Published by :
https://www.ijert.org/
An International Peer-Reviewed Journal

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 04 , April - 2026

Enhancing Hotel Sustainability by Harnessing Greywater for Reduced Freshwater Consumption

Siddhi Choubey, Shruti Rathore, Ekta Chandra,
Shreya Meshram, Aditi Singh
Student, Department of Civil Engineering, Bhilai Institute of Technology, Durg, C.G., India

Mrs. Mallika Jain
Assistant Professor, Department of Civil Engineering, Bhilai Institute of Technology, Durg, C.G., India

Abstract - Municipal freshwater scarcity and large-volume wastewater generation by the hospitality sector present a compelling case for on-site greywater recycling. This study evaluates the feasibility of treating hotel greywater using a dual organic coagulant system comprising Moringa oleifera seed extract and Okra (Abelmoschus esculentus) seed mucilage, coupled with coagulation–flocculation–sedimentation–multi-media filtration. Composite greywater samples were collected over four sessions from a 45-room, 3-star hotel in Durg, Chhattisgarh, and subjected to comprehensive physicochemical characterisation. Raw greywater exhibited elevated turbidity (53.4 NTU), TSS (178 mg/L), BOD_5 (87 mg/L), COD (221 mg/L), TDS (820 mg/L), and pH 8.4. Jar test experiments identified 15 mL/L Moringa + 15 mL/L Okra as the optimum combined coagulant dose, achieving 87.3% turbidity removal, markedly superior to Moringa alone (74%) or Okra alone (65%). Post-treatment analysis confirmed 84.3% TSS removal, 73.8% COD reduction, 69.0% BOD reduction, and ~85% colour removal. All key post-treatment parameters; pH (7.2), turbidity (6.8 NTU), TDS (510 mg/L), EC (890 µS/cm), and Total Hardness (198 mg/L), comply with IS 10500:2012 permissible limits. The treated effluent is assessed as suitable for non-potable reuse in toilet flushing, landscape irrigation, floor cleaning, and cooling tower makeup, collectively representing 35–45% of hotel water demand. Annual freshwater savings of approximately 3.65 million litres and monetary savings of ₹1.09 lakh are projected for the study hotel, with a system payback period of 2–3 years. This work establishes organic coagulant-based greywater treatment as a technically sound, economically viable, and environmentally responsible strategy for the Indian hospitality sector.

Keywords: Greywater treatment; Moringa oleifera; Okra mucilage; Organic coagulation; Hotel water management; Coagulation–flocculation; IS 10500:2012; Non-potable reuse; Durg, Chhattisgarh

1. INTRODUCTION

Global freshwater stress has intensified sharply over the past three decades. India, which supports over 17% of the world's population on just 4% of its freshwater resources, has seen per-capita surface water availability fall from approximately 2,300 m³ in 1991 to a projected 1,191 m³ by 2050. Well below the internationally accepted water-stress threshold of 1,700 m³ per capita per year (UN-WWDR, 2023). Within this context, the hospitality sector constitutes a disproportionately large freshwater consumer: a typical mid-size hotel (50–150 rooms) consumes 200–400 litres per guest per night, while luxury properties can exceed 600–800 litres, figures four to six times higher than average residential per-capita consumption of 135–150 litres per day in Indian cities.

Greywater; the non-toilet wastewater fraction generated from bathroom showers, washbasins, and laundry operations constitutes 50–80% of total hotel wastewater by volume. Unlike blackwater, greywater contains substantially lower concentrations of pathogens and faecal-origin contaminants, making it technically amenable to treatment and non-potable reuse at relatively modest cost. In Chhattisgarh, a state classified as water-surplus at the regional level but experiencing significant urban supply-demand deficits in cities such as Durg and Bhilai, the rapid expansion of the hospitality and tourism sector is adding measurable strain on municipal water infrastructure. Systematic greywater recycling within hotel premises offers a practical, decentralised solution to simultaneously reduce freshwater consumption, lower wastewater discharge loads, and improve operational sustainability credentials.

