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A Comprehensive Review on Post-Treatment of Domestic Wastewater Using Hybrid Reed Bed Systems

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ABSTRACT

Domestic wastewater management is one of the most critical challenges associated with rapid urbanization and population growth worldwide, as households generate large volumes of sewage on a daily basis, making it a major source of municipal effluent. Therefore, there is a strong need for economical, efficient, and sustainable treatment methods. A hybrid reed bed system provides a low-cost, nature-based solution for the treatment of domestic wastewater. Reed beds, which are engineered and managed ecological systems, utilize natural processes involving plants, microorganisms, and substrates, and are increasingly adopted across the world for decentralized domestic sewage treatment due to their simplicity, low energy requirement, minimal sludge generation, and suitability for small communities and institutional applications. The objective of this study is to assess the efficiency of a hybrid reed bed system in lowering biochemical oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS), total dissolved solids (TDS), and pH at different hydraulic retention times, using Domestic wastewater discharged from an up-flow anaerobic sludge blanket (UASB) reactor. The findings show that the system effectively reduces BOD, COD, and pH. Phragmites australis plays a crucial role in eliminating organic matter from the system. The study also reveals that longer detention or retention periods lead to higher pollutant removal rates.

Keywords: Hybrid Reed bed, Domestic wastewater, Root zone, Wastewater.

1. Introduction

The domestic wastewater sector has expanded significantly with rapid urbanization, population growth, and improved living standards, and it plays a crucial role in public health and environmental protection in India. With increasing household water

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use for bathing, cooking, washing, and sanitation, large volumes of domestic wastewater are generated daily in both urban and rural areas. India produces millions of cubic meters of domestic sewage every day, much of which remains untreated or partially treated, posing serious threats to surface water bodies, groundwater, and soil quality. Major urban centers and rapidly growing towns across states such as Maharashtra, Uttar Pradesh, Tamil Nadu, Gujarat, Karnataka, and Delhi contribute substantially to domestic wastewater generation.

Domestic wastewater is characterized by high concentrations of biodegradable organic matter, suspended solids, nutrients such as nitrogen and phosphorus, pathogens, detergents, and oils and grease. If discharged untreated, it leads to depletion of dissolved oxygen in receiving waters, eutrophication, spread of waterborne diseases, and degradation of aquatic ecosystems. Conventionally, domestic wastewater is treated using methods such as activated sludge processes, oxidation ditches, trickling filters, and waste stabilization ponds.

Although these technologies are effective, they often involve high capital and operational costs, require continuous power supply, and depend on skilled manpower for proper operation and maintenance. Therefore, there is a growing need for low-cost, energy-efficient, and sustainable domestic wastewater treatment alternatives that are suitable for decentralized applications and adaptable to Indian climatic and socio-economic conditions.

2. Background / Theoretical Framework

In recent years, water-pollution control systems have increasingly shifted toward mechanized treatment methods. However, rising energy and labor costs have made these systems expensive to operate. Therefore, treatment options that require more land but use less energy and manpower are becoming more appealing. Among these, reed bed systems offer a low-cost, eco-friendly method for controlling water pollution.

The use of reed beds for treating Domestic wastewater, especially domestic effluents, is growing. This rise is driven by the need for clean, sustainable technologies that can replace traditional environmentally harmful treatment systems.

OBJECTIVE OF THE STUDY

To design and build a hybrid reed bed system to effectively treat the domestic wastewater.

To monitor the performance of a hybrid reed bed system by reducing total suspended solids, total dissolved solids, biochemical oxygen demand and chemical oxygen demand and pH by different hydraulic retention time receiving Domestic wastewater.

- This study focus on hybrid reed bed system to treat the domestic wastewater coming from up flow anaerobic sludge blanket outlet.
- The study also focuses to treat domestic wastewater by horizontal flow reed bed followed by vertical flow reed bed.

3. Methodology

Describe the criteria for selecting sources, databases and search terms used, and inclusion/exclusion criteria.

