International Journal of Recent Development in Engineering and Technology
Website: www.ijrdet.com (ISSN 2347-6435 (Online) Volume 15, Issue 03, March 2026)

Transforming Grey Water for Sustainable Water Use

Anzil Navas[1], Nasrin F[2], Rahul Rajeev[3], Sreelekshmi S[4], Mophin Kani K[5]

[1,2,3,4]UG Scholar, Department of Civil Engineering, UKF College of Engineering and Technology, Kollam, India
[5]Associate Professor, Environmental Engineering and Management, UKF College of Engineering and Technology, Kollam, India

***Abstract*-- Water scarcity is an escalating global concern driven by urbanisation, population growth, and climate variability, necessitating sustainable water management strategies. This study presents the design and performance evaluation of a low-cost, decentralised greywater treatment system for non-potable reuse.**

Greywater collected from kitchen sources was treated through a multi-stage process comprising pre-treatment, coagulation–flocculation using *Moringa oleifera* seed powder (optimum dosage: 2.5 g/L), sand–gravel filtration, and a constructed wetland planted with vetiver (*Chrysopogon zizanioides*).

The system achieved significant improvement in water quality, with turbidity reduced from approximately 20.3 NTU to 2.5 NTU, COD from 376 mg/L to 96 mg/L, and BOD from 94.4 mg/L to 25 mg/L. pH was stabilised within acceptable limits (8.01 to 6.9), and electrical conductivity decreased from 1808 µS/cm to 1200 µS/cm.

Adsorption studies indicated that the Langmuir isotherm model provided a better fit than the Freundlich model, suggesting monolayer adsorption. Kinetic analysis of the constructed wetland followed first-order behaviour, confirming effective pollutant removal over time.

The treated greywater meets criteria for non-potable applications such as irrigation and cleaning. The study demonstrates an eco-friendly and cost-effective approach for decentralised greywater management in water-scarce regions.

***Keywords*-- Adsorption isotherms, constructed wetlands, decentralised wastewater treatment, greywater treatment, *Moringa oleifera*, natural coagulant, sustainable water use, water reuse**

I. INTRODUCTION

Water scarcity has emerged as one of the most pressing environmental challenges of the twenty-first century, driven by rapid population growth, accelerating urbanisation, and the intensifying effects of climate variability [1, 2]. According to the United Nations, more than two billion people currently live in water-stressed regions, and projections indicate that global freshwater demand will exceed supply by 40% by 2030 [3]. In this context, the sustainable management of available water resources has become a critical imperative for both developed and developing nations.

Greywater, defined as domestic wastewater generated from kitchens, bathrooms, and laundry facilities, excluding toilet discharge, constitutes approximately 50–70% of total household wastewater [4]. Unlike blackwater, greywater carries a relatively low pathogenic load and is amenable to treatment using low-cost, decentralised technologies, making it an attractive candidate for non-potable reuse applications such as irrigation, toilet flushing, and outdoor cleaning [1, 5]. Recycling greywater at the household or community level not only reduces freshwater withdrawal but also alleviates the burden on centralised sewage infrastructure, a significant advantage in rapidly urbanising areas of countries like India, where sanitation networks remain incomplete [6].

Several treatment approaches for greywater have been documented in the literature, ranging from constructed wetlands and sand filtration to membrane bioreactors and advanced oxidation processes [2, 7]. However, many of these systems remain prohibitively expensive or technically complex for household-scale deployment in low- and middle-income settings. The use of natural coagulants, particularly Moringa oleifera seed powder, which contains cationic proteins capable of neutralising negatively charged colloidal particles, presents a sustainable and cost-effective alternative to chemical coagulants such as alum and ferric chloride [5, 8].

