

# To Study and Analyze the Effectiveness of Floating Wetlands for Household Sullage Water Treatment

Vinit W. Jadhav<sup>1</sup>, Harshal Y. Patil<sup>2</sup>, Harshad S. Suryawanshi<sup>3</sup>, Vijay H. Jadhav<sup>4</sup>

<sup>1</sup> Student, Department of Civil Engineering, Latthe Education Society's Polytechnic, Sangli, Maharashtra, India

Affiliated to Maharashtra State Board of Technical Education (MSBTE), Mumbai, India

Faculty Guides: Ms. Trupti Gane & Mr. Aditya Vagyani

## Abstract

This paper presents a comprehensive study on the design, development, and performance analysis of a Floating Treatment Wetland (FTW) system for treating household sullage (greywater). Household wastewater generated from bathing, laundry, and kitchen activities contains organic matter, detergents, nutrients, and suspended solids that cause significant environmental pollution if discharged untreated. Conventional treatment systems are costly and unsuitable for individual households in rural and semi-urban areas. This study fabricated a lab-scale FTW model (80 cm × 40 cm × 15 cm) using an acrylic tank with two baffle walls and Water Hyacinth (*Eichhornia crassipes*) as the primary treatment plant. Greywater was monitored over 15 days for pH, Turbidity (NTU), Total Dissolved Solids (TDS), and Dissolved Oxygen (DO). Results showed an average turbidity removal of 70.08%, pH stabilization efficiency of 10.83%, and dissolved oxygen improvement of 45.56%. TDS increased due to mineral leaching, a correctable design issue. The full household-scale design requires approximately 3.31 m<sup>2</sup> of surface area, processes 290 L/day of sullage, and is estimated at ₹25,000–₹30,000. The study confirms FTWs as a sustainable, low-cost, eco-friendly, and decentralized solution for household greywater treatment with potential for water reuse in irrigation and cleaning.

**Keywords:** Floating Treatment Wetlands (FTW), Household Sullage, Greywater, Water Hyacinth, Phytoremediation, Turbidity, Dissolved Oxygen, pH Stabilization, Water Reuse, Decentralized Wastewater Treatment.

## 1. Introduction

Water is among the most vital natural resources, yet its quality is continuously threatened by improper disposal of domestic, agricultural, and industrial wastewater. At the household level, a large fraction of wastewater is categorized as sullage or greywater — effluent originating from kitchens, bathrooms, laundry, and washing activities, excluding toilet waste. Although sullage is less contaminated than blackwater, it still carries a significant load of organic matter, oils, grease, synthetic detergents, nutrients such as nitrogen and phosphorus, and suspended solids. When discharged untreated into open drains or

water bodies, sullage causes soil degradation, groundwater contamination, foul odour, and pollution of aquatic ecosystems.

Floating Treatment Wetlands (FTWs), also known as Constructed Floating Wetlands (CFWs) or Ecological Floating Beds, have emerged as one of the most promising nature-based solutions for wastewater treatment. These systems consist of buoyant floating platforms on which emergent aquatic plants are rooted, with their shoots growing above the water surface while dense fibrous root systems hang freely into the water column below. This root zone creates an ideal microhabitat for microbial biofilm formation, enabling concurrent physical filtration, biological degradation, and nutrient uptake to occur without the need for any external energy input.

FTWs offer significant advantages for household-level application: they are low-cost, simple to construct, require minimal maintenance, and can be installed in small tanks, ponds, or specially designed containers. They are particularly relevant in rural and peri-urban regions of India, such as the Sangli district of Maharashtra, where sullage is routinely discharged untreated into open drains, posing serious environmental and public health risks. The present study investigates a lab-scale FTW model using Water Hyacinth as the primary macrophyte and evaluates its performance over a 15-day experimental period. A full-scale household system is also designed and estimated.

## **2. Background and Problem Statement**

Population growth, urbanization, and rising living standards have significantly increased household wastewater generation across India. According to Wagh and Kamat (2014), household greywater in the Sangli region has an average influent BOD of 114 mg/L, primarily from detergents, food residues, and organic matter. Despite this load, most rural and semi-urban households lack access to centralized sewage treatment plants, which are expensive, energy-intensive, and require skilled technical operation. As a result, sullage is frequently discharged directly into the environment, contributing to eutrophication, loss of aquatic biodiversity, and contamination of groundwater resources.

