© June 2026 | IJIRT | Volume 13 Issue 1 | ISSN: 2349-6002

Treatment and Utilization of Greywater for Nonportable Applications Using a Decentralized Multilayer Filtration and Phytoremediation System

R. S. More[1], Vivek P. Patil[2], Avadhut S. Bhopale[3], Prathamesh D. Patil[4], Rushikesh S. Kumbhar[5] Pratik V. Upadhye[6]

[1]Professor, Department of Civil Engineering Tatyasaheb Kore Institute of Engineering and Technology Warananagar, India

[2,3,4,5,6]Department of Civil Engineering Tatyasaheb Kore Institute of Engineering and Technology Warananagar, India

***Abstract*—Increasing freshwater scarcity, rapid urbanization, and population growth have intensified the need for sustainable water management strategies worldwide. Greywater, which constitutes approximately 50–70% of domestic wastewater, represents a valuable alternative water resource that can be treated and reused for nonportable applications. This study presents the design, development, and evaluation of a lowcost decentralized greywater treatment system employing multilayer filtration and phytoremediation techniques. The proposed system consists of four major treatment stages, namely sedimentation, primary filtration, secondary filtration, and aeration. The filtration unit incorporates locally available materials such as coarse aggregate, fine aggregate, activated charcoal, soil media, and lemongrass (Cymbopogon spp.) to facilitate physical filtration, adsorption, biological degradation, and nutrient uptake. A laboratoryscale prototype was developed and tested using domestic greywater collected from residential sources. Water quality assessment was conducted using key physicochemical parameters including pH, Total Dissolved Solids (TDS), Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), hardness, chloride, and nitrate concentrations. The integrated treatment process demonstrated significant improvement in water quality through the combined action of sedimentation, adsorption, microbial activity, and phytoremediation. The treated effluent was found suitable for various nonportable applications such as landscape irrigation, toilet flushing, floor cleaning, and gardening. Furthermore, the proposed system offers advantages including low installation cost, minimal energy consumption, simple operation, and reduced environmental impact. The findings indicate that decentralized greywater reuse systems can substantially reduce freshwater demand, alleviate pressure on municipal wastewater infrastructure, and contribute to sustainable urban water management practices, particularly in water stressed regions.**

I. INTRODUCTION

Water is one of the most critical natural resources for sustaining human life, economic development, agricultural productivity, and ecological balance. However, increasing population growth, rapid urbanization, industrial expansion, and climate change have significantly intensified the pressure on available freshwater resources worldwide. According to recent global assessments, nearly half of the world's population experiences severe water scarcity for at least part of the year, and this situation is expected to worsen in the coming decades due to increasing water demand and declining freshwater availability [1], [2]. Developing countries, particularly India, face substantial challenges in maintaining sustainable water supplies because of uneven rainfall distribution, excessive groundwater extraction, inadequate wastewater management, and growing urban populations.

India is currently among the countries facing significant water stress, with many metropolitan cities experiencing periodic water shortages and declining groundwater levels. The rapid increase in domestic water consumption has resulted in the generation of large volumes of wastewater, placing additional pressure on municipal treatment facilities and receiving water bodies [3]. Conventional water management practices primarily follow a linear approach involving freshwater extraction, consumption, wastewater generation, treatment, and disposal. Such practices are becoming increasingly unsustainable under present environmental and socioeconomic conditions. Consequently, the concept of circular water management, emphasizing wastewater reclamation, reuse, and resource recovery, has gained considerable attention among researchers and policy makers [4].

Among various wastewater streams, greywater represents a particularly promising alternative water resource. Greywater is defined as domestic wastewater generated from household activities such as bathing, laundry, handwashing, and kitchen operations, excluding toilet wastewater commonly referred to as blackwater. Greywater typically accounts for approximately 5070% of total household wastewater generation and possesses significantly lower concentrations of pathogenic microorganisms and organic pollutants compared to blackwater [5]. Owing to its relatively lower contamination level, greywater can be treated using less complex technologies and subsequently reused for various nonportable applications, including toilet flushing, landscape irrigation, gardening, vehicle washing, and floor cleaning.

The treatment and reuse of greywater offer several environmental, economic, and social benefits. Reusing treated greywater reduces freshwater demand, decreases wastewater discharge volumes, minimizes environmental pollution, and lowers the operational burden on centralized wastewater treatment plants [6]. Furthermore, decentralized greywater treatment systems can significantly reduce energy consumption associated with water extraction, transportation, and treatment processes. Such systems are particularly beneficial in water scarce regions and densely populated urban areas where centralized treatment infrastructure may be insufficient or economically infeasible.

Various greywater treatment technologies have been investigated over the past two decades. Physical treatment methods such as sedimentation, screening, filtration, and membrane separation are widely employed to remove suspended solids and particulate contaminants [7]. Chemical treatment techniques, including coagulation, flocculation, oxidation, and disinfection, are utilized to reduce dissolved pollutants and microbial contamination. Biological treatment processes involving aerobic and anaerobic microorganisms have also demonstrated considerable effectiveness in reducing Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), and nutrient concentrations [8]. More recently, nature-based treatment systems such as constructed wetlands, green walls, phytoremediation units, and biofiltration systems have gained popularity because of their sustainability, low operational costs, and minimal environmental impacts [9].

Several researchers have reported significant improvements in greywater quality using multistage filtration systems incorporating natural media. Pingale et al. reported COD and BOD removal efficiencies exceeding 85% using a multilayer filtration unit for domestic greywater treatment [10]. Similarly, Ngo et al. demonstrated turbidity removal efficiencies greater than 80% through a combination of layered filtration media and membrane technology, highlighting the effectiveness of integrated treatment systems for nonportable reuse applications [4]. Knutsson and Knutsson further demonstrated that building scale greywater reuse systems can reduce potable water demand by more than 30%, thereby contributing substantially to water conservation and energy savings [6].

