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Greywater as a Sustainable Alternative in Water Management: A Review of Practices and Technologies

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Abstract

Water scarcity is a pressing concern in Chhattisgarh, India, where rapid urbanization and agricultural demands have strained water resources. Greywater reuse presents a sustainable solution for efficient water management by recycling wastewater from sinks, showers, and kitchens for non-potable purposes. This review examines recent practices and technologies for greywater treatment in Chhattisgarh, focusing on decentralized and community-driven approaches.

Chhattisgarh has implemented greywater management strategies through initiatives like the Sujalam 2.0 Greywater Recycling Project and Jal Jeevan Mission, promoting household and village-level treatment systems. Techniques such as soak pits, constructed wetlands, and bio-filtration units are being utilized to enhance water conservation and groundwater recharge. Urban areas are exploring decentralized greywater treatment plants integrated with smart monitoring systems.

Challenges include limited public awareness, inadequate infrastructure, and regulatory gaps. However, the economic and environmental benefits, such as reduced freshwater demand and enhanced irrigation potential, highlight the viability of greywater reuse. Policy-driven incentives and technological innovations can further optimize its adoption.

This review underscores the need for a structured greywater management framework in Chhattisgarh, integrating advanced treatment methods and local community participation to achieve long-term water sustainability.

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1. Introduction

Water scarcity is a growing global challenge, making sustainable water management crucial for future resilience. Greywater, which includes wastewater from sinks, showers, and laundry, has emerged as a viable alternative for water conservation. This review provides a comprehensive analysis of recent research (2020–2025) on greywater reuse, treatment technologies, and its role in **sustainable urban water management**.

Water scarcity is a global crisis, driven by population growth, climate change, and inefficient water usage. Many countries, including Australia, Israel, and the United States, have successfully implemented greywater reuse strategies to address this challenge. Greywater, which originates from domestic sources like sinks, showers, and laundry, constitutes 50–80% of household wastewater and can be treated for non-potable purposes such as irrigation, toilet flushing, and industrial processes. By incorporating advanced treatment technologies, greywater recycling reduces the strain on freshwater resources and mitigates environmental pollution.

Greywater Reuse in India

India faces severe water stress, particularly in states like Rajasthan, Gujarat, Maharashtra, and Chhattisgarh. The country generates billions of liters of wastewater daily, with most of it left untreated. Recognizing the importance of water conservation, the Indian government has launched initiatives such as the Jal Jeevan Mission and Sujalam 2.0 Greywater Management Project to promote decentralized treatment systems. Smart filtration units and IoT-based monitoring to ensure efficient water reuse are now complementing traditional methods like soak pits, wetlands, and bio-filtration.

Greywater Management in Chhattisgarh

Chhattisgarh, known for its agrarian economy and industrial sectors, faces growing water demand. Community-driven solutions, including village-level soak pits,

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decentralized treatment plants, and municipal greywater reuse policies, have gained traction. The state government is also integrating greywater reuse into urban and rural water conservation frameworks, ensuring that sustainable water management practices contribute to long-term resilience.

By scaling up greywater recycling efforts, integrating advanced treatment technologies, and fostering policy-driven incentives, global and local stakeholders can transform greywater into a viable resource for future sustainability.

2. Review of literature

Several studies highlight the potential of greywater in reducing freshwater demand and minimizing wastewater discharge. Research by Fekih et al. (2022) emphasizes the physicochemical and biological characteristics of greywater and explores various treatment methods, such as membrane filtration, biological treatments, and chemical processes. The study concludes that greywater reuse is a promising strategy for mitigating water scarcity and improving water cycle sustainability.

The study published in Environmental Science and Ecotechnology (2023) examines greywater reuse as a key enabler for enhancing urban wastewater management. It discusses how integrating greywater systems into city infrastructures can lead to cost-effective water solutions while reducing pressure on municipal treatment plants. Advanced greywater treatment solutions, such as decentralized greywater recycling systems, have been explored, offering insights into their energy efficiency, economic feasibility, and public acceptance.

Another review by Rodrigues et al. (2023) in Water Supply focuses on combined rainwater harvesting and greywater reuse systems in urban areas. The study highlights the effectiveness of hybrid approaches that combine multiple water sources to ensure a sustainable and reliable water supply. The integration of sensor-based monitoring, IoT-driven water quality assessment, and automation in greywater treatment is also discussed.