1) Selection of Vegetation

Reed bed plants contribute to water treatment mainly through their physical presence. They offer a large surface area for microbial attachment, help stabilize the bed material, slow water movement, and improve sediment settling, which increases water clarity.

Wetland plants are also important for nutrient removal, reducing the risk of eutrophication. Species such as **Phragmites karka**, **Typha angustifolia (Cattail)**, and **Phragmites australis** are effective in absorbing nutrients. These plants develop extensive above-ground and below-ground biomass, creating more surface area for nutrient and ion uptake. Their hollow tissues transport oxygen from the leaves to the roots and surrounding media, supporting aerobic microbial activity and pollutant breakdown. In this hybrid reed bed system, **Phragmites australis** was chosen as the vegetation species.

Soil Permeability

When selecting a site for a reed bed, the permeability of the underlying soil is an important factor. The ideal permeability range is **10^{-6} to 10^{-7} m/s** (0.14–0.014 in/hr). Sandy clays and silty clay loams are generally suitable when properly compacted. Highly permeable soils may still be used for small wastewater volumes by creating narrow trenches and lining the trench walls and base with clay or synthetic liners. In dense clay soils, adding topsoil can improve permeability and support faster initial plant establishment.

COLLECTION OF SUBSTRATE MATERIAL

The media perform several functions such as:

1. They are rooting material for vegetation,
2. They help to evenly distribute or collect flow at inlet and outlet,
3. They provide surface area for microbial growth, and
4. They filter and trap particles.

The materials used in substrate are soil, sand and aggregate. The soil and sand was collected from the farm. Aggregate was collected from the construction site. Before placing the soil, sand and aggregate in the bed, it was cleaned properly and was ensured free from impurities.

2) Starting of Experiment

After preparing the bed for the hybrid reed bed system, the actual operation was initiated. The untreated wastewater from the domestic was collected and stored in the influent tank. The initial wastewater parameters such as pH, BOD, COD, TSS, and TDS were analysed using the procedures outlined in standard methods. The domestic effluent was then introduced onto the top section of the horizontal-flow reed bed unit for treatment. The wastewater then passed from the horizontal-flow bed into the vertical-flow bed. The treated effluent from the vertical-flow unit was gathered from the bottom outlet by opening the valve provided at the base of the unit at different hydraulic retention times of **12, 24, and 36 hours**. The characteristics of the purified wastewater were also examined using standard analytical techniques.

HYBRID REED BED SETUP PHOTOS



Figure: Horizontal Flow reed bed



Figure: First layer of vertical flow reed bed



Figure: Second layer of vertical flow reed bed



Figure: Third layer of vertical flow reed bed



Figure: Top layer of vertical flow reed bed



Figure : Hybrid reed bed system

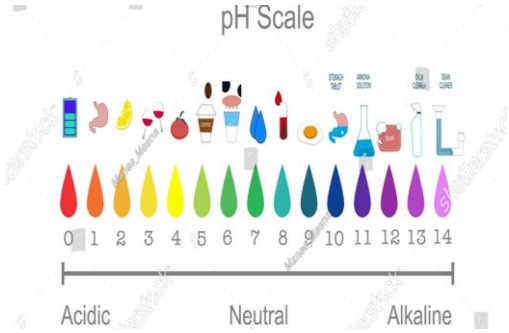


Figure: pH measurement



Ammonical nitrogen measurement

PHOTOS OF ANALYSIS OF DIFFERENT WASTEWATER PARAMETERS

4. Thematic Review / Discussion

Asda

4.1 Theme/Subtopic 1

Summary of Current Knowledge and Key Findings from Literature

Research shows that constructed wetlands and reed bed systems are effective for treating municipal, industrial, textile, dairy, and greywater. Various plant species—such as Typha latifolia, Phragmites karka, Phragmites australis, Vetiveria zizanioides, and floating plants—play a crucial role in removing organic matter, nutrients, pathogens, and heavy metals. Many studies found that optimal pollutant removal occurs at **shallow water**

depths (around 0.3 m) and that treatment efficiency is generally higher in **warmer seasons** due to improved plant and microbial activity.