Despite significant advancements in greywater treatment technologies, several limitations remain. Many existing treatment systems rely on sophisticated equipment, membrane technologies, chemical additives, or advanced operational control mechanisms that increase installation and maintenance costs. Such systems may not be economically feasible for household level implementation, particularly in developing regions. Furthermore, many studies focus primarily on treatment efficiency while giving limited attention to affordability, operational simplicity, and the integration of natural treatment processes suitable for decentralized applications [3], [8]. Therefore, there is a need for sustainable, low-cost, and easily maintainable greywater treatment systems capable of achieving acceptable treatment performance while remaining accessible to residential users.

To address these challenges, the present study proposes a decentralized greywater treatment system based on sedimentation, multilayer filtration, phytoremediation, and aeration processes. The developed system utilizes locally available materials including coarse aggregate, fine aggregate, activated charcoal, soil media, and lemongrass (Cymbopogon spp.) to achieve physical, chemical, and biological treatment simultaneously. Activated charcoal serves as an effective adsorbent for dissolved organic contaminants and odor causing compounds, while lemongrass contributes to nutrient uptake, microbial activity enhancement, and natural phytoremediation. The treatment unit has been designed as a compact, low-cost, and energy efficient system suitable for decentralized household applications.

The primary objectives of this research are to evaluate the treatment performance of the developed greywater filtration system, assess improvements in key physicochemical water quality parameters, and investigate its suitability for nonportable reuse applications. Additionally, the study aims to demonstrate the feasibility of integrating natural treatment media and phytoremediation techniques within a decentralized framework to promote sustainable water management practices. The outcomes of this research are expected to contribute toward the development of affordable and environmentally sustainable greywater reuse solutions capable of reducing freshwater demand, minimizing wastewater discharge, and enhancing water security in urban and semiurban communities.

II. LITERATURE REVIEW

The increasing demand for freshwater resources and the growing volume of domestic wastewater have stimulated extensive research on greywater treatment and reuse technologies. Greywater reuse has emerged as a sustainable approach for reducing potable water consumption while minimizing environmental impacts associated with wastewater disposal. Numerous researchers have investigated different treatment techniques, including filtration, adsorption, biological treatment, phytoremediation, membrane separation, and hybrid treatment systems.

Early investigations by Nolde [11] demonstrated the feasibility of greywater recycling for urban water conservation.

The study reported that properly treated greywater could safely replace potable water for toilet flushing and landscape irrigation, resulting in significant reductions in household freshwater demand. Similarly, Friedler [12] analyzed individual greywater streams and concluded that wastewater originating from bathrooms and laundry activities possesses considerable reuse potential due to its relatively low pathogen concentration compared with blackwater.

Filtration based greywater treatment systems have received considerable attention because of their simplicity, low operational requirements, and cost-effectiveness. Li et al. [13] evaluated several household greywater filtration systems and reported substantial reductions in turbidity, suspended solids, and organic contaminants through multilayer filtration media. Their findings indicated that the arrangement and composition of filter media significantly influence treatment performance. Studies conducted by Pidou et al. [14] further confirmed that sand-based filtration systems can effectively remove particulate matter while providing suitable conditions for microbial degradation of dissolved pollutants.

Activated carbon adsorption has been extensively investigated as a polishing treatment process due to its high adsorption capacity for organic compounds, surfactants, detergents, and odor causing substances. AlJayyousi [15] reported significant improvements in aesthetic water quality through activated carbon treatment, particularly with respect to color, odor, and dissolved organic matter removal. Similar observations were reported by Gross et al. [16], who found that adsorption-based treatment significantly improved the suitability of greywater for landscape irrigation applications.

Biological treatment processes constitute another important category of greywater treatment technologies. Jefferson et al. [17] reported that biological systems can achieve high BOD and COD removal efficiencies through microbial degradation mechanisms. However, the study emphasized that treatment performance depends strongly on hydraulic retention time, organic loading rate, and environmental conditions. Abu Ghunmi et al. [18] reviewed multiple greywater treatment systems and concluded that biofiltration units integrating physical filtration and biological degradation exhibit superior performance compared with single stage treatment approaches.

Recent studies have increasingly focused on nature-based treatment systems because of their sustainability and low energy requirements. Masi et al. [19] demonstrated that constructed wetlands can effectively remove suspended solids, nutrients, pathogens, and organic pollutants from domestic greywater. The authors highlighted the potential of decentralized wetland systems for small communities and residential developments. Similarly, Wu et al. [20] reported that vegetation assisted treatment systems improve nutrient removal through rootzone microbial activity and plant uptake mechanisms.

Phytoremediation has emerged as an environmentally friendly treatment approach that utilizes plants for contaminant removal and nutrient recovery. Vymazal [21] reported that aquatic and terrestrial plant species contribute significantly to pollutant reduction through filtration, adsorption, micro

bial stimulation, and nutrient uptake processes. The use of aromatic grasses such as lemongrass has attracted growing interest because of their extensive root systems, rapid growth characteristics, and ability to absorb nutrients from wastewater streams.

Membrane based greywater treatment technologies have also demonstrated excellent treatment performance. Herna´ndez Leal et al. [22] investigated membrane bioreactor systems and reported high removal efficiencies for suspended solids and organic contaminants. Despite their effectiveness, the authors noted that membrane fouling, energy consumption, and operational complexity remain major limitations for householdscale applications.

The economic feasibility of greywater reuse systems has been investigated by several researchers. Dome`nech and Saur´I [23] observed that decentralized greywater reuse systems can substantially reduce potable water demand in urban environments while providing long-term economic benefits. March et al. [24] similarly demonstrated that building level greywater recycling systems contribute to both water conservation and operational cost savings.

