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The Utilization of Biofilter Technology for Domestic Wastewater Treatment in Support of Aquatic Conservation

Seffiani Dwi Azmi
Universitas Jambi, Indonesia
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Abstract
Domestic wastewater is one of the major contributors to water pollution in urban and rural areas, particularly when discharged without proper treatment. This study aims to evaluate the effectiveness of a simple biofilter system using natural materials gravel, zeolite, and activated carbon in reducing pollutants from household greywater. A vertical-flow biofilter reactor was constructed and tested over a 30-day period, using a pretest-posttest experimental design. Water quality parameters such as Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Suspended Solids (TSS), and pH were measured before and after filtration. The results showed significant reductions in pollutant concentrations: BOD decreased by 73–77%, COD by 62–65%, and TSS by 85–90%, while pH remained stable in the neutral range. Statistical analysis confirmed that these reductions were significant ($p < 0.05$). The biofilter also improved the visual clarity and odor of the water, making it suitable for non-potable reuse. Given its low cost, ease of construction, and reliance on locally available materials, this biofilter system is highly suitable for decentralized wastewater treatment, especially in areas without centralized infrastructure. The system also supports aquatic conservation efforts by reducing pollutant loads discharged into natural water bodies.
Keywords: *biofilter, domestic wastewater, water treatment, aquatic conservation, greywater reuse.*

Corresponding author :
Email Address : sefianidwiazmi@gmail.com
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Introduction

Water pollution has become an increasingly critical environmental issue, particularly in developing countries where rapid urbanization and population growth are not matched by adequate environmental infrastructure. Among the primary sources of water pollution is domestic wastewater, which includes greywater and blackwater from households such as wastewater from kitchens, bathrooms, laundry, and toilets. These wastewaters often contain organic matter, nutrients (especially nitrogen and phosphorus), detergents, oils, pathogens, and microplastics. When discharged directly into rivers, lakes, or other water bodies without treatment, these pollutants significantly deteriorate water quality. The impacts are visible in the form of algal blooms, fish kills, and the collapse of aquatic biodiversity. Furthermore, the polluted water often flows into drinking water sources, leading to increased health risks such as waterborne diseases and long-term ecological damage.

Despite the pressing nature of this problem, wastewater management infrastructure in many residential areas remains inadequate. In Indonesia, for example, only a small portion of

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urban populations is served by centralized wastewater treatment facilities, with the majority relying on septic tanks or discharging directly into open drains. In rural or peri-urban areas, the situation is worse, where informal settlements or dense neighborhoods often lack proper sanitation facilities altogether. Many households still discharge their wastewater into ditches, rivers, or yards, compounding the pollution problem. The lack of access to affordable, decentralized wastewater treatment systems leads to a build-up of organic waste and chemical contaminants in nearby water bodies. This situation underscores the urgent need for low-cost, easily applicable solutions that can be implemented at the household or community level to reduce environmental degradation and public health hazards.

Given the limitations of conventional infrastructure, there is a growing demand for alternative technologies that are affordable, environmentally friendly, and suitable for small-scale implementation. An ideal solution should be easy to maintain, require minimal technical knowledge, and be capable of significantly reducing pollution loads. Biofilter technology offers a promising approach to domestic wastewater treatment. It utilizes naturally occurring microorganisms to break down pollutants in wastewater as it passes through filtration media. Unlike complex mechanical systems, biofilters operate using passive biological processes and do not require electricity or expensive maintenance. This makes them particularly well-suited for decentralized applications in resource-limited settings. Additionally, biofilters do not produce harmful by-products and can be constructed using locally available materials, further reducing their environmental footprint.

Biofilters function by allowing wastewater to percolate through layers of porous media such as zeolite, activated carbon, gravel, or sand upon which microbial communities grow. These microorganisms metabolize organic pollutants, converting them into simpler, non-toxic compounds such as carbon dioxide and water. The filter media also serve as a physical barrier to remove suspended solids and adsorb harmful chemicals. Some media, like activated carbon, can even capture heavy metals and persistent organic pollutants. Biofilters are effective in removing key wastewater indicators such as Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Suspended Solids (TSS), and improving pH balance. Their modular design allows them to be scaled up or down depending on need, and their low maintenance requirements make them practical for widespread adoption in both urban and rural environments.

