HARNESSING AUTOMATED ANALYSIS OF TURBIDITY AND DISSOLVED OXYGEN FOR SUSTAINABLE WATER SOLUTIONS

Mukesh Chandra Kestwal[1], Dr. Jitendra Kumar Pandey[2], Dr. Surajit Mondal[3]

Article History: Received: 20.03.2023 **Revised:** 31.05.2023 **Accepted:** 11.07.2023

Abstract:

The reuse of greywater (GW) is indeed a popular and effective approach to address water scarcity and manage water availability in specific areas. When properly managed and treated, greywater can serve as a valuable resource for sectors like agriculture and horticulture. Greywater is readily recyclable at the household level with minimal design changes. After primary and secondary treatment, it can be reused for garden watering and toilet flushing. Greywater from student accommodations was collected, characterized, and treated using a series of organic materials. Parameters such as total dissolved solids (TDS), pH, turbidity, biochemical oxygen demand (BOD), chemical oxygen demand (COD), nitrate, and phosphorus were measured. The majority of the measured parameters were within acceptable ranges post-treatment.

This method allows households to effectively treat and recycle greywater for non-potable uses by using natural adsorbents. However, the success and feasibility of this method depend on certain factors, such as the specific characteristics of the greywater, the choice and effectiveness of the natural adsorbents used, and the treatment processes applied. Regular monitoring and maintenance are essential to ensure the continued efficiency and effectiveness of the greywater treatment system. Moreover, compliance with regulatory standards and guidelines is crucial when implementing such systems to ensure safety and environmental concerns.

In general, reusing treated greywater using natural adsorbents offers a workable alternative for managing water resources and easing the burden on freshwater supplies in locations where water shortage is a problem.

Keywords: Greywater, Water Treatment, Wastewater, Turbidity Sensor

[1]Ph.D. Scholar, Department of Research and Development; School of Advanced Engineering University of Petroleum and Energy Studies, Dehradun, India
[2]Professor, School of Advanced Engineering, University of Petroleum and Energy Studies, Dehradun, India
[3]Assistant Professor-Senior Scale, Electrical Cluster, School of Advanced Engineering, University of Petroleum and Energy Studies, Dehradun, India

Email: [1]mukesh.rt20@gmail.com, [2]jkpandey@ddn.upes.ac.in, [3]smondal@ddn.upes.ac.in

DOI: 10.31838/ecb/2023.12.s3.638

1. Background

Wastewater management that uses natural adsorbents to recycle greywater (GW) is both economical and ecologically good. Greywater is the term used to describe wastewater produced by domestic tasks such as bathing, laundry, and dishwashing but not toilet waste. (Cosgrove & Rijsberman, 2000; Halalsheh et al., 2008) Materials formed from nature that may adsorb or remove pollutants from water are known as natural adsorbents.

Greywater recycling can employ a number of natural adsorbents, including:

- **Activated Carbon:** Due to its great capacity for adsorbing both organic chemicals and some inorganic substances, activated carbon is a frequently utilized adsorbent. Greywater may be efficiently cleaned of a variety of impurities, including scents, colors, and even chemicals.
- **Zeolites:** Microporous minerals called zeolites have a strong affinity for heavy metals and ammonia. They are able to be used to take nitrogen ions and certain metal ions out of greywater. Zeolites can be created artificially or naturally.
- **Peat Moss:** Peat moss is an organic substance with a high ability to store water and to exchange cations. Greywater can be treated with it to get rid of organic debris, suspended particles, and certain nutrients.
- **Coconut Coir:** Made from the husk of the coconut, coconut coir is a fantastic natural adsorbent for organic compounds, suspended particles, and heavy metals. It can be utilized for greywater treatment as a filtration media or as a component of manmade wetlands.
- **Biochar:** Made from the pyrolysis of biomass, biochar is a substance that is rich in carbon. Its enormous surface area and very porous structure make it efficient in removing organic pollutants, nutrients, and some heavy metals from greywater.
- **Banana Peels:** Studies have revealed that banana peels have the ability to adsorb a variety of pollutants, such as heavy metals, chemical compounds, and colors. They can be utilized as an inexpensive adsorbent for the treatment of greywater.

Greywater recycling techniques that use natural adsorbents must take into account elements including adsorbent dose, contact duration, and regeneration techniques. (Parjane & Sane, 2011; Supply & Programme, 2015) Natural materials' adsorption capacities can change based on their properties and the specific pollutants found in the greywater.(Anderson, 1983; Seo et al., 2007) The efficiency of natural adsorbents for greywater treatment is often investigated through pilot studies and the adjustment of operating parameters.

