JEE Journal of Ecological Engineering

Journal of Ecological Engineering 2023, 24(12), 258–267
https://doi.org/10.12911/22998993/173414
ISSN 2299–8993, License CC-BY 4.0

Received: 2023.09.20
Accepted: 2023.10.21
Published: 2023.11.04

Assessing a Low-Cost Multi-Media Filter with Biological Contact Aeration for Greywater Treatment in Domestic Applications

Abdelkader T. Ahmed[1] , Md. Shafiquzzaman[2*], Amimul Ahsan[3,4]

[1] Civil Engineering Department, Faculty of Engineering, Islamic University of Madinah, Saudi Arabia
[2] Department of Civil Engineering, College of Engineering, Qassim University, Buraydah, 51452, Saudi Arabia
[3] Department of Civil and Environmental Engineering, Islamic University of Technology (IUT), Gazipur, Bangladesh
[4] Department of Civil and Construction Engineering, Swinburne University of Technology, Melbourne, Australia
* Corresponding author's e-mail: shafiq@qec.edu.sa

ABSTRACT

Treatment and reuse of greywater for non-potable applications especially in scarce countries is a feasible option. In this study, a simple greywater treatment system consisting of a low-cost simple multi-media filter with biological contact aeration system was developed and installed in a selected household in Muscat, the capital of Oman. Monitoring and measurements were made to investigate the productivity and efficiency of this system in treating the greywater from laundry and shower sources. The greywater from the collected laundry and shower contained 360 mg/L of COD and 28.5 mg/L of BOD. The experimental results showed that the greywater treatment unit achieved more than 99% of turbidity removal, more than 74% of BOD removal, and more than 50% of COD removal. BOD removal was primarily achieved through bacterial degradation whereas COD removal was attributed to the adsorption of organic compounds by activated carbon. The effluent quality of the treated greywater fell within the standard level and can be safely reused for various non-potable applications.

Keywords: greywater, treatment, pollutant removal, recycling, contact aeration, multimedia-filter.

INTRODUCTION

Most Middle Eastern countries have experienced rapid economic development and population growth, which have put immense pressure on their limited water resources. The primary sources of water in the Middle East are seawater and groundwater. The reliance on these water sources does indeed present a significant challenge due to their limited availability and the potential for overexploitation. Muscat, the capital city of Oman is facing water scarcity due to the shortage of rainfall and other surface water sources. Moreover, sustainable solutions are essential to ensure that the region can meet the water needs of its growing population and expanding economies while preserving its environment. The ideal solution to overcome this issue is to discover alternative water resources such as grey water for non-potable water applications to save freshwater (Alfiya et al. 2013). Chanakya et al. (2013) reported that the reuse of treated greywater is one instant option to solve the current and future water shortage. Greywater is one component of domestic wastewater excluding human feces and contains two-thirds of the produced wastewater.

The idea of using greywater for non-potable applications is indeed a practical and sustainable solution to alleviate water scarcity issues, particularly in regions like the Middle East where freshwater resources are limited (Alfiya et al. 2013; Chanakya et al., 2013). Greywater, which is wastewater generated from household activities excluding human feces, can be a valuable resource for various purposes, including toilet flushing, landscape irrigation, and industrial processes. The greywater can be treated and reused specifically for toilet flushing purposes. Toilet flushing is one of the largest domestic water uses, and it usually involves using potable (drinking) water. By substituting treated greywater for toilet flushing, there is potential to save a significant amount of potable water. A significant amount of fresh water can be conserved by reusing the treated greywater for gardening and other outdoor household applications (Friedler and Lahav, 2006; Bani-Melhem et al. 2015). Reusing greywater to protect freshwater resources and reducing sewage production are highly relevant and emphasize the multifaceted benefits of greywater recycling (Santos et al., 2012). However, adequate and safe treatment of greywater is critically important to ensure its quality for non-potable applications. Moreover, advanced treatment can potentially enable the broader use of greywater for various applications beyond drinking water (Gibson and Apostolidis, 2001). By addressing these considerations, greywater reuse systems can be implemented safely and accurately, reducing the strain on potable water supplies while safeguarding public health and the environment.

The source of greywater includes wastewater from laundries, handwashing, kitchen water, and shower water (Abdel-Kader 2013; Boddu et al. 2016). Greywater generated from kitchens typically contains organic materials, oils, and fats, which can be more challenging to treat compared to greywater from sources like showers and laundry (Paulo, 2013). Greywater contributes around 60-70% of total domestic wastewater (Abdel-Kader 2013). Although greywater is less polluted compared to black water, there would be health risks if used without treatment. The different greywater systems are said to be effective and efficient if only satisfy the following conditions such as good effluent quality, ease of operation, simplicity in maintenance, and affordable cost. The study done by Nolde et al., (1999) concluded that the treatment system shall fulfill the four criteria, hygienic safety, environmental tolerance, and technical as well as economic feasibility. The study conducted by Nolde et al. (1999) highlights four important criteria that a greywater treatment system should fulfill to ensure sustainable and safe reuse. These criteria including hygienic safety, environmental tolerance, technical feasibility, and economic feasibility provide a comprehensive framework for evaluating and designing effective greywater reuse systems. Therefore, the households-based greywater treatment system would be feasible and more economical. The feasibility and economic viability of household-based greywater treatment systems depend on various factors, including the specific technology chosen, local water quality, treatment requirements, and available financial resources.

