Scholars Academic Journal of Biosciences
Abbreviated Key Title: Sch Acad J Biosci
ISSN 2347-9515 (Print) | ISSN 2321-6883 (Online)
Journal homepage: https://saspublishers.com
NIH National Library of Medicine National Center for Biotechnology Information
NLM ID: 101629416
OPEN ACCESS
Medicine

Water Hyacinth is a Potential Aquatic Plant Used in Water Treatment: A Short Review

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DOI: https://doi.org/10.36347/sajb.2025.v13i07.004 | **Received:** 02.06.2025 | **Accepted:** 11.07.2025 | **Published:** 16.07.2025

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Abstract **Review Article**

Water hyacinth (WH), *Eichhornia crassipes* is a rapidly propagating, free-floating aquatic plant known for its impressive capacity to absorb contaminants from polluted water bodies. Its expansive root system, rapid growth rate and resilience to various pollutants make it a viable tool for phytoremediation that works as an eco-friendly and sustainable source of biomass and biochar that has drawn attention for its remarkable phytoremediation capabilities. It is an efficient agent for eliminating pollutants from a variety of water bodies due to its quick development, wide root system and high tolerance to pollutants. This short review explores the mechanisms, effectiveness and potential uses of WH in water treatment are covered, which also emphasises the plant's potential as a justifiable solution for problems with water pollution. Additionally, this review cites research on the water hyacinth's ability to absorb substances, lowering the levels of heavy metals, organic substances and a number of other physiochemical parameters in textile wastewater like TSS (total suspended solids), TDS (total dissolved solids), COD (chemical oxygen demand) and BOD (biological oxygen demand) etc. ***Novelty Statement****:* This short review offers a concise but complete available information of water hyacinth's phytoremediation potential, highlighting the plant's capacity to eliminate a wide range of contaminants from different wastewater sources such as heavy metals, nutrients and organic contaminants. This work's uniqueness is, it incorporates treatment efficiency, application techniques, and current experimental data to provide academics and policymakers looking for long-term water treatment solutions with a useful resource. It adds value to existing literature by bridging ecological insights with real-world wastewater management practices.

Keywords: Water hyacinth; Phytoremediation; Heavy metals; Herbal method; Cost effective.

INTRODUCTION

Water pollution is a growing concern that threatens both ecosystems and human health across the globe. As industrialization, urban expansion and agricultural practices continue to intensify, large amounts of pollutants for example heavy metals, excess nutrients and organic compounds are being discharged into waterways [1,2]. In India, water pollution is a major issue. According to studies, 70 and 80 percent of India's water is seriously contaminated and 38 million people especially children are suffering with waterborne illnesses such as cholera, diarrhoea and typhoid each year. More people die from water-borne illnesses globally than from other disease like measles, TB and AIDS combined with children under 5. In addition to impacting children's health, it also lowers India's GDP and causes economic issues. An estimated 80 billion dollars are lost to India each year. The industries are one of the main causes of water contamination. The wastewater released by the manufacturing units contains a various types of metal ions, like Mg, Zn, Ni, Fe, Co, Pb, Hg and Sr [3]. WH has been proved to enhance overall efficiency at removing several contaminants from wastewater including nitrogen, phosphorus, organic compounds, suspended particles, phenols, pesticides, heavy metals, chemical and biochemical oxygen demand [2]. While conventional treatment methods are effective, they often come with significant costs and high energy demands. In contrast, phytoremediation offers a more sustainable, eco-friendly and cost-effective solution by utilizing the natural capabilities of plants to clean contaminated water [4].