Conventional greywater treatment approaches rely predominantly on chemical coagulants, aluminium sulphate (alum), ferric chloride, and polyaluminium chloride (PAC). While effective, these coagulants introduce secondary chemical residues in treated water, generate large volumes of metal-laden sludge requiring specialised disposal, demand careful chemical storage and handling, and impose recurring procurement costs that can be challenging for small to mid-size hotel operators. Natural organic coagulants, particularly Moringa oleifera seed extract and Okra (Abelmoschus esculentus) seed mucilage, present a compelling biodegradable alternative: they are locally available, non-toxic, produce minimal sludge, and require no specialised chemical infrastructure. Despite

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 04 , April - 2026

substantial evidence of their efficacy in treating surface water and domestic wastewater, their application to hotel greywater treatment in the Indian context has not been previously reported in peer-reviewed literature.

This study addresses that gap by investigating the performance of a combined Moringa–Okra organic coagulant system, optimised via jar tests and applied within a bench-scale coagulation–flocculation–sedimentation–filtration treatment train, for hotel greywater collected in Durg, Chhattisgarh. The specific objectives were: (i) to characterise raw hotel greywater across twelve physicochemical parameters; (ii) to prepare and dose-optimise organic coagulants from Moringa seeds and Okra seed mucilage; (iii) to evaluate post-treatment water quality against IS 10500:2012 permissible limits; (iv) to assess the suitability of treated greywater for non-potable hotel applications; and (v) to estimate the economic and water-conservation benefits of system adoption.

2. LITERATURE REVIEW

The physicochemical characteristics of greywater have been extensively studied. Eriksson et al. (2002) reviewed data from over 40 studies across Europe, Australia, and North America and established that greywater constitutes approximately 60% of household wastewater flows, with BOD concentrations up to 300 mg/L, elevated suspended solids, surfactants, and trace metals, but with substantially lower pathogen concentrations than blackwater. In the Indian context, Patil et al. (2022) characterised household greywater at COD 150–450 mg/L and TSS 100–250 mg/L, and demonstrated that a multi-stage physical treatment system (screening → sand filtration → activated carbon) achieved up to 86% BOD and 94% TSS removal. Baxi et al. (2015) investigated greywater reuse at NIT Raipur; geographically proximate to the present study area, and demonstrated the economic viability of a settling–filtration–disinfection system for toilet flushing applications. Sudarsan et al. (2021) reported 60–70% treatment efficiency for commercial building greywater using simple physical methods and recommended greywater recycling as standard practice for urban commercial establishments.

The use of Moringa oleifera as a primary coagulant is well-established. Ndabigengesere et al. (1995) first isolated the active cationic coagulant protein (MW ~13 kDa) from Moringa seeds and demonstrated 80–99% turbidity removal from surface water comparable to or exceeding alum at optimal doses. Ghebremichael et al. (2005) confirmed that the Moringa protein operates through charge neutralisation of negatively charged colloidal particles, forming dense, rapidly settling flocs and producing biodegradable sludge in volumes 20–30% of those generated by alum. For greywater and wastewater applications, Moringa has been reported to achieve turbidity removal of 70–95%, BOD reduction of 50–75%, and significant colour removal, with optimal performance at pH 6.5–8.0.

Okra (Abelmoschus esculentus) seed mucilage, comprising long-chain galactose–rhamnose polysaccharides (galacturonan) with molecular weights of 50–800 kDa, acts primarily as a flocculant aid through bridging flocculation. Balasubramanian et al. (2009) demonstrated 65–80% turbidity removal from surface water, with the notable advantage of producing only 10–15% of the sludge volume generated by alum at equivalent treatment performance. Sanghi et al. (2006) found that Okra achieved up to 85% colour removal from textile effluent, superior to guar gum and comparable to alum, and recommended it for high-colour, high-TSS wastewater a category representative of hotel laundry greywater. Mechanistically, Okra's anionic/neutral polysaccharide chains complement the cationic Moringa protein through bridging flocculation, and Ang and Mohammad (2020) confirmed that binary combinations of such coagulants consistently outperform either component alone, yielding larger, denser, more rapidly settling floc structures.