Public opinion and acceptance play a pivotal role in the successful implementation of water reuse applications. The negative response or reluctance of the public can create significant challenges for the planning, construction, and operation of wastewater reclamation and reuse facilities. Understanding and addressing public concerns and perceptions is crucial for achieving acceptance and trust in water reuse programs. Several studies have been conducted in various regions; providing valuable insights into the dynamics of public opinion on water reuse (Friedler and Lahav, 2006; Domènech and Saurí, 2010; Troy, 2006; Kantanoleon et al., 2007). A high percentage of public acceptance toward the feasibility of reusing treated greywater for non-potable applications is promising and highlights the potential for implementing greywater systems more widely. The role of government and media in raising social awareness and promoting acceptance is indeed critical. Recently, a comprehensive survey was conducted to assess public acceptance and perception of greywater treatment and reuse systems in household areas in Muscat, Oman (Shafiquzzaman et al., 2018). Survey results revealed that a significant percentage (91.82%) of households in Muscat are willing to reuse greywater, primarily for plant watering (22.05%) and agriculture (17.70%) (Shafiquzzaman et al., 2018).

To date, several greywater treatment methods have been studied and proposed including physical, chemical, and biological processes (Metcalf et al., 2007; Li et al., 2009; Prajapati et al., 2019; Ding et al. 2017). Filtration and or Reverse osmosis process are included in the physical process (Zipf et al., 2016; Prajapati et al., 2019), coagulation and flocculation, electrocoagulation, and photocatalysis included the chemical process (Li et al., 2009) Biological treatment technologies are biological aerated filters, rotating biological contactors, and constructed wetlands (Metcalf et al., 2007; Li et al., 2009; Prajapati et al., 2019; Ding et al. 2017). Although these technologies have many advantages and disadvantages, single use of many of these technologies failed to treat the greywater effectively to remove pollutants below the reuse standard and criteria. An integrated approach, combining two or more of these processes, is often necessary to effectively treat greywater. Moreover, this integrated approach can provide better results by addressing a wider range of contaminants and optimizing treatment efficiency. The specific combination of treatment processes would depend on factors such as the composition of the greywater, the desired water quality standards, available resources, and budget constraints. It's crucial to conduct a thorough feasibility study and consult with experts in water treatment to determine the most suitable and cost-effective integrated approach for greywater treatment needs. Additionally, public awareness and support for greywater reuse should be encouraged to ensure the success of such initiatives and promote sustainable water management practices in the region.

To improve the treatment efficiency, the activated sludge process combined with contact aeration was investigated for the treatment of domestic sewage in a recent study (Chen et al., 2020). The study suggests that the integration of these two processes may complicate the operation due to the presence of two biological tanks. Thus, as an alternative, replacing of activated sludge process with a simple multimedia filter would make the process simple and ease the operation. This study aimed to assess a low-cost treatment process for laundry and shower greywater. The system is composed of a biological contact aeration tank followed by a multi-media filter. The main goal of this study was to treat the natural greywater from the local household and assess the effluent quality for recycling purposes. Accordingly, the treatment unit was run continuously and greywater samples were collected before and after treatment and investigated treatment efficiency.

METHODOLOGY

Greywater collection

This research involved a thorough investigation into the physical and chemical quality of greywater to propose a cost-effective treatment system. Greywater samples were collected from three different sources: laundry, hand wash, and shower water. These samples were collected from four selected households within the areas covered in the questionnaire survey. Some of the householders willingly volunteered to participate in this research. Volunteers were provided with detailed instructions on how to collect greywater samples from various wastewater sources, excluding kitchen sink and toilet flushing wastewater, which were not recommended for reuse due to quality criteria. A form was provided for volunteers to fill out, which included details such as the location of the house, the volunteer's name and contact information, and the source of the wastewater sample. Volunteers were informed to store the collected samples in a cool box at a temperature below 4°C to ensure that the samples remained in a suitable condition for transportation. After collection, the greywater samples were transported to the laboratory for testing.

