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Systematic Review of Phytoremediation: Efficacy of Aquatic Plants in Wastewater Treatment and Pollutant Removal

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ABSTRACT

The swift process of industrialization and urbanization in our society has resulted in a growing issue of wastewater production, which presents a substantial danger to ecosystems and human well-being. This study examines the efficacy of aquatic plants in wastewater treatment by using their innate ability to remove pollutants. Water hyacinth (Eichhornia crassipes), water lettuce (Pistia stratiotes), and duckweed (Lemnaceae) are types of aquatic plants that have been thoroughly researched due to their capacity to cleanse domestic, industrial, agricultural, and wastewater. This study encompasses a range of studies completed from 2014 to 2024, which investigate the efficacy of different aquatic plants in eliminating contaminants and provide insights into the specific mechanisms employed by these plants. Research has revealed remarkable findings, indicating that specialist plants have the ability to eliminate pollutants, including nitrogen, phosphate, and heavy metals, with an efficiency of up to 100%. Furthermore, the incorporation of these plants into wetlands and natural purification systems has been demonstrated to enhance the purification process by stimulating increased biomass production and the absorption of noxious gases. Future research should give priority to genetically modifying plants to enhance their capacity for absorbing contaminants and to develop integrated systems for treating wastewater. In summary, this study showcases the capacity of aquatic plants to serve as a highly effective and eco-friendly substitute for wastewater treatment. Implementing phytoremediation techniques can enhance the sustainability of water management practices and aid in safeguarding our ecosystems and the health of society.

Key Words	Aquatic Plants, Water Pollutant, Waste Water, Environmental Health
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INTRODUCTION

As the outcome of industry, population growth, and urbanization, a significant quantity of wastewater is discharged into the environment. Population increase and economic development have a significant influence on water pollution, causing detrimental effects on ecosystems and presenting the most significant environmental hazard.(Bashir et al., 2020). Wastewater treatment is a very efficient method of restoring wastewater to its initial condition following industrial, home, or municipal utilization. Phytoremediation, utilizing aquatic plants, has gained popularity during the past twenty years. The objective of this assessment is to determine the most effective aquatic plants for the treatment of wastewater by doing a thorough examination of current models. Phytoremediation is a sort of biological treatment that can be implemented by different ways, including phytoextraction, rhizosphere filtration, phytostabilization, and phytotransformation. This technique facilitates the photosynthesis and proliferation of specific plants, enabling them to acclimate to pollution and eliminate organic or inorganic contaminants.(Silva, 2023) The fundamental aspects and qualities of the operation rely on the process of degradation, extraction, transformation, or detoxification. This procedure is conducted within a well or pond that has a depth ranging from 0.4 to 1.5 meters. Employ strategies to regulate the proliferation of aquatic vegetation in wetland ecosystems.(Kaur et al., 2020)

Rendering to the United Nations, a portion of the wastewater from both public and industrial sources is released without undergoing any treatment in developing countries. Wastewater can be utilized for irrigation in underdeveloped nations with scarce water supplies, which presents a health risk to the population while also supplying nutrients to agricultural systems.(S. Mishra et al., 2023) Wastewater may contain non-biodegradable heavy metals such as zinc (Zn), nickel (Ni), copper (Cu), chromium (Cr), mercury (Hg), cadmium (Cd), lead (Pb), and arsenic (As), along with a substantial quantity of agriculturally significant nutrients.(Zaynab et al., 2022) As a effect, there is an increasing worldwide interest in environmentally sustainable technology for treating wastewater that allow for the reuse of essential nutrients.(Ugwuanyi et al., 2024) In addition to industrial activities, the photo engraving technique, which is also referred to as metal engraving, photochemical treatment, or chemical milling, has the potential to contaminate water sources with different amounts and combinations of metal ions. Annually, substantial amounts of agricultural waste are generated globally. Some of these agricultural wastes are directly disposed of in water bodies, resulting in significant water pollution.(Bokov et al., 2021) In addition, disposing of kitchen trash into untreated or improperly treated wastewater can result in several detrimental environmental consequences, such as the introduction of hazardous materials (HMs). Exceeding the sensitivity threshold of specific metals can be hazardous to both humans and other biological systems. As a result, the issue of water contamination by heavy metals is a significant worry in many developing countries, impacting both the quality of drinking water and the health of the aquatic ecosystem.(Elbasiouny et al., 2021a) Consequently, it is imperative to meticulously regulate and supervise HM levels to guarantee compliance with the specific environmental criteria for each type of water source. The majority of heavy metals (HMs) are regarded as elemental remnants, present in small quantities (parts per billion: < 10 ppm) in different environmental matrices. Significant quantities of municipal waste, untreated industrial waste, & significant quantities of agrochemicals have been discharged into exposed lakes and rivers at alarming concentrations, leading to a rise in the concentration of heavy metals (HMs) and a deterioration in water quality.(US EPA, 2015) The escalating global need for drinkable water, coupled with the need to address water pollution, has become a critical concern owed to its potential to induce cancer, Parkinson's disease, Alzheimer's disease, anemia, and negative impacts on the gastrointestinal, neurological, skeletal, and cutaneous systems.(Shetty et al., 2023)