Hybrid systems combining **vertical-flow and horizontal-flow** units consistently show higher nitrogen removal, especially for ammonium. The choice of media also influences system performance. Materials such as **coco-peat, sugarcane bagasse, sylhet sand, granite, iron-rich substrates, and newspaper residue** improve oxygen transfer, adsorption, and decolorization, depending on the type of wastewater.

Across the literature, removal efficiencies for **BOD, COD, TSS, nitrates, phosphates, pathogens, and heavy metals** are typically high, ranging from **65–99%**. Longer **hydraulic retention times** result in greater pollutant reduction, particularly for nutrients and toxic metals. In several studies, treated effluent met permissible discharge limits and could be reused for **irrigation**, **gardening**, or **general non-potable applications**.

Some research also highlights additional benefits of reed beds, such as converting sludge into compost-like material, supporting biodiversity, and serving as low-cost, low-maintenance treatment solutions. Overall, the literature confirms that constructed wetlands, especially hybrid systems, are an effective and sustainable option for wastewater treatment in various contexts.

4.2 Theme/Subtopic 2

Comparative Analysis and Critical Evaluation of Studies

The reviewed literature presents a wide range of approaches to constructed wetlands and reed bed systems, demonstrating their versatility across different wastewater types. However, the studies vary significantly in plant species used, system configuration, media selection, and operational conditions, which influence their overall performance.

1. Plant Species and Their Influence on Treatment Efficiency

Several studies highlight the importance of vegetation type. Typha latifolia (Dandigi et al., 2011) and Phragmites karka (Sangotola et al., 2015) show strong pollutant removal, while Vetiveria zizanioides (Dhanya et al., 2013) performed exceptionally well in removing heavy metals and nutrients from industrial wastewater. Floating plant systems (Ribadiya et al., 2014) were also found to enhance biodiversity, although removal efficiency varied widely by species.

Critical Insight: While plant choice clearly influences performance, most studies focus on single species, limiting the understanding of synergistic effects in multi-species systems, which could potentially enhance resilience and pollutant uptake.

2. System Configurations: Vertical, Horizontal, and Hybrid Designs

Vertical-flow wetlands (Sangotola et al., 2015) showed significant reductions in toxic metals, particularly when retention times increased. Horizontal-flow systems were effective for greywater (Abinaya et al., 2015), while hybrid HF–VF systems (Vymazal, 2013) consistently achieved superior nitrogen removal.

Critical Insight: Hybrid systems outperform single-stage designs, particularly for nitrogen transformation. However, some studies did not adequately compare systems under identical conditions, making direct performance comparison challenging.

3. Variety of Media and Its Contribution to Treatment

Several studies tested alternative substrates: coco-peat and cupola iron media (Saeed et al., 2012), sugarcane bagasse and sand (Saeed et al., 2012), granite and washed sand (Sangotola et al., 2015), and even newspaper residue (Abinaya et al., 2015). These materials improved aeration, adsorption, and pollutant breakdown in different ways.

Critical Insight: While innovative media can enhance treatment efficiency, many of these studies are small-scale or pilot-level. Their practicality, long-term stability, and cost-effectiveness at larger scales remain uncertain.

4. Hydraulic Retention Time (HRT) and Seasonal Variations

Longer retention times consistently produced better removal rates (Sangotola et al., 2015; Sehar et al., 2015). Dandigi et al. (2011) noted significantly higher performance in summer, highlighting temperature dependence.

Critical Insight: HRT and seasonal climate conditions are key performance drivers, yet several studies do not explore optimized HRTs or system performance in fluctuating seasonal conditions, which limits applicability in colder climates.

