International Journal of Environmental Impacts
Vol. 8, No. 4, August, 2025, pp. 687-694
Journal homepage: http://iieta.org/journals/ijei

Development and Performance Evaluation of Phytoremediation System for the Treatment of Wastewater

Ekta Dhande*, Shantanu Khandeshwar

Department of Civil Engineering, Yashwantrao College of Engineering, Rashtrasant Tukadoji Maharaj Nagpur University, Nagpur Maharashtra 441110, India

Corresponding Author Email: ektadhande29@ gmail.com

https://doi.org/10.18280/ijei.080406

Received: 18 April 2025
Revised: 28 May 2025
Accepted: 17 July 2025
Available online: 31 August 2025

Keywords:
wastewater, phytoremediation, heavy metal removal, constructed wetland, bioremediation

ABSTRACT

This experimental study aimed to identify suitable plant species for wastewater treatment in a constructed wetland system. Cymbopogon flexuous (lemon grass) and Clitoria ternatea (Asian pigeon wings) were planted with both wastewater and fresh water over a 24-week period. Growth parameters were recorded at specified intervals. Lemon grass exhibited the greatest plant height, the highest number of new leaves, and the newest shuts, while Clitoria produced the highest number of pods. In terms of treatment efficiency, both species demonstrated significant pollutant removal, achieving reductions of 90% in BOD, 80% in COD, and 95%-90% in TDS. With the exception of BOD, which was not effectively treated by elephant grass and giant bluestem, all other effluent parameters complied with CPCB guidelines. To evaluate long-term performance, further research is recommended with a continuous wastewater feed and an extended duration.

1. INTRODUCTION

Water is a vital resource and an essential component of the environment, playing a crucial role in sustaining life and maintaining ecological balance. Wastewater refers to water that has already been utilized for a specific purpose and subsequently becomes contaminated with physical, chemical, and biological pollutants. Domestic wastewater mainly comprises sewage generated from washrooms, bathrooms, laundries, kitchens, and black water containing urine, fecal matter, and toilet flush water. When this mixture is directed into a sewer system or septic tank, it is termed sewage [1]. Domestic wastewater carries substantial pollutants, including complex organic compounds, nitrogen-based substances, phosphorus-rich elements, and harmful microorganisms such as bacteria, viruses, and protozoa. If not managed properly, these contaminants can pose serious health risks [2].

When appropriately treated, wastewater can serve as a sustainable source of water and nutrients for agriculture [3]. Treated wastewater can be repurposed for irrigation and other agricultural needs or discharged into sewer systems, thereby alleviating the operational burden on centralized wastewater treatment facilities. This, in turn, can improve public health and enhance livelihoods. Although conventional wastewater treatment technologies have demonstrated efficiency, they are often costly, labor-intensive, and require site-specific solutions to minimize environmental impacts. Cost-effectiveness remains a significant challenge in wastewater management. Phytoremediation presents an environmentally friendly, cost-efficient, and non-invasive alternative to traditional treatment methods. This technique has been widely applied in constructed wetlands for wastewater treatment. Constructed wetlands offer a low-cost and sustainable solution for treating both domestic and industrial wastewater in developing nations [4]. Additionally, these wetlands can provide economic benefits, encouraging small communities to adopt natural wastewater treatment methods.

2. RELATED WORK

Phytoremediation, which uses plants' natural ability to absorb, break down, stabilize, or get rid of toxins in water and soil, has become popular as an environmentally friendly and long-lasting option to traditional wastewater treatment. A lot of research has been done on different phytoremediation methods, like phytoextraction, phytostabilization, phytodegradation, and rhizofiltration [5]. Engineered wetlands, especially those that are built with reeds (Phragmites australis) and willows (Salix spp.) as plants, are good at getting rid of nutrients and organic pollutants while also supporting microbial communities [6]. But these systems need a lot of room and have to be used for longer amounts of time. New ideas, like mixed marshes with both aerated and non-aerated areas, have made it easier to get rid of nitrogen and organic pollutants [7]. Water hyacinth (Eichhornia crassipes) and duckweed (Lemna minor) are often used because they grow quickly and take in a lot of nutrients, especially nitrogen and phosphorus. Because their roots are so big and they lose a lot of water, willows and poplars have been shown to be good at heavy metal phytoextraction [8]. But these species often need certain weather and water conditions, which limits how versatile they are.

While many studies have been done on common phytoremediative plants, not as much has been done on Asian pigeon wings (Clitoria ternatea) and lemongrass (Cymbopogon citratus). Both of these plants have good phytoremediation potential that has not been fully explored yet. Lemongrass is known to kill microbes and be able to handle stress in the environment. It may help microbes break down plants more effectively in rhizospheres. Similarly, Clitoria ternatea is a legume that fixes nitrogen and may help with the cycling of nutrients and the uptake of pollutants through interactions with beneficial microbes.

