Assess the effectiveness of Heliconia Plant in the Phytoremediation of wastewater

Mamilla Vijaya Kumar[1*], *B.* Jagadeesh[2]

[1]Assistant Professor, Department of Civil Engineering, K.S.R.M College of Engineering, Kadapa, Andhra Pradesh, India.
[2]Assistant Professor, Department of Civil Engineering, Vasavi College of India, Hyderabad, Telangana, India.

Abstract. The world is experiencing a significant increase in the need for freshwater due to the rapidly growing population and the loss of the global freshwater supply. As a result, the world faces a worldwide water crisis that makes it necessary to develop environmentally safer methods of wastewater treatment. Contamination from untreated sewage and waste products is greatly contributing to the global water crisis, thus impacting our freshwater sources and affecting human health. Conventional methods of treating sewage are costly and have a large negative impact on the environment. Phytoremediation is one eco-friendly, low-cost method of treating wastewater through the use of plants. Phytoremediation involves using living plants to remove and break down contaminants in soil, sediment, and water and therefore has a strong potential for the decontamination of the environment. In addition, phytoremediation has shown a tremendous ability to decontaminate the environment, indicating that now is truly the time to begin utilizing this green method towards creating a safer and cleaner environment. The selection of plants for the study was based on their cost-effectiveness, growth rate, and availability; they were tested using wastewater, and their efficacy over several days was then measured. The research investigates the effectiveness of Heliconia Plant (a type of flowering plant) at treating wastewater using phytoremediation techniques. Wastewater samples were collected over 12 days and analyzed every 3 days. Based on the results, the heliconia plants reduced pH, Total Dissolved Solids (TDS), turbidity, alkalinity, chlorides, and Biological Oxygen Demand (BOD) by 3.8%, 28.3%, 86.6%, 84.6%, 22.2%, and 72.7%, respectively, over the course of the study. The study achieved reductions of greater than 50% in turbidity, alkalinity, and BOD, thus improving the overall quality of the wastewater.

* Corresponding author : civilvijay1@gmail.com.

1 Introduction

Basic human needs include clean water, food, and shelter. Access to clean and affordable drinking water is a major challenge in the 21st century due to growing populations [1]. Approximately 40% of the world's population is experiencing some degree of water scarcity as a consequence of climate change, rapid urban growth, and excessive resource consumption [2]. Pollution of safe drinking water is an important global problem. Contaminated water is not clean enough for the ever-increasing population to use routinely. According to the World Health Organization (WHO) about 2.2 billion people use non-potable & untreated drinking water from unsafe & unreliable sources [3].

The benefits of industrialization are numerous; however, it has contributed to various forms of environmental pollution [4]. The discharge of organic and inorganic waste into natural water bodies can disrupt aquatic systems and pose potential health risks for humans [5]. In addition to posing threats to human health, the bulk of this water pollution arises from both domestic and industrial sources, which primarily affect many species that reside in the water, including amphibians [6]. Therefore, the reclamation of wastewater for use in meeting increasing water demands within the water-dependent industries and agriculture is now an important solution.

The Central Pollution Control Board (CPCB) is responsible for establishing and enforcing pollutant discharge standards, both before and after treatment, for industrial discharges; the CPCB categorizes these processes as primary, secondary, and tertiary processes [7]. Urban India generates approximately 73 billion litres of sewage daily, and only approximately 37% of this volume of sewage is treated before being discharged into surface or groundwater; therefore, untreated sewage contributes substantially to the degradation of surface and groundwater. While the creation of additional wastewater treatment facilities is one approach to addressing this problem, the primary obstacle to creating additional facilities is the lack of economic viability, particularly in rural areas where the population density is relatively low [8].

1.1 Phytoremediation

Pollution of the water supply is a major global problem with many solutions; however, most methods available today, such as adsorption methods, biological remedies, chlorine or chloramine disinfectants, advanced oxidation processes (AOP), etc. are expensive to build and maintain. Phytoremediation is considered by many researchers to be one of the most effective and sustainable ways to clean up the environment since it uses plants and their associated microorganisms to 'volatilise', 'stabilise', 'degrade', or 'extract' contaminants [9]. It provides a means of reducing and treating harmful pollutants until they pose no risk to human health and have no impact on the environment by removing from the environment toxic chemicals such as antibiotics, heavy metals, and pesticides [10]. Furthermore, this solar energy-driven process not only cleans and treats water but also helps to create and maintain healthy, vibrant ecosystems [11].