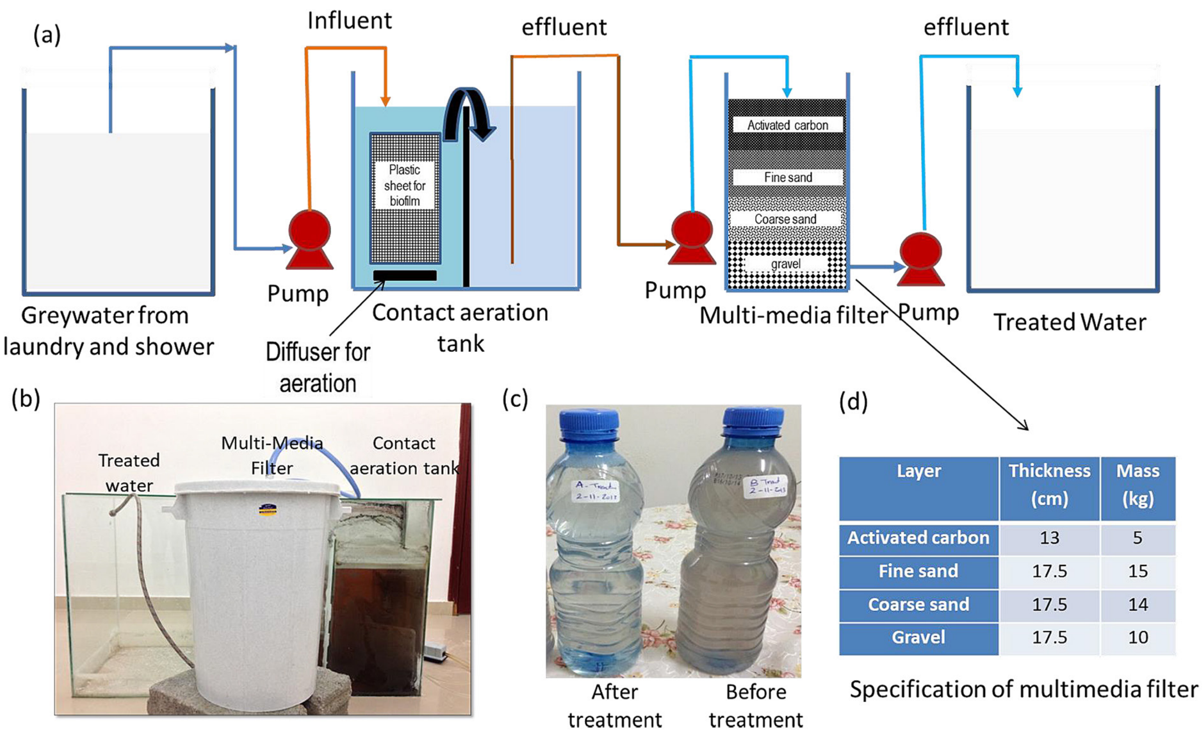
Experimental setup

The study aimed to address both the acceptance of using treated greywater systems among Omani households and the development of a cost-effective, homemade greywater treatment system. This system is intended to treat greywater originating from laundry, hand washing, and showering. This is because, greywater from laundry, hand washing, and showering typically contain fewer contaminants compared to kitchen greywater, which may contain food particles, oils, and grease. This makes the treatment and reuse of this type of greywater more straightforward and requires fewer treatment steps. The studied greywater treatment system consisted of contact aeration followed by a multimedia filtration process. Contact aeration involves exposing the water to air, which can promote the breakdown of organic matter by attached bacteria and enhance water quality. The filtration process consisted of different media layers including activated carbon, sand, and gravel to further remove the other contaminants. Figure 1 shows the schematic of the greywater treatment unit operated in this study. The treatment unit was set up in a selected house in Muscat city. Greywater samples from various sources, including the laundry, handwashing basin, and shower, are initially collected in an influent storage tank. The greywater is then pumped into a dual-chamber tank made of plexiglass which has a total capacity of 175 L. The first was used as an aeration tank (100 L in size) and the second chamber was for the steeling tank (75 L in size) as shown in Fig. 1 (a) and 1(b). To support the bacterial attachment, growth, and biofilm development, a plastic sheet of 40×40 cm size was installed in the aeration tank. Continuous aeration was implemented using a diffuser located at the bottom of the aeration tank to ensure a sufficient supply of oxygen for the bacterial activities occurring in the biological contact aeration tank.After the biological degradation of organic matter and other contaminants in the aeration tank, the treated water is directed to the settling tank to settle the suspended solids (SS). The water from the settling tank was then pumped to the multimedia filter made of a 180 L plastic bucket and consisted of layers of 13 cm activated carbon, 17.5 cm fine sand, 17.5 cm coarse sand, and 17.5 cm gravel. Finally, the treated water from the multimedia filter is pumped into the effluent tank. Table 1 shows the operational conditions of the treatment unit, the flow rate of the system at different treatment stages were maintained at 1.25 L/min using three Iwaki controller pumps (MODEL-EHNC-BR, IWAKI, KOREA) as shown in Fig. 1a. At this flow rate, 1800 L of water can be treated per day. The hydraulic residence time of the aeration tank was estimated at 80 min whereas the residence time was calculated at 144 min for the multimedia filter. For the first 22 days, the greywater unit was run with only the aeration tank and after that, the multimedia filter was added to the system and run for another 7 days. The influent and final effluent (Fig. 1c) were sampled regularly and analyzed for different water quality to investigate the treatment performance of the system. The water quality parameters included pH, dissolved oxygen (DO), Total dissolved solids (TDS), turbidity, electrical conductivity (EC), biological oxygen demand (BOD), chemical oxygen demand (COD), and total organic carbon (TOC). All water quality analysis was performed using Standard Methods for the Examination of Water and Wastewater (APHA 2012).