Plants serve as the main reservoir of nourishment, textiles, and energy. Nevertheless, a number of aquatic plants possess the ability to eliminate contaminants present in wastewater. The presence of toxic contaminants in synthetic compounds has experienced a significant surge throughout ecosystems in recent times. Water supplies are contaminated with toxic contaminants, including solvents, pesticides, dyes, and other chemicals, resulting in ecological harm.(Aziz et al., 2023) Aquatic plants have a significant role in the removal of detrimental pollutants. Aquatic plants, such as Water Typha, Colocasia Hyacinth, Canna, Arabica, and other plant species are employed for the purpose of eliminating toxic substances from water. These aquatic plants effectively absorb both organic and inorganic contaminants in their environment through competition.(Carvajal-Flórez & Santiago-Alonso Cardona-Gallo, 2019; Hendrasarie & Redina, 2023). Water hyacinth plants could potentially treat almost all types of wastewater (Panday & K., 2023). The term used to describe this process is "phytoremediation". The presence of polluted water, coupled with a limited supply of water, has exerted a substantial burden on the environment. Water scarcity impacts more than 40% of the global population due to climate change, increasing food demand, rapid urbanisation, and unsustainable utilisation of natural resources.(WORLD-SCIENTIFIC-NEWS, 2023) Discharging waste material and residues into water bodies can have fatal repercussions for marine ecosystems, presenting significant hazards to both the environment and human life. Therefore, it is crucial to expose wastewater to suitable treatment and purification procedures before releasing it into the environment. Currently, traditional methods of wastewater treatment do not consistently achieve the desired level of contaminant reduction in the water.(Medeiros et al., 2022) Therefore, trace levels of contaminants may still be present in the purified water. Due to the hazardous properties of pollutants, these substances have the potential to pose a threat to the ecosystem and disrupt many cellular processes in plants. Contaminated wastewater poses significant risks to both the well-being of aquatic organisms and the total health of the environment. Wastewater reclamation is sole remaining option to address the increasing need for water in the agricultural and industrial fields.(R. K. Mishra et al., 2023)

Although phytoremediation utilising aquatic plants for wastewater treatment has been increasingly popular in the last twenty years, there is a significant lack of systematic research on identifying the most efficient aquatic plants for this specific purpose. Prior research has predominantly concentrated on individual plant species or limited features of phytoremediation, lacking a comprehensive evaluation that compares diverse species and their capacities in varied situations. In addition, while the individual processes of phytoremediation, such as phytoextraction and rhizosphere filtration, have been studied, there is a lack of comprehensive research that combines these findings to provide a clear evaluation of the overall efficacy of phytoremediation techniques. In light of the increasing global attention towards sustainable wastewater treatment technologies and the urgent need to address water pollution and scarcity, it is imperative to carry out a methodical evaluation. This evaluation aims to collect and arrange up-to-date material, determine the most efficient approaches, and offer direction for future research and implementation efforts. This review aims to resolve the issue by doing a comprehensive analysis of existing models and identifying the most effective aquatic plants for the purpose of wastewater treatment.

Aim

The objective of this systematic review is to assess and determine the most efficient aquatic plants for the removal of contaminants and the purification of wastewater. This review aims to assess the efficacy and versatility of various phytoremediation techniques, offering a thorough examination of current models and practices to inform future research and use in sustainable wastewater treatment technologies. The review question involves,

1. What are the effective aquatic plants for removing pollutants and purifying wastewater?
2. What are the methods for eliminating pollution in wastewater?
3. What are the Wastewater treatment mechanisms employed by aquatic plants?
4. How do different phytoremediation methods compare in terms of efficiency and adaptability in various environmental contexts?

Methods

This is a comprehensive and methodical review. To locate databases containing references, a variety of internet search engines were also employed. The review questions had a direct impact on the exact criteria that were employed to select the research. Written justifications were provided for both inclusion and exclusion.

The inclusion criteria were as follows.

1. Studies published within the last 10 years (2014-2024) to ensure the review includes recent advancements.
2. Research focusing on various aquatic plants used for phytoremediation, including but not limited to Water Hyacinth, Canna, Colocasia, and Typha.
3. Studies examining different phytoremediation methods such as phytoextraction, phytostabilization, and phytotransformation.
4. Studies addressing a range of pollutants, including heavy metals, organic contaminants, nutrients, and other common wastewater pollutants.
5. Research conducted in various environmental contexts, including industrial, domestic, municipal wastewater, and agricultural runoff.
6. Studies published in English.