5. Overall Removal Efficiency and Practical Application

Most studies reported high removal efficiencies for BOD, COD, nutrients, and pathogens—often exceeding 70–90%. Treated effluent was frequently suitable for irrigation or non-potable reuse (Pachpute et al., 2014; Dhanya et al., 2013). Reed beds were also shown to convert sludge into compost-like material (Sushil, 2012).

Critical Insight: Despite strong laboratory and pilot-scale results, few studies evaluate long-term maintenance challenges, clogging issues, or performance under variable loading, which are critical factors for real-world implementation.

3) Overall Critical Assessment

Collectively, the studies confirm that constructed wetlands are **effective, low-cost, and environmentally sustainable** wastewater treatment systems. However, gaps remain in long-term field performance, scalability, and comparative evaluations under uniform operating conditions. While innovative media and hybrid configurations show great promise, additional research is needed to assess their durability, economic feasibility, and adaptability across diverse climates and wastewater types.

5. Challenges and Research Gaps

Comparison of Conventional Wetlands and Hybrid Reed Bed Technology: Challenges and Research Gaps

Aspect	Conventional Wetlands	Hybrid Reed Bed Systems	Inconsistencies, Gaps, and Limitations	Areas Needing Further Research
Treatment Efficiency	Effective for BOD, COD, and TSS removal; limited nitrogen and phosphorus removal.	Higher nutrient removal efficiency (especially nitrogen) due to combined HF and VF flows.	Studies often report high removal rates but vary widely due to differences in plant species, HRT, and wastewater type; lack of standardized evaluation.	Systematic optimization of HRT, depth, and hybrid configuration under different wastewater loads.
Plant Selection	Usually single species like Typha latifolia or Phragmites australis; seasonal and climate dependent.	Can support multiple plant species to enhance pollutant removal and system resilience.	Limited research on multi-species interactions, long-term survival, and adaptability to industrial or high-strength wastewater.	Studies on synergistic effects of mixed plant species and plant resilience under extreme conditions.
Media/Substrate	Soil, sand, or gravel; prone to clogging; limited adsorption for heavy metals or micro pollutants.	Engineered or organic media (coco-peat, sugarcane bagasse, iron-rich substrates) enhance pollutant removal and aeration.	Long-term stability, maintenance requirements, and cost-effectiveness of alternative media remain underexplored.	Pilot and full-scale studies testing durability, media replacement cycles, and economic feasibility.
Hydraulic Retention Time (HRT)	Longer HRT improves efficiency but requires more land.	Higher treatment in compact design; HF–VF combination allows smaller footprint.	HRT optimization is inconsistent across studies; many studies only test a few fixed HRTs without exploring variability.	Research on dynamic HRT design for variable loading and seasonal flow fluctuations.
Seasonal and Climate Effects	Performance declines in cold weather due to reduced microbial and plant activity.	Hybrid systems may maintain slightly better performance by combining aerobic and anaerobic zones.	Very few studies quantify year-round performance across climates; data on cold-season efficiency are limited.	Long-term monitoring in different climatic conditions and strategies to mitigate seasonal performance drop.
Scaling and Practical Implementation	Well-suited for low-strength wastewater; land-intensive; low-cost.	More compact; can handle higher-strength wastewater; supports nutrient and heavy metal removal.	Most studies are pilot-scale; limited real-world implementation data; maintenance challenges such as	Full-scale field studies, lifecycle cost analysis, and maintenance strategies for hybrid systems.

			clogging not fully addressed.	
Additional Benefits	Can support biodiversity and some sludge stabilization.	Converts sludge into compost-like material; higher biodiversity potential; better nutrient cycling.	Few comparative studies quantify ecological and resource recovery benefits across systems.	Integrated studies assessing wastewater treatment along with sludge management, energy use, and ecological impacts.