RESULTS AND DISCUSSION

Greywater quality

The results obtained from the physicochemical characterization of greywater collected from the laundry and shower sources are presented in Table 2. The average pH value measured as 7.91 which is slightly alkaline. This is because of the alkalinity of the greywater from laundry and bathing that contains detergent and/or soap. As shown in Table 3, the average DO value of greywater was 8.81 mg/L. An average turbidity of 37.5 NTU suggests that the greywater samples have relatively low levels of colloidal particles and suspended solids. The total solids (TS) concentrations in the collected greywater samples were measured as 1486 mg/L which was attributed to the use of detergents and soaps in laundry and shower water.



Layer	Thickness (cm)	Mass (kg)
Activated carbon	13	5
Fine sand	17.5	15
Coarse sand	17.5	14
Gravel	17.5	10

Fig. 1. (a) Schematic of the greywater treatment unit, (b) photograph of the greywater treatment unit, (c) a greywater sample before and after treatment, and (d) specification of multimedia filter

The average conductivity of the greywater samples was measured as 4111 μS/cm indicating the high salinity of the greywater samples from laundry and shower sources. High conductivity in the greywater samples is associated with an elevated concentration of dissolved salts and minerals, which come from detergents, soaps, and minerals in laundry and shower sources.

The BOD value for the collected greywater is relatively low at 28.5 mg/L. This indicates that there is a lower concentration of biodegradable organic substances that consume oxygen in the water. The COD value is 360 mg/L, which is significantly higher than the BOD value. The TOC value is 143 mg/L, which is also higher than the BOD value. The higher COD suggests the presence of a substantial amount of non-biodegradable organic compounds in the greywater from laundry and shower sources. Greywater from laundry and shower sources typically contains non-biodegradable organic compounds, which do not readily break down in natural processes. As a result, the COD and TOC values are higher than the BOD value in this type of greywater.

Table 1. Operational conditions of the greywater treatment unit

Operation conditions	Values
Volume of aeration side tank (L)	100 L
Volume of settlement side tank (L)	75 L
Volume of storage tank (L)	180 L
Flow rate	1.25 L/min
HRT biological side tank	80 min
HRT settlement side tank	144 min

Table 2. Average quality of collected greywater samples

Parameters	Concentrations
pH	8.2 ± 0.6
DO (mg/L)	8.8± 0.06
Turbidity (NTU)	57.4 ± 6.1
TDS (mg/L)	722 ± 374
EC (μS/cm)	4282 ± 655
BOD (mg/L)	28.8 ± 7.4
COD (mg/L)	472 ± 19
TOC (mg/L)	141.2 ± 6.5

Removal performance

The greywater treatment unit was continuously run for 25 d and the removal efficiency of different water qualities was monitored by analyzing the influent and effluent samples. A total of 5 samples were collected at regular intervals and laboratory testing of water quality was carried out. The results of the removal performances are presented in Figures 2–5. The treatment unit described in this study employs a two-step process to treat greywater. The steps involved a biological process where organic pollutants are degraded by microorganisms in the attached biofilm within the contact aeration tank followed by additional treatment through adsorption and filtration in a multimedia filter. The pH of the influent (untreated greywater) averaged 8.22, and after treatment, it decreased to 7.4. This indicates a slight reduction in pH in the treated (effluent) water (Fig. 2a). The change in pH may be attributed to the biological processes within the treatment unit. DO concentrations in the greywater remained consistent at 8.8–9.0 mg/L (Fig. 2b). This stability in DO levels in the influent and effluent is likely due to the continuous aeration provided in the aeration tank of the treatment unit. Adequate DO is important to support the biological processes responsible for organic matter degradation. The treatment unit demonstrated high efficiency in removing turbidity from the greywater. Turbidity decreased from 57.4 NTU in the influent to 1.4 NTU in the effluent (Fig 2c). This substantial reduction indicates the effective removal of colloidal particles, which were either biologically degraded or completely adsorbed by the multimedia filter. The treatment process significantly reduced TDS in the greywater (Fig. 2d). Despite variations in influent TDS ranging from 400-1090 mg/L, the removal rate was consistently around 50% for each sample. This suggests that the treatment unit is effective at reducing the concentration of dissolved solids in the water. It is worth noting that the TDS data for sample 3 was excluded due to an error during laboratory analysis.

The removal of conductivity and TOC are presented in Figure 3a. It was noticeably observed that conductivity significantly increased during the treatment process. The average conductivity in the influent was 4288 μS/cm, and it rose to 5230 μS/cm in the effluent. The increase in conductivity is attributed to the release of minerals from the media used in the multimedia filter. The filter contains materials such as activated carbon, sand, and gravel. The interaction of the