Recent investigations have emphasized integrated treatment approaches that combine multiple treatment mechanisms. Ghaitidak and Yadav [25] concluded that hybrid systems incorporating sedimentation, filtration, adsorption, and biological treatment offer improved contaminant removal compared with individual treatment processes. Boyjoo et al. [26] further highlighted that integrated greywater treatment systems are particularly suitable for decentralized applications because they combine treatment efficiency with operational simplicity. A comprehensive review conducted by Shaikh and Ahammed [27] revealed that future greywater treatment systems should prioritize sustainability, affordability, and resource recovery. The authors recommended the integration of natural filtration media, adsorption materials, and phytoremediation processes to enhance treatment performance while minimizing environmental impacts.

A. Comparative Analysis of Existing Studies

The comparative analysis presented in Table I highlights the performance of various greywater treatment technologies reported in the literature. Filtration based systems demonstrated effective removal of suspended solids and turbidity, while biological treatment processes achieved substantial reductions in organic pollutants such as BOD and COD. Constructed wetlands and vegetated treatment systems provided additional benefits through nutrient uptake and natural purification mechanisms. Membrane based technologies exhibited superior treatment efficiencies; however, their implementation is often associated with higher installation and maintenance costs. Hybrid treatment systems integrating multiple treatment mechanisms consistently showed improved overall performance compared to single stage treatment approaches. These findings indicate that combining physical filtration, adsorption, biological treatment, and phytoremediation can provide an effective

TABLE I: Comparison of Previous Greywater Treatment Studies

Ref.	Treatment Method	Scale	Major Findings
[11]	Greywater recycling system	Residential	Significant potable water savings through greywater reuse.
[13]	Multilayer filtration	Household	Effective removal of turbidity and total suspended solids (TSS).
[15]	Activated carbon	Pilot scale	Improved colour, odour, and dissolved

	adsorption		organic matter removal.
[17]	Biological treatment	Laboratory	High BOD and COD reduction through microbial degradation.
[19]	Constructed wetlands	Field scale	Effective nutrient and pathogen removal perfomance.
[20]	Vegetated treatment system	Pilot scale	Enhanced nutrient uptake and pollutant removal.
[22]	Membrane bioreactor	Laboratory	Excellent treated water quality with high contaminant removal.
[24]	Buildingscale reuse system	Residential	Reduced freshwater consumption and improved sustainability.
[26]	Hybrid treatment system	Pilot scale	Improved overall treatment efficiency through integrated processes.

and sustainable solution for decentralized greywater treatment and reuse applications.

B. Research Gap

The reviewed literature indicates that substantial progress has been achieved in greywater treatment technologies. However, many existing systems depend on membrane filtration, chemical treatment, or mechanically intensive processes that increase operational complexity and cost. Furthermore, limited studies have investigated the combined application of sedimentation, activated charcoal adsorption, biofiltration, phytoremediation using lemongrass, and aeration within a compact decentralized treatment unit. Therefore, there remains a need for an affordable, sustainable, and easily maintainable greywater treatment system that can achieve acceptable treatment performance using locally available materials while supporting household level nonportable water reuse. The present study addresses this gap through the development and evaluation of a decentralized multilayer filtration and phytoremediation-based greywater treatment system.

III. MATERIALS AND METHODOLOGY

A. Study Area

The present study was carried out at Warananagar, Kolhapur, Maharashtra, India. The objective of the study was to develop a low-cost and decentralized greywater treatment system capable of treating domestic greywater for nonportable reuse applications. The experimental setup was fabricated and tested under laboratory conditions using greywater collected from residential activities.

B. Greywater Collection

Greywater was collected from household sources such as bathrooms, wash basins, laundry activities, and floor cleaning operations. Toilet wastewater was excluded from the collection process. The collected greywater was stored in containers and subsequently introduced into the treatment system for analysis and treatment. Raw and treated water samples were analyzed for pH, Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Dissolved Solids (TDS), Total Hardness, Chloride, and Nitrate concentrations.

C. Materials Used

The treatment system was fabricated using inexpensive and locally available materials. The selected materials were intended to provide physical filtration, adsorption, and biological treatment of greywater.

TABLE II: Materials Used in the Greywater Treatment System

Material	Purpose
Plastic Buckets	Treatment chambers
PVC Pipes	Water conveyance
Perforated PVC Pipe	Water collection and drainage
Activated Charcoal	Adsorption of organic pollutants
Coarse Aggregate	Primary filtration
Fine Aggregate	Fine particle removal
Soil Layer	Plant growth medium
Lemongrass Plant	Phytoremediation
Mosquito Mesh	Separation of filter layers
Submersible Pump	Water transfer and aeration
NRV Valve	Prevention of backflow

The fabricated treatment chambers used in the study are shown in Fig. 1.

D. Methodology

The treatment methodology consisted of sedimentation, filtration, adsorption, phytoremediation, and aeration processes. Greywater first entered the sedimentation chamber, where heavier suspended particles settled due to gravity. The partially clarified water was then passed through a multilayer filtration system.

Activated charcoal was incorporated into the filtration unit to adsorb dissolved organic contaminants, coordaining compounds, and underproducing substances. The charcoal layer used in the system is shown in Fig. 2.

A phytoremediation chamber containing lemongrass (Cymbopogon citratus) was employed to improve nutrient removal and enhance biological treatment. The root zone provided a suitable environment for microbial activity, contributing to further degradation of organic pollutants.

Fig. 1: Fabrication of treatment chambers showing PVC drainage and water collection arrangement.

Fig. 2: Activated charcoal layer used in the filtration unit for adsorption of dissolved contaminants.

The treated water was finally aerated and collected for laboratory analysis and reuse applications.