But there aren't any serious comparison studies that compare these species to plants that have been studied a lot, like Eichhornia or Phragmites. Unlike most macrophytes, lemongrass and Clitoria ternatea can grow in a wide range of agro-climatic zones and need less upkeep. This means they could be used on a larger scale in wastewater treatment systems that are limited by land or that are spread out. The current body of research is lacking because it doesn't do a thorough analysis of how quickly they take in pollutants, how well roots and microbes work together, or how well they do across different levels of pollution. These two species have not been the subject of any in-depth life cycle assessments (LCAs), uptake efficiency, or practical resilience studies.

Also, progress in genetic engineering and the use of floating treatment wetlands (FTWs) [9] have made phytoremediation more useful in a variety of situations. Still, there is no present research that shows how these technologies can be used on lemongrass or Clitoria ternatea. The study [10] looked at phytoremediation as a long-lasting and environmentally friendly way to clean up kitchen wastewater. It emphasized how cost-effective it is, how well it cleans up organic pollutants, and how good it is for the environment. It also emphasized how it could be used instead of traditional wastewater treatment methods. Performance measures have grown beyond how well something is removed to include things like how much it costs, how it affects the environment, and how long it lasts [11, 12]. However, information about these factors for lemongrass and Clitoria ternatea is either scattered or, at best, oral. Also, phytoremediation has some problems, like taking a long time to work, leaving chemicals in the biomass, and the need to get rid of waste after harvesting [13]. These limitations make it even more important to use mixed systems that include biochar amendment or microbial inoculants to better take in pollutants and break down lingering toxins. We want to fill in that important gap by doing a full comparison of how well lemongrass and Asian pigeon wings clean up wastewater by testing them against known phytoremediative standards in controlled wastewater treatment situations. The goal is to measure how well the removal works, how much biomass is produced, and how the system works. This will lay the groundwork for future scaling up and incorporating into mixed eco-technologies.

3. PHYTOREMEDIATION

'Phytoremediation Technology' integrates physical, chemical, and biological processes to achieve effective wastewater treatment. This system operates without electricity, requires minimal maintenance and workforce, and is largely self-sustainable. It plays a crucial role in water pollution control by acting as a sink for pollutants such as sediments and nutrients [14]. Several mechanisms contribute to wastewater treatment in wetlands, including sedimentation, bacterial action, filtration, decomposition, nutrient absorption, and vegetation-based processes [15].

Unlike chemical-based treatments, 'Phytoremediation Technology' naturally purifies wastewater using aquatic and semi-aquatic plants along with their associated microorganisms. This enhanced wetland-based treatment system optimizes biological treatment capabilities while incorporating engineered design parameters [16]. Phytoremediation is becoming more popular as a long-lasting and environmentally friendly way to clean up wastewater. The study [8] gave a short summary of how to get rid of pollutants, and Sharma et al. [9] talked about the future of sustainable management. The research [17] used Entropy-Fuzzy AHP-TOPSIS to choose macrophytes that float on the water. Additionally, the study [18] used ensemble learning in hydroponic treatment systems, and study emphasize [19] looked at Lemna minor for cleaning up dairy wastewater. Figure 1 shows Phytoremediation system for the treatment of Wastewater shows a planned way to use phytoremediation to smooth up wastewater. The image suggests how sure plants eliminate or neutralize exclusive forms of pollutants, consisting of heavy metals like Cadmium and Lead, organic pollutants like Benzene and Toluene, and important vitamins like Nitrogen and Phosphorus. This photograph suggests the plant-based totally treatment technique and stresses the significance of flowers in cleansing water in a method that is secure for the environment and lasts for a long term.

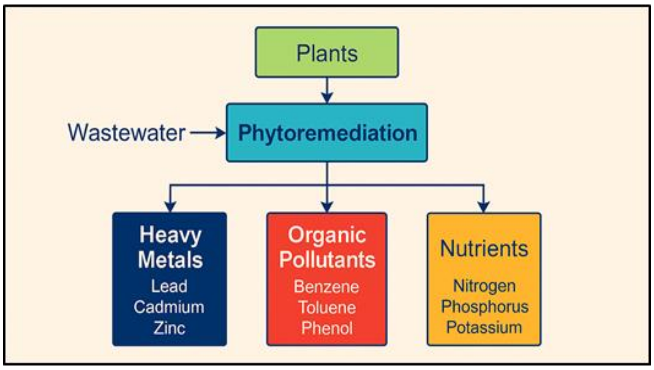

Figure 1. Phytoremediation system for the treatment of wastewater

In phytoremediation works, especially how chemicals interact with each other, we can create models that show things like chemical uptake, change, and stabilization.