Alternative decentralized treatment technologies such as septic tanks, soak pits, and constructed wetlands have been explored, but each presents limitations including land requirements, clogging risks, high maintenance, and chemical inputs. In this context, Floating Treatment Wetlands represent an advanced and practical evolution of constructed wetland technology. Unlike subsurface or surface-flow constructed wetlands that require dedicated land areas and gravel substrates, FTWs float on the surface of existing water bodies or purpose-built tanks, eliminating the need for substrate and minimizing civil infrastructure requirements. Their application at the household level is therefore particularly compelling.

The core problem this project addresses is: how to design, fabricate, and evaluate an efficient household-scale floating wetland system for sullage treatment that is simultaneously cost-effective, eco-friendly, easy to maintain, and capable of producing treated water suitable for non-potable reuse. Key challenges include selecting appropriate plant species, designing for adequate hydraulic retention time (HRT), preventing TDS accumulation, and ensuring reliable year-round performance under the semi-arid climate of Maharashtra.

### 3. Literature Review

#### 3.1 Floating Treatment Wetlands: A Review and Bibliometric Analysis

**Colares and Dell’Osbel (2020):** This comprehensive review confirms that FTW systems use naturally occurring plants as floating hydroponic mats, with root systems acting as natural filters while promoting hydraulic flow. FTWs are now applied globally to treat secondary effluents, stormwater, agricultural runoff, and polluted rivers. The review validates FTW efficiency through combined physical, biological, and chemical treatment processes, and identifies nutrient removal, biomass harvesting, and low operational cost as principal advantages.

#### 3.2 Effect of FTW Coverage Ratio on Nitrogen Removal

**Gerente and Andres (2023):** This study investigated FTW coverage ratio and hydraulic residence time effects on total nitrogen (TN) removal from agri-food effluents over 16 months. TN removal efficiency ranged from 34–85% across different FTW sizes, with higher coverage ratios consistently yielding better performance. The study confirms that FTWs have reduced land footprints and no clogging risk compared to conventional constructed wetlands, though variable seasonal performance and lack of standardized design guidelines remain challenges.

#### 3.3 Water Hyacinth for Organic Contaminants Removal

**Amalina and Razak (2022):** Water Hyacinth (*Eichhornia crassipes*) has been used for water pollution control since the 1980s. It grows to extremely dense volumes exceeding 60 kg/m<sup>2</sup> and can double its population every 5–15 days. Its roots, stems, and leaves serve as adsorbents and phytoremediation agents for organic dyes, heavy metals, and dissolved pollutants. Two weeks is typically sufficient for effective treatment of domestic water with Water Hyacinth under controlled conditions, making it highly suited to the HRT of household FTW systems.

#### 3.4 FTW Design, Performance, and Application Review

**Kilian (2023):** This review identifies key FTW design parameters: plant selection, planting medium, plant establishment phase duration, treatment medium depth, surface coverage ratio, HRT, and FTW placement. The biofilm–rhizosphere symbiosis is identified as critical to pollutant removal efficiency. Construction and maintenance costs range from 3.67 to 137.22 EUR/m<sup>2</sup>/year depending on system complexity — significantly lower than conventional constructed wetlands (11.8–33.3 EUR/PE/year). Despite growing research interest, a lack of standardized design guidelines remains a significant gap.

#### 3.5 Nutrient Removal from Waste Stabilization Ponds Using CFWs

**Huth and Kulkarni (2022):** This field-scale Australian study is among the first to assess CFWs treating raw sewage. Harvesting of four CFW islands after 375 days removed an estimated 23.2 kg of nitrogen and 2.97 kg of phosphorus. Among the tested species, *Baumea articulata* achieved the highest nutrient uptake rates. The study confirms that plant species selection critically influences nutrient removal performance and that CFWs can function effectively at full scale under real wastewater conditions.

### 3.6 Summary of Literature Gaps

The reviewed literature confirms the effectiveness of FTWs for wastewater treatment and identifies Water Hyacinth as an excellent plant choice for tropical and semi-arid climates. However, most studies are conducted at mesocosm or lab scale with synthetic wastewater. Very few studies address household-scale sullage treatment in the Indian context, particularly for the semi-arid climate of Maharashtra. There is also a lack of data on TDS dynamics and mineral leaching in small acrylic or plastic tank systems, which is a specific contribution of the present study.