The Exclusion criteria were as follows,

1. Non-peer-reviewed articles, editorials, opinion pieces, and conference abstracts.
2. Research focusing on terrestrial plants or non-plant-based wastewater treatment methods.
3. Studies focusing on pollutants not typically found in wastewater or not relevant to water purification

The chosen studies underwent a comprehensive quality review utilising broad criteria for critical evaluation. The PEO factors were considered to assess any potential impact of aquatic plants in removing pollutants from waste water.

Search Strategy: The selected databases were utilised throughout the entire data collection process in this investigation. We conducted a thorough search on Pubmed, CINAHL, and Medline. To minimise data saturation, keywords were searched using logical operators and keywords like {“plants” (MeSH Terms) OR (“Phytoplankton” (All Fields) AND “water” (All Fields) AND “pollution” (All Fields)) OR “Biodegradation” (All Fields) OR (“Phytoremediation” (All Fields) AND “Environmental Pollutants” (All Fields)) OR “metals, heavy” (All Fields)}). Furthermore, the reference lists of all the discovered papers were examined to find other qualifying publications. The study adhered to the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) standards. In order to ensure that the updates are based on reliable research, we have only included papers from the past 10 years.

Study Selection

The procedure for choosing these papers entailed an initial assessment of the titles and abstracts, followed by a comprehensive analysis of the whole articles. After the selection process, a consensus meeting was organised to resolve the disagreements, and the third author's input was used as a deciding factor. Disputes among researchers on the appropriateness of an article for inclusion were settled by convening a meeting of the three authors to reach a consensus.

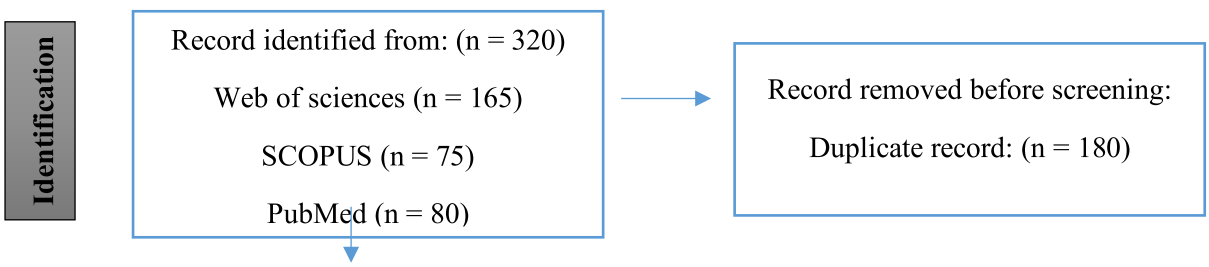
Data Extraction

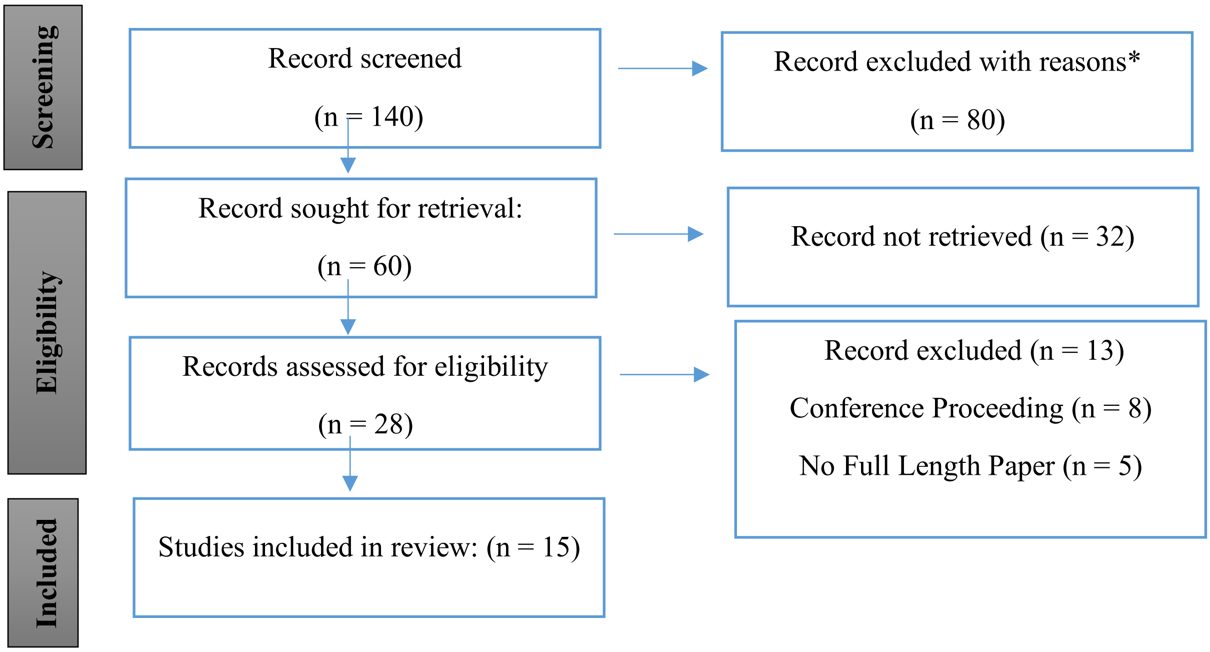
Two researchers independently collected data using a standardized form and later verified the accuracy of the information. Disagreements were settled by reaching a consensus. Each study collected data on the name of the initial author, the year of publication, the geographic location, the methodology used in the study, the types of plants studied, the type of wastewater used, and the nutrient uptake or removal efficiency that was of interest.