Phytoremediation: Chemical Composition Equations

a. Adsorption of Contaminants onto Plant Roots:

$$qt = qe * (1 - \exp(-kad * t)) \quad (1)$$

where,

qt = amount of contaminant adsorbed at time t (mg/kg)
qe = equilibrium adsorption capacity (mg/kg)
kad = rate constant for adsorption (1/day)
t = time (days)

b. Bioaccumulation in Plant Tissue:

$$Cplant = Cwater * BCF \quad (2)$$

where,

$Cplant$ = concentration of the contaminant in the plant (mg/kg)

$Cwater$ = concentration of the contaminant in the water (mg/L)

BCF = bioconcentration factor (dimensionless)

c. Volatilization of Contaminants from Plant Surfaces:

$$\frac{dV}{dt} = kv * A * Cplant \quad (3)$$

where,

V = mass of contaminant volatilized (mg)

kv = volatilization rate constant (mg/m²/day)

A = surface area of the plant exposed to air (m²)

d. Degradation of Contaminants by Plant-Associated Microbes:

$$\frac{dC}{dt} = -kdeg * C \quad (4)$$

where,

C = concentration of the contaminant (mg/L)

$kdeg$ = microbial degradation rate constant (1/day)

e. Rhizodegradation in the Root Zone:

$$\frac{dC}{dt} = -krh * C * R \quad (5)$$

f. Chemical Transformation Due to Plant Enzymes:

$$\frac{dC}{dt} = -kenz * C * E \quad (6)$$

where,

C = concentration of the contaminant undergoing transformation (mg/L)

$kenz$ = rate constant for enzymatic transformation (1/day)

E = enzyme activity (units/L)

g. Stabilization of Heavy Metals in Soil:

$$Mstabilized = Mtotal * (1 - \exp(-kst * t)) \quad (7)$$

where,

$Mstabilized$ = mass of metal stabilized in the soil (mg)

$Mtotal$ = total mass of the metal in the soil (mg)

kst = stabilization rate constant (1/day)

t = time (days)

4. MATARIALS AND METHOD

4.1 Sewage

Sewage sample was directly pumped from wastewater sewer line and was collected in drum of 200 liters approximately. No other treatment or chemicals were used before introducing wastewater to reed bed I and reed bed II. Tests on waste water were conducted to determine wastewater characteristics such as: Color, Turbidity, Electric Conductivity, Temperature, PH, Total dissolved solids, Hardness, Chloride, Sulphate, Alkalinity, Dissolved Oxygen, Biochemical oxygen demand, Chemical oxygen demand, Nitrates, Phosphorus, Potassium, Total Nitrogen etc.

This research employed an organized random composite sampling strategy to provide a representative and accurate wastewater sample. A municipal home waste sewer system near the research location provided the sewage samples. A well-sealed HDPE barrel held 200 liters of untreated sewage. Samples were taken for 7 days. To account for daily household wastewater flow fluctuations, two 1-liter grab samples were obtained each morning (8–9 AM) and evening (5–6 PM). To create a homogenous, time-biased sample, these 14 grab samples were thoroughly mixed. Routine sample errors were reduced by randomly selecting business hours collection times. All samples were brought to the lab and tested within 6 hours after collection to prevent spoilage. We recorded pH, EC, BOD, COD, TDS, nitrates, phosphates, and chlorides, biological markers (DO), and physical parameters (color, temperature, and turbidity).

4.2 Plant efficacy in wastewater treatment

Certain plants: Studies on phytoremediation have found a few types of plants that are especially good at cleaning up wastewater because they grow quickly, can handle pollutants, and can store pollutants. These are some of the most studied:

- Water hyacinths (Eichhornia crassipes): The water hyacinths can quickly grow and produce a lot of biomasses. They are also good at removing nutrients and heavy metals from rainwater. Their deep roots cover a lot of ground, which makes it easier for bacteria to form and break down organic pollution.
- Duckweed (Lemna spp.): Another very good plant for treating wastewater, this time because it can quickly cover the surface of water. This cuts down on light getting in, which helps keep algae blooms under control. It also takes in a lot of nutrients, which makes it perfect for wastewater that is high in nutrients.
- Reeds (Phragmites australis): Reeds are often used in man-made marshes because they can get rid of both organic and artificial pollution. Their strong root systems help keep the ground stable, which makes it easier to remove solids that are floating in the water and encourages settling.
- Willows (Salix spp.): Willows are known for being able to take in heavy metals and biological pollutants. They can be taken to control the amount of waste and get rid of pollutants that have built up in the system. This makes them good for phytoremediation methods that need to get rid of contaminants.

4.3 Dealing with pollutants

These plants are good at getting rid of a lot of different pollutants that are common in wastewater, such as:

- Heavy Metals: There are plants, like water hyacinths and willows, that can take in metals like lead, cadmium, and chromium from polluted water. They can store a lot of metals in their bodies, which makes them useful for bioextraction and then recovering or safely getting rid of these metals.
- Organic Pollutants: The microbes that live in the roots of reeds and other marsh plants can break down organic compounds, such as those found in medicines, personal

care products, and many industrial poisons. These chemicals can also be taken up by plants and stored or changed by them.

Nitrogen and phosphorus are two nutrients that are very bad for garbage because they cause eutrophication. Duckweed and water hyacinths are especially good at getting rid of these chemicals. Because they grow so quickly, they can take in a lot of nitrogen and phosphorus, which are important for their growth.