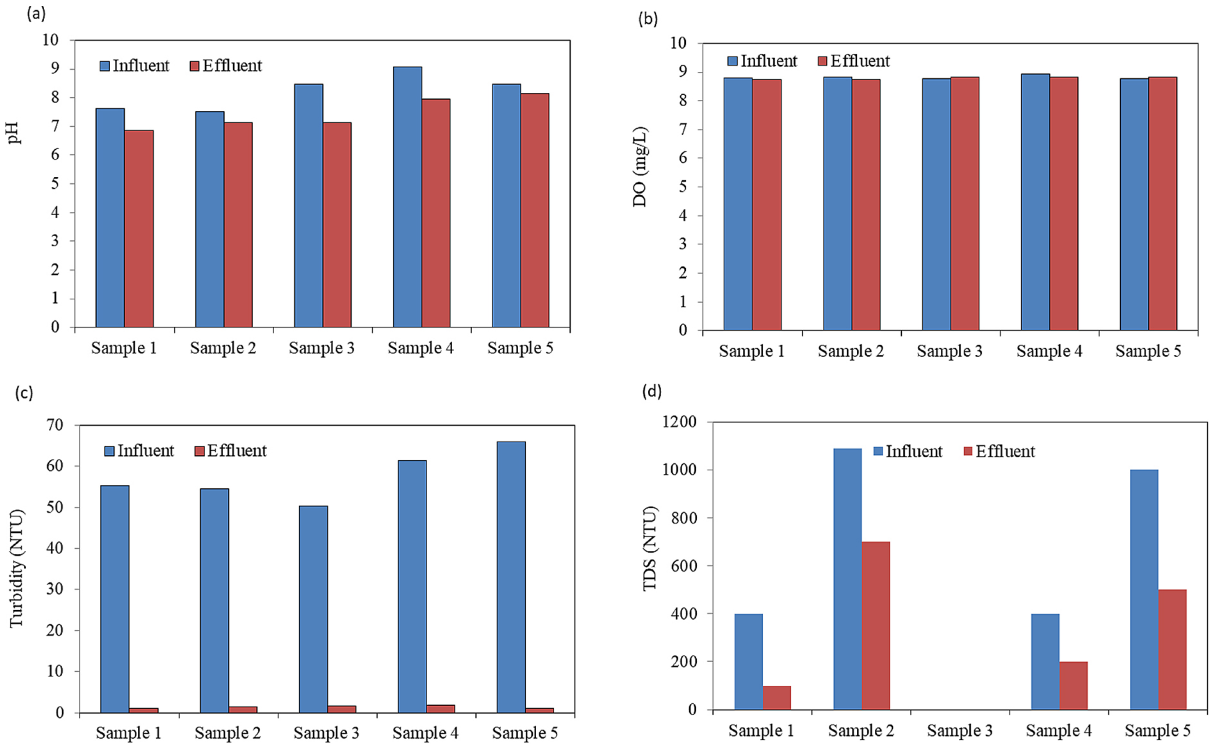


Fig. 2. Influent and effluent concentrations (a) pH, (b) DO, (c) turbidity, and (c) TDS of 5 samples collected during the greywater treatment experiments. TDS data of Sample 3 was excluded due to the error during analysis

greywater with these materials could lead to the release of minerals into the treated water. Significant reduction in TOC levels was observed during treatment as shown in Fig. 3b. The influent had around 141.2 mg/L of TOC, which decreased to 65.5 mg/L in the effluent. This reduction indicates effective biodegradation and adsorption of organic pollutants in the treatment system.

BOD and COD are the critical parameters to assess the greywater treatment performance of any process. The removal of BOD and COD was monitored and the results are presented in Figure 4. BOD was removed from 28.85 mg/L to 7.5 mg/L whereas the COD removal was found to be from 472 mg/L to 203 mg/L. The experimental data showed that BOD removal was more efficient than COD removal. This suggests that the treatment system was particularly effective at degrading the biodegradable organic matter present in the greywater. BOD removal is attributed to the activity of attached bacteria in the aeration tank. These bacteria, particularly certain heterotrophic bacteria species like Pseudomonas, Flavobacterium, Archromobacter, and Alcaligenes spp, play a crucial role in breaking down biodegradable organic substances (Mozaheb et al., 2010). This results in the reduction

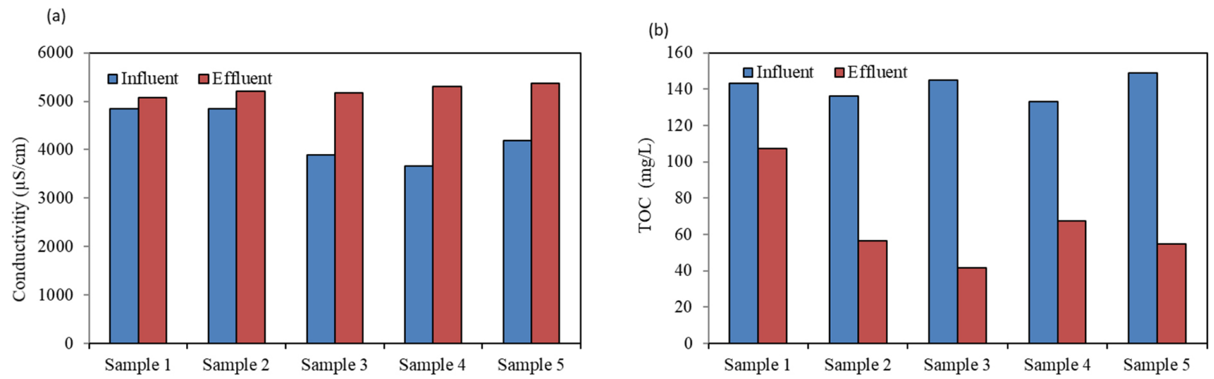


Fig. 3. Influent and effluent concentrations (a) conductivity, and (b) TOC of 5 samples collected during the greywater treatment experiments