### 4. Objectives of the Study

The following specific objectives were established for this study:

- To study the role of aquatic plants, specifically Water Hyacinth, in household wastewater treatment through phytoremediation and rhizosphere microbial activity.
- To design a full-scale floating wetland system for an individual household based on calculated hydraulic and BOD loading, with a detailed structural estimation and cost analysis.
- To design, fabricate, and operate a lab-scale floating wetland model using an acrylic tank with baffle walls and Water Hyacinth plants.
- To evaluate the treatment effectiveness by measuring pH, Turbidity (NTU), Total Dissolved Solids (TDS, mg/L), and Dissolved Oxygen (DO, mg/L) at inlet and outlet over 15 days.
- To calculate and compare removal efficiencies for each parameter and draw conclusions about overall system performance and suitability for domestic water reuse.

### 5. Role of Aquatic Plants in Wastewater Treatment

Aquatic macrophytes are the biological engine of any floating wetland system. Their role extends far beyond simple nutrient absorption; they create the physical, chemical, and biological conditions necessary for comprehensive pollutant removal. The following mechanisms have been established in the literature and were observed in this experimental study.

#### 5.1 Nutrient Uptake (Phytoextraction)

Aquatic plants absorb nitrogen (N) and phosphorus (P) — the primary contributors to eutrophication — directly from the water column through their roots and shoots. In greywater, these nutrients originate primarily from synthetic detergents (phosphate-based surfactants), food residues, and personal care products. By converting dissolved inorganic nitrogen (ammonium, nitrate) and phosphorus into plant biomass, FTWs provide a permanent nutrient sink that can be removed from the system by periodic plant harvesting, thereby achieving a true pollutant removal rather than mere transformation.

#### 5.2 Microbial Degradation via Rhizosphere Biofilm

The submerged root systems of floating macrophytes provide an enormous surface area for microbial colonization. Bacteria, fungi, and protozoa colonize the root surfaces to form complex biofilms. These biofilms contain both aerobic and anaerobic microhabitats due to the gradient of dissolved oxygen from the root exodermis outward, enabling concurrent nitrification (aerobic), denitrification (anoxic), and organic matter decomposition (aerobic/anaerobic). This biodegradation activity significantly reduces

BOD and COD without any chemical addition. Radial oxygen loss (ROL) from plant roots further sustains aerobic zones in the rhizosphere, promoting efficient decomposition.

### 5.3 Sedimentation and Particulate Filtration

The baffle wall design of the lab-scale model and the physical presence of dense root mats both contribute to sedimentation and filtration. Reduced flow velocity in baffled chambers allows gravity settlement of suspended solids. Additionally, the fibrous root network physically intercepts and retains fine particulates, colloids, and debris that have not settled. This dual mechanism — sedimentation plus root-mat filtration — accounts for the high turbidity removal observed in the experimental results (average 70.08%).

### 5.4 Water Hyacinth (*Eichhornia crassipes*): Key Properties

Water Hyacinth was selected as the primary treatment plant for this study due to its exceptional phytoremediation capabilities and practical advantages in the Sangli climate. Scientifically classified as *Eichhornia crassipes* (Mart.) Solms-Laubach of the family Pontederiaceae, it is a free-floating perennial macrophyte native to the Amazon Basin of South America. It produces broad glossy leaves on spongy inflated petioles that provide natural buoyancy. Its dense fibrous roots hang 20–30 cm below the water surface, providing an extraordinarily large surface area for microbial biofilm formation.

Key properties relevant to this study include: (1) Population doubling time of 5–15 days under optimal conditions; (2) Temperature tolerance of 15–30°C, well-matched to Sangli's climate; (3) Documented ability to absorb nitrogen, phosphorus, BOD-contributing organics, and heavy metals (Pb, Cd, Hg, As) via phytoremediation; (4) Dense fibrous roots providing 1,000–2,000 m<sup>2</sup> of surface area per m<sup>3</sup> for biofilm formation; (5) High oxygen transfer capacity through root-surface radial oxygen loss. However, Water Hyacinth can become invasive if released into natural water bodies without management; therefore, regular harvesting is an essential operational requirement.

## 6. Methodology

### 6.1 Overview

The study followed a structured experimental methodology comprising literature review and plant selection, full household-scale system design with structural estimation, lab-scale model fabrication, controlled experimental operation over 15 days, and systematic water quality sampling and analysis. The methodology was designed to be replicable at minimal cost using locally available materials in the Sangli district.