In terms of phytoremediation, *Eichhornia crassipes* represents one among the most promising aquatic plants. Known for its fast growth and potential to thrive in various water conditions, this free-floating plant can absorb a broad spectrum of pollutants [2,5]. The main mechanisms for reducing contaminant exposure are found in the branched root system, that is where contaminants are mainly absorbed by plants. The root system's massive surface area allows it to absorb and retain the nutrients and water needed for growth, along with other undesirable contaminants [2]. Originally native to South America, water hyacinth has spread aggressively to freshwater habitats across Asia, Africa and North America, often forming dense mats that interfere with aquatic ecosystems and human activities. Historically recognised as a weed, water hyacinth (Jal kumbhi) is problematic in water bodies all over the Globe. The exceptionally fast growth and water-repellent nature of water hyacinth have made it an extremely difficult plant to manage. Based on estimates, water hyacinth can produce large quantity of dry biomass approximately 0.26 tonnes per hectare daily in optimum conditions. [4,6] It is estimated that water hyacinth can reproduce in 4–58 days and double its weight in 6-28 days, depending on the environmental circumstances [4,7,8]. Despite being classified as an invasive plant, water hyacinth possesses extraordinary characteristics that make it an effective tool for water purification. Its branched fibrous root system serves as a natural environment for microorganisms that help break down organic contaminants. Additionally, the plant has demonstrated a strong ability to effectively accumulate and absorb toxic metals. Such as lead, cadmium and arsenic, alongside excess nutrients like nitrogen and phosphorus. These characteristics have made it effective for treating a wide range of wastewaters, from industrial discharges and agricultural runoff to household sewage. By capitalizing the natural purification abilities of water hyacinth, researchers and environmentalists continue to explore its potential in large-scale wastewater treatment. Its widespread availability and effectiveness make it a valuable asset in promoting cleaner waterways while addressing the environmental challenges posed by pollution.

Mechanisms of Phytoremediation by Water Hyacinth [9]

Bioaccumulation (Phytoextraction):

Water hyacinth has an incredible ability to cleanse polluted water by absorbing and storing harmful and toxic metals like lead (Pb), cadmium (Cd), chromium (Cr) and arsenic (As) etc through a meticulous process called bioaccumulation or phytoextraction, the plant takes up these contaminants through its roots and moves them into its tissues, effectively locking them away. Its sprawling root system plays a crucial role by offering a vast surface area for metal absorption, while its rapid growth ensures that significant amounts of pollutants are removed in a short time. According to researches, water hyacinth is a promising natural solution for environmental remediation since it significantly reduces the concentration of heavy metals in wastewater. Despite its reputation as an invasive species, its remarkable filtering properties are turning it into an eco-friendly ally in the fight against water pollution.

Phytostabilization:

It is a crucial step in phytoremediation that focuses on containing contaminants within the root zone of plants, effectively preventing their movement and reducing their availability to water bodies. The process relies on several mechanisms including:

- **Root Adsorption and Absorption**: Plants with extensive root systems like water hyacinth offer a large surface area for contaminants to adhere. Pollutants in the water or soil attach to the root surfaces or are absorbed into the plant tissues, effectively trapping them in place and preventing their further spread
- **Chemical Alterations in the Rhizosphere**: The rhizosphere is the area around the roots that helps stabilize contaminants. Various chemical reactions occur here, leading to the precipitation of pollutants into less soluble forms. Additionally, the plant roots release organic compounds (exudates) that can bind with heavy metals, forming stable complexes that further restrict their movement.
- **Changes in Metal Toxicity**: Water hyacinth has the potential to alter the oxidation states of metals, effectively reducing their toxicity. Like the conversion of hexavalent chromium (Cr^{6+}), a highly toxic form, into trivalent chromium (Cr^{3+}) significantly decreases its solubility and harmful effects, making it less mobile in the environment.
- **Microbial Interactions for Enhanced Stability**: The rhizosphere is home to diverse microbial communities that interact with pollutants. Beneficial microbes can degrade organic contaminants and further immobilize inorganic ones by facilitating biochemical changes that make pollutants less bioavailable.

Rhizofiltration:

It is a phytoremediation method that uses plant's branched fibrous root to absorb, reduce and precipitate pollutants from contaminated water sources, particularly excess nutrients and heavy metals. Rhizofiltration is nature's way of purifying water, where plant roots act as living filters that trap and absorb harmful contaminants. Water hyacinth, with its dense and fibrous root system, excels in this process, helping to cleanse polluted water bodies.