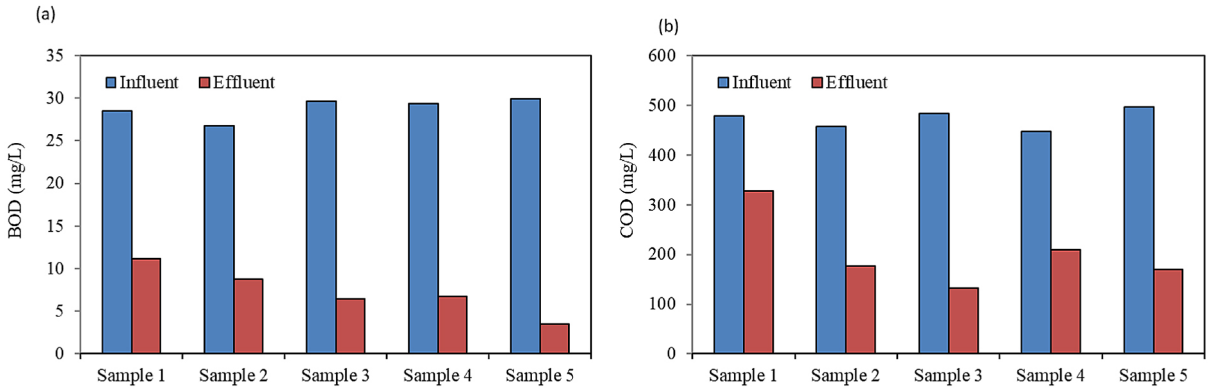


Fig. 4. Influent and effluent concentrations (a) pH, (b) DO, (c) turbidity, and (c) TDs of 5 samples collected during the greywater treatment experiments

of BOD in the wastewater. In contrast, refractory organic compounds that are less susceptible to biological degradation may have remained non-degradable. Part of these refractory organics might have been adsorbed by the activated carbon layers within the multimedia filter. It was also observed that the BOD and COD removal efficiency was consistent and did not decline over time indicating the well-maintained biological activities within the system. The overall removal % of turbidity, TDS, BOD, TOC, and COD is calculated and the results are presented in Fig. 5. The turbidity removal was found to be more pronounced as 99% removal was calculated. TDS removal was achieved around 50%. BOD removal was 75 % whereas COD and TOC removal were calculated as 53% and 56%, respectively. The high overall removal percentages for these key water quality parameters suggest that the proposed greywater treatment system is effective and efficient. It can be considered a viable alternative for household-level greywater treatment and has the potential to be used for greywater recycling in arid and semi-arid regions.

Assessing the treatment process and reuse potential of effluents

The reuse potential of treated greywater of the proposed method was assessed by comparing the water quality parameters of the effluents with Oman's national standards and the World Health Organization (WHO) permissible standard (Table 4). According to Table 4, the average effluent pH value of 7.44 falls within the recommended range of 6-9 for reusing treated greywater, as specified by all standards. This indicates that the treated water is suitable for various non-potable uses without significant deviations in acidity or alkalinity. The average effluent BOD value of 7.63 mg/L is lower than the recommended value of 20 mg/L set by the Oman standard and the 10 mg/L standard set by the World Health Organization (WHO). The COD value in the effluent was 200 mg/L which complies with the COD standard for greywater reuse in Oman. The effluent's turbidity (1.4 NTU) and TDS (375 mg/L) levels are well below the Oman standard limits.

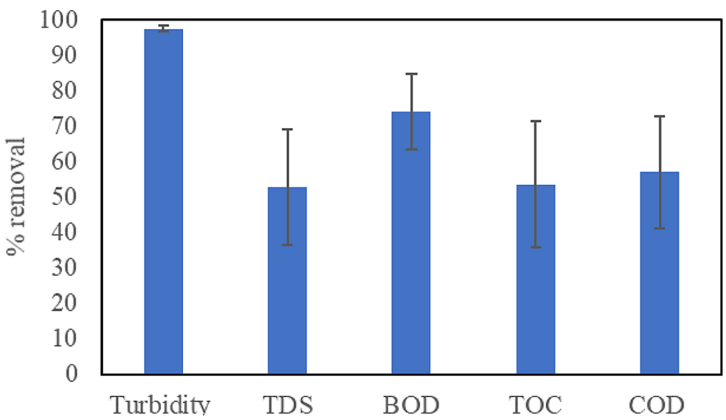


Fig. 5. % removal of turbidity, TDS, BOD, TOC, and COD by the tested greywater treatment process

It is also worth mentioning that the current study did not assess the microbiological quality of the effluents. Therefore it is essential to conduct microbiological analyses to determine the presence of pathogens and bacteria. In this context, it is recommended to include a disinfection tank in the process for unrestricted irrigation or non-potable use. Moreover, monitoring additional parameters such as residual chlorine, nitrogen (N), and phosphorus (P) in the treated effluent is crucial and is recommended for ensuring the safe use of reclaimed water.