### 6.2 Full Household-Scale Design and Calculations

The household-scale design was developed using the following data:

Parameter	Value	Source
Daily Wastewater Volume	290 L/day	Field Assessment, Sangli
Influent BOD	114 mg/L	Wagh & Kamat (2014)

Permissible BOD Loading	10 g/m <sup>2</sup> /day	MPCB / CPCB Guidelines
Available Household Space	3–4 m <sup>2</sup>	Site Assessment
Selected Plant Species	Water Hyacinth	Literature Review
Hydraulic Retention Time	4–5 days	Design Requirement

**Table 1: Household-Scale Design Input Data**

BOD Load (g/day) = Daily Volume (L) × Influent BOD (mg/L) / 1000 = 290 × 114 / 1000 = 33.06 g/day  
 Required Wetland Area = BOD Load / Permissible Loading = 33.06 / 10 ≈ 3.31 m<sup>2</sup>

The calculated area of 3.31 m<sup>2</sup> confirms that 3–4 m<sup>2</sup> of household space is sufficient. The platform was designed as 2.0 m × 1.75 m of HDPE/foam modular floating mats with Water Hyacinth root depth of 20–30 cm. The structural tank uses RCC with outer dimensions 2.48 m × 1.71 m × 1.25 m and four internal partition walls.

### 6.3 Structural Volume Estimation

Component	Calculation	Volume (m <sup>3</sup> )
External Long Walls (2 nos.)	2 × 2.48 × 1.25 × 0.10	0.620
External Short Walls (2 nos.)	2 × 1.51 × 1.25 × 0.10	0.378
Bottom Slab	2.48 × 1.71 × 0.10	0.424
Internal Partition Walls (4 nos.)	4 × 1.75 × 1.25 × 0.10	0.875
Total RCC Volume	—	2.30 m <sup>3</sup>

**Table 2: Structural Volume Calculations (Long Wall – Short Wall Method)**

### 6.4 Cost Estimation (Abstract Sheet)

Sr. No.	Description	Qty.	Unit	Rate (₹)	Amount (₹)
1	Excavation for Foundation	14.12 m <sup>3</sup>	Per m <sup>3</sup>	6.50	280.28
2	PCC (1:4:8) in Foundation	7.84 m <sup>3</sup>	Per m <sup>3</sup>	84.00	658.56
3	RCC Work (Tank Structure)	2.30 m <sup>3</sup>	Per m <sup>3</sup>	7,000	16,100
4	Formwork (~19.2 m <sup>2</sup> )	19.20 kg	Per kg	50.00	9,200
	TOTAL				₹26,238

**Table 3: Cost Estimation – Abstract Sheet**

Total RCC volume = 2.30 m<sup>3</sup>; Steel required ≈ 184 kg; Formwork area ≈ 19.2 m<sup>2</sup>. Estimated total construction cost: ₹25,000–₹30,000. This is well within the budget of a typical rural/semi-urban household in Maharashtra.

### 6.5 Lab-Scale Model Design and Fabrication

The lab-scale model was designed using the following parameters:

$$V = \text{Flow} \times \text{HRT} = 10 \text{ L/day} \times 3 \text{ days} = 30 \text{ L} = 0.030 \text{ m}^3 \approx 0.028 \text{ m}^3$$

$$\text{Surface Area} = V / \text{Depth} = 0.028 / 0.10 = 0.28 \text{ m}^2$$

$$\text{Width } W: 2W^2 = 0.28 \rightarrow W = 0.37 \text{ m} \approx 0.40 \text{ m (40 cm)}; \text{ Length } L = 2W = 0.80 \text{ m (80 cm)}$$

**Final Dimensions:** Length = 80 cm, Width = 40 cm, Depth = 15 cm

The tank was fabricated from acrylic sheets joined with acrylic adhesive. Acrylic was chosen for its transparency (allowing direct observation of sedimentation, root development, and flow patterns), lightweight nature, and water-tightness. Two baffle walls were installed at 27 cm from each end to prevent short-circuiting and increase the effective flow path, thereby maximizing HRT and contact time between wastewater and plant roots. The inlet was positioned at one end and the outlet at the other, slightly below the design water level to maintain a constant water depth. Water Hyacinth plants were placed directly on the water surface without an additional floating platform, allowing roots to freely suspend in the wastewater.