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Furthermore, a state-of-the-art review published in Environmental Challenges (2024) assesses the role of constructed wetlands in greywater treatment and reuse. Constructed wetlands have been recognized for their low maintenance requirements, high pollutant removal efficiency, and environmental sustainability. The study evaluates the performance of different wetland configurations, including subsurface flow and floating treatment wetlands, demonstrating their ability to treat greywater efficiently.

Here is a tabular analysis of the given research papers:

Study	Key Focus	Findings	Implications
Tabassum-Abbasi et al.	Phytoremediation using *Bacopa monnieri* (Indian Pennywort) for greywater treatment	Demonstrated the plant's ability to absorb and degrade contaminants, making it a viable eco-friendly wastewater treatment option	Highlights natural treatment methods for sustainable greywater management
B. Jeppesen	Domestic greywater reuse in Australia	Greywater contains harmful chemicals and microorganisms but can reduce potable water usage by 30–50%	Emphasizes public awareness and regulatory guidelines for safe greywater reuse
Pei-Ying Hong et al.	Safety concerns of reusing treated wastewater	Identifies risks of antibiotic-resistant bacteria (ARB) and genes (ARGs) in treated wastewater	Calls for stricter wastewater treatment modifications to enhance safety
W. R. Abma et al.	Cost-effective industrial wastewater treatment	Separate treatment of industrial wastewater	Demonstrates sustainable wastewater

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		improves efficiency and biogas production	management through public-private partnerships
José Luiz Tambosi et al.	Removal of pharmaceuticals from sewage treatment plants (STPs)	Pharmaceuticals and their metabolites pose environmental risks, including aquatic toxicity and antibiotic resistance	Calls for improved STP technologies and stricter environmental policies
KalyanPrachi N. Wakode & Sameer U. Sayyad	Performance evaluation of a 25 MLD STP in Thane, India	Sequential Batch Reactor (SBR) technology effectively reduces pollutants like BOD, COD, and TSS	Highlights the need for continuous monitoring to improve wastewater treatment efficiency
Yong Qiu et al.	Nitrogen & phosphorus removal in China's municipal WWTPs	Major processes used include AAO, OD, and SBR, but operational inefficiencies remain	Calls for better process optimization and real-time control to enhance treatment efficiency
Peter Dillon	Water reuse trends in Australia	Water reuse projected to double in four years due to demand and regulatory changes	Identifies gaps in research and need for coordinated national water reuse strategies
Claudio Lubelloa et al.	Municipal wastewater reuse for plant nurseries	Reclaimed wastewater effectively irrigates ornamental plants with	Demonstrates sustainable irrigation practices,

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		proper filtration and disinfection	reducing freshwater demand
Marlies J. Kampschreura et al.	Nitrous oxide (N_2O) emissions from WWTPs	Significant N_2O emissions during nitrogen removal, influenced by oxygen levels and COD/N ratio	Highlights the need for emission reduction strategies to mitigate climate impact

The highlight key aspects of greywater treatment and reuse. Studies on STPs, such as in Thane, India, and China, show how different treatment technologies like SBR and AAO optimize pollutant removal but require better efficiency monitoring. In Australia, water reuse is rapidly increasing, requiring new regulations. Research on wastewater reuse for plant irrigation demonstrates sustainable practices, while studies on N_2O emissions stress the need for emission reduction strategies. Overall, optimizing wastewater treatment is crucial for environmental and public health sustainability.

Overall, the reviewed studies indicate that greywater reuse presents significant opportunities for sustainable water management. However, challenges such as public perception, regulatory barriers, and maintenance of decentralized treatment systems must be addressed. Future research should focus on policy frameworks, economic incentives, and technological advancements to enhance the adoption of greywater recycling on a broader scale. By integrating innovative treatment methods and smart water management strategies, greywater reuse can play a pivotal role in achieving global water sustainability goals.

The Sujalam 2.0 Grey Water Recycling Project aims to promote wastewater management by reusing greywater for non-potable purposes in rural India. It aligns with the Jal Jeevan Mission to improve water sustainability through decentralized wastewater treatment. The initiative focuses on low-cost solutions, community involvement, and policy integration to enhance water conservation.