As water flows through the plant's root zone, pollutants including heavy metals and excess nutrients get either absorbed into the plant tissues or cling to the root surfaces. This natural filtration process effectively removes toxins, improving water quality and restoring balance to aquatic ecosystems. Rhizofiltration with water hyacinth supports the health of surrounding aquatic life by mitigating the amounts of harmful substances. Its ability to thrive in various environmental conditions makes it an invaluable tool for sustainable water treatment. Scientists and environmentalists continue to explore ways to harness its potential while managing its invasive nature responsibly.

Phytodegradation:

Water hyacinth has a remarkable ability to clean polluted water, due to its natural enzymatic systems that break down harmful organic compounds. Through metabolic processes within the plant, contaminants like pesticides, phenols and hydrocarbons are transformed into less toxic forms. Some of these degraded substances get absorbed into the plant's biomass, while others continue to break down further, reducing their environmental impact. This built-in purification system enables water hyacinth to tackle a broad range of organic contaminants, helping to restore water quality in contaminated environments. Its efficiency in breaking down toxins makes it a valuable natural tool for environmental cleanup.

Efficacy in Contaminants Removal

Research has indicated that water hyacinth is effective at eliminating a range of contaminants:

Heavy Metals: More than 80% of Pb, Cu, Cd and As can be eliminated from contaminated water by heavy metals. According to a study conducted in Bangladesh, the whole plant (WH) totally (100%) removed arsenic while 80 percent of the arsenic was removed by the fibrous roots and 0% was removed by the leaves or leaf stalks [56].

Industrial Effluents: Efficient in lowering Cr (VI) and other metal concentrations in effluent from the mining and textile sectors.

Nutrients and Organic Matter: Improves the general quality of water by lowering nitrate, phosphate, BOD and COD levels.

Applications in Water Treatment

There are several uses for water hyacinth:

Sewage Treatment: Used to extract nutrients and heavy metals from municipal wastewater in stabilisation ponds.

Industrial wastewater: Used to treat industrial effluents and significantly lower pollutant concentrations.

Constructed Wetlands: Integrated into designed systems for passive water treatment are constructed wetlands.

Table 1: **Efficacy in Contaminant Removal** [1]

S. N	Part used of WH	Heavy metal	Source	Adsorption capacity	Optimised condition
1	"Dried water hyacinth shoot & root" [10]	Cd^{+2}, Pb^{+2}	Aqueous solution	75% for Cd and >90% for Pb	Dosage of 5.0 g/L and pH 5.0
2	"*Eichhornia crassipes* biomass" [11]	Cd^{+2}, Pb^{+2}, Zn^{+2}	Aqueous solution	Sorption capacities (qm) of 26.32, 12.60 & 12.55 mg/g for Pb^{+2}, Cd^{+2} & Zn^{+2}	(C0=10–60 mg/L), 3 h contact time, 30 ^{0}C, 2 g/L, 150 rpm and pH 4.84
3	"*E. crassipes* type Biosorbent" [12]	Cd^{+2}, Zn^{+2}	Batch binary system	0.65 m equiv./g maximum metal uptake	30^{0}C temperature and with non-uniform biosorbent grain sizes
4	"Dry hyacinth roots (DHR)" [13]	As	Spiked drinking water sample	90% Arsenic removal	Concentration of 20 g/L DHR
5	"WH plant" [14]	Fe	Fe rich wastewaters in constructed wetlands	6707 Fe mg/kg dry weight	-
6	"WH plant" [15]	Al	Al rich waste water in constructed wet lands	Highest phytoremediation efficiency of 63%	-
7	"WH" [16]	Mn	Synthetic wastewater in constructed wetlands	Phytoextraction mode of Mn removal	pH (6.2 to 7.1)
8	"WH plant" [17]	Cu, Cd, Pb, Zn	Anaerobic up flow packed bed reactor with WH ponds	98% for Cd, 99% for Cu, 98% for Pb and 84% for Zn	10 days with a hydraulic retention time of one day
9	"WH roots" [18]	Pb^{+2}	Aqueous solutions	-	-
10	"WH plant" [19]	Zn, Cr	Aqueous solutions	95% of Zn and 84% of Cr	-