It's important to remember that while natural adsorbents can get rid of some contaminants, they might not be able to handle all of the toxins found in greywater.(Gual et al., 2008; Kim et al., 2009) So, in addition to adsorption utilizing natural materials, a thorough greywater management system may also include numerous treatment phases including filtration, biological processes, and disinfection. (Kujawa-Roeleveld & Zeeman, 2006)

2. Literature survey

It is a viable strategy for water conservation to advise using greywater as an alternate supply of water, as suggested by (Emmerson & Emmerson, 1998). Greywater is the term used to describe the water produced by home bathroom and laundry drains, but not toilet waste. Greywater may be treated and diverted for use in safe applications like garden irrigation, which can result in a family saving between 30 and 50 percent on water usage. Reusing greywater has positive effects on the environment in addition to water conservation. The need for freshwater resources can be decreased by using greywater for non-potable uses like irrigation. This ease concerns about water shortage and lessens the burden on water resources.

Greywater reuse systems must be installed carefully to reduce any potential dangers to the environment and public health. Pathogens, chemicals, and other pollutants can all be found in greywater as well as other contaminants. Therefore, to guarantee that the greywater is safe for its intended reuse, adequate treatment and management are crucial. Depending on the unique qualities and quality of the greywater, the proper treatment procedures, such as filtration, disinfection, and/or biological treatment, should be used to reduce any possible dangers. In order to safeguard the general public's health and prevent any negative environmental effects, it is also crucial to abide by the rules and laws governing the reuse of greywater. Additionally, for the greywater reuse system to remain efficient and safe, correct greywater system design and installation, frequent maintenance, and monitoring are essential.

By examining samples from five business locations in Massachusetts, the research (Veneman & Stewart, 2002) sought to evaluate the diversity and features of greywater. The effect of loading rates and soil depth on treatment effectiveness was especially looked at by the researchers. According to the study's findings, the impact of various loading rates—the amount of greywater that is injected into the soil—was not statistically significant. This suggests that raising the loading rates did not seem to have a negative impact on how well greywater was treated. The study did, however, show that a major influence on treatment effectiveness was caused by a reduction in soil depth. The thickness or depth of the soil layer where greywater is applied and treated is referred to as soil depth. The results imply that the effectiveness of greywater treatment may suffer as the soil depth falls. This research emphasizes how crucial it is to take soil depth and features into account when planning and putting in place greywater treatment systems. A sufficient depth of soil enables optimal biological, filtration, and absorption processes, all of which are necessary for the efficient treatment and removal of pollutants from greywater. It's important to note that the study was limited to commercial settings in Massachusetts, and that the results might differ in other areas owing to differences in the soil types, climate, and other elements. Therefore, while developing greywater treatment systems, it is crucial to take into account regional factors and carry out site-specific assessments. Overall, the research indicates that while increasing loading rates may not have a negative influence on treatment effectiveness, reducing soil depth may. These results highlight the need of correct soil depth and design considerations when putting in place greywater treatment systems to guarantee the best possible treatment results.

In order to effectively manage water and wastewater, (Rajarama & Sheaffer, 2010) recommended an integrated strategy, highlighting the significance of recycling every last drop of wastewater in India's rural and urban regions. The goal was to protect drinking water supplies from pollution and save limited water supplies to fulfill the demands of the whole population. The study's result emphasizes how crucial it is for India to recycle and utilize its wastewater. Without effective management, wastewater can pollute sources of drinking water, posing a risk to human health. Water contamination hazards can be reduced by recycling and treating wastewater, so maintaining the supply of clean drinking water. Wastewater recycling also contributes to the conservation of limited water supplies. Due to issues including population expansion, urbanization, and climate change, India experiences water shortage concerns similar to those experienced by many other regions. Reusing wastewater can help ease the load on scarce freshwater resources and ensure that there is always enough water for varied uses. The creation of suitable treatment technologies, infrastructure, and regulations to support wastewater recycling are essential components of an integrated strategy to water and wastewater management. Suitable storage and distribution systems for recycle water as well as cutting-edge treatment techniques like membrane filtration and disinfection may be included. The acceptance and understanding of wastewater recycling as a secure and workable option must also be promoted, and this calls for public awareness and education campaigns. The viability and sustainability of projects for wastewater recycling may be greatly influenced by community involvement and engagement. In order to avoid drinking water supplies from being contaminated and to preserve India's water resources, the study's overall findings underline the significance of wastewater recycling and reuse. The nation can deal with the problems caused by a lack of water by implementing an integrated strategy to water and wastewater management. This will also help to ensure that the entire population uses water sustainably.

