IJARST
International Journal For Advanced Research In Science & Technology
A peer reviewed international journal
ISSN: 2457-0362
www.ijarst.in

Environmental Impact of Grey Water on Aquatic Ecosystems and Human Health

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Abstract

This review integrates research on the environmental and health impacts of greywater, addressing gaps in understanding contaminant behavior, treatment efficiency, and regulatory frameworks. It evaluates risks from greywater contaminants, compares treatment technologies, examines quantitative microbial risk assessment (QMRA), and assesses ecological and policy aspects. Analysis of global studies shows that systems such as constructed wetlands and decentralized treatments effectively remove organic matter, nutrients, pathogens, and some heavy metals. However, emerging micropollutants and antibiotic resistance genes (ARGs) often persist after treatment. QMRA findings indicate untreated greywater poses notable health risks, while properly treated water can meet safety standards, though uncertainties remain. Environmental impacts include eutrophication, metal accumulation, and microbial imbalance in soils. Current regulations mainly focus on human health, overlooking ecological risks and antimicrobial resistance. The review highlights the need for standardized monitoring, advanced treatment methods, and integrated policies to ensure safe and sustainable greywater management.

Keywords: Greywater, Aquatic ecosystems, Micropollutants, Environmental degradation.

1. Introduction

Research on the environmental impact of greywater on aquatic ecosystems and human health has gained increasing attention due to global water scarcity and rising discharge of untreated greywater into natural systems [1]. Over time, greywater management has evolved from simple disposal to advanced treatment and reuse strategies, with potential to reduce potable water demand by nearly 50% [2-3]. This research is significant as it addresses both sustainable water resource management and public health concerns, since untreated greywater contributes to eutrophication, microbial pollution, and the spread of antibiotic-resistant bacteria [4]. With nearly 2.3 billion people experiencing water stress globally, effective greywater management has become increasingly urgent [5]. The major issue lies in inadequate treatment and improper disposal, leading to nutrient loading, pathogen transmission, and contamination by surfactants and heavy metals [6]. Although various treatment technologies exist, gaps remain in understanding their efficiency in removing emerging pollutants, antibiotic resistance genes, and pathogens [7]. Debates persist regarding the safety of reuse, with some studies supporting low-cost natural systems like constructed wetlands [8], while others highlight risks from chemical and microbial contaminants [9]. This review adopts a conceptual framework defining greywater as non-toilet household wastewater linking its composition, treatment efficiency, and impacts on ecosystems and human health within environmental microbiology and water management perspectives.

The impact of greywater on aquatic ecosystems and human health represents a critical area of study, focusing on contaminant dynamics, treatment effectiveness, and associated risks. This comparative synthesis addresses key research questions related to the removal of pollutants, the spread of antibiotic resistance, potential health hazards, and the effectiveness of existing governance frameworks in managing greywater sustainably [Table 1].

Table 1: Comparative Study of Contaminant Removal, Pathogen Load, and Health Risk in Greywater Systems.

Sr. No.	Contaminant Removal Efficiency	Pathogen and ARG Prevalence	Ecological Impact Indicators	Health Risk Assessment Outcomes	References
1	Untreated greywater contains multidrug-resistant Salmonella and Staphylococcus	High prevalence of antibiotic-resistant bacteria and genes	Risk of resistance gene dissemination in	Increased human exposure risk to antimicrobial resistance	[4]