Aquatic plants are a critical part of wastewater treatment because they improve water quality by removing organic and inorganic compounds, while promoting the health of the environment through sustainability. The use of aquatic plants provides not only an economic benefit but also improves the efficiency of wastewater treatment because of the increased surface area for microorganisms to grow. The effectiveness of a plant at absorbing pollutants is dependent on many factors, including plant species, wastewater quality, rate of growth, and root depth. Therefore, the correct species of plant must be selected to ensure successful removal of pollutants from wastewater. The best plants for treatment are those that grow quickly, have high biomass, have deep roots, tolerate pollutants, and are easy to grow [12].

Many different plants, such as grasses, trees, and monocots and dicots, have proven to be good at phytoremediation [13]. Terrestrial plants have two major types of root systems: fibrous roots and taproots, which both absorb contaminants from wastewater. The fibrous roots create dense mats that increase buoyancy and absorb large amounts of water. The taproots will give stability and store nutrients because they grow deep into the ground. Choosing native species decreases the chance of biological invasion, and phytoremediation is cost-effective and doesn't require special skills or tools, so it can also be used on a large scale [14].

1.2 Aquatic plants for Phytoremediation

Phytoremediation is a method used to decontaminate both industrial and municipal wastewaters through the use of the vegetation growing on (or constructed) wetland areas within their natural habitat. This eco-friendly and cost-effective technology has the added benefit of eliminating many of the contaminants — particularly heavy metals and some types of organic compounds that are considered toxic — from groundwater and soils directly. This method will reduce remediation costs, enhance existing habitats, and eliminate on-site contamination. Aquatic life (hydrophytes), which are organisms that have adapted to living in the water, are typically employed in phytoremediation.

The macrophytes, which are a critical component of healthy wetlands, are also important in furthering the natural filtration of water by providing a substrate for stabilizing sludge, creating the ideal conditions for filtering, and providing a habitat for beneficial microorganisms. To make them adaptable to aquatic habitats, macrophytes have developed structures that allow them to distribute oxygen to all parts of their body by having thin coatings or outer surfaces and developing air-exposed regions above ground. Additionally, the abundance of these plants within nature reduces the cost of gathering them for use. Macrophytes are also capable of accumulating contaminants and are capable of degrading many xenobiotics, enabling them to survive in polluted areas.

By using macrophytes, we can improve the quality of water and help with sustainability. It is important to know what happens when wastewater contaminants come into contact with hydrophytes (aquatic plants) so that constructed wetlands can be healthy. There are several risks due to oxidative stress on hydrophytes caused by metal toxicity, changing temperatures, and pathogens [15]. While reactive oxygen species (ROS) are a critical part of plant defenses against damage, they also cause damage themselves. To reduce that damage, phytoremediation plants produce antioxidants, such as free proline and catalase, to assist in detoxifying themselves from the various contaminants that they have been exposed to. In summary, macrophytes play a crucial role in phytoremediation and thus play a significant role in improving constructed wetland health.

Macrophytes are important in both natural and man-made filters for cleaning up water by providing stabilization to the sludge, increasing the effectiveness of the system through biofiltration, and being a major resource for the growth of positive microorganisms. These versatile plants have adaptations that allow them to adapt to wetland conditions; they are very good at growing in water because they have thin (outer) layers of tissue and have aerenchyma, tissue that helps get oxygen into plant parts that are submerged in water. Since macrophytes are very abundant in nature, they will help reduce the cost of obtaining macrophytes.

Another great property of macrophytes is that they are great at bioconcentrating pollutants and can take up and metabolize xenobiotic compounds, and can grow well in contaminated environments. By utilizing macrophytes, water quality can be greatly improved, and sustainability can be promoted in our environment.