This study presents the design, development, and performance evaluation of a multi-stage decentralised greywater treatment system integrating pre-treatment screening, Moringa oleifera-based coagulation–flocculation–sedimentation, sand-gravel filtration, and a constructed wetland planted with vetiver grass (Chrysopogon zizanioides). The system was assessed based on key water quality parameters, pH, turbidity, Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), and Electrical Conductivity (EC), and kinetic and adsorption models were applied to characterise treatment performance. The overarching objective is to demonstrate a replicable, eco-friendly treatment pathway suitable for household or community-level greywater reuse in water-scarce regions [9].

II. METHODOLOGY

Canteen greywater was collected exclusively from kitchen sinks to avoid contamination with blackwater. Kitchen greywater contains organic matter, oils, and suspended solids, making it suitable for treatment studies.

The canteen wastewater is collected from the institute canteen in a sterile, precleaned 20 L container for the present study periodically before the experimental run, along with the measurement of on-site parameters like pH and Electrical conductivity. A portion of the greywater is stored for the BOD and COD analysis as per standard protocols.

Storing System:

High-density polyethene (HDPE) storage tanks (25 L) were employed to store and regulate the inflow of greywater for the treatment.

Pre-treatment Units:

Screen and Oil-Grease Trap:

An oil-grease trap was fabricated along with a fine screen to separate the larger particles and to trap the oil and grease from the canteen wastewater.

Coagulation Unit

Glass Coagulation Tank and Natural Coagulant:

A laboratory-scale glass coagulation tank was designed with a treating capacity of 15 litres of canteen wastewater. The transparent nature of the tank allowed direct observation of floc formation, growth, and settling characteristics.

Coagulant:

Moringa oleifera seed powder was used as a natural coagulant. The seeds contain cationic proteins that neutralise negatively charged particles, facilitating floc formation. The optimum particle size (~0.075 mm) enhances dissolution and coagulation efficiency. This eco-friendly coagulant reduces turbidity and suspended solids while producing biodegradable sludge.

Constructed Wetland System

A constructed wetland system was developed for phytoremediation and as a natural treatment process. It consisted of layered media and selected plant species.

Media Layers:

Top Soil: Supports plant growth and microbial activity, aiding in organic matter degradation.

Sand: Acts as a fine filtration layer, removing suspended solids.

Medium Gravel (20 mm): Facilitates drainage and prevents clogging.

Coarse Gravel (40 mm): Provides structural support and ensures proper water flow.

Vegetation:

Vetiver (Chrysopogon zizanioides) enhances pollutant removal through extensive root systems and microbial interactions.

Collection Unit

Treated canteen wastewater was stored in covered tanks to prevent contamination, algal growth, and mosquito breeding. These tanks ensured a continuous supply of treated water for reuse applications.

Monitoring Tools

Water quality was monitored using the following instruments: pH Meter, Electrical Conductivity (EC) Meter, Turbidity Meter, BOD Incubator, and COD Digester, which were employed for the continuous and periodical monitoring of the treatment efficiency.

Coagulation-Flocculation Unit

A cylindrical coagulation tank with a diameter of 31 cm, a height of 20 cm, and a volume of 15 L was designed and fabricated using glass for the present research.

Moringa seed powder was added as a coagulant. Rapid mixing (120 RPM) ensured uniform dispersion, followed by slow mixing (12 RPM) to promote floc formation. The mixture was then allowed to settle for floc sedimentation. After coagulation, flocs settled at the bottom.

The supernatant was passed through the constructed wetland system, where plant uptake reduced BOD and COD. Vetiver roots enhanced oxygen transfer, supporting aerobic conditions throughout the process.

Water Quality Testing

Periodical samples were collected and analysed before and after each treatment unit process.

Removal Efficiency was calculated using the formula;

$$\text{Removal Efficiency (\%)} = \frac{C_0 - C}{C_0} \times 100$$

Where C_0 is the initial concentration, C is the final concentration

Data Analysis and Performance Evaluation

System performance was evaluated by comparing initial and final values of water quality parameters and calculating removal efficiencies. Mathematical expressions for design and data processing were calculated using Microsoft Excel.