The study by (Kundu et al., 2015) concentrated on the creation of a greywater treatment system to allow its reuse in a variety of applications, including gardening, toilet flushing, and street cleaning. The study's suggested treatment method improved the quality of greywater through the use of natural processes and a number of treatment stages. An equalization cum sedimentation tank and a filter bed made of marbles and sand aggregates made up the treatment system. The equalization cum sedimentation tank is made to enable the separation of suspended particles from the greywater by allowing sediment and solids to settle. The main treatment phase is the filter bed, which is made of marbles and sand aggregates.

The filtering procedure aids in removing pollutants and finer suspended particles from the greywater. Filtration results in a rise in the concentration of variables such dissolved oxygen (DO), which signifies an improvement in water quality. According to the study, filtration significantly contributes to increasing the use of greywater by removing different impurities and raising several water quality indicators. The filtered greywater is made appropriate for uses including gardening, toilet flushing, and street cleaning by eliminating particle matter and contaminants. It's crucial to remember that a number of variables, including the starting quality of the greywater, the design and operation of the treatment system, and the precise specifications of the planned reuse applications, may affect the treatment system's performance. Overall, the study proposes a greywater treatment system that makes advantage of natural processes including equalization, concomitant sedimentation, and filtration to enhance the quality of the water for reuse. The results imply that filtering can increase the utility of greywater by raising water quality indicators, making it appropriate for particular non-potable uses.

Membrane filtration has been a popular water treatment method in recent years, notably for the desalination of saltwater and the purification of wastewater. Based on the dimensions of their pores, membrane filters may be divided into four categories: microfiltration, ultrafiltration, nanofiltration, and reverse osmosis membranes, with pore diameters range from 0.1 nm to 1 nm. Polymeric ultrafiltration (UF) membranes have drawn a lot of interest as an efficient way to filter out macromolecules, viruses, proteins, chemical compounds, and suspended particles from water.(Ali et al., 2022) Because they can function at low pressures, polymeric UF membranes have the benefit of requiring less energy to operate. They are excellent for a variety of applications due to this quality. However, with UF membrane systems, membrane fouling continues to be a significant problem. Membrane fouling is the buildup of materials on the membrane's surface or inside its pores, which impairs the membrane's ability to conduct fluids.(Abdulkarem et al., 2021) Fouling results in higher energy expenditures, more frequent cleaning needs, shorter membrane lifespans, and higher membrane replacement expenses. Reversible and irreversible fouling of membranes can be distinguished. Reversible fouling happens when foulants build up on the membrane's surface and can be cleaned away. On the other hand, irreversible fouling is the buildup of foulants inside the membrane pores, making them challenging to clear out. Biofouling, inorganic fouling, and organic fouling are a few kinds of fouling. While inorganic fouling originates from the formation of colloidal and particulate debris, biofouling is caused by the deposition of biological components on the membrane surface.(Gu et al., 2020) Natural organic materials including humic acid (HA) and proteins can clog membrane surfaces through a process known as organic fouling. For UF membrane systems to continue operating effectively, membrane fouling must be addressed. To reduce the effects of fouling and increase membrane longevity, a variety of techniques are used, including pre-treatment procedures, routine cleaning, and the use of antifouling coatings.(Abdullah et al., 2022) Overall, membrane fouling continues to be a problem even though polymeric UF membranes provide considerable benefits in water treatment applications. The performance and lifetime of UF membrane systems are being improved by ongoing research and development efforts to create novel fouling management solutions.