Many plants growing in aquatic environments have proven to be excellent at taking up heavy metals from their environment, as demonstrated by a number of scientific studies. They are great at removing heavy metal contaminants from heavily polluted waters. In addition, they help to keep the environment healthy by taking in nutrients and producing biomass. These factors, combined with their relatively low cost of operation, make aquatic plants the best choice for treating municipal wastewater. Due to how heavy metals accumulate in the various parts of aquatic plants, cellular changes occur that promote tolerance to heavy metals. Aquatic plants also have an advantage over land-based plants because heavy metals exist in soluble form in the water, which makes them easier for the plant to take up, thereby providing a natural opportunity for a cleaner future.

Phytoremediation is a biological approach to contaminant clean-up that is often much slower than traditional engineering approaches. However, one requires addressing these deep contamination issues and is at the mercy of many different physical (i.e., climate, geology) or resource limitations that may inhibit plant growth, which could potentially allow the pollutants to enter the ecosystem via the plant-animal food chain.

For this research, Heliconia Psittacorum was selected as the most viable species for phytoremediation because of its ecological fit and practical application. Other more common phytoremediation species (Eichhornia crassipes — Water hyacinth; Vetiveria zizanioides — Vetiver Grass; Phragmites australis — Common Reed) have also been demonstrated to perform well in terms of pollutant removal; however, they all have their own drawbacks. For example, Eichhornia crassipes has a very high-water pollutant uptake potential; however, it is also classified as an invasive plant that causes serious disruption to aquatic ecosystems.

Although Vetiveria zizanioides can be used effectively for water treatment, the plant is typically used more successfully as a soil cleaning agent. Conversely, due to high maintenance requirements, Phragmites australis may not consistently grow well in all tropical environments.

On the other hand, Heliconia Psittacorum grows rapidly and is a naturally occurring fast grower without being an invasive tropical plant with a deep-rooted tap root system. This will continue to siphon nutrients and contaminants from the deeper layers of soil. It also has a high biomass yield and looks good, making it a strong candidate for small-scale and landscape-friendly wastewater treatment. Its proven ability to adapt to Indian climates further supports its use for sustainable phytoremediation in semi-urban and institutional areas.

1.3 Mechanism of Phytoremediation

Plant metabolism is crucial for the remediation of contaminated sites, as pollutants enter through the root systems, which contain detoxifying mechanisms and facilitate nutrient adsorption. Absorbed pollutants may be stored in the roots, stems, or leaves, converted into less harmful compounds, or released as gases during transpiration. The process of phytoremediation is shown in Figure 1.

2 Materials and methods

2.1 Selection of plants

Effective phytoremediation requires hardy plant species that can tolerate toxins, produce high biomass, and have good absorption capacities while being unattractive to herbivores. Sometimes, plants need assistance to improve their effectiveness. Aids such as biochar, EDTA, endophytic bacteria, Arbuscular mycorrhiza, or transgenic plants can help by reducing pollutant toxicity, increasing pollutant availability, or promoting plant growth. Heliconia Psittacorum, a species with a taproot, has been determined to be effective at removing contaminants from wastewater; it is being used for phytoremediation. The sewage used to treat Heliconia was collected from the College's Mini STP on a non-rainy day to prevent contamination. Three separate samples of sewage were collected at different times to provide an array of sewage sample compositions from a plastic container.

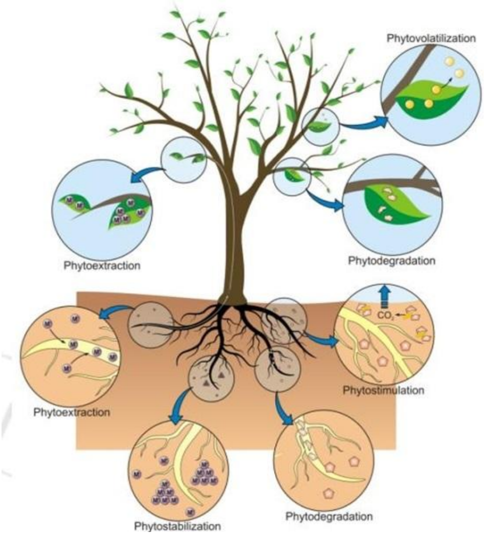

Fig. 1. Process of Phytoremediation [8].

