific heavy metal ions and efficiency over a broad pH and metal concentration range. This approach can also be utilized in conjunction with other treatment methods to improve the effectiveness of removing heavy metals altogether. However, to guarantee optimum removal effectiveness and reduce energy consumption in electrochemical treatment procedures, parameters including electrode material, cell design, and operating conditions need to be properly optimised.

Using Metal-Organic Frameworks (MOFs) in commercial products has hit a serious roadblock, but the [29] approach offers hope for progress. ZIF-8 crystals were added to either TEMPO (2, 2, 6, 6-tetramethylpiperidine-1-oxyl radical)-oxidized cellulose nanofibrils (TOCNF) or Cellulose Pulp (CP) using an in-situ or ex-situ approach; these materials were referred to as CelloZIFPaper_In Situ and CelloZIFPaper_Ex Situ, respectively. The materials were utilised as adsorbents to remove heavy metals from water. Their adsorption capabilities ranged from 66.2 to 354.0 mg/g. CelloZIFPaper may also be utilized as a standalone working electrode for the selective sensing of dangerous heavy metals, including lead ions ($Pb2+$), using electrochemical-based techniques with an 8 M Limit of Detection (LOD). The 'Lab-on CelloZIFPaper' technology for label-free detection of heavy metal ions may be improved by the electrochemical measurements.

To generate adsorbents with high metal removal capabilities, Li *et al* demonstrate the incorporation of Metal-Organic Frameworks (MOFs), specifically ZIF-8 crystals, into cellulose-based composites. The resulting materials, CelloZIFPaper_In Situ and CelloZIFPaper_Ex Situ offer promising adsorption capabilities and may be employed as electrodes for the selective detection of heavy metals. Yu *et al* established a special centrifugal electrode reactor for the electrochemical treatment of wastewater containing heavy metals. To improve the treatment of simulated heavy metal wastewater using an aluminium anode, [30] devised and implemented a unique centrifugal electrode reactor. The removal effectiveness of heavy metals was greatly increased by the centrifugal electrodes as compared to the stationary electrodes, according to the results. An enhanced rotating disc electrode system was utilized to examine the electrochemical behaviour of centrifugal electrodes. Instead of passivation under static conditions, the anodic polarisation behaviour of aluminium revealed a common feature of dissolution in centrifugal electrodes. The diffusion of the Cl ion, which was accelerated by centrifugal electrodes, regulated the dissolution of the anode. Anode passivation was therefore decreased. The centrifugal electrode removal of heavy metals from EC also conformed to the Variable-Order-Kinetic (VOK) model based on Langmuir adsorption, per the kinetics research.

6.4. Water purification technologies from heavy metals

Technologies for water purification are essential for removing heavy metals from tainted water sources. To efficiently cleanse water and remove heavy metal ions, several techniques are utilized. With the help of physical and chemical interactions, activated carbon adsorbs heavy metals in one regularly utilized process called activated carbon filtration. Ion exchange, which utilizes resins to selectively bind and swap out hazardous ions for heavy metal ions, is another extensively utilized approach. Another efficient technique is reverse osmosis, which filters out heavy metals using a semipermeable membrane. Additionally, chemical agents are utilized throughout the coagulation and flocculation processes to generate bigger particles that can be easily removed using sedimentation or filtration. Advanced oxidation techniques are utilized to break down and change heavy metal ions into less harmful forms, such as ozonation and ultraviolet (UV) light. To effectively and safely remove heavy metals from water, different heavy metal contaminants and water purification methods can be combined or tailored to specific water sources and heavy metal contaminants.

[31] in the world, particularly in undeveloped or emerging nations, water contamination is one of the major causes of human fatalities. As industrialization and urbanisation increase, water contamination is becoming a threat to public health and quality of life. There are a wide variety of contaminants that can be found in the water, depending on the source. To clean up tainted water, some methods have been utilized. All of the methods have at least one drawback that prevents widespread utilisation, long-term effectiveness, and sustainability. The development of nanoscience and nanotechnology has generated new opportunities for replacing or improving traditional approaches with more effective ones. Currently, water purification utilizes green nanoparticles that were synthesised. Due to the different chemicals required in their production process, nanomaterial-based procedures could harm the environment, undermining the aim of using them in the first place. In this context, green nanomaterials may show to be quite beneficial in terms of efficiency and sustainability.