3. METHODOLOGY

3.1 Study Site and Sample Collection

Greywater samples were collected from a 45-room, 3-star rated hotel in Durg, Chhattisgarh, which operates 365 days per year with a daily freshwater consumption of approximately 25,000–30,000 litres at full occupancy. The hotel has no existing greywater treatment or recycling infrastructure. An internal drainage survey identified a suitable sampling point on the grey drainage line, excluding toilet-drain blackwater and kitchen drain (routed separately to a grease trap). Composite samples of 5 litres each were collected over four sessions at 10-day intervals during October–November 2025, during the peak check-out and housekeeping period (08:00–11:00 h), using grab sampling at 30-minute intervals aggregated into pre-cleaned HDPE containers. Samples were transported to the Environmental Engineering Laboratory, Department of Civil Engineering, BIT Durg within 2 hours of collection, stored at 4°C, and analysed within 24 hours. All sampling and preservation procedures followed IS 3025 (Part 1).

3.2 Preparation of Organic Coagulants

Moringa oleifera seed extract: Dried Moringa seeds procured from a local agricultural market were de-hulled, and the white cotyledon kernels were oven-dried at 60°C for 2 hours and ground to <500 µm particle size. A 50 g/L stock solution was prepared

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 04 , April - 2026

by dissolving 5.0 g of seed powder in 100 mL distilled water, stirring at 400 RPM for 30 minutes on a magnetic stirrer, and filtering through Whatman No. 1 filter paper to obtain a clear coagulant filtrate. Fresh stock was prepared for each experimental session and used within 12 hours.

Okra seed mucilage: Fresh Okra pods were dried at 50°C for 24 hours, seeds were extracted and coarsely ground, and the powder was soaked in distilled water (1:10 w/v) for 2 hours with periodic stirring. The viscous mucilaginous filtrate obtained after Whatman No. 1 filtration served as the Okra stock solution (~1% w/v biopolymer) and was used within 24 hours to prevent fermentation.

3.3 Jar Test; Coagulant Dose Optimisation

Standard jar tests (APHA, 2017) were conducted using a six-position jar test apparatus with 1-litre aliquots of raw greywater per jar. The protocol comprised rapid mixing at 100 RPM for 2 minutes (coagulation), slow mixing at 30 RPM for 20 minutes (flocculation), and quiescent settling for 30 minutes. A 200 mL supernatant aliquot was then withdrawn from each jar and analysed for residual turbidity and pH. Moringa alone, Okra alone, and combined Moringa + Okra (1:1 volume ratio) were tested at doses of 5, 10, 15, 20, and 25 mL/L. All jar tests were conducted in triplicate and mean values reported.

3.4 Treatment Train

At the optimum coagulant dose identified, bulk greywater treatment was conducted through the following sequential stages: (i) pre-screening through a 2 mm mesh; (ii) pH adjustment to 7.5–8.0 if required; (iii) coagulant addition followed by rapid mixing (100 RPM, 2 min) and slow mixing (30 RPM, 20 min); (iv) quiescent sedimentation in a 2-litre graduated cylinder for 60 minutes; and (v) passage through a laboratory-scale multi-media filter column (10 cm PVC pipe, 60 cm height) comprising, from bottom to top: coarse gravel (5 cm), coarse sand (10 cm), fine sand (15 cm), granular activated carbon (10 cm), and fine gravel (5 cm). Post-filtration pH was checked and adjusted to 6.5–7.5 as required.

3.5 Analytical Methods

Twelve parameters were measured for both raw and treated greywater. pH was measured potentiometrically using an IKON pH/mV Meter calibrated with pH 4.0, 7.0, and 9.0 buffers; turbidity was measured nephelometrically with a Digital Turbidity Meter (Model 331) calibrated with formazin standards. Electrical conductivity was measured using an IKON Conductivity/Temperature Meter calibrated with 0.01 N KCl. Total dissolved solids and total suspended solids were determined gravimetrically. Total hardness was determined by EDTA titrimetry (EBT indicator, pH 10.1 buffer); alkalinity by H_2SO_4 titrimetry; dissolved oxygen by polarographic membrane electrode (IKON DO Meter). BOD_5 was measured by the 5-day incubation method at 20°C ± 1°C; COD by the open reflux dichromate method; colour and odour by visual/olfactory assessment per APHA. All measurements were performed in triplicate and mean values reported. Treatment efficiency was calculated as: $E (\%) = [(C_0 - C_1) / C_0] \times 100$, where C_0 and C_1 are pre- and post-treatment concentrations respectively.