2.2 Experimental setup

The Heliconia plants shown in Figure 2 will be grown in a tank laid with 20cm of soil and will be allowed 3 days for acclimation before being submerged in sewage water, for the purpose of assessing the ability to remove pollutants from sewage. Water quality, including six physicochemical parameters, was monitored every three days. Regular assessments of plant growth involved measuring height and spread and checking for disease or pests, with any abnormalities addressed promptly. The plants sourced essential nutrients from the sewage water, which was regularly monitored and adjusted.

Fig. 2. Heliconia Psittacorum Plant

3 Results and discussion

Sewage samples were tested for pH, temperature, turbidity, TDS, BOD, chlorides, and alkalinity every three days over 12 days. The results are presented in Table 1.

Table 1. An overview of the physicochemical parameters associated with wastewater treatment employing Heliconia plants.

Parameter	Day- 1	Day- 3	Day- 6	Day- 9	Day- 12
pH	7.8	8.4	8.2	7.6	7.5
Total dissolved solids (mg/l)	260	201	178.2	198	180
Turbidity (NTU)	16	14	13.2	3.1	2
Alkalinity (mg/l)	300	98	92	49	44
Chlorides (mg/l)	272	272.2	264	243	210
BoD (mg/l)	52	36.4	34.3	24.4	15

Table 2. One-way ANOVA Summary for Selected Parameters During Heliconia Treatment.

Parameter	F value	P- Value	Significant Difference ($p < 0.05$)?
p H	1.75	0.184	Yes
Total dissolved solids (mg/l)	4.89	0.016	Yes
Turbidity (NTU)	45.27	<0.0001	Yes
Alkalinity (mg/l)	22.11	0.0001	Yes
Chlorides (mg/l)	2.03	0.122	No
BoD (mg/l)	16.32	0.0002	Yes

A one-way ANOVA followed by Tukey's post hoc test was used to evaluate the significance of the differences in parameter values across the sampling days (Day 1, 3, 6, 9, and 12) represented in Table 2

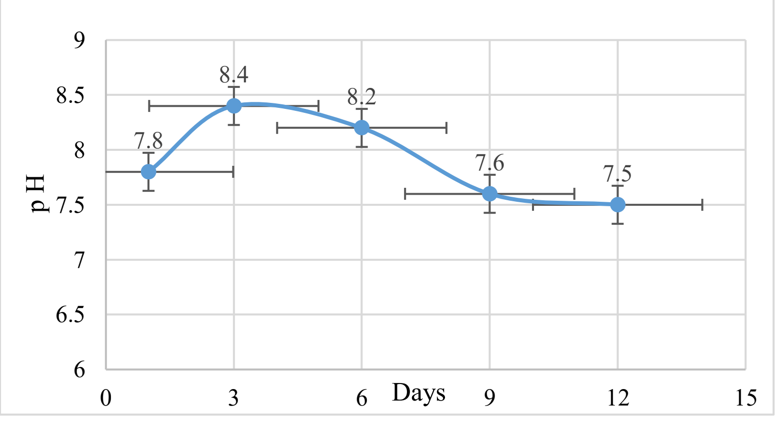

Fig. 3. Graph showing the pH value of wastewater treated with Heliconia plants

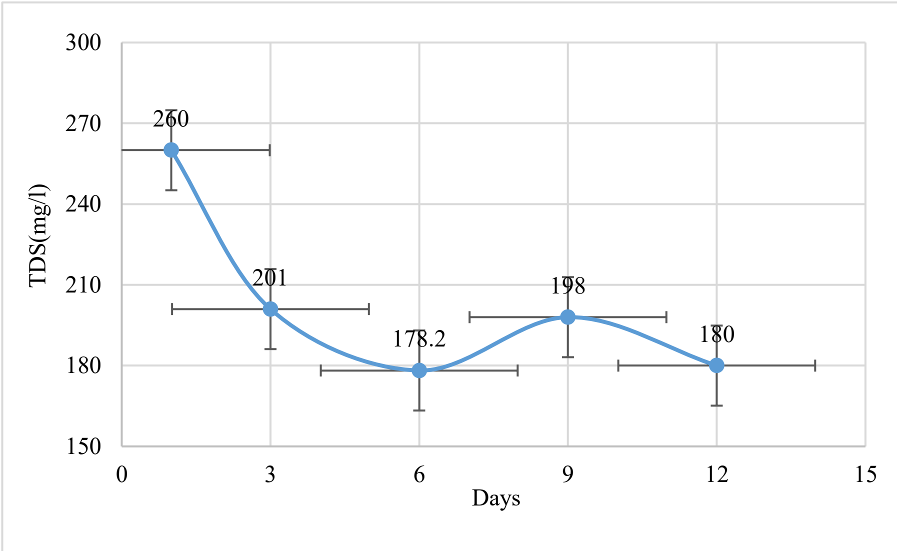

Fig. 4. Graph showing the TDS values of wastewater treated with Heliconia plants.