IV. SYSTEM DESIGN

A. Greywater Generation Calculation

Greywater generated from domestic activities such as bathing, laundry, hand washing, and floor cleaning was con-sidered as the influent for the developed treatment system. Greywater typically constitutes 50–70

$$Q_g = P \times q \times f \qquad (1)$$

where

- Q_g = greywater generation (L/day)
- P = number of occupants
- q = per capita water consumption (L/person/day)
- f = greywater fraction of domestic water use

Fig. 3: Lemongrassbased phytoremediation unit incorporated in the treatment process.

For a typical household consuming 135 L/person/day and assuming a greywater fraction of 0.65,

$$Q_g = P \times 135 \times 0.65 \quad (2)$$

The present laboratoryscale treatment unit was operated using greywater collected directly from residential sources. The collected volume was sufficient to evaluate the treatment performance under controlled conditions.

B. Sedimentation Tank Design

The sedimentation chamber constituted the first stage of treatment and was designed to facilitate the gravitational settling of suspended solids. The settling process reduces the particulate load entering the filtration unit and improves the overall treatment efficiency.

The hydraulic retention time (HRT) of the sedimentation chamber is expressed as: laboratory analysis and reuse applications.

$$HRT = \frac{V_s}{Q} \quad (3)$$

Where

• HRT = hydraulic retention time (h)

• Vs = volume of sedimentation tank (L)

• Q = influent flow rate (L/h)

The settling velocity of particles can be approximated using Stokes' law:

$$V_t = \frac{g(\rho_p - \rho_w)d^2}{18\mu} \quad (4)$$

Where

• Vt = settling velocity (m/s)

• g = acceleration due to gravity (9.81 m/s2)

• ρp = particle density (kg/m3)

• ρw = water density (kg/m3)

• d = particle diameter (m)

• μ = dynamic viscosity of water (Pa·s)

A plastic bucket was used as the sedimentation chamber because of its simplicity, low cost, and ease of maintenance.

C. Filter Tank Design

The filter tank was designed as a multilayer treatment unit incorporating physical filtration, adsorption, and biological treatment mechanisms. The filtration media consisted of coarse aggregate, fine aggregate, activated charcoal, soil media, and lemongrass roots.

The filtration rate can be expressed as:

$$FR = \frac{Q}{A} \quad (5)$$

where

• FR = filtration rate (m3/m2/h)

• Q = flow rate (m3/h)

• A = filtration area (m2)

The pollutant removal efficiency of the filtration unit is determined using

$$\eta = \frac{C_i - C_o}{C_i} \times 100 \quad (6)$$

Where

• η = removal efficiency (

• Ci = influent concentration (mg/L)

• Co = effluent concentration (mg/L)

The activated charcoal layer provides adsorption of dis-solved organic contaminants, detergent residues, and odour-causing compounds. The soil and lemongrass root zone sup-port microbial activity and nutrient uptake, thereby enhancing biological treatment.

An internal perforated PVC pipe arrangement was installed to ensure uniform water distribution and efficient collection of filtered water throughout the treatment chamber.

D. Storage Tank Design

The treated greywater obtained after filtration and phy-toremediation was collected in a storage chamber for reuse and laboratory analysis. The storage tank provided temporary retention of treated water before utilization.

The storage volume requirement may be estimated as

$$V_t = Q_d \times t \quad (7)$$

where

• Vt = storage tank volume (L)

• Qd = daily treated water quantity (L/day)

• t = storage duration (days)

The storage chamber was positioned downstream ofthe treatment unit to facilitate sample collection and reuse

of treated greywater for non-potable applications such as garden-ing, toilet flushing, and floor cleaning.

The complete experimental setup comprising sedimentation, filtration, phytoremediation, aeration, and storage

units is shown in Fig. 5.

Fig. 4: Internal PVC pipe arrangement used for water collection and distribution within the filtration chamber

Fig. 5: Complete greywater treatment system consisting of sedimentation, filtration, phytoremediation, aeration, and storage units.

V. EXPERIMENTAL SETUP

The experimental setup was developed to evaluate the effectiveness of a decentralized greywater treatment system for nonportable reuse applications. The treatment unit consisted of four sequential treatment stages, namely sedimentation, primary filtration, secondary filtration, and aeration. Greywater collected from domestic sources was introduced into the system and allowed to flow through each treatment stage before being collected for laboratory analysis.

The complete experimental setup is shown in Fig. 5. The treatment process was designed to achieve the removal of suspended solids, dissolved organic pollutants, nutrients, and odorcausing compounds through a combination of physical, chemical, and biological treatment mechanisms.

A. Stage 1: Sedimentation

Sedimentation was employed as the preliminary treatment stage to remove settleable solids and reduce the suspended particle load entering the filtration system. Raw greywater was introduced into the sedimentation chamber, where the flow velocity was reduced to allow heavier particles to settle under gravitational action.

This process facilitated the removal of dirt particles, grit, food residues, and other suspended matter. The reduction of suspended solids at this stage improved the performance and lifespan of the subsequent filtration units by minimizing clogging.

B. Stage 2: Primary Filtration

Following sedimentation, partially clarified greywater was passed through the primary filtration chamber. The filtration unit consisted of aggregate layers and activated charcoal media. The aggregate layers removed suspended particles through physical straining and interception mechanisms.

Activated charcoal played a significant role in adsorbing dissolved organic contaminants, detergent residues, colourcausing substances, and odorproducing compounds. The activated charcoal layer used in the treatment system is shown in Fig. 2.

The primary filtration stage significantly improved the physical appearance and quality of the greywater by reducing turbidity and organic pollutant concentrations.

C. Stage 3: Secondary Filtration

The effluent from the primary filtration chamber was directed to the secondary filtration unit incorporating a phytoremediation layer. Lemongrass (Cymbopogon citratus) plants were cultivated within a soil medium to facilitate biological treatment and nutrient uptake.