4.4 Statistical analysis

This research compared pollutant levels and plant growth before and after phytoremediation using descriptive statistics. Included were mean, percentage reduction, and graph comparison. The exploratory and proof-of-concept research purposefully used these basic methodologies. The major objective was to test Cymbopogon flexuous and Clitoria ternatea in a controlled man-made marsh habitat. Simple statistics are fine since the experiment was done in one system with controlled variables and specified input. For determining treatment effects, complicated inferential procedures like regression or ANOVA are less relevant. The biggest variations were between pre- and post-treatment results. Clear patterns in pollutant reduction and plant biomass increase were observed.

We believe that inferential statistics approaches like t-tests or confidence intervals may strengthen findings, particularly in larger or multi-site investigations. For future work with copies, annual datasets, or comparable plant groups, parametric or non-parametric tests, association studies, and multivariate approaches will improve proof and variability measurement.

5. EXPERIMANTAL SETUP

By considering all parameters set up of constructed wet land was made. Horizontal flow CW was chosen to accomplish maximum time of travel and contact period with media.

(Pilot type) set up consists of PVC drum approximately 200 liters followed by glass chamber of size: length 9000 mm, Width 300 mm and depth 600 mm which again has partitions in it which acted as Reed bed – 1 Glass chamber was again followed by PVC crate which acted as Reed bed – 2 and treated water was again collected in PVC drum of approximately 200 liters. Setup structured illustrate in Figure 2 Reed beds are layered with different supporting media for plant growth which includes sand, aggregate and charcoal respectively.

Figure 2. Setup of constructed wetland

5.1 Study area

The research was also performed on Site (already Existing) at Baner, Municipal Corporation Pune. Which was already planted with Indian Cannae and replaced partially by Cymbopogon flexuous (lemon grass) and Clitoria ternatea (Asian pigeon wings), as shown in Figure 3.

5.2 Identification of plants

The following plants were selected after conducting various trials. Trial plants which showed sustainability in media and growth and developments are by Cymbopogon flexuous (lemon grass) and Clitoria ternatea (Asian pigeon wings) both are perineal plants and belongs to Poaceae and Fabaceae family respectively.

They are all locally available plants and shows well growth and development in wide range of soil, aggregate and charcoal, the Figure 4 illustrate the phytoremediation plants. Capable of growing in rainfall as well as on dry days.

Figure 3. On site plantation at Pune

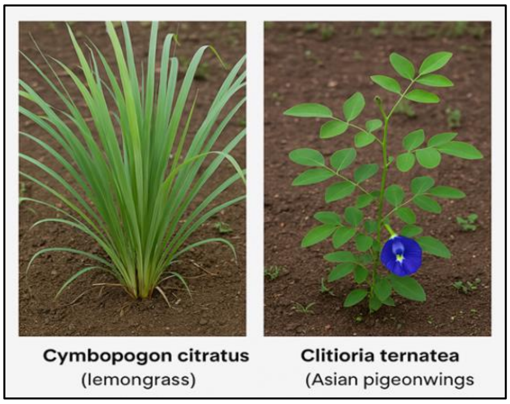

Figure 4. Phytoremediation plants: Cymbopogon flexuosus and Clitoria ternatea

5.3 Support or growth media

- Sand – zone 2 (Medium sand with a maximum particle size of 4.75 mm) Which also acted as binding material to roots and their substantial growth.
- Aggregate – Aggregate used where 10 mm aggregate gradation zone is 100% passing for both grading zone 1 and grading zone 2 (More the aggregate size more will be the absorption through materials).
- Charcoal – Due to porous surface of the charcoal, they are very effective in trapping contaminants and removing harmful chemicals if any.

They also may act as absorbent for removal of pollutants content in waste water. It will not remove any bacteria, calcium and magnesium (hard water) nitrates, chlorides and other inorganic chemicals.

TSS removal, BOD, organic compound.

5.4 Method of application

Horizontal flow CW was chosen to accomplish maximum time of travel and contact period with media.

With Flow of 0.002 m/h. with the help of perforated pipes wastewater was introduced in reed bed I which is made up of glass with has 5 partitions and flow was maintained in order to have maximum contact time with plants roots and supporting media. Further reed bed I was connected with reed bed II and same procedure was followed in it and lastly it was connected with treated water PVC drum.

5.5 Theoretical model for the phytoremediation process

Theoretical Model for Phytoremediation Process:

Step 1: Adsorption of Contaminants on Plant Roots

$$\frac{dCr}{dt} = kad * (Cw - Cr) \quad (8)$$

where,

Cr = contaminant concentration adsorbed on roots (mg/kg)

Cw = contaminant concentration in wastewater (mg/L)

kad = adsorption rate constant (1/day)

Step 2: Bioaccumulation of Contaminants in Plant Tissue

$$\frac{dCp}{dt} = kup * Cr - kmet * Cp \quad (9)$$

Step 3: Microbial Degradation in Rhizosphere

$$\frac{dCw}{dt} = -kdeg * M * Cw \quad (10)$$

where,

$kdeg$ = microbial degradation rate constant (L/mg/day)

M = microbial biomass/activity factor (mg/L)