Key Inconsistencies, Gaps, and Limitations

1. **Variability in Performance Metrics:** Many studies report different removal efficiencies due to inconsistent HRTs, plant types, and media, making cross-study comparisons difficult.
2. **Limited Multi-Species and Media Research:** Most research focuses on single plant species and conventional media; hybrid systems with mixed plants and engineered media need more exploration.
3. **Seasonal and Climate Effects:** There is insufficient data on winter performance or in colder regions; most studies are conducted in tropical/subtropical climates.
4. **Scale-Up and Long-Term Studies:** Few full-scale implementations; most studies are short-term or pilot-scale, with little information on maintenance, clogging, and operational costs.
5. **Standardization of Hybrid Systems:** Lack of universally accepted design guidelines for hybrid reed bed systems (e.g., HRT, bed depth, media type, plant selection).

6. Future Directions

Areas Needing Further Research

1. Optimization of hybrid designs, including plant combinations, media selection, and hydraulic retention time.
2. Long-term performance studies at full-scale, including maintenance requirements, clogging prevention, and cost analysis.
3. Year-round and multi-climatic studies to assess seasonal variations in pollutant removal.
4. Comparative studies between conventional wetlands and hybrid systems under identical conditions for consistent benchmarking.
5. Integration of sludge management, resource recovery, and ecological benefits in system evaluation.

Future research should focus on optimizing hybrid system designs for diverse wastewater types, assessing long-term operational performance, and establishing scalable, cost-effective solutions. Studies are also needed to evaluate seasonal performance, multi-species interactions, and the integration of sludge management, resource recovery, and ecological benefits. Addressing these gaps will enhance the reliability, efficiency, and broader adoption of hybrid reed bed technology as a sustainable wastewater treatment solution.

7. Conclusion

The literature shows that both conventional constructed wetlands and hybrid reed bed systems are effective for wastewater treatment, but hybrid systems generally offer superior performance. Conventional wetlands, typically using a single plant species and simple soil or gravel media, are effective at removing BOD, COD, and

suspended solids but often show limited nutrient removal and are sensitive to seasonal and climatic variations. In contrast, hybrid reed bed systems, combining horizontal-flow and vertical-flow units, achieve higher nitrogen and phosphorus removal, can support multiple plant species, and allow the use of engineered or organic media to enhance pollutant uptake.

Key factors affecting both systems include plant selection, hydraulic retention time, media type, and seasonal conditions. While hybrid systems overcome many limitations of conventional wetlands, gaps remain in optimizing design parameters, understanding long-term performance, and developing standardized guidelines for full-scale implementation.

Overall, hybrid reed bed technology represents an evolution of traditional wetland methods, providing higher efficiency, greater flexibility, and better adaptability for diverse wastewater types. Its potential to meet stringent water quality standards and support ecological benefits makes it a significant advancement in sustainable wastewater management.

For high efficiency, nutrient removal, compact design, and versatility across wastewater types, **hybrid reed bed systems outperform conventional wetlands**. However, for low-strength wastewater in rural or land-abundant areas, **conventional wetlands remain a simpler, low-cost solution**.

REFERENCES

[1]. Dandigi, A., et al. (2011). Treatment of municipal wastewater using Typha latifolia in constructed wetlands.

[2]. Choudhary, A. K., Kumar, S., & Sharma, S. (2011). Constructed wetlands for wastewater treatment in India: A review. Indian Journal of Environmental Protection, 31(6), 1–12

[3]. Saeed, T., & Sun, G. (2011). A review on nitrogen and organics removal mechanisms in subsurface flow constructed wetlands. Critical Reviews in Environmental Science and Technology,

[4]. Saeed, S., et al. (2012). Use of organic coco peat media in vertical flow wetlands for textile wastewater treatment.

[5]. Sushil. (2012). Use of constructed reed beds for converting domestic sludge to compost-like material.

[6]. Ramprasad. (2012). Comparison of reed bed technology, conventional treatment plants, and simple filter bed systems for wastewater treatment.

[7]. Chang, J., et al. (2012). Treatment of municipal wastewater using hybrid vertical–horizontal constructed wetlands in cold regions. Journal of Environmental Science and Health, 47, 1523–1530.