Given the negative environmental effects of conventional nanomaterials, De *et al* emphasise the significance of using green synthesised nanoparticles for effective and sustainable water filtration. Peydayesh *et al*, on the other hand, look at the effectiveness of hybrid membranes incorporating nanotubes for the exclusion of heavy metal ions. The hybrid membranes have better antifouling qualities, excellent rejection rates, and increased water flux. In a study published in 2020, Peydayesh *et al* examined the effects of varying nanotube loading on the membrane's surface roughness, hydrophilicity, isoelectric point, and mechanical and thermal stabilities. The hybrid membranes showed outstanding heavy metals rejection rates in the following order: Zn (96.7 %) > Mg (95.01 %) > Cd (92.4 %) > Cu (91.9 %) > Ca (91.3 %) > Ni (90.7 %) > Pb (90.5 %). This is because of the Donnan exclusion. Additionally, the composite membranes' pure water flux (PWF) increased by 122 % when compared to the pure PES membrane and reached 80.5 L/m2 h. The membrane's antifouling characteristics are considerably improved by the high surface hydrophilicity and minimal surface roughness. By using the ranking efficiency product (REP), the membranes' total performance was evaluated while taking into account all important parameters. The outcomes showed that the best membrane is produced when nanotubes are added at a loading ratio of 0.6 weight per cent. Finally, the outcomes of this work present a successful method for heavy metal ion removal from water using a PES Nanofiltration membrane combined with an ED-g-MWCNT.

[35,32] evaluated human civilization are sustainable growth and restoration of the ecosystem. Currently, the continuous release of effluents containing heavy metals from tanneries, and the mining, printing, and pharmaceutical industries into the aquatic environment has become a serious issue. Hou *et al.*, 2023 environmentally friendly modified sludge biochar (TBC) was successfully synthesized by modifying sludge with biosynthetic calcium precipitation as a template. TBC effectively activated peroxydisulfate (PDS), achieving a tetracycline (TC) removal efficiency of 95.07 %. Iftikhar *et al.*, 2023 considered current advances in the field of fluorescence sensors developed for the sensing of heavy metals (having higher toxicity concerns) in water bodies. The analysis of the recent advancements reveled the small organic molecules' potential with efficient sensing performances to broaden the scope of practical applications. [35,32] investigated in terms of electrical and optical properties, as well as organic dye adsorption performance. The electrical conductivity reached its maximum value of $3.42 \times 10-2$ S/cm at the optimum FeCl3:Py molar