Figure 1: Greywater Treatment System

III. RESULTS

Table 1.
Optimisation of coagulant dose

S. No	Dose	Turbidity (NTU)
1	0g/l	25
2	0.5g/l	31
3	1.0g/l	31
4	1.5g/l	22
5	2.0g/l	13
6	2.5g/l	8
7	3.0g/l	9

The effect of *Moringa oleifera* seed powder dosage on turbidity removal is presented in Table 1. The initial turbidity of the greywater was approximately 25 NTU. In the absence of coagulant (0 g/L), turbidity remained nearly unchanged, indicating negligible natural settling.

At lower dosages (0.5–1.0 g/L), turbidity increased to 31 NTU, suggesting destabilisation of colloidal particles and ineffective coagulation.

From 1.5 g/L onwards, turbidity decreased significantly, indicating improved floc formation and settling. The optimum dosage was identified as 2.5 g/L, at which turbidity was reduced to 8 NTU, corresponding to a removal efficiency of approximately 68%. A slight increase in turbidity at 3.0 g/L suggests overdosing effects.

SVI Calculation

The Sludge Volume Index (SVI) was determined using 20 mL of settled sludge obtained from a 1000 mL coagulated sample. The calculated SVI value was 7.7 mL/g, indicating good settling characteristics and compact sludge formation. The Mixed Liquor Suspended Solids (MLSS) concentration was measured as 2.59 g/L, further confirming efficient coagulation–flocculation performance.

Experimental Data (Average Of Five Runs)

Table 2:
Experimental Data

Time	Turbidity (NTU)	pH	EC (µS/cm)	BOD (mg/l)	COD (mg/l)
0 min	24.7	8.01	1808	94.4	376
30 min	24.1	7.83	1707	88.4	336
60 min	23.3	7.64	1605	80.8	328
90 min	25.7	7.46	1504	72.0	304
120 min	29.8	7.27	1403	62.0	272
150 min	27.1	7.09	1301	51.6	232
180 min	31.1	6.97	1250	38.0	186
W.T	2.5	7.53	1180	25	96

[0 min to 180 min (coagulation); W.T - After constructed wetland treatment]

The variation of key water quality parameters during the treatment process is summarised based on the average of five experimental runs.

During the coagulation stage (0–180 minutes), gradual reductions were observed in organic and physicochemical parameters. COD decreased from 376 mg/L to 186 mg/L, while BOD reduced from 94.4 mg/L to 38 mg/L, indicating progressive removal of organic matter.

Electrical conductivity (EC) decreased from 1808 µS/cm to 1250 µS/cm, reflecting a reduction in dissolved ions. The pH showed a gradual decline from 8.01 to 6.97, approaching neutral conditions.

Following treatment through the constructed wetland, further significant improvements were observed. Final values recorded were: turbidity 2.5 NTU, COD 96 mg/L, BOD 25 mg/L, pH 7.53, and EC 1180 µS/cm, demonstrating the effectiveness of the integrated treatment system.

Kinetics Model For Coagulation

Freundlich and Langmuir Isotherm Analysis (using COD Values)

Experimental Data Initial COD = 376 mg/L

Freundlich Isotherm

- Equation: $\log q_e = \log K_f + 1/n \log C_e$

Table 3:
Freundlich Isotherm Analysis Using COD Values

Time	COD (Ce) mg/L	qe = (C_0 − Ce) mg/L	log Ce	log q_e
0 min	376	0		
30 min	336	40	2.526	1.602
60 min	328	48	2.516	1.681
90 min	304	72	2.483	1.857
120 min	272	104	2.435	2.017
150 min	232	144	2.365	2.158
180 min	200	176	2.301	2.246
(W.T) Final	96	280	1.982	2.447

Observation:

Freundlich Plot: log (qe) vs log (Ce)

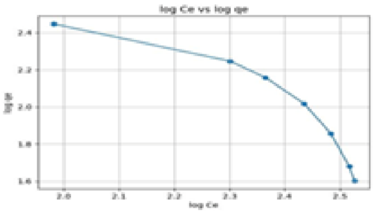

Figure 2: Freundlich Isotherm Plot for COD Removal

The graph suggests invalid adsorption behaviour for the model, indicating that the Freundlich isotherm model is not suitable for our treatment model.