The root zone of the plants supported microbial growth and enhanced biodegradation of organic matter. In addition, the plants absorbed dissolved nutrients and contributed to the polishing of treated greywater. The phytoremediation chamber employed in the study is shown in Fig. 3.

The combined action of plant uptake, microbial activity, and soil filtration improved the overall treatment efficiency and water quality.

D. Stage 4: Aeration

The final stage of treatment consisted of aeration. Treated greywater was transferred to an aeration chamber using a submersible pump. Aeration increased the dissolved oxygen concentration of the treated water and promoted aerobic biological activity.

This stage facilitated the oxidation of residual organic matter, reduced undesirable odours, and improved the overall quality of the treated effluent. The aerated water was subsequently collected in the storage chamber and subjected to laboratory analysis to evaluate treatment performance.

The treated greywater obtained after aeration was considered suitable for nonportable applications such as toilet flushing, gardening, floor cleaning, and landscape irrigation.

VI. WORKING MECHANISM

The developed greywater treatment system operates through a sequential treatment process involving sedimentation, filtration, adsorption, phytoremediation, and aeration. The treatment mechanism combines physical, chemical, and biological processes to improve the quality of greywater for nonportable reuse applications.

Initially, greywater collected from domestic activities such as bathing, laundry, and floor cleaning enters the sedimentation chamber. In this stage, the flow velocity is reduced, allowing heavier suspended particles to settle at the bottom under gravitational action. This preliminary treatment decreases the suspended solids load entering the subsequent treatment units. After sedimentation, the partially clarified greywater flows into the primary filtration chamber. The filtration media consisting of coarse aggregates and fine aggregates remove suspended solids through physical straining and interception mechanisms. The water then passes through an activated charcoal layer, where dissolved organic compounds, detergents, colourcausing substances, and odorproducing contaminants are removed by adsorption.

The filtered water subsequently enters the phytoremediation chamber containing lemongrass (Cymbopogon citratus) plants. The plant roots absorb nutrients present in the greywater while simultaneously supporting microbial communities within the rhizosphere. These microorganisms contribute to the biodegradation of residual organic matter and enhance overall treatment efficiency. In addition, the soil layer acts as a natural biofilter and improves the polishing of treated water.

Following phytoremediation, the treated water is transferred to the aeration chamber. Aeration increases dissolved oxygen concentration, promotes aerobic microbial activity, and facilitates the oxidation of remaining organic pollutants. This stage also helps in reducing unpleasant odours and improving the aesthetic quality of the treated effluent. Finally, the treated greywater is collected in the storage chamber, where it is available for reuse in nonportable applications such as garden irrigation, toilet flushing, floor cleaning, and landscape watering. The complete treatment process provides an economical and environmentally sustainable approach for decentralized greywater management.

VII. RESULTS AND DISCUSSION

The performance of the developed greywater treatment system was evaluated through laboratory analysis of raw and treated greywater samples. The effectiveness of the treatment process was assessed by comparing important physicochemical parameters before and after treatment. The obtained results demonstrate the capability of the proposed system to improve water quality for nonportable reuse applications.

A. Water Quality Analysis

Table III presents the measured water quality parameters before and after treatment.

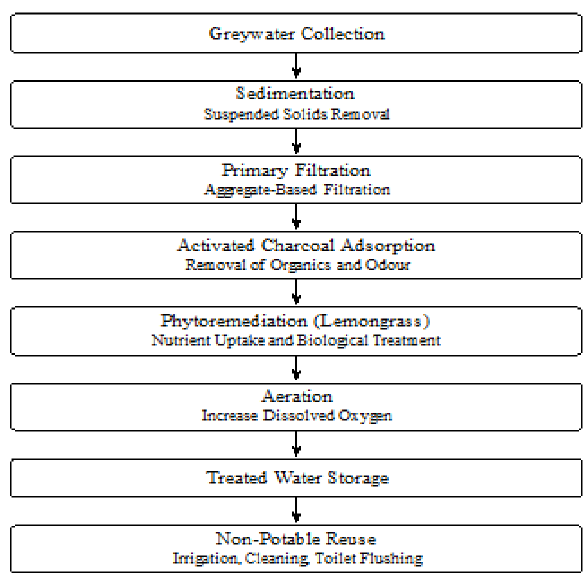

Fig. 6: Working mechanism of the developed greywater treatment system.

TABLE III: Water Quality Parameters Before and After Treatment

Parameter	Raw Water	Treated Water
pH	7.54	6.90
BOD (mg/L)	60	20
COD (mg/L)	240	65
TDS (mg/L)	588	540
Total Hardness (mg/L)	754	184
Chloride (mg/L)	95	116
Nitrate (mg/L)	124.49	221

The results presented in Table III indicate a considerable improvement in greywater quality following treatment. Significant reductions were observed in BOD, COD, TDS, and total hardness, demonstrating the effectiveness of the integrated treatment system. The observed reduction in organic and inorganic pollutants confirms the contribution of filtration, adsorption, phytoremediation, and aeration processes toward improving the suitability of greywater for nonportable reuse applications.

Figure 7 illustrates the variation in major water quality parameters before and after treatment. A substantial decrease in BOD and COD concentrations was observed, indicating effective removal of biodegradable and oxidizable organic matter. The reduction in total hardness further demonstrates the capability of the treatment media to remove dissolved mineral constituents. Overall, the graph confirms the positive impact of the developed treatment system on greywater quality.

The pH values shown in Fig. 8 remained within the acceptable range for nonportable water reuse. A slight decrease in

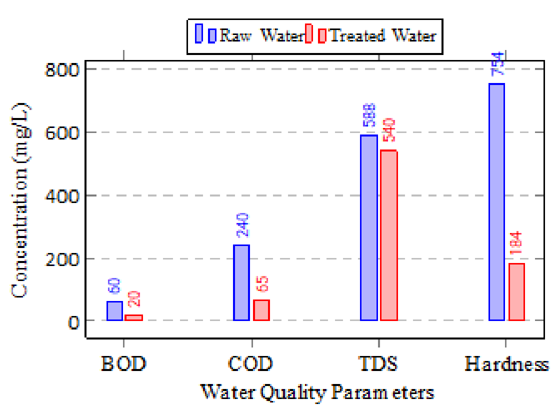

Fig. 7: Comparison of major water quality parameters before and after treatment.