Assessment of quality of papers

The majority of studies focused on school-age children and adolescents upto 18 years of age. The median quality score of the included studies, calculated using the modified Newcastle-Ottawa Quality Assessment Scale (Herzog et al. 2013), was seven points (range 2–9). Eleven papers were deemed to be of better quality The remaining studies were of lesser quality generally because of the research samples’ poorer representativeness, their lack of study power, or their insufficient ability to adjust for potential confounding variables during analysis. The quality check was done by two authors.

Search Results





*In sufficient data (22), non-English language (14), Outcomes are not relevant (44)

Figure 1. Prisma Flowchart

After performing a Boolean search to identify relevant phrases, the terms were sorted using various filters based on the inclusion criteria. This process resulted in the identification of 320 pertinent records, with 165 entries discovered in Web of Science, 75 in SCOPUS, and 80 in PubMed. The review adhered to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines for documenting findings, and flow diagrams were created to illustrate the selection process (Figure 1).

During the initial stages, various aspects were excluded due to their lack of relevance to the subject matter of the study. Specifically, 180 duplicate articles were eliminated. Subsequently, a thorough examination of each article's abstract was conducted. Two independent reviewers screened 140 records, excluding 80 for the following reasons: 22 records contained insufficient data, 14 were in non-English languages, and 44 had outcomes not relevant to the study.

Out of the remaining 60 records sought for retrieval, 32 could not be retrieved. Ultimately, 28 records were assessed for eligibility, resulting in the exclusion of 13 additional records. Consequently, a total of 15 papers met the inclusion criteria and were included in the final evaluation.

Results

The studies are summarized in Table 1 below. The synthesis of results adopted a convergent approach, amalgamating a plethora of outcomes gathered. The publications from different countries, such as China (Chen et al., 2019; Lu et al., 2018; Zhou et al., 2019) , India (Ansari et al., 2020; Gupta & Tyagi, 2022; R. K. Mishra et al., 2023; Sompura et al., 2024), Argentina

(Maine et al., 2022), Brazil (Escoto et al., 2019), Pakistan (Raza et al., 2023), Malaysia(Mohd Nizam et al., 2020; Mustafa & Hayder, 2021), Thailand (Sricoth et al., 2018), Sri Lanka (Wickramasinghe & Jayawardana, 2018) and Egypt (Saleh et al., 2020), to explore the possible usage of aquatic plants for this purpose. For this work, a systematic mapping review procedure was employed. The primary objective of this review paper is to examine the latest advancements in wastewater phytoremediation methods. It aims to identify the limitations and places within the phytoremediation process that may necessitate future research. Up until this point, over 20 aquatic plants have been mentioned in this article. This document offers comprehensive guidance for researchers in selecting suitable facilities and determining the optimal hydraulic retention period for conducting wastewater treatment tests.

Table 1 depicts the study characteristics and details are discussed as follows,

Authors	**Type of study**	**Plants**	**Classification of wastewater**	**Remediation**	**Desired nutrient absorption/ Efficiency of nutrient removal**
Lu Bin, et al (2018) Shanghai, China	Experimental Research Study	Water hyacinth and Water lettuce	polluted rural rivers	Situ remediation.	TN and NH_4^+-N & phosphorus.
Ansari, Abid Ali, et al (2020) India	Literature review	water hyacinth (Eichhornia) and Lemnaceae Azolla, Eichhornia, Lemna, Potamogeton, Spirodela, Wolfia, and Wolfialla	Bioremediation of contaminated waters	Phytoremediation, Bioaccumulation	Despite their hazardous attributes, there are elevated levels of heavy metals, phenols, formaldehydes, formic acids, acetic acids, and oxalic acids. Similarly, the proportion of biological oxygen demand (BOD), chemical oxygen demand (COD), and different ionic forms of nitrogen and phosphorus.
Hadad, Hernán Ricardo, et al., (2022) Argentina	Experimental Research Study	Pontederia rotundifolia, Typha domingensis	peri-urban wetlands	Phytoremediation	Chromium, Nickel, Zinc, Lead, total phosphorus (TP), and total Kjeldahl nitrogen (TKN)
Escoto, Dandara Fidélis, et al, (2019) Brazil	Experimental Research Study	Pistia stratiotes	clomazone in water	Phytoremediation	LCT and HCT