ratio of 2:1 (P2), while it displayed the lowest optical bandgap energy of 3.72 eV. FTIR results exhibited minor changes in peak intensity with increasing FeCl3:Py molar ratio. [33] explained a series of coumarin-based organic dyes, namely, 4-(naphthalene-1-yl)-2-oxo-2H-benzo[h] chromene-3-carbonitrile loaded over Pt–TiO_2 is referred to as TC-2. Results show that TC-2 photocatalyst depicted enhanced activity of (H2 rate-5.54 mmol − 1 h − 1) under neutral pH (AQY-14.5 %, TON-5970), which is majorly obtained due to the increased conjugation of the naphthalene ring which thereby increases the light-sorption capacity of the materials in comparison to that of the others, synthesized materials in presence of TEOA. [34] explained the impact of the different weight percentages of MWCNTs (1, 3, 5, and 7 wt%) on TiO_2 optical, structural, and morphological properties were investigated. The photodegradation efficiency of TiO2/7 wt% MWCNTs nanocomposite increased from 63.63 % to 92.36 % for MB and 71.56 % to 94.13 % for RhB compared to pure TiO2, after 60 min UV light exposure. [35,32] delve into the influence of calcination temperature, on the structural, optical, and PC activity of CCTO nanoparticles, formulated via the sol–gel procedure. The C900 sample delivered outstanding results in recycle tests, in which it shed merely 8 % of efficiency in the fourth cycle. [36] investigated in presence of ultraviolet (UV) light. Obtained results indicated that PANI/MWCNT NCs with 7 wt% MWCNT showed photodegradation efficiencies of 62.18 %, 59.94 %, and 98.39 % compared to PANI Standalone with efficiencies of 22.17 %, 18.80 %, and 79.80 % for MB, RhB, and MO dyes within 45 min, respectively. [37]: Ti-MOF functionalized with CoS as a cocatalyst for the hydrogen evolution reaction (HER) application using conductive polyaniline (PANI) chain embedding. DFT results demonstrate the importance of CoS in improving the photocatalytic performance of hybrid Ti-MOF catalyst, which leads to superior catalytic behaviour. [38] exhibited the ultrasonic-assisted in-situ chemical polymerization route was used to synthesize polypyrrole-multiwall carbon nanotubes (PPy-MWCNTs) nanocomposites. Almost 99.36 % and 78.30 % of RhB and MB dye degradation were achieved after 35 min of reaction for the highest loading of MWCNTs. Ahmadipour *et al.*, 2021the effects of MWCNT (0, 0.1,0.2, and 0.3 wt%) on the structural, morphological, optical and photocatalytic properties of CaCu3Ti4O12 were investigated using the following methods: XRD, FTIR, HRTEM-EDAX, FESEM, BET surface area, UV–vis, and photodegradation of Rhodamine B (RhB) dye under UV and visible irradiation illumination. [39] a forthright dye removal technique by CCTO/SiO2 core–shell composites produced via chemical precipitation was introduced. The photodegradation efficiency (η%) of core–shell CCTO/SiO2 composite prepared using 1 ml of TEOS was 76.5 % after 40 min exposure to UV light; better than the product from the system with 0.5 ml TEOS. The C1S photocatalyst was very stable with a high photodegradation efficiency of 73.5 % even after 4 cycles of RhB degradation.

7. State of the art of survey

The state-of-the-art for the removal of heavy metal ions from wastewater encompasses a range of advanced techniques. Among these, adsorption-based methods have gained significant attention, with the development of various adsorbents including activated carbon, graphene oxide, nanomaterials, and biochar. These adsorbents offer high surface area and specific interactions, allowing for the efficient removal of heavy metal ions. State of the art survey for the removal of heavy metal ions is shown in Table 3. Additionally, advanced oxidation processes (AOPs) such as photocatalysis, Fenton's reagent, and electrochemical methods have demonstrated promising results in degrading and removing heavy metal ions from wastewater.

Membrane-based technologies like reverse osmosis, ultrafiltration, and nanofiltration have also been explored for their ability to separate heavy metal ions. Furthermore, emerging approaches such as bio-based methods utilizing microorganisms, biofilms, or phytoremediation techniques have shown potential in remediation. Overall, the state-of-the-art emphasizes a multi-faceted approach, combining different techniques and technologies to achieve efficient and sustainable removal of heavy metal ions from wastewater.

Comprehensive coverage of various removal techniques such as

Table 3
State of the Art of Survey for Removal of Heavy Metal Ions.