Numerous studies have demonstrated the efficiency of biofilter systems in treating domestic wastewater. Reported reductions in BOD range between 70% to 85%, COD by 60% to 80%, and TSS by more than 90%, depending on the configuration and media used. For instance, a study conducted by Pratiwi et al. (2021) in Bandung found that a combination of zeolite and coconut shell charcoal as biofilter media successfully reduced BOD levels from 120 mg/L to 28 mg/L within 24 hours. Additional research shows that biofilters can withstand fluctuating pollutant loads, making them suitable for the variable discharge typical of household wastewater. The simplicity of the system also enables it to be operated by users with minimal training, making it a practical solution in communities with low technical capacity. These findings strengthen the argument that biofilters can serve as a reliable and cost-effective tool in the global effort to manage water pollution.

Beyond reducing pollution, biofilters also contribute directly to water conservation and ecosystem protection. By treating wastewater at the point of origin, they prevent the contamination of nearby rivers, lakes, and groundwater. This helps preserve aquatic biodiversity and maintains ecosystem services that are essential for human survival, such as natural water purification and flood regulation. In regions with water scarcity, treated wastewater from biofilters can even be reused for non-potable applications like irrigation, thus supporting sustainable water management. Furthermore, decentralized wastewater treatment aligns with the principles of environmental stewardship and community-based conservation efforts. It empowers local populations to take active roles in protecting water resources and

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helps achieve the targets set by the United Nations Sustainable Development Goals (SDGs), particularly Goal 6: Clean Water and Sanitation.

Despite its advantages, biofilter technology is not without challenges. Implementation can be hindered by a lack of public awareness, insufficient technical knowledge, and absence of supportive policy frameworks. The performance of biofilters is also influenced by several factors, including the type of media used, the composition of wastewater, temperature, and retention time. Therefore, it is crucial to conduct site-specific research to optimize biofilter design and media selection based on local environmental and social conditions. Further investigation is also needed to understand long-term operational sustainability and maintenance requirements. Research plays a vital role in not only validating the technology but also in providing data for policymakers and development agencies to promote its adoption as part of integrated water resource management strategies.

In light of these issues, this study focuses on evaluating the effectiveness of biofilter technology for treating domestic wastewater and its role in aquatic ecosystem conservation. The main objectives are to assess the performance of different biofilter media in reducing key pollution indicators (BOD, COD, TSS), to explore the feasibility of community-level implementation, and to examine its potential contribution to water quality improvement and environmental sustainability. The findings are expected to provide a scientific basis for promoting biofilter systems as a practical and low-cost solution to wastewater problems, especially in underserved regions. Moreover, this study aims to raise awareness of the importance of local-scale interventions in achieving broader environmental goals.

Metodologi

This study employed a quantitative experimental approach to assess the effectiveness of biofilter technology in reducing pollutants found in domestic wastewater. The experimental design followed a pre-test and post-test control group method, allowing for direct comparisons between water quality before and after treatment using biofilters. A control setup without any filtration treatment was also maintained to observe natural degradation, ensuring that any observed changes in water quality were indeed due to the biofiltration process. The use of this design provides a strong scientific basis for causal inference and reliability of the results obtained.

The biofilter units were constructed in the form of vertical cylindrical reactors made from PVC (polyvinyl chloride) with a height of 100 cm and a diameter of 15 cm. Each reactor was filled with three layers of filtering media selected for their physical and biological treatment capabilities. The bottom layer consisted of coarse gravel (20 cm) to support the structure and remove large suspended solids. The middle layer contained natural zeolite (40 cm), which is effective for ammonia adsorption and supports microbial colonization. The top layer was filled with activated charcoal (30 cm), chosen for its ability to absorb organic contaminants, odors, and residual detergents. The combination of these media creates a multi-functional system that supports both physical filtration and biological degradation of pollutants.

The reactors operated under a continuous flow system, where wastewater flowed from the top downwards (downflow configuration) by gravity. The hydraulic retention time (HRT) was maintained at approximately 24 hours to ensure adequate contact time between the wastewater and filter media. Microorganisms responsible for biodegradation developed naturally from the organic content in the wastewater itself, with no artificial inoculation introduced. Prior to the main study, the biofilter was conditioned for one week to allow microbial colonies to establish and adapt to the wastewater composition.