Chen, Guoke, et al., (2019) China	Experimental Research Study	Duckweed	rural wastewater	Phytoremediation and bioremediation	NO3−-N and TN
Zhou, Qi, et al., (2019) China	Experimental Research Study	Duckweed	swine wastewater	Phytoremediation	ammonia nitrogen (NH3single bondN) and total phosphorus (TP) increased at 0.1–1.0 mg/L of Cu2+, while dropped at 2.0–5.0 mg/L of Cu2+.
Raza, Mahnoor, et al, (2023) Pakistan	Experimental Research Study	water lettuce (WL), alligator weed (AW), pennywort (PW), and duckweed (DW)	household and industrial wastewater	Phytoremediation	lead (Pb), zinc (Zn), phosphate, sulfate, potassium.
Mohd Nizam, Nurul Umairah, et al., (2020) Malaysia	Experimental Research Study	Centella asiatica, Ipomoea aquatica, Salvinia molesta, Eichhornia crassipes, and Pistia stratiotes	Aquaculture Wastewater	Phytoremediation	Suspended solids (TSS), ammoniacal nitrogen (NH3-N), and phosphate.
Sricoth, Theeta, et al., (2018) Thailand	Experimental Research Study	Typha angustifolia and Eichhornia crassipes	Market wastewater	Phytoremediation	NO3 −-N, NH3-N, and metal (Pb, Cd, and Zn)
Wickramasinghe, S., & Jayawardana, C. K. (2018) Sri Lanka	Experimental Research Study	Eichhornia crassipes (water hyacinth), Pistia stratiotes (water lettuce) and Salvinia molesta (water fern)	Textile wastewater	Phytoremediation	Chemical oxygen demand (COD), total solids (TS), total suspended solids (TSS), total dissolved solids (TDS), nitrates, phosphates, and heavy metals such as cadmium (Cd), nickel (Ni), and zinc (Zn).

Mustafa, H. M., & Hayder, G. (2021) Malaysia	Review paper	S. molesta plants	Domestic wastewater	Phytoremediation	turbidity, phosphate, ammoniacal nitrogen and nitrate
Kumar, S., & Deswal, S. (2020) India	Experimental Research Study	water hyacinth, water lettuce, salvinia, and duckweed	rice mill wastewater	Phytoremediation	phosphorus (TP) and chemical oxygen demand (COD)
Saleh, Hosam M., et al., 2019 Egypt	Experimental Research Study	Ludwigia stolonifera	Biological treatment of wastewater	Stabilization and Solidification	Cu, Fe and Mn
Gupta, A., & Tyagi, T. (2022) India	Experimental Research Study	E. crassipes	Industrial wastewater	Phytoremediation	Cd, Cr, Co, Ni, Pb, and Hg
Sompura, Yashwant, et al., (2024) India	Literature review	Eichhornia crassipes, Pistia stratiotes, and Lemna minor	Polluted wastewater	Phytoremediation with Genetic Engineering Enhancements	Iron (Fe), manganese (Mn), zinc (Zn)

Discussion

Efficacy of the plants

Several extensive research has been carried out to explore the possible applications of plants in the treatment of wastewater. Only research conducted from 2015 onwards that focused on the use of aquatic plants for wastewater treatment were chosen for link with this review article. Table 1 summarises the findings of our study, which examined several papers on wastewater phytoremediation. Some researchers focused on individual plants and provided detailed information on their effectiveness in treating wastewater. Meanwhile, other researchers studied multiple species for this purpose.