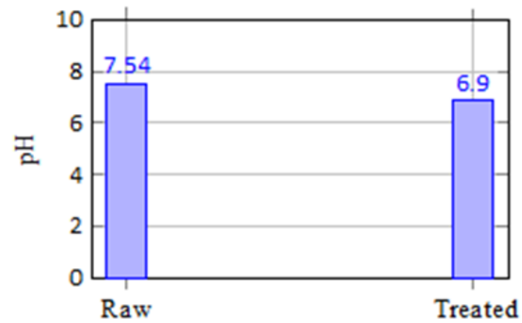

Fig. 8: Variation in pH before and after treatment.

pH was observed after treatment, which may be attributed to biological activity and adsorption processes occurring within the treatment unit. However, the treated water maintained a nearneutral pH, indicating its suitability for applications such as gardening and landscape irrigation.

B. Removal Efficiency

The removal efficiency of the developed treatment system was calculated using Eq. and is presented in Table IV.

TABLE IV: Removal Efficiency of the Developed Treatment System

Parameter	Removal Efficiency (%)
BOD	66.67
COD	72.92
TDS	8.16
Total Hardness	75.60

Table IV summarizes the pollutant removal efficiencies achieved by the developed greywater treatment system. The highest treatment efficiency was recorded for total hardness, followed by COD and BOD. These results indicate that the combination of sedimentation, filtration, activated charcoal adsorption, and phytoremediation effectively reduced the contaminant load present in greywater.

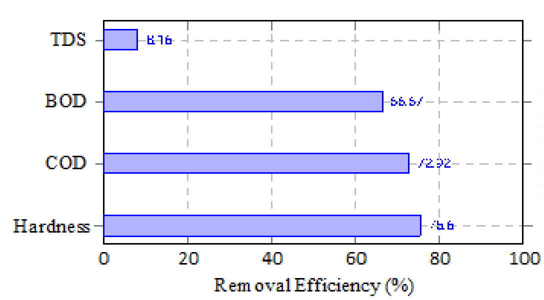

Fig. 9: Removal efficiency achieved for different water quality parameters.

Figure 9 compares the treatment efficiency achieved for different water quality parameters. The highest removal efficiency was obtained for total hardness (75.60%), while COD and BOD removal efficiencies exceeded 65%. The relatively lower reduction in TDS was expected because dissolved salts are more difficult to remove through conventional filtration systems. Nevertheless, the observed reduction demonstrates the capability of the treatment system to improve overall water quality.

C. Performance Evaluation

TABLE V: Overall Performance Summary

Performance Indicator	Value
BOD Reduction	66.67%
COD Reduction	72.92%
TDS Reduction	8.16%
Hardness Reduction	75.60%
Adsorbent Used	Activated Charcoal
Plant Used	Lemongrass
Treatment Process	Multistage
Reuse Application	Nonportable Uses

The performance indicators presented in Table V demonstrate the overall effectiveness of the developed greywater treatment system. The integration of activated charcoal and lemongrassbased phytoremediation contributed significantly to pollutant removal and water quality enhancement. The obtained treatment efficiencies indicate the suitability of the system for decentralized greywater management and reuse.

The overall results demonstrate that the developed greywater treatment system successfully improved water quality through a combination of physical, chemical, and biological treatment mechanisms. Significant reductions in BOD, COD, and total hardness confirm the effectiveness of activated charcoal adsorption and lemongrassbased phytoremediation. The treated water obtained from the system can be safely utilized for nonportable applications such as toilet flushing, landscape irrigation, floor cleaning, and gardening. Furthermore, the use of low-cost and locally available materials enhances the practical applicability of the proposed system for sustainable and decentralized water resource management.

VIII. APPLICATIONS

A. Toilet Flushing

Treated greywater can be utilized for toilet flushing in residential, commercial, and institutional buildings. Since toilet flushing accounts for a significant portion of domestic water consumption, the reuse of treated greywater can substantially reduce potable water demand and improve overall wateruse efficiency.

B. Floor and Surface Cleaning

The treated water can be employed for floor cleaning, pavement washing, and general housekeeping activities. These applications do not require potable quality water and therefore represent an effective means of utilizing treated greywater while conserving freshwater resources.

C. Vehicle Washing

The treated greywater may be used for washing vehicles in residential complexes, parking facilities, and service stations. The reduction in organic contaminants achieved through the treatment process makes the water suitable for this purpose while minimizing the consumption of freshwater.

D. Groundwater Conservation

The implementation of greywater reuse systems reduces dependence on groundwater extraction and municipal water supplies. By substituting freshwater with treated greywater for nonportable purposes, significant water savings can be achieved, contributing to sustainable groundwater management.

E. Water Conservation in Residential Buildings

The developed greywater treatment system can be integrated into residential buildings and housing societies to facilitate decentralized water reuse. Such systems help reduce freshwater consumption, lower water utility costs, and promote environmentally sustainable living practices.

F. Environmental Benefits

The reuse of treated greywater reduces the volume of wastewater discharged into drainage systems and nearby water bodies. This contributes to reduced environmental pollution, lower stress on sewage treatment infrastructure, and improved conservation of natural water resources.

G. Environmental Benefits
The reuse of treated greywater reduces the volume of wastewater discharged into drainage systems and nearby water bodies. This contributes to reduced environmental pollution, lower stress on sewage treatment infrastructure, and improved conservation of natural water resources.