### 6.6 Experimental Procedure

1. Tank Preparation: The acrylic tank was cleaned thoroughly; baffle walls, inlet, and outlet connections were verified for watertightness and proper function.
2. Wastewater Collection: Household greywater was collected from bathrooms, kitchens, and laundry drains in clean containers and transferred to the experimental tank.
3. Plant Placement: Healthy Water Hyacinth specimens were gently placed on the water surface; roots were allowed to hang freely and fully submerge in the greywater.
4. Baseline Sampling (Day 0): Water samples were collected from the inlet to establish initial pH, Turbidity, TDS, and DO values before treatment commenced.
5. Treatment Operation: Wastewater was retained in the baffled tank for 3–4 days (HRT). During this period, sedimentation, root filtration, microbial degradation, and nutrient uptake occurred continuously.
6. Routine Monitoring: pH was measured daily; Turbidity every 1–2 days; TDS every 2–3 days; DO using Winkler Titration at defined intervals over 15 days.
7. Outlet Sampling: Treated water was collected from the outlet at the end of each retention cycle and analyzed for the same four parameters.

8. Efficiency Calculation: Removal efficiency (%) = (Inlet Value – Outlet Value) / Inlet Value × 100 was applied to pH, Turbidity, and DO; TDS increase (%) = (Outlet – Inlet) / Inlet × 100 was used for the TDS anomaly.

**Fig 1 : Lab Scale Model**



## 6.7 Water Quality Measurement Methods

Parameter	Instrument / Method	Unit	Significance in FTW Evaluation
pH	Digital pH Meter (calibrated with pH 4, 7, 10 buffers)	pH units	Neutralization of alkaline detergent residues; suitability for reuse
Turbidity	Nephelometer / Turbidimeter	NTU	Effectiveness of sedimentation and root-mat filtration
TDS	Digital TDS Meter (conductivity probe)	mg/L (ppm)	Mineral load; plant nutrient uptake vs. leaching dynamics
Dissolved Oxygen	Winkler Iodometric Titration Method	mg/L	Aerobic condition assessment; indicator of biological activity

**Table 4: Water Quality Measurement Methods**

Dissolved Oxygen was measured by the Winkler Method: (1) Sample collected in 300 mL DO bottle, no air bubbles; (2) Added 2 mL each of  $MnSO_4$  and alkaline iodide azide reagent — a brown precipitate forms as  $Mn^{2+}$  oxidizes; (3) Added 2 mL concentrated  $H_2SO_4$  to dissolve the precipitate and liberate  $I_2$  proportional to DO; (4) Titrated 203 mL sample with 0.025 N  $Na_2S_2O_3$  using starch indicator (blue → colourless endpoint).  $DO (mg/L) = V \times N \times 8 \times 1000 / V_s$ , where  $V$  = titrant volume (mL),  $N$  = normality,  $V_s$  = sample volume (mL).

## 7. Results and Discussion

### 7.1 pH Monitoring Results

pH was recorded daily at both inlet and outlet over 15 days. The inlet pH ranged from 7.32 to 9.57, reflecting the alkaline character of household greywater due to soap, shampoo, and detergent residues. The outlet pH consistently ranged lower, from 7.11 to 8.16, confirming the system’s capacity to neutralize alkalinity. The average pH reduction efficiency was 10.83%. The most pronounced stabilization was observed in Days 12–15, suggesting a “priming effect” as the microbial biofilm on root surfaces matures and becomes more effective at organic acid production and  $CO_2$  release, both of which lower pH.

Day	Inlet pH	Outlet pH	Reduction (%)
1	8.80	7.40	15.91
2	8.98	7.83	12.81
3	8.08	7.20	10.89
4	7.80	7.26	6.92
5	7.32	7.11	2.87
6	8.54	8.16	4.45
7	8.76	7.69	12.21
8	8.18	7.22	11.74

9	8.53	7.63	10.55
10	8.65	7.86	9.13
11	8.57	7.80	8.98
12	9.57	7.33	23.41
13	9.30	7.49	19.46
14	8.64	7.23	16.32
15	8.56	7.55	11.80

**Table 5: pH Inlet vs. Outlet Monitoring (HRT = 3 Days)**

### 7.2 Turbidity Monitoring Results

Turbidity results demonstrated the strongest pollutant removal performance of all four parameters. Inlet turbidity ranged from 9.6 to 37.6 NTU across 15 days, while outlet turbidity was consistently lower, ranging from 3.2 to 22.0 NTU. Average removal efficiency was 70.08%, with peak single-day removals exceeding 89% on Days 2, 11, and 12. This confirms the combined effectiveness of gravity sedimentation in baffled chambers and physical root-mat filtration. The gradual improvement in turbidity removal from Day 1 (20.29%) to Day 15 (85.00%) further validates the priming effect of maturing root biofilms. Suspended solids such as soap scum, fine soil particles, and food debris were effectively trapped by the root network.