A lot of attention has been paid in the past 20 years to enhancing the antifouling capabilities of polymeric ultrafiltration (UF) membranes. The addition of nanofillers to the liquid polymer solution before creating the membrane is one method that has drawn interest.(Liu et al., 2022) It has been discovered that these nanofillers increase water flow and the antifouling capabilities of the membranes. Nanofillers can alter the membranes' surface charge and physicochemical properties in addition to their antifouling properties, making them appropriate for certain applications like pollution removal. For instance, the zeta potential of polysulfone UF membranes decreased when the metal-organic framework UiO-66 was added.(Lu et al., 2022) Compared to the bare membrane, this hybrid membrane showed enhanced removal of humic acid and heavy metals. Abdallah et al.'s integration of tungsten oxide with polyether sulfone (PES) UF membranes for the improved removal of Congo red dye was shown in another investigation. When tungsten oxide was added to the PES membrane, dye removal was better than with a bare PES membrane.(Chen et al., 2021) These illustrations show how adding nanofillers to polymeric UF membranes might improve their functionality and applicability for particular applications. The use of nanofillers enhances the membranes' antifouling abilities while also giving the option to modify their physicochemical qualities to specifically target particular pollutants or contaminants.(Almanassra et al., 2022) In order to enhance the performance, longevity, and selectivity of polymeric UF membranes for a variety of water treatment applications, ongoing study in this field seeks to examine and optimize the usage of nanofillers in these membranes.

2.1. Greywater treatment existing technologies:

Based on the literature survey, existing technologies for greywater treatment can be classified into several categories(Karpiscak et al., 1994):

2.1.1. Physical Treatment:

- Sedimentation: Allowing suspended solids to settle at the bottom of a tank.
- Filtration: Passing greywater through various filters, such as sand filters or membrane filters, to remove solids and impurities.

2.1.2. Biological Treatment:

- Constructed Wetlands: Using plants and natural processes to filter and treat greywater in specially designed wetland systems.

- Bioreactors: Employing microorganisms to break down organic matter and remove contaminants in a controlled environment.

2.1.3. Chemical Treatment:

- Chlorination: Adding chlorine to disinfect greywater and kill harmful microorganisms.
- Ozonation: Treating greywater with ozone to disinfect and remove odors.
- Coagulation and Flocculation: Adding chemicals to promote the clumping of particles, facilitating their removal.

2.1.4. Advanced Treatment:

- Membrane Filtration: Utilizing membranes with different pore sizes, such as microfiltration, ultrafiltration, nanofiltration, and reverse osmosis, to remove particles, microorganisms, and dissolved contaminants.
- Activated Carbon Adsorption: Using activated carbon to adsorb organic compounds and improve water quality.
- Advanced Oxidation Processes: Applying techniques like UV irradiation, hydrogen peroxide, or advanced oxidation agents to degrade organic pollutants and disinfect the water.

2.1.5. Greywater Recycling and Reuse Systems:

- Greywater Recycling Systems: Treating greywater for reuse in non-potable applications like toilet flushing, irrigation, and washing machines.
- Greywater Diversion Systems: Diverting greywater to be used directly for irrigation without extensive treatment.

Some of the salient features and key findings from various studies related to greywater treatment and recycling. Here is a summary of the details:

Grey Water Dam Design for Single and Multiple households (Gravity Based System):

- Designed for 5 households within a shared homestead.
- Greywater is collected by the residents and discharged into a common tank.
- Awareness programs for health, hygiene, and sanitation are conducted.
- Accepts up to 2000 L/D of greywater for treatment via pipes.
- Air is introduced for aerobic breakdown of organic matter.
- Control measures are implemented to avoid overflow.
- Vertical-based pipe systems showed higher efficiency.
- Hydraulic equations are used to determine seepage paths.

GW Recycling: Treatment options and application:

- Potential for 40% water savings and cost reductions in 200 dwellings.
- Decentralized greywater systems are suitable for high-density areas.
- More than 90% removal of BOD5, COD, TSS, and ammonia.
- Effluent meets WHO GW management requirements for BOD5 (<10mg/L).
- Treated water is discharged as surface water to stormwater drains.

Constructed Wetland Treatment:

- Utilizes physical, chemical, and biological processes for contaminant removal.
- Removes contaminants such as BOD, suspended solids, heavy metals, and toxic substances.
- The treatment rate depends on factors like surface loading rate and electron acceptor availability.

Hybrid Treatment Process:

- Lab-based treatment plant with a capacity of 180 L/hr.
- Four-stage treatment process involving primary settling, aeration, agitation, and filtration.
- Natural adsorbents used in filtration remove 83% of organic load and adsorb anions and cations.
- Traces of potassium, magnesium, and calcium are removed.

Filtration Characteristics for Domestic Wastewater Reclamation:

- Organic removal percentages: TOC & BOD (95%), TN (50%), TP (85%).
- Monitoring of Indoor Plants for GW Reuse:
- Monitoring parameters include turbidity (18%), pH, SS (28%), TOC (20%), TN, and COD (25%).