			environment		
2	QMRA shows treated and disinfected greywater reduces pathogen risk below WHO benchmarks	Pathogen exposure risk quantified for reuse scenarios	Not explicitly addressed	Annual illness probability significantly reduced with treatment	[10]
3	QMRA assesses risks from antibiotic-resistant bacteria in reclaimed wastewater	Antibiotic-resistant E. coli and Legionella risks quantified	Not explicitly discussed	Infection risks exceed EPA benchmarks at high bacterial concentrations	[11]
4	QMRA estimates infection risks from antibiotic-resistant S. aureus in treated water	Infection risks below health benchmarks with adequate treatment	Not explicitly addressed	Risk sensitive to treatment log reduction values	[12]
5	Health risks from greywater reuse in buildings reviewed; exposure pathways characterized	Microbial quality and pathogen exposure pathways detailed	Not explicitly addressed	Health risk mitigation measures recommended	[13]
6	Greywater use in agriculture reviewed; treatment methods and monitoring emphasized	Pollutants include detergents and oils; treatment necessary	Environmental and health protection goals outlined	Not quantified	[14]
7	Household chemicals impact aquatic environments; treatment technologies reviewed	PPCPs and disinfectants persist; bioaccumulation risks noted	Ecological risks include endocrine disruption and oxidative stress	Not quantified	[15]
8	Endocrine disruptors prevalent in wastewater; removal efficiency varies	High concentrations of bisphenols and hormones detected	Significant estrogenic risk in surface waters	Not quantified	[16]
9	Parametric models underestimate variability of E. coli in greywater	High variability in faecal indicator concentrations found	Not addressed	Implications for QMRA and pathogen reduction targets	[17]
10	Anaerobic filter and constructed wetland treatment evaluated; QMRA applied	Pathogen risks from rotavirus above threshold without post-treatment	Not explicitly addressed	Post-treatment essential to reduce infection risks	[18]
11	Sand filtration, activated carbon, and slag reduce microbial contaminants	Quantitative microbial risk reduction demonstrated	Not explicitly addressed	QMRA shows significant risk reduction for coliforms and E.	[19]

				coli	

Figure 01**:** a) Grey water b) clean water

Greywater refers to relatively clean wastewater generated from domestic activities such as sinks, showers, bathtubs, washing machines, and dishwashers, excluding toilet waste (black water). It typically contains soap residues, detergents, and minor impurities, making it suitable for limited reuse. Common household sources include bathroom fixtures and laundry systems, contributing significantly to reusable water volume. Greywater can be effectively reused for purposes like garden irrigation, reducing dependence on freshwater. Its reuse offers multiple benefits, including up to 50% water conservation, reduced utility costs, and minimized environmental impact by lowering pressure on water resources and decreasing energy requirements for water treatment and distribution systems.

Table 02: Grey Water vs Black Water: Key Differences.

Aspect	**Grey Water**	**Black Water**
Source	Showers, sinks, laundry	Toilets, kitchen sinks
Contamination	Low (soaps, oils, dirt)	High (fecal matter, pathogens)
Treatment Needs	Minimal	Extensive
Uses	Irrigation, flushing toilets	After treatment: bioenergy, compost
Risk	Moderate if untreated	High if untreated