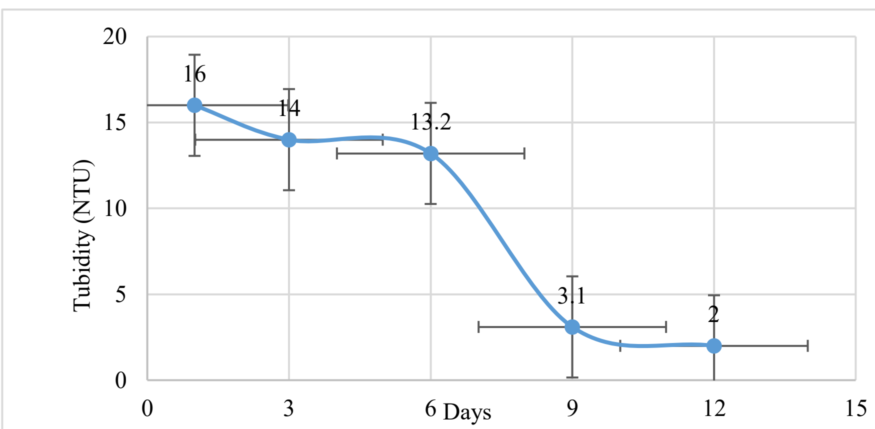

Fig. 5. Graph showing the Turbidity values of wastewater treated with Heliconia plants.

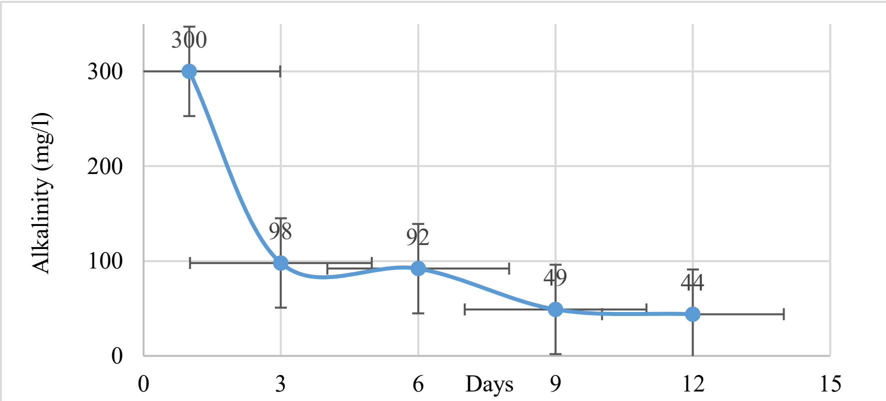

Fig. 6. Graph showing the Alkalinity values of wastewater treated with Heliconia plants

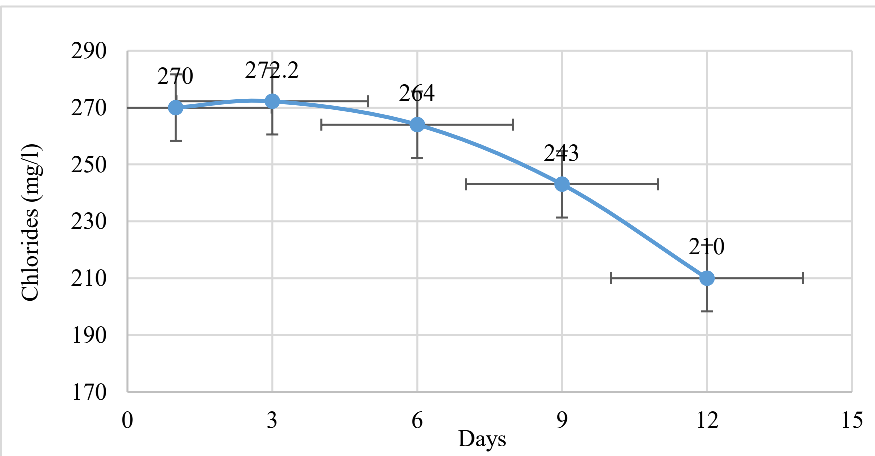

Fig. 7. Graph showing the Chloride values of wastewater treated with Heliconia plants