Lab-Based GW Treatment System:

- Filtration efficiency percentages: Turbidity (99%), pH, color (98%), COD (99%), SS (99%).

Performance of GW Treatment:

- Removal percentages: Hardness (60%), COD (91%), TDS (81%), TSS (90%), oil and grease (98%), nitrates (75%), nitrites (100%), cations (49%), and anions (46%).

These findings demonstrate various approaches and technologies for greywater treatment and emphasize the effectiveness of different treatment processes in removing contaminants and improving water quality for potential reuse purposes.(Gleick, 2003) It is important to note that the selection of a specific technology depends on factors such as the quality and quantity of greywater, the intended reuse application, cost-effectiveness, available space, and local regulations.(Kannan & Donnellan, 2021) Combining multiple treatment processes in a treatment train is often necessary to achieve the desired level of treatment and ensure water safety.(Pidou et al., 2007; Tiruneh, 2014)

2.2. Greywater generation formulation:

To estimate the generation of greywater, we need to consider the water usage per person or per household. Without that information, it is challenging to provide an accurate estimation.

Greywater is typically generated from sources such as bathroom sinks, showers, bathtubs, and laundry activities. The amount of greywater generated can vary based on factors such as the number of people, their water usage habits, and the efficiency of water fixtures.

To formulate the greywater generation as samples we were collected greywater from various place; mainly accommodation of students with the population of 974 Person. Approximate water being used per day:

- Tentative water generation: $(135) \times 974 = 131.49$ Kilo Litre Per Day, and

approximate generation of greywater was as follows:

- Sewage Generation: $\frac{974 \times 135 \times 0.8}{10^3} = 105.192$ Kilo Liter Per Day, and
- Grey Water Generation: 80% of Sewage $= 84.1536$ KLPD.

Based on the provided data in Table 1, the characteristics of greywater from four different sources can be summarized as follows:

Table 1: The characteristics of greywater from four different sources

Parameter	Source #1	Source #2	Source #3	Source #4	Range
TDS (mg/l)	1723	1462	1925	1735	1462-1925
pH	8.53	7.2	9.5	8.5	7.2-9.5
Turbidity (NTU)	40.66	34.25	45.05	40.26	34.25-45.05
Nitrate (mg/l)	9	7.47	10.7	8.81	7.47-10.7
Phosphorus (mg/l)	0.9	0.74	1.04	0.87	0.74-1.04
BOD (mg/l)	180	150	305	333	150-333
COD (mg/l)	580	537	773	896	537-896

From the data, it can be observed that greywater from these sources generally has lower levels of contamination compared to industrial wastewater. The total dissolved solids (TDS) levels range from 1462 to 1925 mg/l, which indicates a relatively low mineral content. The pH values range from 7.2 to 9.5, indicating a slightly alkaline to alkaline nature. Turbidity levels range from 34.25 to 45.05 NTU, which represents the clarity or cloudiness of the water.

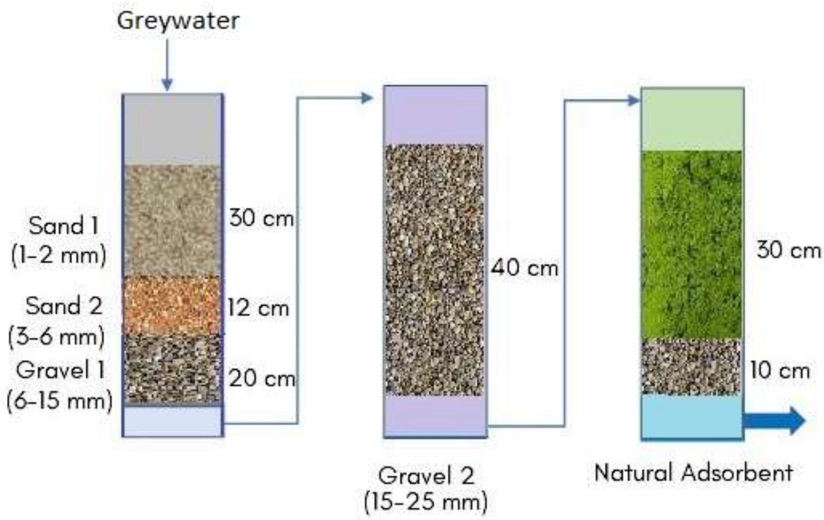

Figure 1: System Flow Diagram for Sand Filtration using Natural Adsorbents

The concentrations of nitrate and phosphorus, which are nutrients, are within the ranges of 7.47-10.7 mg/l and 0.74-1.04 mg/l, respectively. BOD (biochemical oxygen demand) levels range from 150 to 333 mg/l, indicating the amount of organic matter present, and COD (chemical oxygen demand) levels range from 537 to 896 mg/l, reflecting the overall organic and inorganic pollutants in the water.