Reference	Objective	Heavy Metal Ions	Performance Outcomes	Limitations or Future Scope
[11]	Fast and extremely effective removal of HMIs from wastewater using a three-dimensional nanoporous starch-based substance	elimination of HMIs from wastewater swiftly and effectively	Only two peaks at 284.2 eV and 532.0 eV were discovered in the natural starch's broad energy spectrum and were assigned to C1s and O1s, respectively.	Less surprising is the recyclability, which shows promise for custom in environmental clean-up and water purification.
[12]	As a capping agent, Syzygium cumini leaf extract was dissolved in an aqueous solution to generate titanium dioxide nanoparticles (TiO_2 NPs).	Lead (Pb) removal from explosive industrial wastewater	Chemical oxygen demand (COD) was removed by 75.5 %, and lead (Pb2 +) by 82.53 %, according to the results.	Variable synthesis efficiency, a lack of stability for the nanoparticles, or difficulties with process scaling
Chyad *et al*2023	The focus of the work is on Turkish pine cone-derived activated carbon as an efficient adsorbent.	Taking out the ions of zinc (II) from industrial effluent	The sorbent has a bound quantity of Zn + 2.	The alternative strategy won't activate this medium and will increase the effectiveness of heavy metal removal.
Onutai *et al*2020	Explains a rapid and efficient method for making geopolymer polymer composite fibre.	Adsorbent that is reasonably priced and environmentally suitable for extracting HMIs from wastewater	Pb2+, Cd2+, Cu2+, and Ni2 + ions' adsorption experimental data were successfully fitted by the Langmuir model, with correlation coefficients above 0.960, 0.985, 0.982, and 0.927, respectively.	The geopolymer composite fibre either lacks adequate binding characteristics or is not stabilised appropriately.
Li *et al*2022	Analyse the impact of the pre-dissolution period on the elimination of arsenic by Fe_3O_4	Arsenic removal from acidic wastewater	In the pre-dissolution stage, arsenic had an adsorption capacity of 143.99 mg g^{-1}.	Increase the in-situ Fe source and consider the effects of pre-dissolved Fe_3O_4 on the amputation of arsenic from smelting wastewater.
Hosseini *et al*2020	Most effective Nano gatherer for ion subtraction utilising ion flotation, which was stable in an aqueous solution and had high efficiency, low consumption, and was effective in wastewater.	Ion flotation is employed to remove nickel ions from synthetic wastewater.	The impeller speed was 800 rpm, the pH was 9, the nano collector concentration was 0.1 g/L, the SDS concentration was 0.05 g/L, and the flotation time was 10 min.	For potential practical uses, it is critical to evaluate the viability of large-scale manufacturing and the economics of the Nano collector.

adsorption, membrane filtration, biological methods, and precipitation should be provided, elucidating their mechanisms, applications, and efficacy in addressing heavy metal contamination. Additionally, a thorough examination of experimental conditions, including factors such as pH, temperature, contact time, and dosage, is essential to understanding the operational parameters influencing removal efficiency. Moreover, insights into recent advancements and innovations in the field, such as the utilization of novel materials, integration of hybrid approaches, and development of sustainable practices, should be discussed to underscore the ongoing evolution and improvement of heavy metal removal technologies.

Comparative Analysis.

In the realm of wastewater treatment, the selection of an appropriate method for heavy metal ion removal is crucial to mitigate environmental contamination and safeguard human health. This comparative analysis delves into various techniques employed for the removal of heavy metal ions from wastewater, scrutinizing their efficacy, operational conditions, and practical feasibility. By juxtaposing these methods, this study aim to discern their relative advantages and limitations, thereby facilitating informed decision-making for efficient wastewater management practices.

Method	Removal Efficiency (%)	Experimental Conditions
Adsorption	High	pH: 3–9, Temperature: 25–35 °C, Contact Time: 1–24 h, Adsorbent Dosage: 1–10 g/L
Membrane Filtration	Variable	Pressure: 1–10 bar, Temperature: 20–40 °C, pH: 2–10, Membrane Pore Size: 0.1–0.5 μm
Biological Methods	Moderate to High	pH: 5–9, Temperature: 20–35 °C, Retention Time: 1–7 days, Microbial Concentration: 10ˆ5–10ˆ8 CFU/mL
Precipitation	Moderate to High	pH: 6–11, Temperature: Ambient, Stirring Speed: 100–500 rpm, Precipitant Dosage: 1–10 g/L

The comparison table outlines various methods for removing heavy metal ions from wastewater, highlighting their removal efficiency and corresponding experimental conditions. Adsorption emerges as a highly efficient technique, with a removal efficiency ranging from moderate to high, depending on factors such as pH, temperature, contact time, and adsorbent dosage. Membrane filtration, while offering variable removal efficiency, depends on parameters like pressure, temperature, pH, and membrane pore size. Biological methods demonstrate moderate to high removal efficiency, contingent upon factors such as pH, temperature, retention time, and microbial concentration. Lastly, precipitation exhibits moderate to high removal efficiency, influenced by parameters like pH, temperature, stirring speed, and precipitant dosage. These insights into the operational conditions and efficacy of each method provide valuable guidance for selecting appropriate strategies to address heavy metal ion contamination in wastewater treatment processes.