4. RESULTS AND DISCUSSION

4.1 Raw Greywater Characterisation

The raw hotel greywater was consistently characterised across four sampling sessions (Table 1). The slightly alkaline pH (8.4 ± 0.3) is attributable to sodium-compound-rich laundry detergents. Turbidity (53.4 ± 4.2 NTU) substantially exceeds the IS 10500:2012 maximum permissible limit of 10 NTU for non-potable use. The BOD_5/COD ratio of 0.39 indicates that approximately 40% of the organic load is biodegradable, consistent with bathroom greywater dominated by soaps and personal care products. Low dissolved oxygen (2.8 ± 0.4 mg/L) confirms partial oxygen depletion attributable to biological activity during sample storage, validating the urgency of timely treatment. All observed raw-water values fall within the typical greywater quality ranges reported in global literature (Eriksson et al., 2002), confirming the representativeness of the study site.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 04 , April - 2026

Table 1: Physicochemical Characterisation of Raw and Treated Hotel Greywater

Parameter	Unit	Raw GW (Mean ± SD)	Treated GW (Mean ± SD)	IS 10500:2012 Limit	Removal (%)
pH	–	8.4 ± 0.3	7.2 ± 0.2	6.5–8.5	–
Turbidity	NTU	53.4 ± 4.2	6.8 ± 0.7	10 (max)	87.3
EC	µS/cm	1240 ± 87	890 ± 55	2500	28.2
TDS	mg/L	820 ± 62	510 ± 40	2000	37.8
TSS	mg/L	178 ± 15	28 ± 5	–	84.3
Total Hardness	mg/L	310 ± 24	198 ± 17	600	36.1
Alkalinity	mg/L	196 ± 18	112 ± 12	600	42.9
DO	mg/L	2.8 ± 0.4	5.4 ± 0.5	–	+92.9↑
BOD_5	mg/L	87 ± 9	27 ± 4	–	69.0
COD	mg/L	221 ± 21	58 ± 7	–	73.8
Colour	Hazen	~20	~3	15 (max)	~85.0
Odour	–	Mild soapy	Odourless	Unobjectionable	–

4.2 Jar Test - Optimum Coagulant Dose

Jar test results established a clear dose–response relationship for all three coagulant configurations (Table 2). Moringa alone achieved a maximum turbidity removal of 74.0% at 20 mL/L, with no further improvement at 25 mL/L - a pattern consistent with overdosing-induced floc restabilisation. Okra alone reached a ceiling of approximately 65.5% at 25 mL/L, confirming that, as an anionic/neutral biopolymer, it is less effective as a standalone primary coagulant for the negatively charged colloids in hotel greywater. The combined Moringa + Okra system at 15+15 mL/L achieved 87.3% turbidity removal, the maximum performance point, which represents a 13.3 percentage-point improvement over Moringa alone and a 21.8 percentage-point improvement over Okra alone. This synergistic enhancement is mechanistically attributable to the cationic Moringa protein first neutralising the surface charge of colloidal particles, while Okra's long-chain polysaccharides subsequently bridge between the destabilised particles to form large, dense, rapidly settling floc aggregates; z a complementary mechanism consistent with the theoretical basis of binary organic coagulant systems described by Ang and Mohammad (2020).

Table 2: Jar Test Results — Turbidity Removal at Varying Coagulant Doses

Coagulant System	5 mL/L	10 mL/L	15 mL/L	20 mL/L	25 mL/L
Moringa only (% removal)	28.5%	59.9%	72.5%	74.0%	73.6%
Okra only (% removal)	21.2%	44.2%	63.8%	65.0%	65.5%
Moringa + Okra (% removal)	48.9%	74.5%	87.3% ✓ OPT.	86.7%	86.1%

4.3 Post-Treatment Performance

Following treatment at the optimum dose (15+15 mL/L Moringa + Okra) through the full treatment train, the treated water was visually clear, colourless to faintly pale yellow, and odourless. Table 1 summarises the complete pre- and post-treatment comparison.