3.Methodology

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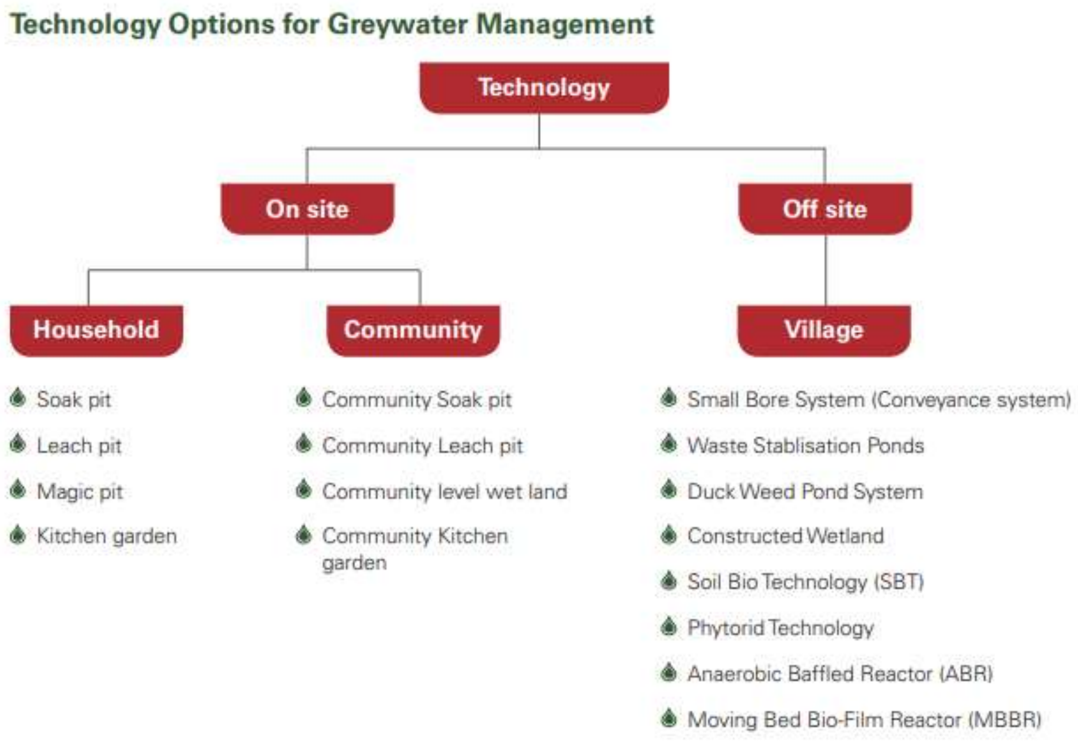

Figure 1.Ref- [Sujalam 2.0' Grey Water Recycling Project]

The image categorizes **greywater management technologies** into **on-site** and **off-site** solutions. These technologies are crucial for **sustainable water conservation** and **wastewater reuse** in different settings.

On-Site Technologies:

1. **Household Level:**
   - **Soak pit:** A simple, cost-effective method for filtering greywater into the soil.
   - **Leach pit:** Allows wastewater to percolate into the ground, reducing surface water pollution.
   - **Magic pit:** A compact, efficient system for treating household wastewater.
   - **Kitchen garden:** Reusing treated greywater for irrigation of household gardens.
2. **Community Level:**
   - **Community Soak Pit:** A larger version of a household soak pit for multiple users.

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- **Community Leach Pit:** Enhances percolation of wastewater for a group of households.
- **Community Wetland:** A natural system using plants to filter greywater.
- **Community Kitchen Garden:** Utilizing treated greywater for food cultivation at a larger scale.

Off-Site Technologies:

1. **Village Level:**
   - **Small Bore System:** A conveyance system for wastewater transport.
   - **Waste Stabilization Ponds:** Low-cost treatment ponds that use natural processes.
   - **Duckweed Pond System:** Uses aquatic plants for wastewater treatment.
   - **Constructed Wetland:** An engineered ecosystem mimicking natural wetlands.
   - **Soil Bio-Technology (SBT):** A soil-based filtration system for wastewater treatment.
   - **Phytorid Technology:** Plant-based bio-filtration to remove contaminants.
   - **Anaerobic Baffled Reactor (ABR):** A biological treatment method improving anaerobic digestion.
   - **Moving Bed Bio-Film Reactor (MBBR):** A compact, advanced wastewater treatment technology.