[8]. Stefanakis, A., & Tsihrintzis, V. (2012). Effects of loading, resting time, and temperature on vertical flow constructed wetland performance. Journal of Environmental Management

[9]. Stefanakis, A. I., & Tsihrintzis, V. A. (2012). Effects of loading, resting period, temperature and plant species on performance of VF wetlands

[10]. Vymazal, J. (2013). Performance of hybrid constructed wetlands for nitrogen removal: A review of 60 systems.

[11]. Dhanya, R., et al. (2013). Treatment of automobile service station and sewage wastewater using Vetiveria zizanioides in wetlands.

[12]. Zhang, D. Q., Jinadasa, K. B. S. N., et al. (2014). Application of constructed wetlands for wastewater treatment in tropical and subtropical regions.

[13]. Ribadiya, N., et al. (2014). Floating plant systems in reed bed wastewater treatment: water quality and biodiversity effects

[14]. Pachpute, S., et al. (2014). Use of constructed wetlands for dairy wastewater treatment and pH neutralization.

[15]. Sehar, S., et al. (2015). Comparative study of Trianthema portulacastrum and Brachiaria reptans in constructed wetlands for removal of SS, TDS, sulphate, phosphate, nitrate, and nitrite.

[16]. Gorky, P. (2015). Performance evaluation of root-zone treatment and hybrid reedbed systems for wastewater treatment efficiency over time.

[17]. Sangotola, K., et al. (2015). Vertical subsurface flow wetlands using Phragmites karka with granite and washed sand substrates for removal of toxic metals.

[18]. Abinaya, B., et al. (2015). Horizontal subsurface flow wetlands using newspaper residue as top layer media for greywater treatment.

[19]. Wu, H., Zhang, J., Ngo, H. H., et al. (2015) A review on the sustainability of constructed wetlands for wastewater treatment. Bioresource Technology, 175, 594–601

[20]. Khan, M., et al. (2018) Performance evaluation of hybrid constructed wetland for municipal wastewater treatment. Environmental Technology & Innovation

[21]. Effects of design/operational conditions on CW performance (2023) Water, Air, & Soil Pollution, 234, 434. – Design and operational impacts on CW efficiency..

[22]. Ali, M., Aslam, A., Qadeer, A., et al. (2024) Domestic wastewater treatment by Pistia stratiotes in constructed wetland.

[23]. Free water surface constructed wetlands: review of pollutant removal performance (2024) Environmental Science and Pollution Research, 31, 44649–44668. – Detailed review of pollutant removal and modeling in free water surface CWs.

[24]. General Carlos Cavalcanti et al. (2024) he Use of Constructed Wetlands to Treat Effluents for Water Reuse

[25]. Biswas Roy, M., Saha, S., & Kumar Roy, P. (2025) Constructed Wetlands for Wastewater Treatment: A Review of Research Development. Ecology, Economy and Society,

[26]. Sánchez, M., Torres, E., Ramos, D. R., et al. (2025) Elimination of faecal indicator microorganisms from wastewater by combining constructed wetlands and heterogeneous photocatalysis.

[27]. Comprehensive review of constructed wetlands with advanced biotechnologies (2025) Bioresource Technology, 439, 133353. – CWs with emerging biotech for nitrogen and greenhouse gas management.

[28]. Domínguez-Solís, D., Martínez-Rodríguez, M. C., & Ramírez-Escamilla, H. G. (2025) Constructed Wetlands as a Decentralized Treatment Option for Domestic Wastewater: A Systematic Review.

Books.

[1]. Wastewater Engineering: Treatment and Resource Recovery. Metcalf & Eddy, Tchobanoglous, G., Burton, F. L., & Stensel, H. D.

[2]. Davis, M. L., Cornwell, D. A. (2019). Introduction to Environmental Engineering.

[3]. Peavy, Rowe & Tchobanoglous - Environmental Engineering.

[4]. Water and Wastewater Technology- Hammer, M. J. & Hammer Jr., M. J.