Day	Inlet (NTU)	Outlet (NTU)	Removal (%)
1	27.6	22.0	20.29
2	37.6	3.6	90.42
3	30.6	9.33	69.51
4	20.0	7.33	63.32
5	25.0	10.26	58.96
6	9.6	6.0	37.50
7	25.7	6.9	73.50
8	30.3	9.0	70.13
9	16.3	8.0	50.92
10	16.6	9.3	43.98
11	27.0	3.6	86.87
12	29.6	3.2	89.19
13	21.0	4.5	78.57
14	28.0	5.6	80.00
15	32.0	4.8	85.00

**Table 6: Turbidity Inlet vs. Outlet Monitoring (HRT = 3 Days)**

### 7.3 Total Dissolved Solids (TDS) Results

TDS results presented an unexpected but informative trend. Rather than decreasing as anticipated, outlet TDS was consistently higher than inlet TDS throughout the 15-day period. Inlet TDS ranged from 27.3 to 80.7 mg/L, while outlet TDS ranged from 72.2 to 141.3 mg/L, representing an average percentage increase of 123.83% and peaking at 398.17% on Day 13. Three factors likely contributed to this anomaly: (1) Mineral leaching from the acrylic sheet adhesives and baffle wall sealant, particularly in early days; (2) Evapotranspiration effect — as plants transpire, water volume decreases and dissolved mineral concentration increases; (3) Mid-experiment relocation of the model to a sunnier position, which significantly accelerated evaporation rates. For full-scale application, this TDS issue can be effectively addressed by using inert construction materials (food-grade HDPE tanks), adding more than three baffle walls for longer hydraulic path and better dilution, and maintaining a stable placement with controlled sunlight exposure.

Day	Inlet TDS (mg/L)	Outlet TDS (mg/L)	Change (%)
1	60.3	80.3	+33.17
2	79.0	85.3	+7.97
3	62.6	72.2	+15.34
4	63.3	85.1	+34.44
5	70.2	95.4	+35.90
6	80.7	114.6	+42.01
7	60.3	132.6	+119.90
8	50.3	141.3	+180.91
9	37.6	139.6	+271.28
10	76.0	141.3	+85.92
11	40.0	138.6	+246.60
12	41.6	131.0	+214.90
13	27.3	136.0	+398.17
14	36.1	130.1	+260.39
15	40.6	122.6	+201.98

**Table 7: TDS Inlet vs. Outlet Monitoring (HRT = 3 Days)**

### 7.4 Dissolved Oxygen (DO) Results

Dissolved oxygen showed consistent and significant improvement from inlet to outlet, providing strong evidence of aerobic biological activity in the system. Inlet DO ranged from 3.5 to 7.7 mg/L (reflecting the oxygen-depleted condition of greywater loaded with organic matter), while outlet DO ranged from 5.2 to 8.7 mg/L. The average DO improvement was 45.56%. Remarkably high improvements of 131.43% and 115.00% were recorded on Days 10 and 11 respectively, coinciding with a period of low inlet DO (3.5–4.0 mg/L), likely following a batch of highly contaminated greywater. This demonstrates the system's strong recovery and resilience capacity. The consistent DO increase confirms that Water Hyacinth roots

actively transfer oxygen into the water column via radial oxygen loss, creating the aerobic microenvironments essential for BOD degradation and nitrification.

Day	Inlet DO (mg/L)	Outlet DO (mg/L)	Improvement (%)
1	5.12	6.80	32.81
2	4.50	6.50	44.44
3	6.50	7.60	16.92
4	5.20	8.20	57.69
5	6.80	8.30	22.06
6	7.20	8.50	18.06
7	6.60	7.10	7.04
8	6.30	6.30	0.00
9	4.10	5.20	26.83
10	3.50	8.10	131.43
11	4.00	8.60	115.00
12	6.70	7.50	11.94
13	7.70	8.70	12.99
14	7.10	7.60	7.04
15	7.20	8.50	15.59

**Table 8: Dissolved Oxygen Inlet vs. Outlet Monitoring (HRT = 3 Days)**

### 8. Overall Performance Summary

Parameter	Trend	Average Efficiency / Change	Assessment
Turbidity	Reduction	70.08% removal	Excellent — highly effective physical filtration and sedimentation
Dissolved Oxygen	Increase	45.56% gain	Strong — aerobic conditions well-supported by root oxygenation
pH	Stabilization	10.83% reduction	Good — alkaline inlet pH neutralized toward near-neutral range
TDS	Increase	123.83% gain	Concern — mineral leaching and evaporation; correctable in scaled design

**Table 9: Final System Performance Summary**

The performance data confirm that the FTW system achieves its primary treatment objectives of clarity improvement and oxygenation. The TDS increase, while a concern, is a correctable artifact of the small-scale acrylic model and does not represent a fundamental limitation of the FTW technology. At full scale using inert HDPE materials and with additional baffle partitions, TDS behavior is expected to normalize.