Langmuir Isotherm Equation: $C_e/q_e = 1/Q_{max}b + C_e/Q_{max}$

Table 4:
Langmuir Isotherm Analysis Using COD Values

Ce	qe	Ce/qe
336	40	8.40
328	48	6.83
304	72	4.22
272	104	2.62
232	144	1.61
200	176	1.14
96	280	0.34

Langmuir Plot: Ce/qe vs Ce

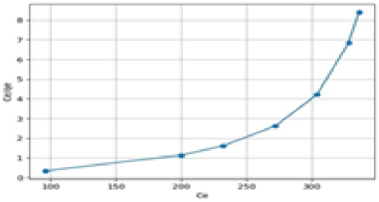

Figure 3: Langmuir Isotherm Plot for COD Removal

As indicated by the graph, the slope = 0.025 and the calculated constants were Qmax = 40mg/g, b = 0.125 L/mg. This graph shows good agreement with the model, indicating monolayer adsorption on a surface with a finite number of active sites.

Freundlich & Langmuir Isotherm (Using BOD Values)

Table 5:
Freundlich & Langmuir Isotherm Analysis Using BOD Values

Time	Ce	qe	log Ce	log qe	Ce/qe
0 min	94.4	0.0			
30 min	88.4	6.0	1.9465	0.7782	14.7333
60 min	80.8	13.6	1.9074	1.1335	5.9412
90 min	72.0	22.4	1.8573	1.3502	3.2143
120 min	62.0	32.4	1.7924	1.5105	1.9136
150 min	51.6	42.8	1.7126	1.6314	1.2056
180 min	38.0	56.4	1.5798	1.7513	0.6738
(W.T) Final	25.0	69.4	1.3979	1.8414	0.3602

Freundlich Isotherm

Freundlich Plot: log (qe) vs log (Ce)

Observation:

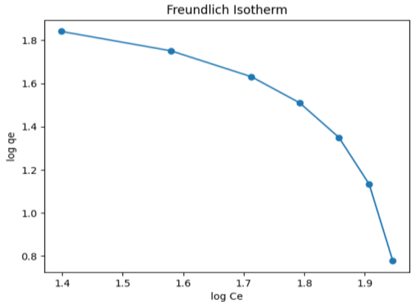

Figure 4: Freundlich Isotherm Plot for BOD Removal

Langmuir Isotherm

Langmuir Plot: Ce/qe vs Ce

Observation:

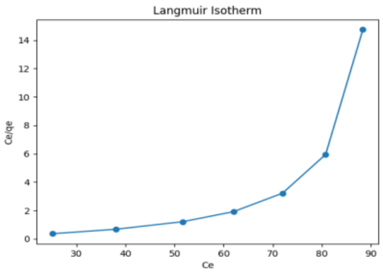

Figure 5: Langm Isotherm Plot for BOD Removal

Adsorption Isotherm Analysis

Freundlich Isotherm

The Freundlich isotherm plots (log qe vs log Ce) derived from both COD and BOD data did not exhibit linear relationships. This indicates that the Freundlich model does not adequately describe the adsorption behaviour of the system. The deviation from linearity suggests that the assumptions of heterogeneous surface conditions and multilayer adsorption are not applicable in this case.The Freundlich isotherm shows a high R² value (0.986), indicating good linearity.

However, the negative slope ($1/n < 0$) suggests that the model is not physically suitable for the system. This may be due to the inverse relationship between Ce and qe, indicating that adsorption does not follow typical Freundlich behavior.

Langmuir Isotherm

The Langmuir isotherm plots (Ce/qe vs Ce) showed good linearity for both COD and BOD datasets, indicating a better fit to the experimental data. The calculated constants for COD adsorption were:

Maximum adsorption capacity (Qmax): 40 mg/g

Langmuir constant (b): 0.125 L/mg

These results suggest monolayer adsorption on a homogeneous surface with a finite number of active sites. The strong agreement with the Langmuir model indicates uniform adsorption energy and stable adsorbate–adsorbent interactions.