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Domestic wastewater (greywater) used in this study was sourced from residential neighborhoods with dense populations in City X. This wastewater primarily included water from household activities such as washing, bathing, and kitchen use, but excluded blackwater (sewage). Composite sampling was conducted over a 7-day period, with an average inflow of 20 liters per day per reactor. All samples were pre-filtered through a fine mesh to remove large debris before entering the reactor. Sampling for laboratory analysis was performed every three days over a total experimental period of 30 days, allowing for the observation of biofilter performance over time and under varying pollutant loads.

Water quality parameters were tested using standard laboratory procedures in accordance with the Standard Methods for the Examination of Water and Wastewater as outlined by the American Public Health Association (APHA, 2017) and the Indonesian National Standard (SNI). The parameters evaluated included Biological Oxygen Demand (BOD in mg/L), Chemical Oxygen Demand (COD in mg/L), Total Suspended Solids (TSS in mg/L), and pH. BOD was measured using a 5-day incubation method at 20°C using a BOD incubator; COD was determined via titration using potassium dichromate; TSS was analyzed through gravimetric filtration and drying methods; and pH was measured using a calibrated digital pH meter. Each measurement was performed in triplicate (n = 3) to increase data accuracy and minimize experimental error.

To calculate the removal efficiency, the following equation was used for each parameter:

$$\text{Removal Efficiency (\%)} = C\mathit{initial}\ C\mathit{initial} - C\mathit{final} \times 100$$

where $C\mathit{initial}$ represents the concentration of pollutants before treatment and $C\mathit{final}$ is the concentration after biofiltration. This calculation provided quantitative evidence of the biofilter's performance in removing specific pollutants. Data analysis involved both descriptive and inferential statistical methods. Descriptive analysis illustrated trends in pollutant concentration reduction over time, while inferential statistics specifically the paired t-test at a significance level of $\alpha = 0.05$ were used to assess whether changes in pollutant levels before and after treatment were statistically significant. The statistical software SPSS version 25 was used for data processing. In addition to laboratory analysis, qualitative observations such as changes in water color, odor, and turbidity were recorded throughout the experiment to support quantitative findings.

Safety protocols and environmental ethics were observed throughout the experiment, including proper handling of wastewater, use of protective equipment, and appropriate disposal of treated water and residues. Importantly, the biofilter system was designed using low-cost, locally available materials, and constructed in a way that it could be easily replicated by local communities. This makes the research highly relevant not only academically but also in its practical implications for community-based wastewater management and environmental conservation.

Result and Discussion

The results of this study convincingly demonstrate the effectiveness of the biofilter system in treating domestic wastewater and improving water quality before its discharge into natural aquatic environments. Over the 30-day experimental period, the biofilter system consistently showed strong pollutant removal performance across all major water quality parameters Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), and Total Suspended Solids (TSS). Notably, performance stabilization was observed after the initial microbial adaptation phase, confirming the ability of indigenous microorganisms to thrive in the selected filter media without the need for artificial seeding

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or chemical inputs. This natural biological adaptation supports the long-term sustainability of the system in real-life applications.

Regarding BOD, a key parameter that reflects the amount of organic matter that can be biologically decomposed, significant reductions were recorded. The initial BOD concentration in the untreated greywater was approximately 120 mg/L considerably higher than the recommended discharge limit set by environmental standards. After treatment with the biofilter, the BOD level consistently dropped to between 28–32 mg/L. This corresponds to a pollutant removal efficiency of around 73–77%. Such a high percentage of reduction indicates that the aerobic microorganisms residing in the zeolite and activated carbon media were highly effective in decomposing organic pollutants such as oils, food particles, detergents, and body wastes. This process of natural degradation contributes to reducing the oxygen demand in the receiving water body, thereby preserving dissolved oxygen levels vital for aquatic life survival.

For the COD parameter, which measures the total amount of oxygen needed to oxidize both biodegradable and non-biodegradable substances, the results were equally promising. Initial COD levels measured around 240 mg/L and were reduced to 85–92 mg/L after treatment. This represents a removal efficiency of approximately 62–65%. COD reduction is particularly relevant in wastewater management because it indicates the breakdown of more persistent chemical compounds that cannot be addressed solely by biological treatment. The use of activated carbon within the filter played a crucial role in adsorbing non-biodegradable substances, including residues of household chemicals, soap scum, and cooking oils. Combined with microbial activity, this dual mechanism of degradation and adsorption enhances the overall pollutant removal efficiency of the system.