## **9. Working Principles of the Floating Wetland System**

The FTW system relies on four synergistic processes operating simultaneously:

### **9.1 Phytoremediation**

Water Hyacinth plants absorb dissolved nitrogen, phosphorus, and micro-pollutants from the water through their roots and translocate them into plant biomass. The plants also accumulate heavy metals (Pb, Cd, Hg, As) in their root and shoot tissues through phytoextraction and phytostabilization mechanisms. This permanent removal of pollutants via biomass harvest distinguishes FTWs from purely physical treatment systems.

### **9.2 Microbial Degradation (Biofilm Activity)**

Root surface biofilms consisting of mixed bacterial and fungal communities perform concurrent aerobic degradation of organic matter, nitrification of ammonium nitrogen, and denitrification under anoxic micro-zones within the root mat. Carbon-rich root exudates from Water Hyacinth feed the heterotrophic microbial community, while radial oxygen loss from roots sustains the nitrifying bacteria. The net effect is a substantial reduction in BOD, COD, and nitrogen species in the treated water.

### **9.3 Sedimentation and Filtration**

Baffled chambers within the tank reduce flow velocity to near-quiescent conditions, allowing gravity settlement of suspended solids. Simultaneously, the fibrous root network — acting as a biological filter media — traps fine particulates, colloids, soap scum, and organic debris that have not settled. Together, these mechanisms account for the strong turbidity removal observed. Settled sludge accumulates at the tank bottom and requires removal during periodic maintenance.

### **9.4 Oxygenation and pH Buffering**

Photosynthesis by Water Hyacinth releases O<sub>2</sub> into the water, while radial oxygen loss from roots creates localized aerobic zones in the rhizosphere. Both mechanisms contribute to the consistent DO increase observed at the outlet. For pH, the biological activity of heterotrophic bacteria produces carbonic acid and other weak acids from CO<sub>2</sub> and organic acid intermediates, which neutralize the alkalinity of the incoming greywater. This natural acid–base buffering brings outlet pH toward the neutral range (7.0–8.0) preferred for irrigation reuse.

## **10. Environmental Impact and Sustainability Analysis**

The floating wetland system demonstrates multiple dimensions of environmental sustainability that distinguish it from conventional treatment technologies. A comparative assessment is presented below.

Aspect	Floating Wetland (FTW)	Conventional Sewage Treatment Plant
Energy Requirement	Zero (no electricity needed)	High (pumps, aerators, UV systems)
Construction Cost	₹25,000–₹30,000 per household	Crores for community-scale infrastructure
Land Requirement	3–4 m <sup>2</sup> per household	Requires large dedicated land parcels
Chemical Use	None	Chlorine, coagulants, flocculants
Maintenance Skill	Basic (plant harvesting, cleaning)	Requires qualified engineers
Biodiversity Support	High (supports birds, insects)	Negligible
Carbon Footprint	Net carbon-negative (plant biomass)	Net carbon-positive (energy use)
Water Reuse Quality	Suitable for irrigation, cleaning	Treated for discharge; reuse varies
Scale Applicability	Individual household to community	Municipal/industrial only

**Table 10: Comparative Assessment – FTW vs. Conventional Treatment**

The FTW system’s zero-energy operation, use of natural biological processes, and contribution to biodiversity make it inherently aligned with circular economy principles. Harvested Water Hyacinth biomass can be composted as organic fertilizer, used as animal fodder, or converted to biogas in anaerobic digesters, creating additional value streams from the treatment process. Treated water reuse for garden irrigation reduces the demand on freshwater sources, contributing to water security at the household level.

## 11. Applications and Future Scope

### 11.1 Current Applications

The treated greywater from this FTW system is suitable for multiple non-potable reuse applications:

9. Garden and landscape irrigation: treated water with low turbidity and near-neutral pH is safe for ornamental and vegetable gardens.
10. Toilet flushing: significant water savings per household when treated greywater replaces potable water for flushing.
11. Courtyard and driveway cleaning: low-turbidity treated water is suitable for general cleaning.
12. Agricultural irrigation for non-food crops in peri-urban and rural farming contexts.
13. Urban water body restoration: FTW islands installed in community ponds and lakes to improve water quality and aesthetics.
14. Decentralized wastewater management in housing societies, small hotels, hostels, and educational institutions.