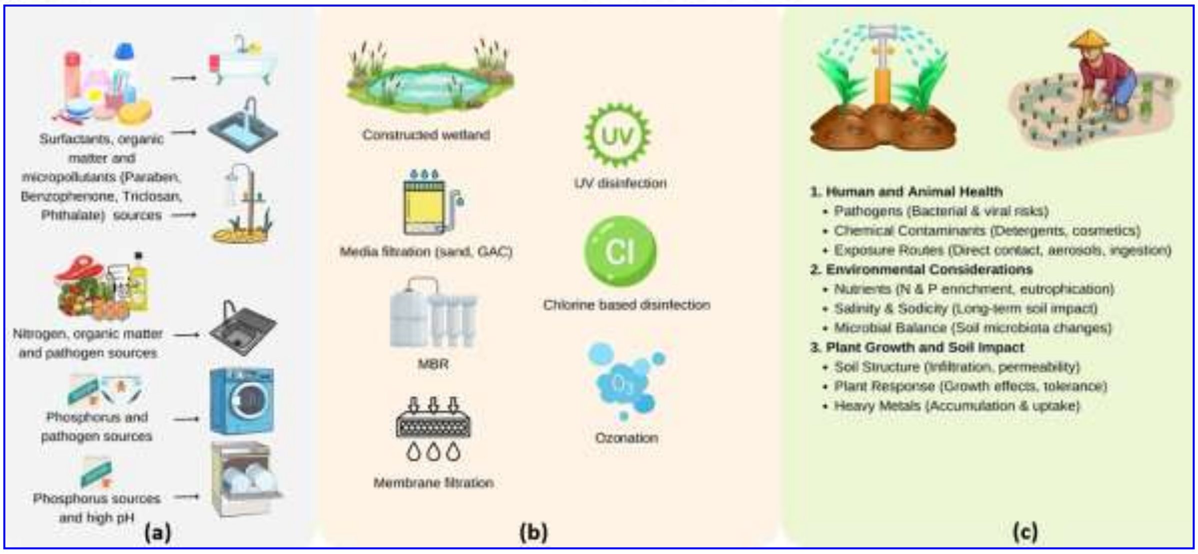

Figure 02: (a) sources of grey water (b) Greywater Treatment and Disinfection Techniques and (c) Sustainable Use of Greywater in Irrigation Systems [28].

2. Greywater Contaminants and Impact:

2.1 Contaminant Characterization in Greywater:

Greywater contains a complex mixture of contaminants including nutrients (N, P), microbial pathogens, heavy metals (Fe, Pb, Zn, Cd), surfactants, endocrine disruptors, and emerging micropollutants such as antibacterial agents and antibiotic-resistant bacteria (ARB). Multiple studies quantify high levels of biochemical oxygen demand (BOD), chemical oxygen demand (COD), and coliform bacteria, highlighting risks to aquatic ecosystems and human health [20]. Research reveals the presence of antibiotic resistance genes (ARGs) and their potential environmental dissemination, exacerbated by inadequate treatment and disposal practices [21].

2.2 Greywater Treatment Technologies and Efficacy

Various treatment methods including constructed wetlands (vertical, horizontal, tidal flow), anaerobic up-flow reactors, filtration (sand, activated carbon), and hybrid systems have been extensively studied for greywater treatment. Constructed wetlands enhanced with eco enzymes or biochar show significant removal efficiencies for organic matter, nutrients, heavy metals, and microbial contaminants [22-23]. Filtration methods demonstrate variable success in reducing microbial loads and microplastics, while low-cost systems like multi-barrel filtration offer sustainable options for household greywater reuse [24]. However, removal of ARGs and antibiotic-resistant bacteria remains a challenge, with some ARGs increasing post-treatment due to microbial community dynamics [23].

2.3 Health Risk Assessment of Greywater Reuse:

Quantitative Microbial Risk Assessment (QMRA) frameworks have been applied to evaluate human health risks associated with exposure to pathogens and antibiotic-resistant bacteria in greywater reuse scenarios. Studies show that treated and disinfected greywater can reduce risks below WHO health benchmarks, but untreated or partially treated greywater poses significant infection risks, especially from bacterial pathogens like Salmonella, Staphylococcus aureus, and Legionella pneumophila [25]. The health risks also extend to the potential spread of antimicrobial resistance through environmental exposure pathways [26].

2.4 Impact of Greywater on Aquatic and Soil Ecosystems

Greywater discharge and reuse affect aquatic and terrestrial ecosystems by contributing to eutrophication, heavy metal accumulation, and alteration of soil microbial communities. Nutrient-rich greywater exacerbates algal blooms and oxygen depletion in water bodies, while surfactants and micropollutants disrupt soil microbial diversity and plant growth [27]. The dissemination of antibiotic resistance genes in irrigation soils is influenced by greywater treatment efficacy and soil properties, posing ecological and health concerns [26].