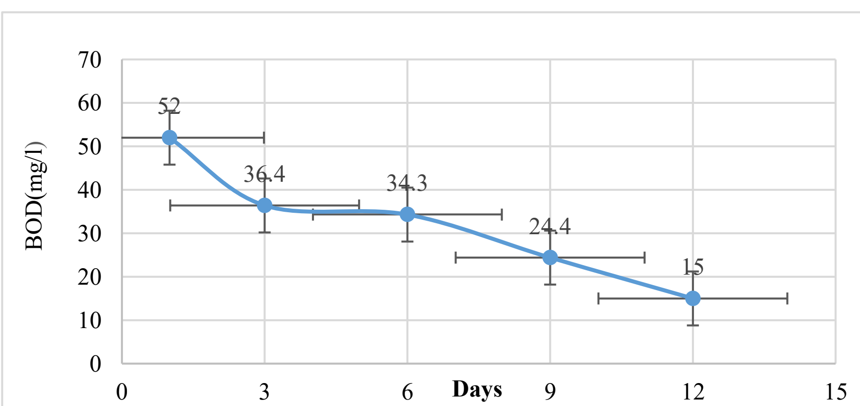

Fig. 8. Graph showing the BOD values of wastewater treated with Heliconia plants

Figure 3 – Figure 8 shows the results of tests conducted in this study. The pH of water treated by the Heliconia plant after 12 days was measured at 7.5, indicating a nearly neutral condition. The total dissolved solids (TDS) were recorded at 180 mg/L, while turbidity was measured at 2.0 NTU, and alkalinity was found to be 44 mg/L. Research into the effectiveness of Heliconia plants for sewage wastewater treatment showed that they resulted in significant reductions in total dissolved solids (TDS), turbidity, and biological oxygen demand (BOD). Findings indicated that the chloride concentration of the effluent sample was 210 mg/l and that BOD was recorded at 15 mg/l. The neutral pH indicates that the plants did not adversely impact the water's acidity. Although the chloride concentrations exceeded the limits set by the World Health Organization (WHO), they remained lower than those in the raw sewage, which indicates that Heliconia can effectively reduce chloride levels. Therefore, employing Heliconia for wastewater treatment presents a promising and sustainable approach to enhancing water quality.

The marked reductions in BOD, turbidity, and chloride found in the Heliconia-treated wastewater system have occurred through several linked phytoremediation processes. One of the most important is the deep taproot system of the Heloconia Psittacorum species, which can utilise dissolved organic matter, nutrients, and specific ions (such as chloride ion) in the water through uptake in conjunction with active actions in the rhizosphere. Here, both beneficial and free-living microbes break down organic pollutants, significantly reducing BOD levels [15].

Additionally, Heliconia roots participate in radial oxygen loss (ROL). This process raises local oxygen levels, which encourages aerobic microbes to break down complex organic compounds. At the same time, the root structure also helps to trap and settle suspended solids, which reduces the turbidity. While chloride was always present in a stable ionic form in aquatic systems, any small decreases in chloride are likely the result of passive measures such as dilution, ionic exchange with soil, and some phytoaccumulation under particular ionic balance.

In summary, these processes describe the many functions of Heliconia Psittacorum and the potential for it to serve as a bioengineered system for the integrated treatment of wastewater to sustainably improve water quality with vegetative management techniques. According to Tukey's post hoc test, there were significant differences in BOD measurements at Day 12 compared to Day 1 and Day 3, with $p < 0.05$ for all comparisons. Additionally, turbidity and alkalinity both were significantly different as well when comparing the earlier stages of the experiment to the later stages, indicating that Heliconia has consistently performed over time.