11	"WH plant" [20]	Fe, Zn, Cu, Cr, Cd	Aqueous solutions	(>90%) of different metals during 15 days experiment	-
12	"WH plant" [21]	Cd, Zn	Aqueous solutions	Metal uptake by the plant was dependent upon the conc. of the metal & the duration of the exposure time	-
13	"*Eichhornia crassipes* biomass" [22]	Cd^{+2}, Pb^{+2}, Zn^{+2}	Binary & ternary systems	Metal sorption followed the order Pb^{+2}>>Cd^{+2}>>Zn^{+2}	30^0C and pH 4.84
14	"Dried powdered stem and leaves of *E. crassipes* biomass" [23]	Cr6+	Batch sorption process	91.5181 mg/g maximum	pH 2.0, 40^0C, 300 mg/L meta concentration.
15	Activated carbon derived from *E. crassipes* [24]	Hg2+	Aqueous solution	28.4 mg/g	pH 5 for a particle size of 125–180 micro meter
16	"WH plant" [25]	Cd, Zn	Aqueous metal solution	Cadmium in shoots - 148.0 µgm/g. roots - 2006 µg/g. zinc in shoots -1899 µg/g; in roots -9646 µg/g.	-
17	"WH fibre" [26]	Cu, Zn	Aqueous solution	99.42 mg Cu2+ and 83.01 mg Zn2+ per 1 g biomass	-

Table 2: Enhancing the wastewater quality parameters through the applications of *E. crassipes*. [27]

S. N	Pollutant	Wastewater source	Experimental conditions	Maximum removal efficiency (%)
1	"COD, TN, TP" [28]	Synthetic wastewater	Constructed wetlands system	COD: 60% RE, TN: 68% RE TP: 87% RE, Results obtained using *E. crassipes*
2	"CH_4" [29]	Wastewater stabilization ponds	Small-scale wastewater stabilization ponds with *E. crassipes* under simulate treating sewage treatment plant effluents for 31 days	*E. crassipes* reduced 52.30–83.21% of CH_4 fluxes at water-atmosphere interface
3	"TN, NO^{3-} -N, NH_4^+-N" [30]	Domestic wastewater	Domestic wastewater pilot plant	TN: 63.9% RE NH^{4+}-N: 81.0% RE NO_3^- -N: 22.8% RE Results obtained using *E. crassipes*
4	"COD, NH_3, NO_3, P" [31]	Municipal wastewater	Reactor tanks	COD: 49% RE, NH_3:81% RE NO_3: 92% RE, P: 67% RE Results obtained using *E. crassipes*
5	"BOD, TN, TP" [32]	Wastewater with dairy effluents	Constructed wetlands	BOD: 90% RE, TN: 58% RE TP: 75% RE, Results obtained after 4d using *E. crassipes*
6	"TSS, Color, COD" [33]	Wastewater from coffee factories	Continuous two-stage constructed wetland system volumetric flow rate of 4.1 L/day. Combination of *P. karka* & *E. crassipes*	Color: 79% RE, COD: 95% RE, *P. karka* 3d and *E. crassipes* 4d
7	"BOD, COD, PO_4^{-3}, NO_3" [34]	Combination various wastewater	Lab-scale mixed wastewater ponds with *P. stratiotes* and *E. crassipes*	BOD: 98% RE, COD: 99% RE, PO_4^{-3}: 73% RE NO_3^-: 91% RE *P. stratiotes* and *E. crassipes*
8	"TSS, BOD, NO3-N" [35]	Metallurgical, textile and pharmaceutical wastewater	T1: Textile wastewater T2: Metallurgical wastewater T3: Pharmaceutical wastewater	TSS: T1: 31.71% RE TSS T2: 63.91% RE TSS T3: 63.57% RE BOD: T1: 66.98% RE BOD T2: 73.33% RE