Cw = contaminant concentration in wastewater (mg/L)

Step 4: Nutrient Uptake by Plants (Phytoassimilation)

$$\frac{dN}{dt} = -knut * B * N \quad (11)$$

where,

N = nutrient concentration in wastewater (mg/L)

$knut$ = nutrient uptake rate constant (L/g biomass/day)

B = plant biomass (g)

Step 5: Biomass Growth Linked to Nutrient Uptake

$$\frac{dB}{dt} = \mu * B * (\frac{N}{N + Ks}) - d * B \quad (12)$$

where,

B = plant biomass (g)

μ = maximum specific growth rate (1/day)

Ks = half-saturation constant for nutrient uptake (mg/L)

d = biomass decay rate (1/day)

6. RESULT AND DISCUSSION

The experiment looked at how well Cymbopogon flexuous (lemongrass) and Clitoria ternatea (Asian pigeon wings) could clean up pollutants in a man-made horizontal groundwater flow wetland system. The findings showed big changes in plant growth, the quality of the wastewater, and the amount of micro- and macronutrients that plants absorbed. These changes were caused by important phytoremediation processes. Several pollutants in wastewater can be successfully removed by Cymbopogon flexuosus (lemon grass) and Clitoria ternatea (Asian pigeon wings). These pollutants include BOD (91.9% reduction), COD (79.6% reduction), nitrates, phosphorus, and potassium. Growth factors like shoot number, leaf length, and biomass all went up a lot, which shows that the plants were able to absorb nutrients well and adapt to the dirty circumstances. The patterns of nutrient intake matched bioaccumulation and phytoassimilation, and the patterns of pollution reduction matched rhizodegradation and bacteria activity in the root zone. These results are very important for making a theoretical model that connects how plants grow, how they take in nutrients, how they get rid of pollutants, and how microbes interact in a marsh system.

6.1 Analysis of pollutant reduction

Significant drops in major pollution were achieved, as shown in Table 1: Nitrate went down from 29.91 mg/L to 20.48 mg/L, BOD from 210 mg/L to 17 mg/L, and COD from 530 mg/L to 108 mg/L. These results can be explained by different phytoremediation mechanisms:

Table 1. Initial and final wastewater parameters

Parameters	BOD	COD	Nitrate	Potassium	Phosphorus
Initial	210	530	29.91	13.5	0.26
Final	17	108	20.48	12.91	0.19

Rhizodegradation and bacteria breakdown probably played big parts in lowering BOD and COD. Both plants' root zones produce both aerobic and anaerobic microenvironments that are home to microbes that can break down organic pollution.

Nitrate, phosphorus, and potassium levels went down because of phytoextraction and nitrogen uptake by plant roots. The comparison analysis of water quality is represented in Figure 5. These nutrients are necessary for plants to grow, and they were taken up by the plants, especially when they were actively growing.

6.2 Growth and biomass response

Table 2 and Figure 6 show that both plant types had big increases in the number of shoots and the length of their leaves, especially when they were given wastewater. This better growth shows that the plant is able to take in nutrients (this is called phytoassimilation) and adapt to surroundings with lots of nutrients. Bioaccumulation is the process by which important nutrients like nitrogen (N), phosphorus (P), and potassium (K) are taken up by plants and kept in their cells.

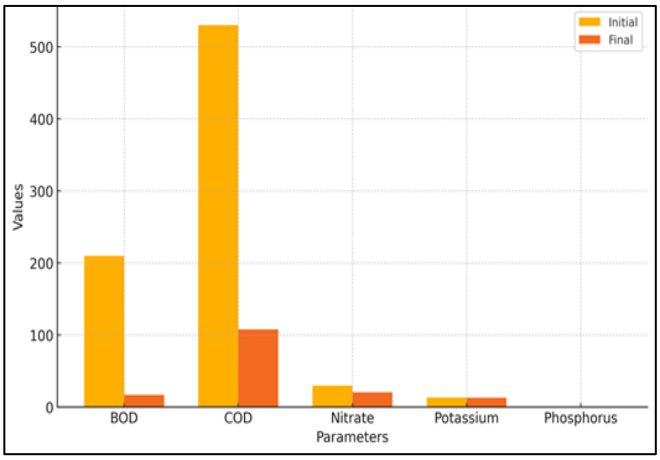

Figure 5. Comparison of water quality parameters
Note: Units for BOD, COD, Nitrate, Potassium and Phosphorus is mg/L

Table 2. Growth in plants before and after wastewater feed

Plants	Weight	Root Length	Before Plantation		After Plantation 3 Months	
			No. of Shoots	Leaves Length	No. of Shoots	Leaves Length
1	67 gm	46 cm	4	82 cm	12	113
2	106 gm	44 cm	6	86 cm	9	97