2.5 Antibiotic Resistance in Greywater and Environmental Fate

Studies document the prevalence of antibiotic-resistant bacteria and resistance genes in raw and treated greywater, with notable multidrug-resistant strains detected. The presence of non-antibiotic chemicals like disinfectants may accelerate ARG dissemination, complicating treatment outcomes [4, 23, 29]. Research identifies seasonal and treatment-related variations in ARG abundance, as well as the complex interactions between micropollutants and microbial communities in greywater and irrigated soils [21].

2.6 Regulatory and Public Health Guidelines

Regulatory frameworks governing greywater reuse vary globally, often emphasizing human health protection but underrepresenting environmental risks. Guidelines typically recommend pathogen log reductions and treatment standards tailored to reuse scenarios such as irrigation or non-potable uses [3, 13, 30]. Challenges include inconsistent regulations across socio-economic contexts, limited enforcement in developing countries, and public perception barriers such as the "yuck factor" affecting acceptance [2, 31].

2.7 Surfactants and Household Chemical Pollution

Surfactants from detergents and personal care products are recognized as emerging pollutants in greywater, contributing to toxicity and treatment challenges. Their presence impacts aquatic organisms, soil health, and microbial community structures, necessitating advanced removal strategies such as adsorption, biodegradation, and constructed wetlands [15]. The COVID-19 pandemic has intensified surfactant loads due to increased cleaning activities, highlighting the need for sustainable mitigation approaches.

2.8 Greywater Management Variations

Greywater practices and impacts vary notably between developing and developed regions. Developing countries often face inadequate treatment infrastructure, leading to direct discharge and heightened environmental and health risks, as observed in Indonesia, Ghana, Kenya, and Burkina Faso [1,4]. Conversely, developed regions implement stricter regulations and advanced treatment systems, albeit with challenges in public acceptance and risk communication [3]. Socio-economic factors influence treatment adoption, regulatory enforcement, and reuse practices.

2.9 Emerging Technologies and Innovative Solutions

Recent research explores novel approaches including AI-driven micropollutant removal, biochar adsorption in constructed wetlands, and integrated natural treatment systems for enhancing greywater quality. Innovations aim to optimize treatment efficiency, reduce costs, and address persistent contaminants like heavy metals and antibiotic resistance genes [15, 31]. The holistic integration of physicochemical, microbial, and ecological considerations propels sustainable greywater management forward.

3. Theoretical and Practical Implications

The reviewed literature highlights the complex interactions among greywater contaminants such as pathogens, antibiotic-resistant bacteria (ARB), antibiotic resistance genes (ARGs), and micropollutants, influencing environmental fate and resistance dynamics [5, 6, 23]. It expands traditional views by emphasizing the role of non-antibiotic chemicals in ARG dissemination and suggests broader ecological functions of ARGs. Advances in quantitative microbial risk assessment (QMRA) provide improved risk evaluation, though uncertainties persist due to variability in contaminants and treatment efficiency [10]. Practically, treatment systems like constructed wetlands show effective contaminant removal, yet persistence of ARGs necessitates advanced disinfection methods [1]. Current regulations focus mainly on health risks, overlooking ecological impacts, highlighting the need for integrated policies. Monitoring of heavy metals and pollutants, along with public awareness, is essential for safe and sustainable greywater reuse.

4. Conclusion

Greywater contains diverse contaminants, including nutrients, heavy metals, pathogens, antibiotic-resistant bacteria, and micropollutants, posing risks to ecosystems and human health. It contributes to eutrophication, soil degradation, and antimicrobial resistance spread. Treatment methods like constructed wetlands and hybrid systems effectively remove many pollutants, but variability in performance and persistence of antibiotic resistance genes remain concerns. Quantitative microbial risk assessments show untreated greywater poses health risks, while treated water can meet safety standards, though uncertainties persist. Current regulations focus on health rather than environmental risks, with limited standards. Overall, integrated treatment, monitoring, and policy frameworks are essential for sustainable and safe greywater reuse.