				BOD T3: 52.94% RE NO_3^- -N: T1: 53.64% RE NO_3^- -N: T2: 45.61% RE NO_3^- -N: T3: 42.42% RE
9	"BOD, COD, NO_3-N, TN, PO_4^{-3}-P" [36]	Municipal wastewater	Mixed culture of *E. crassipes* and *Salvinia natans*	BOD: 84.5% RE COD: 83.2% RE PO_4^{-3}-P: 56.6% RE NO_3^--N: 26.6% RE TN: 53.0% RE
10	"TSS, NH_4^+-N, COD, PO_4^{-3}" [37]	Domestic wastewater in situ	T1: wastewater treatment with microorganisms + plants (*E. crassipes and Ipomoea aquatica*) T2: wastewater treatment with plants (*same plants*)	Better results in T2 TSS: range 37.8–53.3% RE COD: range 44.4–53.4% RE PO_4^{-3}: range 56.7–61.4% RE NH_4^+-N: range 26.8–32.6%RE
11	"TDS, BOD, COD, TSS, TS, NO_3^-, turbidity" [38]	Wastewater from refinery and petrochemical	Lab-scale in 5L containers	TDS: 90% RE COD: 54.3% RE NO_3^-: 86.3% RE BOD: 13.7% RE TSS: 55.7% RE Turbidity 18% RE TS: 87% RE
12	"COD, BOD, TSS, PO_4^{-3}-P, TP, NH_3-N" [39]	Domestic wastewater	Engineered attached microbial growth technique (termed Bio-hedge)	COD: reduction range 75.53–80.93% BOD: reduction range 86.42–90.90% TSS: reduction range 67.40–73.02% NH_3-N: reduction range 69.27–74.193% PO_4^{-3}-P: reduction range 30.80–41.23%
13	"COD, TP, TN" [40]	Wastewater from a duck farm	Constructed wetlands	COD: 64.44% RE TN: 21.78% RE TP: 23.03 RE

**BOD*- biochemical oxygen demand, *COD*- chemical oxygen demand, *d*- days, *DO*- dissolve oxygen, NO_3^-- nitrate, NO_3^- *N*- nitrate nitrogen, *NH3*- ammonia, NH_4^+-*N*- ammonium, PO_4^{-3} phosphate, *RE*- removal efficiency, *T*- treatment, *TN*- total nitrogen, *TP*- total phosphorus, *TS*- total solids, *TSS*-total suspended solids

Table 3: Applications of *Eichhornia crassipes* in the immobilization and accumulation of heavy metals from wastewater. [27]

S.No.	Pollutant	Wastewater source	Experimental conditions	Maximum removal efficiency (%)
1	"Fe, Mn, Cu" [41]	Wastewater from electroplating (battery & aeronautical industry)	Plants directly from the wastewater area were analyzed to determine their bioaccumulation capacity by measuring the metal content in both water and plants	*E. crassipes* was able to accumulate: * Fe: 4052.44 µg/g Mn: 788.42 µg/g Cu: 315.50 µg/g
2	"Cd, Cu, As, Al, Pb" [42]	HMs present in steel effluent, with a conc. of 250 g/10 L of effluent	Lab-scale study with *E. crassipes* or *P. stratiotes* samples at 0, 20 and 30 d	Better results with *E. crassipes* Cd: 82.8% RE Cu: 78.6% RE As: 74% RE Al: 73% RE Pb: 73% RE
3	"Pb, Cd, Cu" [43]	Simulated wastewater: supplemented with Pb (NO3)2 CuSO4.5H2O, and(3CdSO4).8H2O	Electrically stimulated phytoremediation of Pb, Cd, and Cu by applying a voltage of 4 V for 2 h daily over 25 days	BCF Cd = 1118.18 BCF Cu = 1152.47 Moderate accumulator of Pb BCF Pb = 932.26
4	"Cr, Cu" [44]	Simulated wastewater supplemented with Cr 1 ppm & Cu 5 ppm	Lab-scale study with *E. crassipes*	Cu: ~ 40% RE Cr: ~ 50% RE
5	"Fe, Mn" [33]	Combination various wastewater	Lab-scale mixed wastewater ponds with	Fe: 89% RE Mn: 74% RE