Adoption Insights:

- **Household and Community Technologies** are suitable for small-scale, decentralized wastewater treatment.
- **Off-Site Village-Level Technologies** are ideal for large-scale wastewater management in rural or semi-urban areas.
- The choice of technology depends on **population density, land availability, cost factors, and local water policies**.

Ghugwa and Patora, two villages in Chhattisgarh's Durg district, effectively addressed their greywater management challenges through community-driven initiatives. Initially, greywater from households flowed into open drains, contaminating village ponds and causing health

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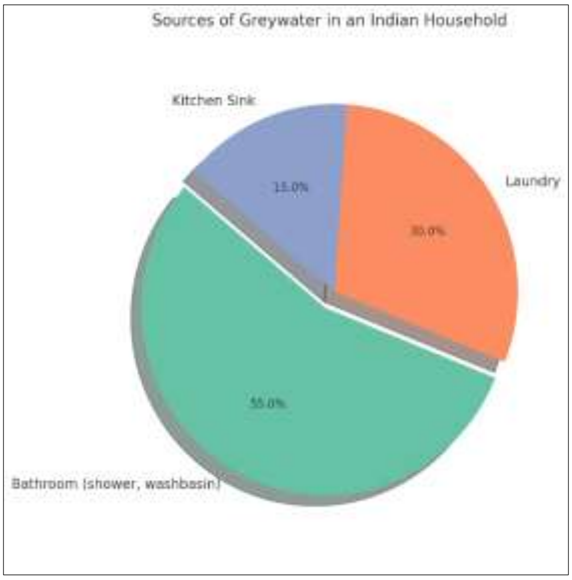
issues like foul odors and skin rashes. Stagnant water near homes also became breeding grounds for mosquitoes.

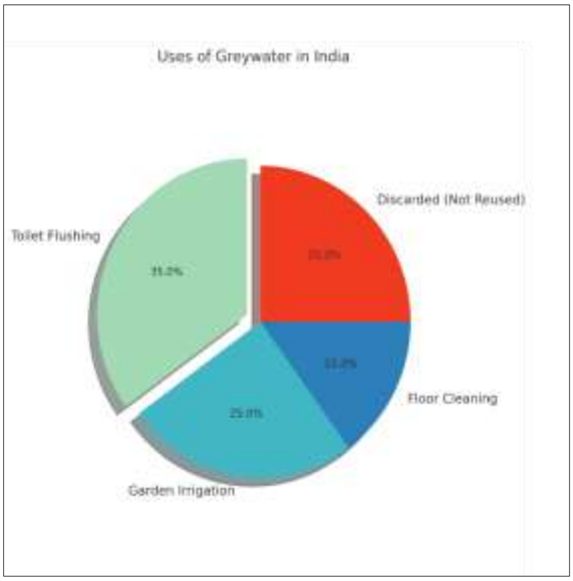
With technical support from WaterAid India, the villages implemented tailored solutions:

Household-Level Interventions: Families constructed honeycomb-patterned leach pits lined with gravel to facilitate greywater percolation. These pits were elevated and covered with concrete lids for safety and ease of maintenance.

Community-Level Solutions: In areas where greywater flowed to lower parts of the villages, larger soak pits and constructed wetlands were developed to manage the wastewater collectively. These systems were funded through a combination of Gram Panchayat resources and corporate social responsibility initiatives.

These efforts significantly improved sanitation and environmental conditions in both villages, showcasing the effectiveness of localized, community-led approaches to wastewater management.





4.Conclusion

Water reuse has become increasingly important due to rising water scarcity, which is expected to worsen in the near future. The excessive withdrawal of water for agriculture, industry, and urban use is a key contributor to this crisis, with agriculture being the largest consumer.

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Additionally, industrial water use generates significant waste, requiring advanced treatment processes. Implementing water reuse strategies can help mitigate water shortages, promote sustainable resource management, and reduce the environmental impact of waste discharge.

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