8. Current trends and developments in traffic flow prediction

The field of eliminating heavy metal ions from wastewater is now characterised by several notable trends and advancements. The growing focus on the creation of environmentally friendly and sustainable methods is one obvious trend. Researchers are investigating cutting-edge methods like the utilisation of organic waste, biochar, and natural adsorbents as economical and sustainable alternatives to conventional chemical treatments. The development of nanotechnology-based techniques that employ nanomaterials for efficient heavy metal ion adsorption and removal, such as nanoparticles and nanocomposites, is another trend. Additionally, combining cutting-edge technologies like photocatalysis, membrane filtration, and electrochemical processes has shown promise in improving the efficacy and selectivity of heavy metal ion removal. The ongoing research in these fields aims to tackle the problems brought on by heavy metal contamination in wastewater and open the door to more efficient and long-lasting water treatment methods. The following are some current trends and advancements in the field of heavy metal ion removal from wastewater:

Advanced Adsorbents: For improved heavy metal removal, scientists are investigating the utilisation of cutting-edge adsorbents such as metal–organic frameworks (MOFs), graphene oxide, nanomaterials, and activated carbon. Wastewater treatment is improved by these materials' wide surface area, increased selectivity, and potent adsorption capacity.

Membrane Technologies: For the removal of heavy metals, membrane-based separation techniques including reverse osmosis, nanofiltration, and ultrafiltration are becoming more and more common. These processes selectively remove heavy metal ions from water using semi-permeable membranes, which offers high removal efficiency and results in treated water of superior quality.

Electrochemical Methods: For the removal of heavy metals, electrochemical processes like electrocoagulation, electroflotation, and electrochemical precipitation are being investigated. These techniques utilize an electric current to help heavy metal ions precipitate or coagulate, allowing for their separation from the effluent.

Biological Treatment: Research is being done on the possibility of heavy metal removal provided by bioremediation techniques using bacteria or plants. The benefits of bioremediation include being economical, environmentally benign, and able to handle vast amounts of wastewater. The removal of heavy metals from contaminated water sources appears to be made possible by the employment of particular bacterial strains, fungi, and plants with metal-accumulating properties.

Hybrid Approaches: To increase the effectiveness of heavy metal removal, researchers are also concentrating on creating hybrid techniques, which integrate several different treatment modalities. The advantages of several techniques, including adsorption, precipitation, and biological processes, can be optimised by these integrated systems, resulting in a more thorough and effective removal of heavy metal ions. Aiming to increase the efficacy, efficiency, and sustainability of the treatment processes, current trends and advancements in heavy metal ion removal techniques from wastewater eventually seek to produce cleaner and safer water resources. The scientific rigour of the presentation could be enhanced by providing more detailed information about the experimental methodologies employed in each removal method. This includes specifying the specific experimental conditions, such as pH, temperature, contact time, and adsorbent dosage for adsorption methods, or pressure, temperature, pH, and membrane pore size for membrane filtration methods. Additionally, the advantages and disadvantages of each method should be discussed thoroughly, including any limitations or challenges encountered during experimentation. This would contribute to a more comprehensive understanding of the effectiveness and feasibility of each removal method, thereby enhancing the scientific validity and credibility of the study.

9. Research problem definition and motivation

Technologies for the removal of heavy metal ions from wastewater are being developed due to the necessity of addressing the growing issues around water pollution brought on by heavy metal contamination. Urbanisation and growing industry have led to the leakage of heavy metals into water sources, which is a severe worry for water treatment facilities and environmental agencies. Due to the harmful effects of heavy metals on aquatic ecosystems and human health, innovative and sustainable methods for effectively removing these pollutants from wastewater are needed. Researchers hope to help water treatment experts, decision-makers, and environmentalists make wise choices about wastewater management and pollution prevention by acquiring insights into the most recent developments in heavy metal removal strategies. The research's ultimate objective is to help generate effective, environmentally friendly techniques for removing heavy metal ions from wastewater, ensuring the availability of safe, clean water resources for both the present and the future. When found in water supplies, heavy metals like lead, mercury, cadmium, and arsenic pose serious threats to the environment and public health. Their primary sources of accumulation in wastewater include industrial processes, urban runoff, and agricultural practices. Conventional wastewater treatment methods typically fall short in their capacity to successfully remove these heavy metal ions, resulting in their release into natural water bodies and the potential for adverse environmental and health effects. Investigating and evaluating alternative methods for the efficient removal of heavy metal ions from wastewater is required to preserve water resources, guarantee the health of ecosystems, and protect human populations.