			Pistia stratiotes and *E. crassipes*	*P. stratiotes* and *Eichhornia crassipes*
6	"As" [55]	As from spiked drinking water samples	DRWH as a function of time (30 mg roots per^{-1} at pH = 6.0 and 200 micro g As l^{-1}. Solution containing 200 micro g As l^{-1} within 60 minutes of exposure to a powder produced from dried roots.	Over 80% of the arsenic was taken up within 30 minutes exposure. 96% of both chemical species of arsenic were removed within one hour, leaving solutions containing 9.50 mgl^{-1} As^{+3} 7.85 mg $l^{-1}As^{+5}$.
7	"Cd, Cu, Cr, Fe, Pb, Zn, Mn" [45]	Wastewater from pulp and paper industry (PPMW)	Laboratory-scale experiment using PPMW at different concentrations (25%, 50%, 75%, and 100%) with *E. crassipes*	At 50% wastewater concentration, *E. crassipes* absorbed the heaviest metals in its vegetative tissues
8	"Cd, Cu, Fe" [35]	Metallurgical, textile, and pharmaceutical wastewater	T1: Textile wastewater T2: Metallurgical wastewater T3: Pharmaceutical wastewater	Cd: T1: 94.87% RE Cd: T2: 95.59% RE Cd: T3: 93.55% RE Cu: T1: 6. 67% RE Cu: T2: 0% RE Cu: T3: 0% RE Fe: T1: 0% RE Fe: T2: 0% RE Fe: T3: 90.91% RE
9	"Cd, Hg, Zn, Mn, Pb, Ag" [38]	Wastewater from refinery and petrochemical	Lab-scale in 5L containers	Cd: 99.0%, RE Hg: 95.0% RE Zn: 96.3% RE Mn:100% RE Pb: 99.3% RE Ag: 94.3% RE
10	"Cd, Cu, Fe, Mn, Pb, Zn" [46]	HMs reduction from highly toxic glass industry effluent (GIE)	Laboratory-scale experiment with using 5 diluted concentrations of GIE and *E. crassipes*	Cd: 91.30% RE Cu: 93.55% RE Fe: 92.81% RE Mn: 93.45% RE Pb: 89.66% RE Zn: 94.44 % RE Treatment most efficiently was at 25% GIE concentration

*BCF = bioconcentration factor, DW = dry weight, GIE = glass industry effluent, PPMW = wastewater from pulp and paper industry, RE = removal efficiency

Table 4: **Organic pollutants removal using *E. crassipes*** [27]

S.No.	Pollutant	Wastewater source/medium	Experimental conditions	Maximum removal efficiency (%)
1	"Ethion" (organophosphate pesticide) [47]	Nutrient solution supplemented with Ethion	Nutrient solutions supplemented with 10mg/L ampicillin (reduce bacterial growth) and Ethion, initial concentrations 0.01, 0.1, and 1 mg/L	Uptake and phytodegradation 69% attributed to plant and 12% microbial degradation. Ethion accumulated in shoots: 55–91% Ethion accumulated in roots: 74–81%
2	"Tebuconazole" [48]	Tebuconazole water solution	Calcium-modified *E. crassipes*–based biochar (ECCBC)	The max. adsorption capacity of ECCBC was 40.5 mg/g
3	"Naphthalene" [49]	Composition of the pond: freshwater with	T1: *E. crassipes* coupled with natural rhizospheric bacteria, T2: *E. crassipes* decoupled of rhizospheric bacteria	T1 removal: 100% in 9 d, T2 removal: 45% in 7 d