The Langmuir isotherm plot (Ce/qe vs Ce) shows a strong linear relationship with an R² value of 0.994, indicating excellent agreement with the model and confirming monolayer adsorption on a homogeneous surface.

Kinetics Model For Constructed Wetland

Treatment efficiency was progressively enhanced by optimising the coagulation process parameters and subsequently fine-tuning the performance of the constructed wetland system.

Table 6:
Kinetic Data for Constructed Wetland

Initial C_0	Final C	HRT (hr)	$\ln(C/C_0)$	K (hr^ -1)
20.3	2.5	0.185	-2.095	11.32
24.5	2.5	0.418	-2.283	5.46
23.3	2.5	0.417	-2.231	5.35
25 .7	2.5	0.428	-2.329	5.44
29.8	2.5	0.430	-2.478	5.76
27.1	2.5	0.427	-2.384	5.58
31.1	2.5	0.432	-2.527	5.85

Graphical Representation

Plot: ln(C/ C0)vs HRT

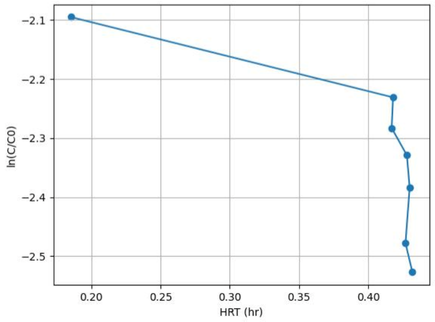

Figure 6: Plug Flow Model Plot

The graph shows a decreasing linear trend. As HRT increases, ln(C/C₀) becomes more negative. The linear decrease of ln(C/C₀) with time indicates that turbidity removal follows first-order reaction kinetics in the constructed wetland.

The kinetics of pollutant removal in the constructed wetland system were analysed using a first-order model. A linear relationship was observed in the plot of ln(C/C₀) versus hydraulic retention time (HRT), confirming that the treatment process follows first-order reaction kinetics.

The calculated rate constants (k) ranged from 5.35 to 11.32 hr^{-1}, indicating efficient pollutant removal within the system. The decreasing trend of ln(C/C₀) with increasing HRT demonstrates enhanced treatment efficiency over time.

The Plug Flow model plot ln (C/ C0 vs HRT) shows moderate agreement ($R^2 \approx 0.55$), indicating first-order behavior, but some deviations occur due to experimental and environmental factors

The integrated treatment system demonstrated significant improvement in greywater quality. Key reductions achieved include:

- COD: 376 mg/L to 96 mg/L
- BOD: 94.4 mg/L to 25 mg/L
- Turbidity: ~20–25 NTU to 2.5 NTU
- EC: 1808 µS/cm to 1180 µS/cm
- pH stabilised within the neutral range

These results confirm the effectiveness of combining natural coagulation, filtration, and constructed wetland processes for greywater treatment.

IV. DISCUSSION

The results demonstrate the effectiveness of the integrated greywater treatment system combining coagulation–flocculation, filtration, and constructed wetland processes.

The significant reduction in turbidity confirms the efficiency of *Moringa oleifera* as a natural coagulant, particularly at the optimum dosage of 2.5 g/L, where effective floc formation and settling were observed. The progressive decrease in COD and BOD during coagulation and subsequent wetland treatment indicates both physicochemical and biological removal mechanisms. The constructed wetland further enhanced pollutant removal through microbial degradation, adsorption, and plant uptake. The adsorption analysis revealed that the Langmuir isotherm better represents the system, suggesting monolayer adsorption on a homogeneous surface. Additionally, the first-order kinetic model adequately described pollutant removal in the wetland, indicating time-dependent treatment efficiency. Overall, the system achieved substantial improvement in water quality, making it suitable for non-potable reuse applications.