4 Limitations and Practical Considerations

Phytoremediation has potential as an eco-friendly and inexpensive treatment technology, but there are constraints on its application at a large scale. One of the largest constraints is the time required for treatment. Plants remove environmental contamination from the soil through biological uptake and ultimately through biodegradation over a much longer time period than is needed for conventional physical and chemical methods. The ability of phytoremediation plants to effectively remove contaminants from soil is also limited to seasonality based on the growth of the plant, as plant growth and metabolism (and therefore, the efficiency of pollutant removal) are all affected by temperature, light intensity, and precipitation. Another serious concern with phytoremediation is whether or not the technology can be applied on a large scale. For example, the logistics of collecting biomass and maintaining the system may present challenges if there are large amounts of wastewater or high levels of contamination.

Recent studies recommend that the combination of phytoremediation techniques with other methods that require little energy, including bioremediation, bioreactors, constructed wetlands, and anaerobic digestion, is the best option for overall remediation success. These combinations provide better rates of contaminant removal and less land use, while making remediation repairs from future changes to the environment more durable. More importantly, these combinations make phytoremediation methods more practical for long-term sustainable treatment of wastewater.

5 Conclusion

The issue of water pollution poses an urgent problem from an environmental support perspective since multiple pathologies can be caused by the consumption of contaminated drinking water. This is why the method of phytoremediation represents an effective approach to cleaning up toxic pollutants; however, this method is also urgent because the cost of the current technologies for cleaning up contamination are beyond reasonable financial means. Phytoremediation has been shown through various studies to be a viable method for treating wastewater by utilizing plant material in order to restore the environment where pollution has occurred.

In addition, the phytoremediation process is both cost-effective and ecologically sound. Aquatic botanical species also possess the ability to manage high volumes of contaminants with little or no filtration after treatment. Since aquatic species have the demonstrated ability to absorb toxins from aquatic or terrestrial environments, and also have the ability to degrade or decompose these toxins, they make an excellent medium for both the treatment of wastewater through phytoremediation and for generating bioenergy. Therefore, if we can begin to implement phytoremediation, we will be able to protect our global water supply and contribute to a much healthier planet for future generations.

Phytoremediation using the heliconia plant to eliminate wastewater through this research will be evaluated in terms of degrading water quality, specifically through the decrease in pH, TDS, turbidity, alkalinity, chlorine, and BOD. There is evidence showing the heliconia plant was responsible for removing all contaminants from the wastewater without any damage or injury, with the elimination of contaminants demonstrated by the following percentages: pH −3.8%; TDS −28.3%; turbidity −86.6%; alkalinity −84.6%; chlorine −22.2%; and BOD −72.7%. Most importantly, the removal of alkalinity, turbidity, and BOD by more than 50% after only 12 days further validates that the heliconia plant was an effective phytoremediator.

To increase acceptance and marketability, it's critical to optimize how plants are managed and implement technologies that will provide treated water that meets safety standards. Plants have proven their ability to remediate contaminants from wastewater, making them a key part of environmental management into the future. Technology needs to continue to develop in the area of biotechnology; scientists and the commercial sector need to work together to improve the efficiency of Phytoremediation and find solutions to contaminated sites.

In addition, effective methods to use biomass will enable remediation costs to be lowered, while maximising their advantages. Phytoremediation is limited by being slower than traditional methods, so to minimise the risks of phytoremediation, it is necessary for on-site processing and harvesting to be performed carefully. The successful use of these methods depends on appropriate communication and data collection, which will help to create positive public attitudes towards them. Phytoremediation is a promising approach to achieving a cleaner, more sustainable future.