The overall study results suggested that the proposed low-cost and simple greywater treatment method is economically and environmentally sustainable. Furthermore, the removal efficiency of the system was compared with the existing greywater treatment systems and presented in Table 4. The COD, BOD, and turbidity removal are comparable with the existing greywater treatment methods. The system is easy to maintain due to the prolonged operations without adding any chemicals.

The maintenance includes frequent cleaning of the support media in the contact aeration tank and replacement or regeneration of the activated carbon layer. The adsorption of COD by activated carbon was not directly conducted in the current study. Instead, the replacement or regeneration period of the activated carbon layer was calculated based on a previous study (Mohammad-Pajooh et al., 2018), which suggested a replacement or regeneration frequency of every 3 months. The system also consumes low energy due to the requirements for only the feed pump and aeration pump eventually needs low operating cost. The system also does not require highly skilled operators as the only malignance requirement is to clean the support media and replace or regenerate the activated carbon layer. This simplicity in operation enhances the system's practicality for household-level implementation. Finally, the system, in its operation, does not generate any by-products or sludge. This is because of the chemical-free operation, and the removal process relies on the attached growth biofilm and activated carbon adsorption process.

In summary, the comparison of the treated greywater's quality with national and international standards, including those of Oman and WHO, demonstrates that the proposed greywater treatment method meets the recommended criteria for reuse. This suggests that the system is well-suited for greywater recycling not only in Oman but also in other arid and semi-arid regions, as indicated by its compliance with WHO standards. The system's economic and environmental sustainability, ease of maintenance, and low operating costs further support its practicality and potential for widespread adoption.

Table 3. Effluent average values of water quality and comparison with national and international standards

Parameters	Effluent Concentrations	Oman Reuse Standard [a]	WHO reuse Standard [b]
pH	7.44	6–9	6–9
BOD_5(mg/L)	7.63	20	10
COD (mg/L)	203	200	-
Turbidity (NTU)	1.4	2	-
TDS (mg/L)	375	2000	-

Note: [a]Jamrah et al., 2008; [b]WHO, 2006

Table 4. Comparison of treatment efficiencies of some selected greywater treatment systems with this study

Treatment methods	Turbidity removal (%)	BOD removal (%)	COD removal (%)	References
Filtration	-	89–98	37–94	Oteng-Peprah et al., 2018
Constructed wetland	-	99	81–82	Oteng-Peprah et al., 2018
Sequencing batch reactor	-	90–98	90–98	Oteng-Peprah et al., 2018
Rotating biological contactors		27–53	21–61	Oteng-Peprah et al., 2018
Membrane bioreactor	98-99	93–97	86–99	Oteng-Peprah et al., 2018; Hasan et al., 2015
Activated sludge/contact aeration	-	98	61–81	Chen et al., 2020
Multi-media filter/contact aeration	97	74	56	This study

CONCLUSION

This study focuses on the development of a low-cost greywater treatment system consisting multi-media filter with a biological contact aeration system. The developed treatment system is effective in treating greywater from laundry and shower sources. The high removal efficiencies of turbidity, BOD, and COD indicate that the system can significantly improve the water quality of greywater. The following conclusions were made from this study. The system achieved more than 99% of turbidity removal more than 74% of BOD removal and more than 50 % of COD removal. BOD removal was achieved by bacterial degradation while COD removal was due to the adsorption of organic compounds by activated carbon. By achieving high levels of removal of organic pollutants and turbidity, the treated greywater can be safely reused for various non-potable applications, contributing to water conservation and sustainability efforts in the region. The system is easy to maintain and does not require the addition of chemicals. This reduces operational costs and simplifies system maintenance, making it more accessible for local households. For assessing the feasibility of the system, a long-term pilot operation is recommended, and it is proposed to include the disinfection process in future studies.

Acknowledgment

The authors gratefully acknowledge Ms. Suhaila Al-Subhi from Caledonian College of Engineering, Oman, for her assistance in collecting water samples and conducting experiments.