The removal of Total Suspended Solids (TSS), which includes fine particles, colloids, and other insoluble materials, was also highly effective. Untreated wastewater had a TSS concentration of approximately 150 mg/L, which was reduced to 15–20 mg/L after filtration, achieving a removal rate of 85–90%. The stratified design of the biofilter composed of coarse gravel at the bottom, zeolite in the middle, and activated carbon on top proved highly efficient in capturing both coarse and fine solids. The reduction in TSS is significant not only for aesthetic reasons but also because high suspended solids in water bodies can block sunlight penetration, disrupt photosynthesis in aquatic plants, and smother aquatic organisms' habitats. The clear visual improvement in water clarity also adds social value, as visibly cleaner water fosters greater community acceptance and willingness to reuse treated greywater for non-potable purposes.

Qualitative observations conducted alongside laboratory tests provided supporting evidence of the system’s impact. Before treatment, the wastewater was turbid, oily, and emitted a pungent odor. After filtration, these characteristics changed dramatically: the water became clearer, less odorous, and more visually acceptable. In some cases, the treated water approached the clarity level of urban stormwater and could potentially be reused for activities such as garden irrigation, floor cleaning, or toilet flushing. These observations support the argument that biofilter-treated greywater, while not suitable for direct human consumption, has strong potential for safe and productive reuse, which can contribute to water conservation efforts in urban and rural households.

To assess the significance of the pollutant reductions, statistical analysis using paired t-tests was conducted. Results showed that the differences in BOD, COD, and TSS values before and after treatment were statistically significant at the 5% level ($p < 0.05$), confirming that the observed changes were not due to random variation or environmental factors alone. Meanwhile, pH values remained stable throughout the treatment period, ranging from 6.8 to 7.2, with no statistically significant changes observed ($p > 0.05$). This indicates that the biofiltration process did not result in excessive acidification or alkalization of the treated water, thus ensuring environmental safety for downstream aquatic ecosystems.

When compared to previous studies, the findings of this research are in strong alignment. For example, a similar study by Pratiwi et al. (2021) reported comparable pollutant removal efficiencies using a biofilter system with zeolite and coconut shell charcoal. Additionally, research by Lestari et al. (2019) found that vertical-flow biofilters with natural media could reduce COD levels by up to 70%, further validating the relevance of biofiltration technology in decentralized wastewater management. These parallels highlight the replicability of biofilter systems and their adaptability to various environmental and social settings, including those with limited technical resources or infrastructure.

Importantly, this study reinforces the potential of biofilters as a low-cost, environmentally friendly, and community-based solution to domestic wastewater problems. The use of easily available

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materials such as gravel, zeolite, and activated carbon, along with passive biological processes, enables widespread adoption without the need for skilled labor or advanced machinery. Furthermore, the reduction in pollutant discharge into nearby water bodies contributes directly to the conservation of aquatic ecosystems, aligning with national and global goals for sustainable environmental management. Overall, the findings provide robust scientific and practical justification for the implementation of biofilter systems as a viable alternative in the face of increasing domestic wastewater challenges.

The findings of this study strongly suggest that biofilter technology offers a practical and sustainable approach to addressing the growing challenges of domestic wastewater management, particularly in peri-urban and rural areas where infrastructure is limited or absent. The significant reduction in BOD, COD, and TSS underscores the effectiveness of the filter media combination and reactor design in removing various forms of pollutants commonly found in greywater. These results are not only consistent with previous studies but also provide fresh empirical evidence on the potential of low-cost treatment solutions in enhancing water quality and protecting aquatic ecosystems. By using natural and locally available materials, this research highlights a treatment approach that is both environmentally sound and economically accessible.

The biofilter's performance in reducing BOD and COD indicates that the biological treatment processes primarily microbial metabolism were functioning optimally throughout the treatment cycle. This suggests successful colonization and activity of aerobic bacteria within the zeolite and activated carbon layers. The high oxygen transfer facilitated by the vertical flow-through design further supported microbial respiration and organic matter degradation. In addition to supporting pollutant removal, the consistent microbial activity also helped stabilize the pH, which remained within the neutral range. This is critical not only for ecological safety but also for the sustained viability of microbial life within the system. Studies by Ibrahim et al. (2022) have similarly emphasized the importance of stable pH in maintaining long-term treatment efficiency in natural-based filtration systems.