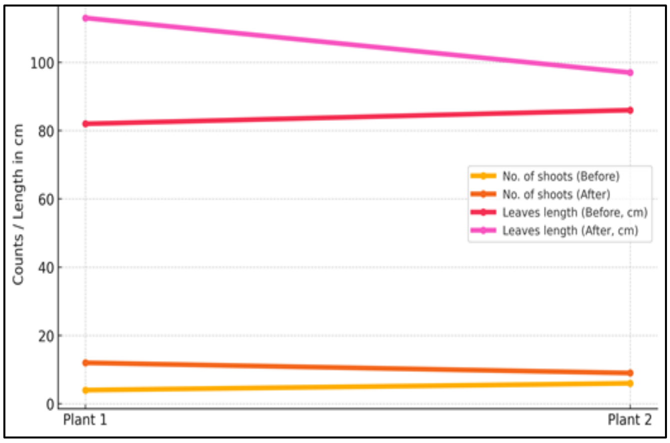

Figure 6. Growth comparison before and after plantation

Table 3. Micro and macro nutrients absorption

Parameters	Clitoria Ternatea		Lemmon grass	
	Ideal	Wastewater	Ideal	Wastewater
N	1.2	1.8	1	2
P	0.21	0.37	0.25	0.41
K	0.8	1.11	0.72	1.23
S	0.23	0.36	0.46	0.32
Fe	14.8	10.84	8.46	12.13

6.3 Nutrient uptake and theoretical linkage

In Table 3 and Figure 7, you can see how much of each nutrient each species had in both ideal and garbage situations. It went from 1.2% (ideal) to 1.8% (wastewater) in Clitoria ternatea. Phosphorus went from 0.21% to 0.37% and potassium from 0.8% to 1.11%. Also, Cymbopogon flexuous took in even more: nitrogen levels doubled from 1% to 2%, and potassium levels rose from 0.72% to 1.23%. These data support the bioaccumulation and translocation models of phytoremediation. In these models, chemicals are taken up by plants through their roots and moved into their stems and leaves. Phytoassimilation, the process of adding nutrients to plant growth, is supported by the fact that plant biomass increased at the same time that nutrients were absorbed.

Iron (Fe) showed interestingly different patterns. For example, in Clitoria ternatea, Fe levels dropped from 14.8 mg/kg to 10.84 mg/kg after being exposed to wastewater. This could be because other ions, like nitrates or phosphates, were competing with Fe for availability. On the other hand, lemongrass took in more Fe (from 8.46 mg/kg to 12.13 mg/kg), which could be because it was better at chelating or changing Fe through enzymes in its root environment. This shows how enzymes change and stabilize things. Also, the fact that lemongrass absorbs less Sulphur in wastewater (from 0.46 to 0.32% less) could mean that nutrients are competing with or suppressing each other, which can happen when the amounts of macronutrients are off. This fits with the ideas of rhizodegradation and nitrogen exchange that were talked about in the theory context.

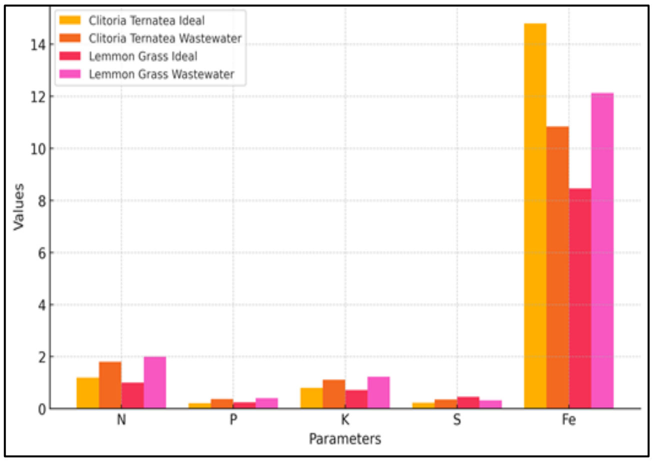

Figure 7. Comparison of nutrient values in ideal and wastewater conditions

The initial phase of experiment covered the growth and sustainability of vegetation Cymbopogon flexuous (lemon grass) and Clitoria ternatea (Asian pigeon wings) development of roots and maturation of the system. Fresh water was fed to the system (Planted in pots) and wastewater was fed to the pilot type system. Increase in weight of roots, number of shoots and length of leaves were observed. Development and growth were observed till 3 months in various seasons.

The initial concentration of pollutants in wastewater and after treatment can be tabulated as:

From Table 2 we can say that there is overall growth in plants as they also absorb nutrients required for supporting media and wastewater. There are certain changes observed in macronutrients and micronutrients of plants feed with fresh water and plants feed with wastewater over a period of three months. Ideal values represent plants feed with fresh water; the growth comparison is illustrated in Figure 6.

Distinct trends in the data show how each plant reacts to different settings when one examines the nutrient absorption of Clitoria Ternatea and Lemmon Grass under optimal and wastewater circumstances, demonstrate in Table 3. When exposed to wastewater, Clitoria Ternatea showed greater nitrogen (N), phosphorus (P), and potassium (K) absorption, with levels increasing from 1.2 to 1.8, 0.21 to 0.37, and 0.8 to 1.11 correspondingly. This implies a strong adaptation to nutrient-rich wastewater, maybe resulting from a higher need for these nutrients under difficult circumstances. Though, its iron (Fe) level drops from 14.8 under optimal circumstances to 10.84 in wastewater, suggesting a probable hindrance in Fe absorption caused by other elements or pollutants in the wastewater.