A combination of aquatic plants, such as water hyacinth and water lettuce, can effectively improve water quality. The researchers found that water hyacinth had the highest removal rates for TN (89.4%) and NH_4^+-N (99.0%), whereas water lettuce had the highest removal efficiency for total phosphorus (93.6%).(Lu et al., 2018)

However, Azolla, Eichhornia, Lemna, Potamogeton, Spirodela, Wolfia, and Wolfialla are effective phytoremediators. These aquatic plant species have the ability to significantly reduce water pollution by accumulating pollutants in their tissues (Ansari et al., 2020) .Water hyacinth (Eichhornia) is extremely resilient and can withstand high levels of heavy metals (Lu et al., 2018), Phenols, formaldehydes, formic acids, acetic acids, and oxalic acids are toxic chemicals that are frequently present in water. (Ansari et al., 2020). P. stratiotes demonstrates notable resilience to clomazone exposure and efficiently eliminates as much as 90% of the herbicide residues. Pistia stratiotes has been found to be a potent phytoremediation agent for the herbicide clomazone in water, according to a study.(Escoto et al., 2019) The review demonstrated the efficacy of five aquatic plants, namely Centella asiatica, Ipomoea aquatica, Salvinia molesta, Eichhornia crassipes, and Pistia stratiotes, in effectively eliminating three pollutants, specifically total suspended solids (TSS), ammoniacal nitrogen (NH3-N), and phosphate, from aquaculture waste water.(Mohd Nizam et al., 2020)

The potential of using locally abundant aquatic plants, such as Eichhornia crassipes (water hyacinth), Pistia stratiotes (water lettuce), and Salvinia molesta (water fern), for phytoremediation in the treatment of textile wastewater has also been highlighted. The efficacy of lowering chemical oxygen demand (COD), total solids (TS), total suspended solids (TSS), total dissolved solids (TDS), nitrates, phosphates, heavy metals (Cd, Ni, and Zn), as well as total and faecal coliform was measured by the wastewater treatment plants.(Wickramasinghe & Jayawardana, 2018) Salvinia molesta and Pistia stratiotes, two species of aquatic plants, have been widely used for the treatment of agricultural, household, and industrial wastewater. The widespread use of these plants can be due to their wide availability, ability to thrive in unfavorable environments, capacity for bioaccumulation, invasive nature, and great potential for biomass production.(Mustafa & Hayder, 2021) Water lettuce shown the most effectiveness in decreasing phosphorus (TP) and chemical oxygen demand (COD), with water hyacinth, duckweed, and salvinia following suit.(Kumar & Deswal, 2020) E. crassipes is an aquatic invasive plant that has a strong inclination to absorb toxins from water, particularly heavy metals. This facility is very conducive for the utilization of living organisms to cleanse industrial wastewater contaminated with the heavy metals Cd, Cr, Co, Ni, Pb, and Hg. In addition, E. crassipes has the capability to eliminate pollutants aside from heavy metals, including cyanide, making it highly beneficial in regions involved in gold mining.(Gupta & Tyagi, 2022)

Similarly, multiple plants belonging to the Lemna family has the capacity to significantly reduce levels of biochemical oxygen demand (BOD), chemical oxygen demand (COD), and also alleviate the effects of heavy metals (HM) and different types of ions. The citation (Ansari et al., 2020) Aquatic macrophytes, including Eichhornia crassipes, Pistia stratiotes, and Lemna minor, have shown promise in utilizing phytoremediation to cleanse wastewater and eliminate heavy metals.(Sompura et al., 2024).

Roots of Pontederia rotundifolia had the most elevated concentration of Pb. Typha domingensis had the greatest levels of Cr, Ni, and Zn, which aligns with the highest concentration found in the sediment. Peri-urban wetlands require plants with a large amount of biomass, such as T. domingensis, in order to effectively remove metals from water.(Maine et al., 2022)

The introduction of a microbial carrier did not affect the growth and biomass components of duckweed. The CDW system unveiled the subsequent characteristics. The removal efficiencies of NO_3^--N and TN were much higher compared to the other two systems, reaching a maximum of 80.02% and 56.42%, respectively. Furthermore, Illumina sequencing demonstrated the utmost microbial diversity. Furthermore, a clear and sequential progression of microbial community was found.(Chen et al., 2019) Efficiency of removing ammonia nitrogen (NH_3-N) and total phosphorus (TP) rose when the concentration of Cu^{2+} was between 0.1 and 1.0 mg/L, but decreased when the concentration of Cu^{2+} was between 2.0 and 5.0 mg/L. A unique kinetic model incorporating Cu^{2+} was subsequently created and utilised to optimise the concentration of Cu^{2+} at 0.96 mg/L for efficient nutrient removal in duckweed systems.(Zhou et al., 2019) The use of duckweed and pennywort in treating effluent resulted in complete removal of lead (Pb) from industrial wastewater, while achieving an 81% removal rate. Additionally, the treatment using AW achieved a complete removal of Pb from domestic wastewater.(Raza et al., 2023) T. angustifolia and E. crassipes have comparable carbon content (about 35%), hydrogen content (around 6%), and gross calorific value. Eichhornia crassipes had ash content of up to 16.9% and moisture content of 65.4%. T. angustifolia has the potential to serve as an alternate energy source in addition to its ability to cleanse wastewater, according to its significant biomass production.(Sricoth et al., 2018) .Efficacy of Ludwigia stolonifera, a wetland plant displayed effective removal three hazardous metals, namely Pb, Cd, and Cr. The plant's ability to survive has been examined in solutions with varying concentrations of three individual metals or as a combination, and the long-term accumulation of these harmful metals has been assessed.(Saleh et al., 2019)