It is important to note that while greywater may be less contaminated compared to industrial wastewater, proper collection and separation are crucial to avoid mixing with other wastewater sources. Adequate treatment measures should still be implemented to ensure the safe and appropriate reuse or discharge of greywater.

3. Material And Methods

The experimental setup for greywater treatment in the laboratory consisted of several stages of treatment. Figure 1 illustrates the setup, which includes two sand columns and two gravel columns of different sizes. The purpose of the setup is to simulate the treatment process and evaluate the effectiveness of each stage.

The treatment process involves sedimentation and aeration in the second stage to reduce contamination present in the water. Tertiary treatment is carried out using a natural adsorbent derived from Azadirachta Indica (AI), commonly known as neem. The seeds and leaves of AI are ground into a powder with a particle size of less than 300 µm, which acts as an activated carbon and a potential coagulant.

Water samples collected from various community buildings, hostels, and houses are treated through this experimental setup. The first stage of treatment involves the use of sand to remove coliform bacteria, suspended particles, and visible contaminants from the greywater. The presence of large gravel columns helps in balancing the levels of biochemical oxygen demand (BOD), chemical oxygen demand (COD), and total dissolved solids (TDS) in the water.

The system's sand and gravel filter is a tank filled with granular layers of graded sand and gravel. Table 2 provides information on the gravel and sand utilized in the setup.

Table 2: Type of gravel and sand used for the setup

Details	Size	Depth
Gravel-2	15-25 mm	40 cm
Gravel-1	6-15 mm	20 cm
Sand-2	3-6 mm	12 cm
Sand-1	1-2 mm	30 cm

While the sand layers serve as the filter medium, the gravel layers support and enable correct flow distribution. Three distinct types of sand membranes with particle sizes of 6 mm, 3 mm, and 1 mm are employed as sand filters in the experimental investigation.
Overall, this experimental design enables the evaluation of various phases of treatment as well as the efficiency of sand and gravel filtration in eliminating impurities from greywater.

4. Results And Discussion

The current study aims to assess the efficiency of a natural adsorbent medium made from locally accessible materials, including sand, in removing organic matter, turbidity, BOD, and COD from greywater (GW) and regulating pH. In order to evaluate the removal efficiencies at various phases of treatment, the system's functionality was tested, and the findings were examined.
Gravel, sand, and fine sand made up the three layers that made up the filter medium. In the initial step, filter medium made of gravel and sand were used, and turbidity, BOD, and COD levels all significantly decreased. The results indicated a 36.42% reduction in BOD from 291 mg/L to 185 mg/L, a 16.01% reduction in COD from 662 mg/L to 556 mg/L, and a 68.57% reduction in turbidity from 35 NTU to 8 NTU.
Aeration and the usage of natural adsorbents were used in the second stage of the therapy. The efficacy of removal was increased by combining various therapeutic methods. The BOD, COD, and turbidity levels were all reduced by 81.08%, 70.86%, and 27.27%, respectively, according to the findings. These gains were made possible by the usage of the gravel layer in combination with aeration and natural adsorbent.
Greywater's inorganic and physical component was found to be especially well-captured by the sand filter medium because of its lower pore size. The sand filter functions as a biological system, including a number of activities including removal inside the sand bed, bacterial adsorption on the biofilm adhered to sand grains, bacterial metabolism, and synthesis of attached bacteria.
Overall, the results showed that during the second stage, which included aeration and the introduction of natural adsorbent AI, the system's performance improved in terms of BOD and COD removal. BOD, COD, and turbidity all experienced increases in system efficiency of 87.97%, 75.52%, and 77.14%, respectively.
Untreated GW, treated water characteristics after the first and second rounds of treatment, and the overall effectiveness of the system in terms of % removal are all summarized in Table 3 together with the status of the primary parameters at various phases of treatment.