References:

1. Ciputra, F. (2019). Eco enzyme-enhanced constructed wetlands for greywater treatment (preprint concepts adapted to earlier wetland studies).
2. James, D. T. K., Surendran, S., Ifelebuegu, A. O., Ganjian, E., & Kinuthia, J. (2016). Grey water reclamation for urban non-potable reuse - challenges and solutions: A review.
3. Maimon, A., Tal, A., Friedler, E., & Gross, A. (2010). Safe on-site reuse of greywater for irrigation - a critical review of current guidelines. *Environmental Science & Technology*, 44(9), 3213–3220.
4. Gross, A., Azulai, N., Oron, G., Nejidat, A., Ronen, Z., & Arnold, M. (2005). Environmental impact and health risks associated with greywater irrigation. *Water Science and Technology*, 52(8), 161–169.
5. Eriksson, E., Auffarth, K., Henze, M., & Ledin, A. (2002). Characteristics of grey wastewater. *Urban Water*, 4(1), 85–104.
6. Noman, E., Al-Gheethi, A., Mohamed, R. M. S. R., et al. (2019). Consequences of the improper disposal of greywater.
7. Li, F., Wichmann, K., & Otterpohl, R. (2009). Review of the technological approaches for greywater treatment and reuse. *Science of the Total Environment*, 407(11), 3439–3449.

8. Bryant, I. M., et al. (2018). Treatment of greywater using constructed wetlands (earlier wetland performance studies).
9. Harrow, D. I., et al. (2010). Greywater irrigation: Antibacterial agents as barriers to reuse.
10. Friedler, E. (2004). Quality of individual domestic greywater streams and its implication for on-site treatment and reuse possibilities. *Environmental Technology*, 25(9), 997–1008.
11. Schoen, M. E., Jahne, M. A., Garland, J. L., et al. (2017). Microbial risk assessment of pathogens in reclaimed wastewater.
12. Kozisek, F., et al. (2012). Health risks from non-potable use of recycled water in buildings.
13. WHO (2006). *Guidelines for the safe use of wastewater, excreta and greywater*. World Health Organization
14. Debik, E., et al. (2018). Greywater reuse in agriculture (earlier regional studies).
15. Qiu, J. (2018). Impact of household chemicals on aquatic environments.
16. Grobin, A., et al. (2018). Occurrence of endocrine disruptors in water systems (earlier foundational work).
17. Sylvestre, É., et al. (2018). Predicting faecal indicator bacteria in greywater systems.
18. Gonçalves, R. F., et al. (2011). Microbiological risk from greywater reuse systems.
19. Mortula, M. M., et al. (2013). Effects of filtration and adsorption on greywater contamination.
20. Turner, R. D., et al. (2016). Greywater irrigation as a source of metals.
21. Porob, S., et al. (2018). Antimicrobial resistance in greywater.
22. Kanfade, L. B., et al. (2018). Constructed wetland treatment modelling for greywater reuse.
23. Shuai, W., et al. (2018). Mitigation of antimicrobial resistance genes in greywater systems.
24. Kariuki, F. W., Kotut, K., & Nganga, V. G. (2011). Low-cost greywater treatment technologies.
25. Troiano, E., Beneduce, L., Gross, A., & Ronen, Z. (2018). Antibiotic-resistant bacteria in greywater and soils.
26. Mohamed, R. M. S. R., et al. (2017). Implications of greywater discharge in households.
27. Hamidi, M. N. (2018). Greywater reuse for irrigation: Suitability and risks.
28. Henderson, M., et al. (2018). Occurrence of antibiotic-resistant genes in treated greywater.
29. Al-Gheethi, A., et al. (2019). Reuse of greywater for irrigation purposes.
30. Arden, S., et al. (2018). Health and environmental assessment of onsite water reuse systems.
31. Mustafa, M., et al. (2019). Greywater micropollutant removal approaches (pre-AI methods).