Methods for eliminating pollution in wastewater:

Prioritisation of treatment has been given to polluted aqueous solutions to prevent their entry into natural water bodies. Bioremediation, electrocoagulation, chemical precipitation, membrane separation, ion-exchange resins, adsorption, coagulation, reduction, reverse osmosis, evaporation, solvent extraction, and flocculation are various techniques used to eliminate heavy metals from water-based solutions. Each of these strategies has advantages and disadvantages. However, most of these procedures are costly and inefficient in terms of removing dangerous substances from large amounts of water. Furthermore, these advantages include non-selectivity, elevated energy consumption, and dependence on chemical compounds, all of which necessitate meticulous removal of the resultant perilous waste. Adsorption is the preferred method for eliminating hazardous pollutants due to its high efficiency, cost-effectiveness, simple design, and user-friendly nature.(Elbasiouny et al., 2021b) Adsorption is a well-recognised and reliable technology that is preferred by many sectors. Activated carbon, fly ash, peat, woody biomass, zeolites, sewage sludge ash, and other biomaterials have demonstrated significant efficacy in the removal of certain metals, such as lead and cadmium, from wastewater. Aquatic plants such as water primrose (Ludwigia stolonifera), water hyacinth (Eichhornia crassipes), blue water well (Veronica anagallisaquatica), and duckweed (Lemna gibba) have effectively eliminated heavy metals (HMs) from aquatic settings. Aquatic organisms have the capacity to absorb and immobilize hazardous metals (HMs), leading to the buildup of these chemicals as solid waste. This technique results in the purification of the liquid solutions containing water.(Hamad & Idrus,

2022) The method offers two notable benefits: cost-effectiveness and ease. It only necessitates the organic development of plants. The dissolved elements are extracted from the liquid solution by the process of adsorption onto the roots or transportation within the plant's stem. Subsequently, the elements are secured through physical and/or chemical interactions. Consequently, phytoremediation is increasingly employed for the treatment of wastewater contaminated with heavy metals.(Saleh et al., 2020) While numerous land-based and water-based plants have been examined, it remains crucial to assess their performance and effectiveness in various scenarios in the majority of instances. Furthermore, it is imperative to examine plant species that have not yet been investigated for their capacity to cleanse aquatic habitats.(Sree et al., 2023)

Wastewater treatment mechanisms employed by aquatic plants:

Recently, natural treatment systems have become increasingly popular as effective treatment solutions for several types of wastewaters. Examples of natural systems encompass soil systems, aquatic systems, and wetlands. These systems depend on sustainable energy sources such as solar power, wind power, and the energy stored in biomass and soil. Phytoremediation and wetland systems have become widely used natural methods for treating wastewater in many countries, especially developed ones, with the establishment of stable pond systems.(Sharma et al., 2023) Presently, there is an increasing fascination with investigating the ability of plants to efficiently decompose and eliminate detrimental microorganisms and pollutants. This has led to an expanded utilization of plant systems and a broader variety of study in this field.(Bala et al., 2022)

Plants in this system have a main function of providing the necessary oxygen for heterotrophic bacteria in the root zone, as well as absorbing nutrients and improving the stability and flow of water in the substrate. Wetlands, functioning as a highly efficient secondary treatment system, have the capability to decrease the concentration of contaminants, such as organic waste, inorganic matter, and various harmful bacteria, to a level that is considered acceptable. Criteria for selecting land treatment or technology include the success of treatments in achieving rehabilitative goals, reducing pollutants, reducing pollutant toxicity, and being cost-effective in both short- and long-term.(Thakur et al., 2023) Typically, common plant species, such as lichens, plankton, and higher plants, provide vital insights into the well-being of an ecosystem. Plants serve as reliable markers for predicting and detecting ecological disruptions. The process of industrialization and urbanization has resulted in a recent increase in pollution in both terrestrial and marine ecosystems. Plants are essential in evaluating the extent of pollution in an ecosystem because they are stationary and have the capacity to adjust to their environment.(Zaghloul et al., 2020) Aquatic plants function as the main provider of nutrients and oxygen for the water. They have a vital function in preserving the equilibrium of the aquatic ecosystem. Aquatic plants serve as the primary source of nourishment and oxygen for the water which play a crucial role in maintaining the balance of the aquatic ecosystem.(Irfan & Alatawi, 2019) The marine environment is an efficient and economical way for cleaning up aquatic plants in a large contaminated area. Aquatic plants naturally mitigate pollution and heavy metals. Utilising aquatic plants is the most optimal and economical approach for eliminating heavy metals and other contaminants from the environment.(Kristanti & Hadibarata, 2023)