Turbidity and TSS: The 87.3% turbidity reduction (53.4 → 6.8 NTU) and 84.3% TSS reduction (178 → 28 mg/L) bring both parameters to compliance with IS 10500:2012. Residual turbidity of 6.8 NTU is within the 10 NTU maximum permissible limit and suitable for toilet flushing, irrigation, and floor cleaning applications.

Organic Load: BOD_5 reduction of 69.0% (87 → 27 mg/L) and COD reduction of 73.8% (221 → 58 mg/L) result from a combination of mechanisms: coagulation of colloid-associated organics, sedimentation of organic-laden floc, and activated carbon adsorption of dissolved chromophoric and odour-causing compounds. The residual BOD (27 mg/L) and COD (58 mg/L) represent non-adsorbable soluble surfactant metabolites and low-molecular-weight organics — acceptable for all non-potable, non-body-contact reuse applications. For potential body-contact applications, a biological polishing stage would be advisable.

TDS, EC, and Hardness: Moderate reductions in TDS (37.8%, 820 → 510 mg/L), EC (28.2%, 1240 → 890 µS/cm), and Total Hardness (36.1%, 310 → 198 mg/L) reflect partial co-precipitation of hardness ions as carbonate complexes and activated carbon adsorption of dissolved organics, while the bulk of dissolved ionic species remain in solution — as expected from a physical-chemical treatment process. All post-treatment values comfortably comply with IS 10500:2012 limits (TDS < 2000 mg/L, EC < 2500 µS/cm, TH < 600 mg/L).

DO, Colour, and Odour: Dissolved oxygen improved markedly from 2.8 to 5.4 mg/L (+92.9%), a consequence of atmospheric oxygen dissolution during mixing operations and filtration confirming that treated water is aerobically stable for storage and distribution within the hotel. Colour was reduced by ~85% (20 → ~3 Hazen units, well within the 15-Hazen IS limit), and soapy odour was completely eliminated, both attributable to activated carbon adsorption of volatile organic compounds and residual surfactants.

4.4 Non-Potable Reuse Suitability

Based on post-treatment quality data and applicable reuse guidelines (IS 10500:2012; WHO, 2006), the treated greywater is assessed as suitable for the following hotel applications: toilet flushing (turbidity < 10 NTU, odourless); landscape and garden irrigation (pH 7.2, turbidity 6.8 NTU, TDS 510 mg/L all within permissible ranges); floor and surface cleaning; cooling tower makeup water (TDS 510 mg/L < 1000 mg/L threshold; TH 198 mg/L < 300 mg/L threshold); and car washing. Collectively, these applications account for 35–45% of total hotel water demand, representing the most impactful reuse opportunity. Swimming pool makeup and potable applications are not recommended without additional disinfection (UV or chlorination) and, in the case of potable use, membrane filtration.

4.5 Economic and Water Conservation Analysis

At the study hotel (45 rooms, ~70% average annual occupancy, daily freshwater consumption 27,000 litres), implementation of the proposed treatment system is projected to recycle approximately 10,000 litres per day for toilet flushing and irrigation, reducing annual freshwater consumption by approximately 3.65 million litres. At the prevailing municipal water tariff in Durg (approximately ₹20/kL), annual water procurement savings amount to approximately ₹73,000, with a further ₹36,500 saved on sewage discharge charges yielding total annual monetary savings of approximately ₹1.09 lakh. The estimated capital cost of a complete hotel-scale system (collection sump, coagulant dosing unit, clarifier, filter column, and distribution piping) is ₹2.0–2.5 lakh, indicating a payback period of approximately 2–3 years. These projections do not account for potential green hotel premium pricing, carbon credit opportunities, or regulatory compliance cost avoidance factors that would further improve the economic case.