REFERENCES

1. Abdel-Kader, A.M. 2013. Studying the efficiency of grey water treatment by using rotating biological contactors system. Journal of King Saud University-Engineering Sciences, 25(2), 89–95.
2. American Public Health Association (APHA) 2012. Standard Methods for the Examination of Water and Wastewater, 20th edn. American Water Works Association and Water Environmental Federation, Washington, DC.
3. Alfiya, Y., Gross, A., Sklarz, M., Friedler, E. 2013. Reliability of on-site greywater treatment systems in Mediterranean and arid environments – a case study. Water Science and Technology, 67(6), 1389–1395.
4. Bani-Melhem, K., Al-Qodah, Z., Al-Shannag, M., Qasaimeh, A., Qtaishat, M. R., Alkasrawi, M. 2015. On the performance of real grey water treatment using a submerged membrane bioreactor system. Journal of Membrane Science, 476, 40–49.
5. Boddu, V.M., Paul, T., Page, M.A., Byl, C., Ward, L., Ruan, J. 2016. Gray water recycle: effect of pretreatment technologies on low pressure reverse osmosis treatment. Journal of Environmental Chemical Engineering, 4(4), 4435–4443.
6. Chen, C.-K., Liang, H.-C., Lo, S.-L. 2020. Feasibility Study of Activated Sludge/Contact Aeration Combined System Treating Oil-Containing Domestic Sewage. Int. J. Environ. Res. Public Health, 17, 544.
7. Chanakya, H.N., Khuntia, H.K. 2013. Treatment of Gray Water Using Anaerobic Biofilms Created on Synthetic and Natural Fibers. Process Safety and Environmental Protection, 91(1–2), 1–158.
8. Ding, A., Liang, H., Li, G., Szivak, I., Traber, J., Pronk, W. 2017. A low energy gravity-driven membrane bioreactor system for grey water treatment: permeability and removal performance of organics. Journal of Membrane Science, 542, 408–417.
9. Domènech, L., Saurí, D. 2010. Socio-technical transitions in water scarcity contexts: public acceptance of greywater reuse technologies in the Metropolitan Area of Barcelona. Retour Conser Recy, 55(1), 53–9.
10. Friedler, E., Lahav, O. 2006. Centralised urban wastewater reuse: what is the public attitude. Water Science. Technology, 54(6–7),423–7.
11. Gibson, H.E., Apostolidis, N. 2001. Demonstration, the solution to successful community acceptance of water recycling. Water Science. Technology, 43(10), 259–266.
12. Hasan, M.M., Shafiquzzaman, M. Nakajima, J., Ahmed, A.T., Azam, M.S. 2015. Application of a Low Cost Ceramic Filter to a Membrane Bioreactor for Greywater Treatment, Water Environment Research, 87(3), 233-241.
13. Jamrah, A., Al-Futaisi, A., Prathapar, S., Al –Harrasi, A. 2008. Evaluating greywater reuse potential for sustainable water resources management in Oman. Environ. Monit. Assess. 137, 315–327.
14. Kantanoleon, N., Zampetakis, L., Manios, T. 2007. Public perspective towards wastewater reuse in a medium size, seaside, Mediterranean city: a pilot survey. Resour Conser Recy, 50(3),282–310.
15. Li, F., Wichmann, K., Otterpohl, R. 2009. Review of the technological approaches for grey water treatment and reuses. Sci. Total Environ., 407, 3439–3449.
16. Metcalf Eddy, I., Asano, T., Burton, F.L., Leverenz, H., Tsuchihashi, R., Tchobanoglous, G. 2007. Water Reuse. McGraw-Hill Professional Publishing, New York.
17. Mohammad-Pajooh, E., Turcios, A.E., Cuff, G., Weichgrebe, D., Rosenwinkel, K.-H., Vedenyapina,

M., Sharifullina, L. 2018. Removal of inert COD and trace metals from stabilized landfill leachate by granular activated carbon (GAC) adsorption. . J. Environ. Manag. 228, 189–196

18. Mozaheb, S.A., Ghaneian, M.T., Ghanizadeh, G. H., Fallahzadeh, M., 2010. Evaluation of the stabilization ponds performance for municipal wastewater treatment in Yazd-Iran. Middle-East J. Sci. Res. 6, 76–82.
19. Nolde, E. 1999. Greywater Reuse Systems for Toilet Flushing in Multi-story Buildings-over Ten Years Experiences in Berlin. Urban Water, 1 (4), 275–284.
20. Oteng-Peprah, M., Acheampong, M.A., deVries, N.K. 2018. Greywater Characteristics, Treatment Systems, Reuse Strategies and User Perception—a Review. Water Air Soil Pollut 229, 255 (2018).
21. Paulo, P.L., Azevedo, C., Begosso, L., Adriana, F., Galbiati, A.F., Boncz, M.A. 2013. Natural systems treating greywater and blackwater on-site: Integrating treatment, reuse and landscaping. Ecol. Eng., 50, 95 –10.
22. Prajapati, B., Jensen, M., Jørgensen, N., Petersen, N. 2019. Grey water treatment in stacked multi-layer reactors with passive aeration and particle trapping. Water Research, 161, 181–190.
23. Santos, C., Taveira-Pinto, F., Cheng, C.Y., Leite D. 2012. Development of an Experimental System for Greywater Reuse, Desalination, 285, 301–305.
24. Shafiquzzaman, M., Haider, H., AlSaleem, S.S., Ghumman, A.R., Sadiq, R. 2018. Development of Consumer Perception Index for assessing greywater reuse potential in arid environments. Water SA, 44(4), 771–781.
25. Troy, W.H. 2006. Public perception and participation in water reuse. Desalination, 187(1–3), 115–26.
26. World Health Organization (WHO). 2006. Guidelines for the Safe Use of Wastewater, Excreta and Greywater, Volume 4: Excreta and Greywater Use in Agriculture. WHO, Geneva 2006.
27. Zipf, M.S., Pinheiro, I.G., Conegero, M.G. 2016. Simplified greywater treatment systems: slow filters of sand and slate waste followed by granular activated carbon, J. Environ. Manage., 176, 119–127.