Table 3: Result and Analysis of GW treatment through the Natural adsorbent

Major Parameters	**Untreated GW**	**Treated water Characteristics post-unit process**	**Overall Performance of the System (% Removal of major parameters)**

BOD (mg/L)	291	185 (36.42%)	35 (81.08%)
COD (mg/L)	662	556 (16.01%)	162 (70.86%)
pH	8.2	7.9	7.7
Turbidity (NTU)	35	11 (68.57%)	8 (27.27%)
Nitrate - N (mg/L)	17	10.37 (39%)	6.22(40.01%)

5. Conclusion

The benefits of greywater recycling are significant and can contribute to sustainable water management. By recycling and reusing greywater, several advantages can be realized:

- **Reduced freshwater use:** Greywater recycling reduces the demand for freshwater, as it allows for the reuse of water that would otherwise be discharged as wastewater. In locations where there is a water shortage or a drought, this preservation of freshwater supplies is extremely crucial.
- **Decreased strain on freshwater sources:** By recycling greywater, freshwater resources are subjected to less overall strain. By guaranteeing their sustainable usage for other purposes, this can assist relieve strain on rivers, lakes, and groundwater supplies.
- **Reducing waste:** Greywater recycling encourages "closing the loop" by treating and reusing wastewater on-site. Because less wastewater is released into sewage systems or treatment facilities, less infrastructure is required for wastewater treatment.
- **Reusing water for non-potable uses:** Greywater, when properly treated, may be used for a variety of non-potable uses, including toilet flushing, gardening, irrigation, and plant development. As a result, less water is needed for these activities, which normally account for a sizable amount of water use in household and communal contexts.
- **Cost savings:** By lowering the amount of freshwater purchased or processed, greywater recycling can result in cost savings. By lowering the volume and pollutant load of wastewater released into the municipal sewage system, it can also aid in lowering wastewater treatment costs.

The results of the current study and previous research, combined with the body of existing literature, point to the possibility of using sand filters and natural adsorbents in place of traditional treatment facilities to handle household and municipal greywater. By efficiently removing organic matter, turbidity, BOD, and COD, these systems provide treated greywater that may be used in a variety of non-potable applications. Communities and individuals can benefit from the reuse of treated greywater for useful purposes while also helping to manage water resources sustainably, conserve freshwater resources, and ease the burden on wastewater treatment infrastructure by putting in place greywater recycling systems.

Acknowledgment

We (The authors) like to express our heartfelt gratitude to the organizations (Department of Science and Technology; UPES Dehradun and other partners) for their invaluable support and contributions to this research work and for sponsoring the project ‘Greywater treatment technology’. The support has been instrumental in the success of this project and has allowed us to explore innovative approaches and implement advanced techniques in the field of greywater recycling, using technology solutions for bringing technology, R&D, and filing of patents for the research.