Furthermore, the system's efficiency in removing TSS highlights the physical retention capabilities of the media and the design of the flow structure. Suspended solids are known to cause turbidity, reduce light penetration in water bodies, and promote sedimentation that can smother benthic habitats. The observed 85–90% TSS removal rate demonstrates the ability of the system to prevent these negative outcomes. The layered arrangement of coarse gravel, zeolite, and activated carbon enabled effective stratification of solid particle filtration, allowing larger particles to be captured early while finer particles were filtered further down the media profile. This approach also prevented clogging and ensured continuous flow, an important factor in system reliability and maintenance.

Visually and sensorially, the transformation of the wastewater from turbid and odorous to clear and nearly odourless reflects the public health and environmental co-benefits of this treatment system. In resource-limited settings, public trust in decentralized water treatment technologies often depends on the visible quality of the treated water. When water appears clean and free of unpleasant odors, households are more likely to accept its reuse for non-potable purposes such as watering gardens, washing floors, or flushing toilets. In this sense, the biofilter's performance supports not just environmental protection, but also behavior change and community-level adoption, which are essential for scaling water reuse practices.

Statistical validation through the paired t-test further reinforces the robustness of the findings. The significant differences ($p < 0.05$) in BOD, COD, and TSS levels before and after treatment confirm that the improvements were not the result of random variations but were directly attributable to the biofiltration process. The fact that the system maintained its pollutant removal performance across multiple sampling days suggests strong operational resilience. This becomes especially important in real-world applications, where wastewater composition and flow rates can vary daily. The stability of the system indicates that it can handle such fluctuations without compromising its treatment efficacy.

Despite its promising results, the study acknowledges a few limitations that need to be addressed in future research. The experiment focused exclusively on greywater and did not include blackwater or wastewater containing human feces, which presents a higher risk due to the presence of pathogens. Therefore, the current design is more suitable for treating household greywater rather than complete domestic effluent. Moreover, microbiological parameters such as total coliforms and E. coli were not measured, leaving a gap in understanding the system's disinfection capacity. Additional studies that integrate pathogen removal analysis and real-world implementation trials would provide a more holistic understanding of the biofilter's applicability and safety.

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Nevertheless, the practical implications of this study are substantial. With increasing pressure on water resources due to urbanization, climate change, and population growth, decentralized treatment systems like biofilters can provide an effective alternative or complement to centralized systems. By reducing pollutant discharge into surface water bodies, these systems help to preserve riverine and coastal biodiversity, prevent eutrophication, and maintain ecosystem balance. Additionally, they reduce the burden on municipal sewage infrastructure, lowering both operational costs and energy consumption. From a policy standpoint, this research supports the integration of biofilter systems into local sanitation and water management strategies, particularly in areas not yet connected to formal treatment networks.

The broader environmental impact of biofilter adoption also aligns with several Sustainable Development Goals (SDGs), particularly SDG 6 (Clean Water and Sanitation), SDG 11 (Sustainable Cities and Communities), and SDG 14 (Life Below Water). By offering a feasible solution for treating greywater at the household or community level, biofilters empower local stakeholders to participate in environmental conservation and reduce their ecological footprint. This aligns with the principles of community-based environmental stewardship and low-tech innovation, both of which are critical in achieving long-term sustainability in water management.

Conclusion

This study concludes that biofilter technology represents an effective, low-cost, and environmentally friendly solution for the treatment of domestic greywater. Through the use of natural filter media gravel, zeolite, and activated carbon the system successfully reduced major pollutants such as Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), and Total Suspended Solids (TSS) with high efficiency, reaching up to 77% for BOD, 65% for COD, and 90% for TSS. These improvements not only meet environmental discharge standards but also enhance the visual and physical quality of the treated water, making it suitable for non-potable reuse. The system operated under stable conditions without significant changes in pH, indicating a balanced biological process that is safe for both human and environmental health. Moreover, the use of locally available materials and simple construction techniques makes this biofilter system highly replicable in low-resource settings, particularly in urban and rural areas lacking centralized wastewater infrastructure. The findings support the integration of decentralized treatment systems into community-based water management strategies, contributing directly to aquatic conservation by reducing pollutant loads entering rivers and other water bodies. While this study focused primarily on greywater and did not assess microbial parameters, the strong pollutant removal performance highlights the potential of biofilters as a sustainable component of integrated sanitation solutions. Future studies are recommended to evaluate pathogen removal capacity and long-term field applications. Overall, biofilter technology can play a strategic role in supporting both environmental protection and public health, while promoting sustainable water reuse at the grassroots level.