On the other hand, Lemmon Grass shows more N, P, and K absorption in wastewater as well, with numbers rising from 1 to 2, 0.25 to 0.41, and 0.72 to 1.23, respectively, comparison of nutrient values for ideal wastewater condition illustrates in Figure 7. Though the rises are more noticeable than for Clitoria Ternatea, this shows a comparable adaptability indicating that Lemmon Grass might be more efficient at using the higher nutrient availability in wastewater. Curiously, the Sulphur (S) level in Lemmon Grass drops from 0.46 in optimal circumstances to 0.32 in wastewater, which might suggest a competitive suppression by other sulphates or a change in nutritional priorities under stress. On the other hand, iron concentration rises from 8.46 to 12.13, which might imply improved mechanisms in Lemmon Grass for handling or profiting from the composition of the effluent, especially with regard to Fe absorption. These findings offer insightful analysis of the possible use of these plants in phytoremediation plans, where particular plants' natural absorption capacity allows wastewater to be treated, therefore transforming a waste disposal problem into an environmental and agricultural chance.

The study's results show that Cymbopogon flexuous and Clitoria ternatea are good at getting rid of pollutants. They also show how important plant-microbe interactions are in man-made marshes across different fields. In plants and microbiology, the patterns of nutrients taken up suggest active rhizospheric interactions. Root exudates may activate microbial groups that break down organic matter, produce nitrogen, and dissolve phosphorus. These interactions speed up the breakdown of pollutants beyond what the roots can absorb. From the point of view of soil science, phytoremediation leads to better soil structure, organic matter content, and microbial variety. These factors support long-term nutrient cycles, lower toxins, and repair soil health in polluted areas.

7. CONCLUSION

This study showed that a horizontal underground-built wetland system grown with Cymbopogon flexuous (lemongrass) and Clitoria ternatea (Asian pigeon wings) can clean up wastewater from homes. Both plant species were very good at getting rid of pollutants—most notably, a 91.9% drop in BOD, a 79.6% drop in COD, and big drops in nitrate, phosphorus, and potassium levels—while also growing healthy biomass and absorbing more nutrients when given wastewater. These results show that they play a part in important phytoremediation processes like phytoextraction, rhizodegradation, and bioaccumulation. The way plants took in nutrients, especially more nitrogen, phosphorus, and potassium, fit well with how phytoremediation is thought to work and showed how their bodies were adapting to the dirty surroundings. Lemongrass was better at absorbing iron and nutrients, while Clitoria ternatea was better at taking in nitrogen but less iron. This suggests that different species react differently and that ions in the rhizosphere compete with each other. Based on these findings, a simple theoretical model is put forward to show how the ability of plants to take in pollutants is linked to the amount of biomass they produce and the amount of nutrients they have over time. This model shows how plant growth, root-microbe interactions, and the supply of contaminants all affect how well phytoremediation works.

8. LIMITATIONS OF THE STUDY

This research found that Cymbopogon flexuous and Clitoria ternatea may treat household wastewater in developed wetland systems. However, several difficulties must be noted to contextualise the findings and inform future modifications.

This research has flaws. It lasted three months and used batch feed instead of continual flow. In reality, phytoremediation systems function for extended periods of time and under varying loads, which may affect plant lifespan, pollution removal, and system stability.

Seasonal variations may also affect plant metabolism, microbial activity, evaporation and condensation, and marsh water retention. Cold and dry conditions inhibit plant growth and waste-degrading microorganisms. Cleaning becomes less effective.

Plant waste accumulates harmful chemicals, another issue. Even while plants removed nutrients and certain heavy metals successfully, these pollutants may pile up in plant cells and reach harmful levels that can inhibit growth or make removal difficult. The study did not examine the long-term impacts of collecting, storing, and safely disposing of biomass (recycling, burning, or biofuel recovery). The selected plant species' development cycles may also affect cleanup. Cymbopogon flexuous and Clitoria ternatea have varied biomass profiles and root growth seasons.

Climate change, including rainfall patterns, higher temperatures, and more severe weather events, may affect man-made marsh biodiversity and water flow. Droughts impede water flow and affect marine vegetation. However, too much rain might induce hydraulic overflow, decreased holding durations, and contamination skipping.

ACKNOWLEDGMENT

The author would like to thank Aquatec Engineers for Sponsorship, Yashwantrao college of Engineering well equipped labs and Agricultural college Nagpur.