### 11.2 Future Research Directions

15. Comparative plant species evaluation: testing *Canna indica*, *Typha latifolia*, Vetiver grass, and *Lemna minor* alongside Water Hyacinth for performance comparison in the Sangli climate.

16. Extended monitoring beyond 15 days to observe long-term steady-state performance, seasonal variations, and plant biomass turnover.
17. Full BOD removal quantification with complete titration-based BOD5 measurements at inlet and outlet.
18. TDS management study: testing HDPE tanks, ceramic/gravel media, and additional baffle configurations to eliminate the mineral leaching artifact.
19. Pilot-scale field implementation at a real household in Sangli with continuous flow and real-time monitoring sensors.
20. Economic feasibility analysis including lifecycle cost, payback period, and comparison with other decentralized treatment options.
21. Investigation of pathogen removal (*E. coli*, total coliforms) to determine fitness of treated water for unrestricted irrigation use.

## **12. Limitations**

### **12.1 Lab-Scale Model Limitations**

22. The 80 cm × 40 cm × 15 cm tank volume does not capture edge effects, dead zones, and scale-dependent hydraulics of a full household system.
23. Controlled lab conditions (stable temperature, artificial light supplementation) may not reflect real outdoor seasonal and diurnal variability.
24. Single plant species (Water Hyacinth) limits conclusions about comparative phytoremediation performance.
25. Frequent sampling disturbed sedimentation layers and may have altered TDS and turbidity readings on sampled days.
26. Model relocation mid-experiment introduced an uncontrolled variable affecting TDS and evaporation rates.

### **12.2 Household Application Limitations**

27. Seasonal performance dependence on temperature and sunlight: Water Hyacinth growth slows below 15°C, reducing treatment efficiency in winter months.
28. Periodic maintenance obligations (plant harvesting every 2–4 weeks, outlet cleaning, sludge removal) require user commitment and awareness.
29. TDS management requires design modifications (inert materials, additional baffles) not captured in the present lab model.
30. The system is not suitable for treating blackwater (toilet waste) or industrial effluents without significant modifications.
31. Space constraints in high-density urban housing may limit direct applicability.

## **13. Conclusion**

This study successfully demonstrates that a Floating Treatment Wetland (FTW) system using Water Hyacinth is an effective, sustainable, and economically accessible method for treating household sullage (greywater) at the individual household level. The 15-day lab-scale experiment using a baffled acrylic tank (80 cm × 40 cm × 15 cm) yielded the following key findings and conclusions:

- Turbidity Removal (Average 70.08%, Peak 90.42%): The combined mechanism of gravity sedimentation in baffled chambers and root-mat filtration proved highly effective at removing suspended solids from greywater. This is the most reliable and consistent treatment performance achieved by the system.
- Dissolved Oxygen Enhancement (Average +45.56%, Peak +131.43%): Consistent outlet DO improvement across all 15 days confirms active aerobic biological conditions in the FTW system. Root-zone oxygenation by Water Hyacinth effectively prevented anaerobic conditions and supported microbial BOD degradation.
- pH Stabilization (Average 10.83% reduction): The system successfully neutralized highly alkaline inlet greywater (pH up to 9.57) toward a near-neutral outlet range (7.11–8.16), making the treated water chemically suitable for irrigation and general reuse.
- TDS Anomaly (+123.83% average): TDS increased throughout the experiment due to mineral leaching from acrylic adhesive and accelerated evapotranspiration after model relocation. This is a correctable experimental artifact; full-scale HDPE systems with additional baffle walls and stable placement are expected to perform significantly better.
- Cost-Effectiveness: The full household-scale system is estimated at ₹25,000–₹30,000 — a one-time cost accessible to rural and semi-urban households in Maharashtra, with near-zero operational expenditure.
- Overall Assessment: The Floating Treatment Wetland represents a practical, nature-based, low-energy, and low-maintenance solution ideally suited to the decentralized wastewater management needs of rural and semi-urban India. With proper plant management, material selection, and system sizing, FTWs can deliver treated greywater suitable for irrigation and cleaning, contributing meaningfully to water conservation and environmental protection.

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