References

1. H. P. Raju, M. V. Kumar, P. Partheeban, Wastewater treatment in constructed wetlands by phytoremediation technique. E3S Web Conf. 455, 03023 (2023). https://doi.org/10.1051/e3sconf/202345503023.
2. P. F. Tee, M. O. Abdullah, I. A. W. Tan, N. K. A. Rashid, M. A. M. Amin, C. Nolasco-Hipolito, K. Bujang, Review on hybrid energy systems for wastewater treatment and bio-energy production. *Renew.* Sustain. Energy Rev. **54**, 235–246 (2016). https://doi.org/10.1016/j.rser.2015.10.011.
3. C. R. Delgado-Gonzalez, A. Madariaga-Navarrete, J. M. Fernández-Cortés, M. Islas-Pelcastre, G. Oza, H. M. N. Iqbal, A. Sharma, Advances and applications of water phytoremediation: A potential biotechnological approach for the treatment of heavy metals from contaminated water. Int. J. Environ. Res. Public Health **19**, 5215 (2022). https://doi.org/10.3390/ijerph19105215.
4. M. Li, M. Leso, M. Buti, E. Bellini, D. Bertoldi, A. Saba, R. Larcher, L. Sanità di Toppi, C. Varotto, Phytochelatin synthase de-regulation in Marchantia polymorpha indicates cadmium detoxification as its primary ancestral function in land plants and provides a novel visual bioindicator for detection of this metal. J. Hazard. Mater. **440**, 129844 (2022). https://doi.org/10.1016/j.jhazmat.2022.129844.
5. M. Petrović, A. Ginebreda, V. Acuña, R. J. Batalla, A. Elosegi, H. Guasch, M. L. de Alda, R. Marcé, I. Muñoz, A. Navarro-Ortega, E. Navarro, Combined scenarios of chemical and ecological quality under water scarcity in Mediterranean rivers. TrAC Trends Anal. Chem. **30**, 1269–1278 (2011). https://doi.org/10.1016/j.trac.2011.04.012
6. N. Chandekar, B. J. Godboley, A review on phytoremediation: A sustainable solution for treatment of kitchen wastewater. Int. J. Sci. Res. **6**(2), 1850–1855 (2017).

7. G. M. Autade, S. R. Yadav, R. G. Shinde, S. S. Walhekar, A. C. Shirle, Treatment of wastewater by using phytoremediation technique: Review. Int. J. Adv. Sci. Res. Eng. Trends **6**(4), 63–68 (2021).
8. S. Roy, J. K. Biswas, S. Kumar, Nutrient removal from wastewater by macrophytes—An eco-friendly approach to wastewater treatment and management. Energy Environ. Res. **4**(2), 55–63 (2014). https://doi.org/10.5539/eer.v4n2p55.
9. F. O. Ajibade, J. R. Adewumi, Performance evaluation of aquatic macrophytes in a constructed wetland for municipal wastewater treatment. FUTA J. Eng. Eng. Technol. 11(1), 1–11 (2017).
10. Esmaili, Z., Cheshmberah, F., Solaimany Nazar, A. R., & Farhadian, M. (2017). Treatment of florfenicol in synthetic trout fish farm wastewater through nanofiltration and photocatalytic oxidation. Environmental Technology, 38(16), 2040–2047. https://doi.org/10.1080/09593330.2016.1245359.
11. Michael, I., Rizzo, L., McArdell, C. S., Manaia, C. M., Merlin, C., Schwartz, T., Dagot, C., & Fatta-Kassinos, D. (2013). Urban wastewater treatment plants as hotspots for the release of antibiotics in the environment: A review. Water Research, 47(3), 957–995. https://doi.org/10.1016/j.watres.2012.11.027
12. Luo, L., He, H. J., Yang, C. P., Wen, S., Zeng, G. M., Wu, M. J., Zhou, Z. L., & Lou, W. (2016). Nutrient removal and lipid production by Coelastrella sp. in anaerobically and aerobically treated swine wastewater. Bioresource Technology, 216, 135–141. https://doi.org/10.1016/j.biortech.2016.05.059
13. Zhou, Q., Li, X., Lin, Y., Yang, C. P., Tang, W. C., Wu, S. H., Li, D. H., & Lou, W. (2019). Effects of copper ions on removal of nutrients from swine wastewater and on release of dissolved organic matter in duckweed systems. Water Research, 158, 171–181. https://doi.org/10.1016/j.watres.2019.04.036.
14. Markou, G., Wang, L., Ye, J. F., & Unc, A. (2018). Using agro-industrial wastes for the cultivation of microalgae and duckweeds: Contamination risks and biomass safety concerns. Biotechnology Advances, 36(4), 1238–1254. https://doi.org/10.1016/j.biotechadv.2018.04.003.
15. Pilon-Smits, E. (2005). Phytoremediation. Annual Review of Plant Biology, *56*, 15–39.