TABLE VI: Potential Applications of Treated Greywater

Application	Suitability
Landscape Irrigation	High
Garden Watering	High
Toilet Flushing	High
Floor Cleaning	High
Vehicle Washing	Moderate to High
Roadside Plantation Irrigation	High
Construction Activities	Moderate
Groundwater Conservation	Indirect Benefit

The results obtained in the present study demonstrate that the developed greywater treatment system is capable of producing treated water suitable for a variety of nonportable applications. The adoption of such decentralized treatment systems can significantly contribute to water conservation, environmental protection, and sustainable urban water management.

IX. ECONOMIC ANALYSIS

The economic feasibility of the developed greywater treatment system was evaluated based on the material cost, operation and maintenance requirements, and potential water conservation benefits. The system was designed using low-cost and locally available materials, making it suitable for household and smallscale community applications.

A. Capital Cost Analysis
The initial cost of the greywater treatment system primarily consists of the treatment chambers, filtration media, piping network, and supporting accessories. Table VII presents the estimated construction cost of the developed system.

TABLE VII: Estimated Cost of the Developed Greywater Treatment System

Component	Cost (INR)
Plastic Buckets (3 Nos.)	450
PVC Pipes and Fittings	350
Activated Charcoal	300
Coarse and Fine Aggregates	250
Soil and Lemongrass Plants	150
Mosquito Mesh	100
Submersible Pump	700
Valves and Accessories	200
Miscellaneous Expenses	200
Total Cost	2700

The total fabrication cost of the treatment system was approximately INR 2700, demonstrating the affordability of the proposed design. The use of readily available materials significantly reduced the overall implementation cost.

B. Operation and Maintenance Cost
The operational cost of the system is relatively low because the treatment process relies mainly on gravity flow, filtration, adsorption, and phytoremediation. Periodic replacement of activated charcoal and routine cleaning of the filtration media constitute the primary maintenance requirements.
The estimated annual maintenance cost is approximately INR 300–500, depending on the frequency of system operation and media replacement.

C. Water Conservation Benefits
The reuse of treated greywater for nonportable purposes can substantially reduce freshwater consumption. Applications such as toilet flushing, gardening, floor cleaning, and landscape irrigation can be supplied using treated greywater instead of potable water.
Assuming a household reuses approximately 100 L/day of treated greywater, the annual water savings can be estimated as:

$$W_s = Q \times 365 \quad (8)$$

where:
- W_s = Annual water savings (L/year)
- Q = Daily reused greywater volume (L/day) For a reuse rate of 100 L/day:

$$W_s = 100 \times 365 = 36500 \text{ L/year} \quad (9)$$

Thus, approximately 36.5 m^3 of freshwater can be conserved annually.

D. Cost Effectiveness

The developed greywater treatment system offers a cost-effective solution for decentralized water reuse. The low capital investment, minimal maintenance requirements, and potential reduction in freshwater demand make the system economically attractive for residential applications.

Furthermore, the utilization of activated charcoal and lemongrass-based phytoremediation minimizes energy consumption and operational complexity. Therefore, the proposed system provides an economically viable and environmentally sustainable approach for greywater management.

E. Benefit Analysis

The economic and environmental benefits of the developed system are summarized in Table VIII.

TABLE VIII: Benefits of the Developed Greywater Treatment System

Parameter	Benefit
Initial Investment	Low
Operating Cost	Low
Maintenance Requirement	Minimal
Water Conservation	High
Environmental Impact	Positive
Suitability for Households	High
Resource Recovery Potential	Moderate

The economic analysis indicates that the proposed greywater treatment system is both affordable and sustainable, making it a practical solution for household level implementation and water conservation initiatives.

X. CONCLUSION

This study presented the design, development, and performance evaluation of a low-cost greywater treatment system for nonportable water reuse applications. The proposed system integrated sedimentation, multilayer filtration, activated charcoal adsorption, phytoremediation using lemongrass (Cymbopogon citratus), and aeration to improve greywater quality through physical, chemical, and biological treatment mechanisms.

Experimental results demonstrated significant improvements in the quality of greywater after treatment. The system achieved removal efficiencies of 66.67% for Biological Oxygen Demand (BOD), 72.92% for Chemical Oxygen Demand (COD), 75.60% for total hardness, and 8.16% for Total Dissolved Solids (TDS). The treated water exhibited acceptable physicochemical characteristics for various nonportable applications, including landscape irrigation, gardening, toilet flushing, and floor cleaning.

The integration of activated charcoal adsorption and lemongrass-based phytoremediation proved effective in reducing organic contaminants and enhancing overall treatment performance. Furthermore, the use of inexpensive and locally available materials resulted in a simple, economical, and environmentally sustainable treatment system suitable for decentralized implementation at the household level.

The economic analysis indicated that the developed system can be constructed and maintained at a relatively low cost while providing significant water conservation benefits. By reducing freshwater consumption and promoting wastewater reuse, the proposed approach contributes to sustainable water resource management and environmental protection.

Overall, the developed greywater treatment system offers a practical and efficient solution for decentralized greywater management. The findings of this study demonstrate the potential of integrating natural treatment processes with conventional filtration techniques to support water conservation and sustainable urban development.

XI. FUTURE SCOPE

Future research may focus on optimizing the filtration media configuration, evaluating longterm system performance under varying hydraulic loading conditions, and investigating the removal of microbial contaminants. The integration of advanced treatment technologies such as membrane filtration, ultraviolet disinfection, and Internet of Things (IoT)based monitoring systems can further enhance treatment efficiency and operational reliability. Additionally, largescale field implementation studies may be conducted to assess the feasibility of the proposed system for residential communities, educational institutions, and commercial establishments.

REFERENCES

[1] UNWater, The United Nations World Water Development Report 2024: Water for Prosperity and Peace, Paris, France: UNESCO, 2024.