		the addition of 20% of the total volume of wastewater		
4	"Formaldehyde" [450]	Wastewater supplemented with formaldehyde	T1: formaldehyde 100 ppm input – 20aC T2: formaldehyde 200 ppm input – 20aC	T1: 100% in 8 d T2: removal: 92.7% in 10d
5	"Emtricitabine" [51]	Wastewater samples	Amounts accumulate in *E. crassipes* roots	11.7 ± 0.52 μg/kg Hartbeespoort Dam SP, 17.2 ± 0.14 μg/kg Springfield SP
6	"Tenofovir" [51]	Wastewater samples	Amounts accumulate in *E. crassipes* roots	7.4 ± 0.582 μg/kg Hartbeespoort Dam SP, 8.65 ± 0.58 μg/kg Springfield SP
7	"Oxybenzone Octocrylene Lindane Diuron" [52]	The water solution contains oxybenzone, octocrylene, lindane and diuron	Powdered dead roots from *E. crassipes*, *P. stratiotes* and *Fallopia japonica*	Octocrylene: 90 ± 2% BE in 2 h Lindane: 88 ± 0% BE in 2 h Diuron: 90 ± 1% BE in 2 h Chlordecone 100 ± 0% BE in 2 h
8	"Efavirenz" [51]	Wastewater samples	Amounts accumulate in E. crassipes roots	17.2 ± 0.14 μg/kg Hartbeespoort Dam SP, 29.6 ± 0.17 μg/kg Springfield SP
9	"Methylene blue Methyl orange Tetracycline" [53]	Nutrient solution supplemented with Methylene Blue Methyl orange tetracycline	Green HTC produced hydrochar, which was activated with KOH and magnetized with Fe^{3+} ions to create magnetic carbon materials	Amounts adsorb Methylene blue: 524.20 mg/g Methyl orange: 425.15 mg/g Tetracycline: 294.24 mg/g
10	"Erythromycin, tetracycline and sulfamethoxazole Mixture" [54]	Synthetic wastewater designed to simulate pharmaceutical industry wastewater	T1: inoculum (anaerobic sludge) + *E. crassipes* + antibiotics Erythromycin 100 mg/L, tetracycline 37.3 mg/L & sulfamethoxazole 100 mg/L	T1: removal: 60% in 12 d

*BE = biosorption efficiency, d = days, ECCBC = calcium-modified E. crassipes–based biochar, RE = removal efficiency, SP = sampling point, T = treatment

BENEFITS AND DRAWBACKS

Benefits

Cost-effective: Simpler and cheaper to operate than conventional treatment techniques. Eco-Friendly: Reduces dependency on chemical processes. Utilisation of Biomass: Harvested plants can be turned into compost, animal feed, or biofuels.

Drawbacks

Invasiveness: Local ecosystems may be upset by uncontrolled growth.
Climate Sensitivity: Seasonal and temperature variations may affect performance.
Challenges with Disposal: In order minimise secondary pollution, accumulated biomass needs to be properly handled.

CONCLUSION

Water hyacinth offers a natural and sustainable solution for improving water quality, utilizing its remarkable capacity to absorb and filter pollutants like heavy metals, excess nutrients and organic contaminants. This aquatic plant efficiently mitigates water pollution through phytoremediation, reducing harmful substances while also enhancing oxygen levels in water bodies. Its tremendous growth and adaptability make it a viable, cost-effective option for wastewater treatment, especially in regions with limited access to conventional purification technologies. Despite its advantages, the unchecked spread of *E. crassipes* can disrupt aquatic ecosystems, outcompeting native vegetation and obstructing waterways. Therefore, strategic management practices are necessary to balance its ecological impact while maximizing its benefits. Measures such as controlled harvesting, incorporation into biogas production and use in composting can mitigate its invasive nature and enhance its contribution to environmental sustainability. Ongoing research and technological advancements can refine water hyacinth-based treatment systems, making them more efficient and scalable. Integrating this method into broader water management strategies alongside engineered treatment solutions can optimize pollution removal while maintaining ecological balance. By exploiting its natural filtration properties responsibly, water hyacinth has ability to perform a vital function in achieving cleaner and healthier water bodies globally.

Disclosure statement: No potential conflict of interest was reported by the author(s).

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