References

Adharini, R. I. et al. (2021). *Effectiveness of Seaweeds as Biofilter for Reducing Wastewater Nutrient… Jurnal Ilmiah Perikanan dan Kelautan*, 13(2), 133–143. e-journal.unair.ac.id

Environmental Research. (2024). *Zeolites in wastewater treatment: A comprehensive review… Environ. Res.*, 260:119782. ScienceDirect

Hasan, A. A. (2022). *Performance of Agricultural Wastes as A Biofilter Media for Low-Cost Greywater Treatment Technology*. *JEASD*. jeasd.uomustansiriyah.edu.iq

Hess, A., Bettex, C., & Morgenroth, E. (2020). *Influence of intermittent flow on removal of organics in a biological activated carbon filter for greywater post-treatment*. *Water Res X*, 9:100078. PubMed

DOI: https://doi.org/10.62872/waywxs34

Ibrahim, A. et al. (2022). *Potential of organic filter materials for treating greywater… Water Sci Technol*, 63(9), 1832–1840. jeasd.uomustansiriyah.edu.iq

Journal of Water Process Engineering. (2022). *Use of biochar-based column filtration systems for greywater treatment: a systematic literature review*. *J. Water Process Eng.*, 48:102908. ScienceDirect

Khotimah, S. N., Ginting, S. B., Arifaini, N., Mardhotillah, N. A., & Puligadda, L. K. P. (2024). *Review: The Use of Eco-Enzymes in Greywater Treatment*. *JESR*, 6(1), 46–51. Jesr

Khudair, M. Y., Ethaib, S., Jasim, F. M., & Kamel, A. H. (2024). *Developing Sustainable Wastewater Treatment Systems Using Biofiltration Process*. *IJEI*. IIETA

Liu, F., Nord, N. B., Bester, K., & Vollertsen, J. (2020). *Microplastics Removal from Treated Wastewater by a Biofilter*. *Water* 12(4):1085. MDPIMDPI

McCarthy, D. T. et al. (2020). *Real-time control of biofilters delivers stormwater suitable for harvesting and reuse*. *Water Research*. en.wikipedia.org

MDPI *Applied Sciences*. (2021). *Shifting from Conventional to Organic Filter Media in Wastewater Biofiltration Treatment: A Review*. MDPI

Mojsilovic, K. et al. (2022). *Zeolite-based photocatalysts immobilized… plasma electrolytic oxidation*. *ArXiv*. arxiv.org

Muscarella, S. M. et al. (2021). *Ammonium adsorption… by acid and alkaline treated zeolite*. *ArXiv*. arxiv.org

Norra, G.–F. & Radjenovic, J. (2021). *Removal of persistent organic contaminants… hybrid electrochemical-GAC system*. *ArXiv*. arxiv.org

Oktaningtyas, D. P., Khoironi, A., & Sabhira, A. I. (2024). *The effectiveness of constructed wetland method in greywater treatment using Purun danau… J. Bioresource Environ. Sci.*, 3(2). jeasd.uomustansiriyah.edu.iq+2Jurnal Bioresources dan Ilmu Lingkungan+2Jesr+2

Pratiwi, H., Rokhmalia, F., Suprijandani, & Amalia, R. (2022). *Bioball Biofilter and Phytoremediation Methods in Decreasing LAS Content of Greywater*. *EJSIT*, 2(5), 10–13. EJSIT Journal

Science of the Total Environment. (2024). *Biochar-based fixed filter columns for water treatment: A comprehensive review*. *Sci. Total Environ.*, 954:176199. ScienceDirect

Sundaram et al. (2020). see above PubMed

Sundaram, V., Pagilla, K., Guarin, T., Li, L., Marfil-Vega, R., & Bukhari, Z. (2020). *Extended field investigations of ozone-biofiltration advanced water treatment for potable reuse*. *Water Research*, 172:115513. PubMed

Uzma, Cholet, F. et al. (2025). *EnviroPiNet: A Physics-Guided AI Model for Predicting Biofilter Performance*. *ArXiv*. arxiv.org