10. Contribution of the research study

Investigating and assessing various methods and approaches for effectively and efficiently removing heavy metal ions from wastewater is the objective of the study on methods for heavy metal ion removal from wastewater. The objective is to identify and evaluate the benefits, drawbacks, and efficacy of various treatment techniques, including chemical precipitation, adsorption, electrochemical treatment, membrane filtration, and methods based on nanotechnology. To provide long-lasting and affordable heavy metal ion removal solutions, the research intends to provide a thorough understanding of the processes, kinetics, optimisation, and viability of these technologies. The objective is also to investigate current trends, advancements, and upcoming technologies in this area while taking into account elements like environmental effects, resource recovery, and the possibility of widespread utilisation. The research's ultimate objective is to help generate effective and dependable techniques for removing heavy metal ions from wastewater, which will reduce water pollution and protect both human health and the environment.

11. Conclusion and future scope

Significant environmental harm from wastewater pollution includes ecosystem destruction, threats to human health, and other negative effects. This review article focused on the presence and effects of heavy metals as pollutants, highlighting the significance of wastewater in environmental deterioration. Wastewater discharge has a significant impact on ecosystems, upsetting natural rhythms and deteriorating water quality. Heavy metals, which are infamous for being harmful and persistent, are a major contributor to this pollution. Their toxicity and property classification offer information about their possible dangers. The substantial health risks that heavy metals bring to living things and the environment are highlighted by their toxicity and carcinogenicity. As contaminants, heavy metal ions harm soils, water bodies, and air quality, which has far-reaching repercussions on both aquatic and terrestrial ecosystems. Additionally, the sources of hazardous heavy metals, such as industrial discharges, agricultural runoff, and urban wastewater, add to their environmental presence and subsequent negative impacts on human health. The adoption of sustainable practices and concentrated efforts are necessary to combat environmental contamination and ensure sustainable futures. This entails putting in place suitable wastewater treatment infrastructure, encouraging ethical business practices, and fostering environmental stewardship. The future potential for techniques to remove heavy metal ions from wastewater lies in the creation of novel and environmentally friendly ways. To improve adsorption capabilities and selectivity, this includes researching cutting-edge adsorbent materials such as nanomaterials and functionalized materials. Improved removal efficiency can be achieved by combining different treatment methods, such as adsorption, precipitation, and membrane filtering. The utilisation of nanotechnology, cost-effective process optimisation, and application of these techniques in real-world settings will also help to remove heavy metal ions from wastewater practically and effectively. Overall, the development of environmentally sound and commercially feasible techniques to ensure the preservation of water resources from heavy metal contamination is a possibility in the future.

Summary.

The current state of the study reveals various techniques and technologies employed to mitigate the environmental and health hazards posed by heavy metal contamination in wastewater. These methods include adsorption, membrane filtration, biological processes, and precipitation, among others. Despite the availability of these techniques, there are limitations in their efficiency, scalability, and cost-effectiveness. Many existing methods are either unable to completely remove heavy metal ions or require extensive resources and infrastructure, making them impractical for widespread implementation, particularly in resource-limited settings. This study is necessary to address these limitations and advance the field of heavy metal ion removal from wastewater. By exploring innovative approaches and optimizing existing methods, the study aims to enhance the efficiency, affordability, and sustainability of heavy metal removal processes. Additionally, the study seeks to identify gaps in current research and technology, paving the way for the development of novel solutions tailored to specific environmental contexts and wastewater compositions. Ultimately, the study's findings will contribute to the protection of human health and the environment by facilitating the implementation of effective and accessible wastewater treatment strategies worldwide.

CRediT authorship contribution statement

Sonali R. Dhokpande: Conceptualization. **Satyajit M. Deshmukh:** Data curation, Conceptualization. **Ajinkya Khandekar:** Data curation, Conceptualization. **Amaya Sankhe:** Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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