Table 7:
Comparison of Initial and Final Water Quality Parameters

Parameter	Initial Value	Final Value	Observation
COD (mg/L)	376	96	Significant reduction
BOD (mg/L)	94.4	25	Effective biodegradation
Turbidity (NTU)	25	2.5	Within acceptable limit
pH	8.01	6.9	Neutralized
EC (µS/cm)	1808	1200	Reduced ions

Overall, the system achieved substantial improvement in greywater quality, meeting criteria for non-potable reuse applications.

V. CONCLUSION

This study successfully demonstrates the design and performance of a decentralised greywater treatment system suitable for sustainable water reuse. The combination of natural coagulation using *Moringa oleifera*, sand–gravel filtration, and a constructed wetland proved effective in significantly reducing turbidity, BOD, COD, and electrical conductivity while maintaining pH within acceptable limits. The optimum coagulant dosage of 2.5 g/L resulted in efficient turbidity removal, and further polishing in the constructed wetland enhanced overall treatment performance.

Adsorption studies confirmed that the Langmuir isotherm best describes the system, indicating monolayer adsorption, while kinetic analysis showed that the treatment follows first-order behaviour. These findings highlight the reliability and efficiency of the system for non-potable reuse applications such as irrigation and cleaning. The proposed treatment approach is cost-effective, eco-friendly, and suitable for decentralised implementation, offering a practical solution for water conservation in water-scarce regions.

VI. FUTURE SCOPE

Future research can focus on enhancing the performance and applicability of the proposed greywater treatment system through several avenues. Long-term studies are required to evaluate system stability, seasonal variations, and maintenance requirements under continuous operation. Further investigation into pathogen removal efficiency and integration of low-cost disinfection methods, such as solar or UV treatment, would improve the safety of reuse. Optimisation of constructed wetland design, including plant species selection and media configuration, can enhance treatment efficiency. Scaling up the system for community-level applications and assessing its economic feasibility through cost–benefit and lifecycle analyses are also recommended. Additionally, the incorporation of real-time monitoring and automation could improve operational control and reliability.

These advancements would support the broader implementation of decentralised greywater treatment systems in water-scarce regions.

REFERENCES

[1] Haddad El-Hajj, R. (2021). Greywater reuse for irrigation: A critical review of suitability and health implications. Science of the Total Environment, 754, 142214–142250.

[2] Gikas, P., & Tchobanoglous, G. (2014). Wastewater treatment and reuse: Sustainability options. Science of the Total Environment, 473, 1–15.

[3] UN-Water. (2021). The United Nations World Water Development Report 2021: Valuing Water. UNESCO, Paris.

[4] Libhaber, M., & Orozco-Jaramillo, J. (2012). Sustainable Treatment and Reuse of Municipal Wastewater: For Decision-Makers and Practicing Engineers. MDPI, pp. 1–300.

[5] Sibiya, N. P., Rathilal, S., & Tetteh, E. K. (2021). Coagulation treatment of wastewater: Kinetics and natural coagulant evaluation. Molecules, 26(3), 698.

[6] Yadav, A. K., Singh, R., Patel, S., & Sharma, N. (2019). Green and sustainable pathways for wastewater purification. Environmental Science and Pollution Research, 26, 12345–12360.

[7] Rahmadyanti, E., & Febriyanti, C. P. (2020). Feasibility of constructed wetland using coagulation-flocculation technology in batik wastewater treatment. Volume 21, Issue 6, pages 67–77.

[8] Mohamed, A. Y. A., Siggins, A., Healy, M. G., Ó hUallacháin, D., Fenton, O., & Tuohy, P. A novel hybrid coagulation–constructed wetland system for the treatment of dairy wastewater.

[9] Thivyatharsan, R., & Rajendran, M. (2017). Efficiency of coagulation process and constructed wetland for the treatment of municipal solid waste landfill leachate. Sri Lanka Sch. J., 5(9), 497–501.