6. References

1. Abdulkarem, E., Ibrahim, Y., Kumar, M., Arafat, H. A., Naddeo, V., Banat, F., & Hasan, S. W. (2021). Polyvinylidene fluoride (PVDF)-α-zirconium phosphate (α-ZrP) nanoparticles based mixed matrix membranes for removal of heavy metal ions. Chemosphere, 267, 128896.
2. Abdullah, R. R., Shabeed, K. M., Alzubaydi, A. B., & Alsalhy, Q. F. (2022). Novel photocatalytic polyether sulphone ultrafiltration (UF) membrane reinforced with oxygen-deficient Tungsten Oxide (WO2. 89) for Congo red dye removal. Chemical Engineering Research and Design, 177, 526–540.
3. Ali, J., Alhseinat, E., Abi Jaoude, M., Al Nashef, I. M., Adeyemi, I. A., Aminabhavi, T. M., & Arafat, H. A. (2022). A mixed matrix polyimide ultrafiltration membrane for efficient removal of bentazon from water. Chemical Engineering Journal, 433, 134596.
4. Almanassra, I. W., Al-Ansari, T., Ihsanullah, I., Kochkodan, V., Chatla, A., Atieh, M. A., Shanableh, A., & Laoui, T. (2022). Carbide-derived carbon as an extraordinary material for the removal of chromium from an aqueous solution. Chemosphere, 307, 135953.
5. Anderson, T. L. (1983). Water crisis: Ending the policy drought.
6. Chen, L., Wang, Y., Chen, Z., & Cai, Z. (2021). The fouling layer development on MD membrane for water treatments: An especial focus on the biofouling progress. Chemosphere, 264, 128458.
7. Cosgrove, W. J., & Rijsberman, F. R. (2000). World water vision: making water everybody's business. Earthscan.
8. Emmerson, G., & Emmerson, G. (1998). Every drop is precious: Greywater as an alternative water source. Queensland Parliamentary Library Publications and Resources Section.
9. Gleick, P. H. (2003). Global freshwater resources: soft-path solutions for the 21st century. Science, 302(5650), 1524–1528.
10. Gu, Q., Ng, T. C. A., Zain, I., Liu, X., Zhang, L., Zhang, Z., Lyu, Z., He, Z., Ng, H. Y., & Wang, J. (2020). Chemical-grafting of graphene oxide quantum dots (GOQDs) onto ceramic microfiltration membranes for enhanced water permeability and anti-organic fouling potential. Applied Surface Science, 502, 144128.
11. Gual, M., Moià, A., & March, J. G. (2008). Monitoring of an indoor pilot plant for osmosis rejection and greywater reuse to flush toilets in a hotel. Desalination, 219(1–3), 81–88.
12. Halalsheh, M., Dalahmeh, S., Sayed, M., Suleiman, W., Shareef, M., Mansour, M., & Safi, M. (2008). Grey water characteristics and treatment options for rural areas in Jordan. Bioresource Technology, 99(14), 6635–6641.
13. Kannan, N., & Donnellan, P. (2021). Algae-assisted microbial fuel cells: A practical overview. Bioresource Technology Reports, 15, 100747.
14. Karpiscak, M. M., Brittain, R. G., & Foster, K. E. (1994). DESERT HOUSE: A DEMONSTRATION/EXPERIMENT IN EFFICIENT DOMESTIC WATER AND ENERGY USE 1. JAWRA Journal of the American Water Resources Association, 30(2), 329–334.
15. Kim, J., Song, I., Oh, H., Jong, J., Park, J., & Choung, Y. (2009). A laboratory-scale graywater treatment system based on a membrane filtration and oxidation process—characteristics of graywater from a residential complex. Desalination, 238(1–3), 347–357.

16. Kujawa-Roeleveld, K., & Zeeman, G. (2006). Anaerobic treatment in decentralised and source-separation-based sanitation concepts. Reviews in Environmental Science and Bio/Technology, 5, 115–139.
17. Kundu, S., Khedikar, I. P., & Sudame, A. M. (2015). Laboratory Scale Study for Reuse of Greywater. J Mech Civil Eng, 12(3), 40–47.
18. Liu, W., Liu, B., & Li, X. (2022). UV/Fe (II) synergistically activated S (IV) per-treatment on HA-enhanced Ca2+ scaling in NF filtration: Fouling mitigation, mechanisms and correlation analysis of membrane resistance in different filtration stage. Chemosphere, 308, 136302.
19. Lu, Q., Zhang, X., Wong, N. H., Sunarso, J., & Li, N. (2022). Anti-biofouling polyvinylidene fluoride/quaternized polyvinyl alcohol ultrafiltration membrane selectively separates aromatic contaminants from wastewater by host–guest interactions. Separation and Purification Technology, 296, 121387.
20. Parjane, S. B., & Sane, M. G. (2011). Performance of grey water treatment plant by economical way for Indian rural development. International Journal of ChemTech Research, 3(4), 1808–1815.
21. Pidou, M., Memon, F. A., Stephenson, T., Jefferson, B., & Jeffrey, P. (2007). Greywater recycling: treatment options and applications. Proceedings of the Institution of Civil Engineers-Engineering Sustainability, 160(3), 119–131.
22. Rajarama, V., & Sheaffer, J. R. (2010). Integrated water management for rural/urban India. Website-Www. Content. Asce. Org/Final Program.
23. Seo, G. T., Moon, B. H., Park, Y. M., & Kim, S. H. (2007). Filtration characteristics of immersed coarse pore filters in an activated sludge system for domestic wastewater reclamation. Water Science and Technology, 55(1–2), 51–58.
24. Supply, W. J. W., & Programme, S. M. (2015). Progress on sanitation and drinking water: 2015 update and MDG assessment. World Health Organization.
25. Tiruneh, A. T. (2014). A grey water dam design for the treatment and reuse of grey water from single and multiple households. Journal of Water Resource and Protection, 6(14), 1259.
26. Veneman, P. L. M., & Stewart, B. J. (2002). Greywater characterization and treatment efficiency. UMass Amherst, Department of Plant and Soil Sciences.