5. CONCLUSION

This study demonstrates that hotel greywater from a mid-size hospitality establishment in Durg, Chhattisgarh, can be effectively treated using a combined Moringa oleifera seed extract and Okra seed mucilage coagulant system to meet IS 10500:2012 physicochemical quality standards for non-potable water reuse. The combined coagulant at 15+15 mL/L achieved 87.3% turbidity removal, significantly superior to either coagulant applied individually with overall removals of 84.3% TSS, 73.8% COD, 69.0% BOD, and ~85% colour across the full coagulation–flocculation–sedimentation–filtration treatment train. The treated effluent is confirmed suitable for toilet flushing, landscape irrigation, floor cleaning, cooling tower makeup, and car washing within the hotel premises, representing 35–45% of daily freshwater demand. Organic coagulants offer compelling operational advantages over conventional chemical alternatives they are locally available throughout India, biodegradable, non-toxic, produce minimal sludge, and require no specialised chemical handling infrastructure, making them particularly well-suited to adoption by small and mid-size hotel operators. The economic analysis projects a capital investment payback period of 2–3 years through water and sewage savings. This approach aligns with India's National Water Policy, the Sustainable Development Goal 6 (Clean Water and Sanitation), and

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 04 , April - 2026

green building certification frameworks such as LEED India and Green Key, positioning greywater recycling as an accessible and high-impact sustainability intervention for the Indian hospitality sector.

REFERENCES

[1] Eriksson, E., Auffarth, K., Henze, M. and Ledin, A. (2002). Characteristics of grey water. Urban Water, 4, 85–104.

[2] Patil, P.D., Bhange, V.P., Shende, S.S. and Ghorpade, P.S. (2022). Grey water characterization of an Indian household and potential treatment for reuse. Water-Energy Nexus, 5, 1–7.

[3] Ndabigengesere, A., Narasiah, K.S. and Talbot, B.G. (1995). Active agents and mechanism of coagulation of turbid waters using Moringa oleifera. Water Research, 29(2), 703–710.

[4] Balasubramanian, N., Manivannan, V. and Kumar, R. (2009). Coagulation of turbid water using Okra (Abelmoschus esculentus) seed mucilage. Bioresource Technology, 100(6), 1764–1767.

[5] Ghebremichael, K.A., Gunaratna, K.R., Henriksson, H., Brumer, H. and Dalhammar, G. (2005). A simple purification and activity assay of the coagulant protein from Moringa oleifera seed. Water Research, 39(11), 2338–2344.

[6] Sanghi, R., Bhattacharya, B. and Singh, V. (2006). Cassia angustifolia seed gum as an effective natural coagulant for decolourisation of dye solutions. Green Chemistry, 8, 613–618.

[7] Ang, W.L. and Mohammad, A.W. (2020). State of the art and sustainability of natural coagulants in water and wastewater treatment. Journal of Cleaner Production, 262, 121267.

[8] Baxi, A., Patel, D.K. and Jaiswal, M. (2015). Grey Water Reuse. Science and Technology, 1(4), 201–206.

[9] Sudarsan, J.S., Vaishampayan, S. and Srihari, V. (2021). Grey water recycling as a tangible solution to water crisis. International Journal of Energy and Water Resources, 5, 1–5.

[10] Pachkor, R.T. and Parbat, D.K. (2017). A literature review on integrated approach for grey water treatment. IJRASET, ISSN: 2321-9653.

[11] Bureau of Indian Standards (2012). IS 10500:2012 — Drinking Water Specification (Second Revision). BIS, New Delhi.

[12] World Health Organization (2006). Guidelines for the Safe Use of Wastewater, Excreta and Greywater. Vol. 2: Wastewater Use in Agriculture. WHO Press, Geneva.

[13] APHA, AWWA and WEF (2017). Standard Methods for the Examination of Water and Wastewater, 23rd Edition. APHA, Washington DC.

[14] Morel, A. and Diener, S. (2006). Greywater Management in Low and Middle-Income Countries. Eawag, Dubendorf, Switzerland.

[15] UN-WWDR (2023). United Nations World Water Development Report 2023. UNESCO, Paris.