[2] World Health Organization (WHO), Progress on Household Drinking Water, Sanitation and Hygiene 2000–2022: Special Focus on Gender, Geneva, Switzerland, 2023.

[3] S. S. Rakesh, P. T. Ramesh, R. Murugaragavan, S. Avudainayagam, and S. Karthikeyan, "Characterization and treatment of grey water: A review," International Journal of Chemical Studies, vol. 8, no. 2, pp. 1500–1506, 2020.

[4] N. A. D. Ho, C. P. Leo, A. T. Ta, and T. Q. Nguyen, "From drainage to resource: A practical approach to reuse greywater for household irrigation purposes," Water Practice and Technology, vol. 19, no. 4, pp. 1123–1138, 2024.

[5] E. Eriksson, K. Auffarth, M. Henze, and A. Ledin, "Characteristics of grey wastewater," Urban Water, vol. 4, no. 1, pp. 85–104, 2002.

[6] J. Knutsson and P. Knutsson, "Water and energy savings from greywater reuse: A modelling scheme using disaggregated consumption data," International Journal of Energy and Water Resources, vol. 5, no. 4,pp. 387–399, 2021.

[7] J. Li, J. Wen, and X. Li, "Performance evaluation of decentralized greywater treatment systems: A review," Journal of Environmental Management, vol. 328, pp. 116965, 2023.

[8] Y. Gross, N. Azulai, A. Oron, Z. Ronen, M. Arnold, and A. Nejidat, "Environmental impact and health risks associated with greywater irrigation: A review," Water Science and Technology, vol. 52, no. 8, pp. 161–169, 2005.

[9] M. Stefanakis, "Constructed wetlands for sustainable wastewater treatment and reuse: A review," Water, vol. 14, no. 5, pp. 840, 2022.

[10] A. V. Pingale, M. M. Deore, and D. G. Bagul, "Greywater reuse: A sustainable solution for water crisis," International Journal of Creative Research Thoughts (IJCRT), vol. 12, no. 4, pp. 245–252, 2024.

[11] K. Nolde, "Greywater reuse systems for toilet flushing in multistorey buildings—Over ten years' experience in Berlin," Urban Water, vol. 1, no. 4, pp. 275–284, 1999.

[12] E. Friedler, "Quality of individual domestic greywater streams and its implication for onsite treatment and reuse possibilities," Environmental Technology, vol. 25, no. 9, pp. 997–1008, 2004.

[13] F. Li, K. Wichmann, and R. Otterpohl, "Review of the technological approaches for grey water treatment and reuses," Science of the Total Environment, vol. 407, no. 11, pp. 3439–3449, 2009.

[14] M. Pidou, F. A. Memon, T. Stephenson, B. Jefferson, and P. Jeffrey, "Greywater recycling: Treatment options and applications," Proceedings of the Institution of Civil Engineers: Engineering Sustainability, vol. 160, no. 3, pp. 119–131, 2007.

[15] O. R. AlJayyousi, "Greywater reuse: Towards sustainable water management," Desalination, vol. 156, no. 1–3, pp. 181–192, 2003.

[16] A. Gross, N. Azulai, A. Oron, Z. Ronen, M. Arnold, and A. Nejidat, "Environmental impact and health risks associated with greywater irrigation: A case study," Water Science and Technology, vol. 52, no. 8, pp. 161–169, 2005.

[17] B. Jefferson, A. Palmer, P. Jeffrey, R. Stuetz, and S. Judd, "Grey water characterisation and its impact on the selection and operation of technologies for urban reuse," Water Science and Technology, vol. 50, no. 2, pp. 157–164, 2004.

[18] L. Abu Ghunmi, G. Zeeman, M. Fayyad, and J. B. van Lier, "Grey water treatment systems: A review," Critical Reviews in Environmental Science and Technology, vol. 41, no. 7, pp. 657–698, 2011.

[19] F. Masi, R. Bresciani, and H. Martinuzzi, "Constructed wetlands for combined wastewater treatment and reuse in small communities," Ecological Engineering, vol. 61, pp. 213–222, 2013.

[20] S. Wu, H. Kuschk, J. Brix, D. Vymazal, and H. Dong, "Development of constructed wetlands in performance intensifications for wastewater treatment: A review," Bioresource Technology, vol. 102, no. 2, pp. 265–273, 2011.

[21] J. Vymazal, "Constructed wetlands for wastewater treatment," Water, vol. 2, no. 3, pp.

530–549, 2010.
[22] L. H. Herna´ndez Leal, H. Temmink, G. Zeeman, and C. J. N. Buisman, "Comparison of three systems for biological greywater treatment," Water, vol. 2, no. 2, pp. 155–169, 2010.
[23] L. Dome`nech and D. Saur´ı, "Sociotechnical transitions in water scarcity contexts: Public acceptance of greywater reuse technologies in the
Metropolitan Area of Barcelona," Resources, Conservation and Recycling, vol. 55, no. 1, pp. 53–62, 2010.
[24] J. G. March, M. Gual, and F. Orozco, "Experiences on greywater reuse for toilet flushing in a hotel," Desalination, vol. 164, no. 3, pp. 241–247, 2004.
[25] D. M. Ghaitidak and K. D. Yadav, "Characteristics and treatment of greywater—A review," Environmental Science and Pollution Research, vol. 20, no. 5, pp. 2795–2809, 2013.
[26] Y. Boyjoo, V. K. Pareek, and M. Ang, "A review of greywater characteristics and treatment processes," Water Science and Technology, vol. 67, no. 7, pp. 1403–1424, 2013.
[27] S. Shaikh and M. M. Ahammed, "Greywater treatment and reuse: A critical review on decentralized treatment technologies," Journal of Water Process Engineering, vol. 52, pp. 103479, 2023.