REFERENCES

[1] Abdallah, M.A.M. (2012). Phytoremediation of heavy metals from aqueous solutions by two aquatic macrophytes. Ceratophyllum demersum and Lemna gibba L. Environmental Technology, 33(14): 1609-1614. https://doi.org/10.1080/09593330.2011.640354

[2] Calheiros, C.S., Rangel, A.O., Castro, P.M. (2007). Constructed wetland systems vegetated with different plants applied to the treatment of tannery wastewater. Water Research, 41(8): 1790-1798. https://doi.org/10.1016/j.watres.2007.01.012

[3] Kasmuri, N., Malik, S.A.A., Yaacob, Z., Miskon, M.F. (2023). Application of water hyacinth in phytoremediation of wastewater. IOP Conference Series: Earth and Environmental Science, 1135(1): 012008. https://doi.org/10.1088/1755-1315/1135/1/012008

[4] Lakshmi, K.S., Sailaja, V.H., Reddy, M.A. (2017). Phytoremediation-a promising technique in waste water treatment. International Journal of Scientific Research and Management, 5(6): 5480-5489. https://doi.org/10.18535/ijsrm/v5i6.20

[5] Saha, P., Shinde, O., Sarkar, S. (2017). Phytoremediation of industrial mines wastewater using water hyacinth. International Journal of Phytoremediation, 19(1): 87-96. https://doi.org/10.1080/15226514.2016.1216078

[6] Kinidi, L., Salleh, S. (2017). Phytoremediation of nitrogen as green chemistry for wastewater treatment system. International Journal of Chemical Engineering, 2017(1): 1961205. https://doi.org/10.1155/2017/1961205

[7] Mojiri, A. (2012). Phytoremediation of heavy metals from municipal wastewater by Typha domingensis. African Journal of Microbiology Research, 6(3): 643-647. https://doi.org/10.5897/AJMR-11-1492

[8] Khan, A.U., Khan, A.N., Waris, A., Ilyas, M., Zamel, D. (2022). Phytoremediation of pollutants from wastewater: A concise review. Open Life Sciences, 17(1): 488-496. https://doi.org/10.1515/biol-2022-0056

[9] Sharma, M., Rawat, S., Rautela, A. (2024). Phytoremediation in sustainable wastewater management: An eco-friendly review of current techniques and future prospects. AQUA—Water Infrastructure, Ecosystems and Society, 73(9): 1946-1975. https://doi.org/10.2166/aqua.2024.427

[10] Chandekar, N., Godboley, B.J. (2017). A review on phytoremediation a sustainable solution for treatment of kitchen wastewater. International Journal of Science and Research, 6(2): 1850-1855.

[11] Kesari, K.K., Soni, R., Jamal, Q.M.S., Tripathi, P., et al. (2021). Wastewater treatment and reuse: A review of its applications and health implications. Water, Air, and Soil Pollution, 232(5): 208. https://doi.org/10.1007/s11270-021-05154-8

[12] Herath, I., Vithanage, M. (2015). Phytoremediation in constructed wetlands. Phytoremediation: Management of Environmental Contaminants, 2: 243-263. https://doi.10.1007/978-3-319-10969-5_21

[13] Mishra, S., Cheng, L., Maiti, A. (2021). The utilization of agro-biomass/byproducts for effective bio-removal of dyes from dyeing wastewater: A comprehensive review. Journal of Environmental Chemical Engineering, 9(1): 104901. https://doi.org/10.1016/j.jece.2020.104901

[14] Martini, S., Roni, K.A. (2021). The existing technology and the application of digital artificial intelligent in the wastewater treatment area: A review paper. Journal of Physics: Conference Series, 1858(1): 012013. https://doi.org/10.1088/1742-6596/1858/1/012013

[15] Chakraborty, R., Asthana, A., Singh, A.K., Jain, B., Susan, A.B.H. (2022). Adsorption of heavy metal ions by various low-cost adsorbents: A review. International Journal of Environmental Analytical Chemistry, 102(2): 342-379. https://doi.org/10.1080/03067319.2020.1722811

[16] Kerur, S.S., Bandekar, S., Hanagadakar, M.S., Nandi, S.S. (2021). Removal of hexavalent chromium-industry treated water and wastewater: A review. Materials Today: Proceedings, 42: 1112-1121. https://doi.org/10.1016/j.matpr.2020.12.492

[17] Coimbra, E.C.L., Borges, A.C., Mounteer, A.H., Rosa, A.P. (2023). Using wastewater treatment performance, biomass and physiological plant characteristics for selection of a floating macrophyte for phytoremediation of swine wastewater through the integrative Entropy-Fuzzy AHP-TOPSIS method. Journal of Water Process Engineering, 53: 103793. https://doi.org/10.1016/j.jwpe.2023.103793

[18] Mustafa, H.M., Hayder, G., Abba, S.I., Algarni, A.D., Mnzool, M., Nour, A.H. (2023). Performance evaluation of hydroponic wastewater treatment plant integrated with ensemble learning techniques: A feature selection approach. Processes, 11(2): 478. https://doi.org/10.3390/pr11020478

[19] Sahi, W., Megateli, S. (2023). Evaluation of lemna minor phytoremediation performance for the treatment of dairy wastewater. Water Practice and Technology, 18(5): 1138-1147. https://doi.org/10.2166/wpt.2023.074