Aquatic vegetation and engineered wetlands have been widely employed for the purpose of wastewater treatment on a global scale. Choosing aquatic plant species that have a high capacity for accumulating heavy metals is crucial for the treatment of aquatic plants. Aquatic plants have gained a commendable reputation for their ability to remediate contaminated areas worldwide throughout time. Aquatic plants possess a complex root system that allows them to accumulate pollutants in their roots and stems, rendering them highly suitable for this purpose.(Ali et al., 2024) The growth & cultivation of aquatic plants need a significant amount of time, which could impede the increasing demand for the treatment of aquatic plants. However, the drawbacks of this issue are overshadowed by the numerous benefits that this technology provides in the field of wastewater treatment.(Harun et al., 2021) An essential benefit of aquatic plant treatment is its status as an environmentally friendly technology that supports sustainable growth over an extended period. This approach harnesses the natural resources of plants and microbes, mitigates environmental degradation, protects ecosystems, and enhances quality of life and well-being.(Obaideen et al., 2022) Aquatic plants has the benefit of efficiently remedying both organic and inorganic contaminants. These mechanisms, including Phytoaccumulation, Phytodegradation, Phytotransformation, Phytovolatilization, and Phytoextraction, make them highly effective in treating mixed types of pollutants. These systems facilitate the elimination and refinement of impurities. At concentrations varying from low to moderate, it effectively restores soil that has been contaminated with significant amounts of pollutants that are spread over a wide area. The task can be accomplished on-site without causing any adverse impact on the soil's texture and structure. This approach is distinguished by its environmentally sustainable methods and aesthetically pleasant architecture, offering the civic a stunning view of the surroundings.(Pathak et al., 2022) By applying pollution mitigation techniques and pursuing specific development objectives, it is possible to rehabilitate damaged soil for agricultural purposes and utilize treated wastewater for sanitation or landscaping. This approach effectively minimizes the adverse effects on the ecosystem. Furthermore, phytotechnology is more economically efficient than alternative chemical and physical treatment methods since it is easy to install and maintain.(Wang & Aghajani Delavar, 2023)

Limitations: The review presents a meticulous and methodical examination of the existing body of literature, providing a comprehensive comprehension of the present level of expertise regarding aquatic plants and their diverse applications and effects. The work of literature contributes to conservation efforts by examining the potential ecological advantages and disadvantages of aquatic plants. Nevertheless, there are specific constraints associated with the review. The efficacy of aquatic vegetation might vary considerably depending on the geographical location and environmental circumstances. The variability observed in the data may restrict the applicability of the results to wider or distinct circumstances. The data utilized in the evaluation may originate from a variety of studies with distinct techniques, scales, and levels of quality. The presence of heterogeneity can lead to biases and impact the consistency and reliability of the results made.

Conclusion:

Aquatic plants have shown a notable ability to remove diseases from wastewater. Plants counteract infections by several mechanisms, such as the absorption by plant roots, interactions with biofilms, and alterations in soil or water chemistry. Aquatic plants provide a multitude of benefits to people, and there are still countless unexplored opportunities for their utilization. At now, the introduction of problematic aquatic plant species is posing a threat to both marine and freshwater habitats. These plant species are commonly imported from other regions for medicinal or horticultural purposes. However, they gradually evade human control and establish self-sustaining populations in the wild. These aquatic plants possess the capacity to effectively eliminate diverse contaminants, including hydrocarbons and other perilous and cancer-causing compounds, from water. Utilizing growth-promoting bacteria to enhance plant development in the rhizosphere and manage overgrown plants is a potential change that can have a substantial therapeutic effect. Aquatic plants are frequently used in wastewater treatment due to their significantly reduced cost and superior efficiency. A multitude of research have demonstrated that aquatic plants serve as effective repositories for wastewater treatment. They are utilised in the treatment process to diminish or restrict the presence of pollutant-laden wastewater. The quality of the treated wastewater met the worldwide effluent criteria for irrigation. In the future, there is potential to utilise genetically modified plants to enhance their ability to absorb heavy metals and facilitate the decontamination process. These modified plants should have accelerated growth cycles, allowing them to complete their life cycle in a shorter period of time, while also possessing a high capacity for phytoremediation. These plants have the ability to eliminate additional pollutants from water, including hydrocarbons and other harmful and cancer-causing substances. Applying growth-promoting bacteria to enhance plant development in the rhizosphere and regulate overgrown plants is a promising intervention that can lead to substantial treatment results.

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