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Sustainable Decentralized Greywater Management Using Hybrid Filtration and Constructed Wetland Systems

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Abstract - Water scarcity and increasing demand for sustainable water management solutions have led to the exploration of decentralized wastewater treatment systems. This study presents the design and performance evaluation of a decentralized greywater treatment system integrating multi-stage filtration with constructed wetland polishing for efficient water reuse. The system consists of primary filtration units for the removal of coarse solids, followed by secondary treatment through sand and activated carbon filters to reduce turbidity, organic load, and contaminants. The final polishing stage employs a constructed wetland system utilizing natural processes involving vegetation, soil, and microbial activity to further enhance water quality. Experimental analysis was conducted to evaluate key performance parameters such as biochemical oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS), and pathogen removal efficiency. Results indicate significant improvement in water quality, achieving removal efficiencies exceeding standard reuse criteria for non-potable applications such as irrigation, flushing, and landscaping. The decentralized nature of the system ensures low operational cost, minimal energy consumption, and adaptability to rural and peri-urban settings. The study demonstrates that integrating conventional filtration with nature-based treatment systems offers a sustainable, eco-friendly, and cost-effective solution for greywater reuse and water conservation. This approach contributes to reducing freshwater demand and supports circular water management practices.

Key words: *Greywater Treatment, Decentralized Systems, Constructed Wetlands, Water Reuse, Sustainable Water Management, Filtration, BOD, COD, Environmental Engineering, Wastewater Recycling.*

1. INTRODUCTION:

Water scarcity and increasing wastewater generation have become major challenges in modern society due to rapid urbanization, population growth, and industrial development. Conventional centralized wastewater treatment systems are often expensive, energy-intensive, and difficult to implement in rural and semi-urban areas. In this context, **decentralized wastewater management systems** have emerged as a sustainable and efficient alternative.

Greywater, which includes wastewater generated from domestic activities such as bathing, washing, and kitchen use (excluding toilet waste), accounts for nearly 60–70% of total household wastewater. If treated properly, greywater can be reused for non-potable purposes such as irrigation, landscaping, and flushing, thereby reducing the demand for fresh water and minimizing environmental pollution.

This study focuses on the development of a **sustainable decentralized greywater management system** using a combination of **hybrid filtration and constructed wetland technologies**. The hybrid filtration unit removes suspended solids and reduces turbidity through layers of natural and engineered materials such as sand, gravel, and activated carbon. The constructed wetland further enhances treatment through biological, chemical, and physical processes involving wetland plants and microorganisms.

The integration of these two methods provides an eco-friendly, low-cost, and efficient solution for greywater treatment. Such systems are particularly suitable for small communities, institutions, and individual households, contributing to sustainable water resource management and environmental protection.

1.1 GREYWATER MANAGEMENT USING HYBRID FILTRATION AND CONSTRUCTED WETLANDS:

Greywater is a major component of domestic wastewater, generated from activities such as bathing, washing, and kitchen use. Improper disposal of greywater leads to environmental pollution, groundwater contamination, and health

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hazards. At the same time, increasing water demand and scarcity make it necessary to reuse wastewater effectively.

Decentralized greywater management systems provide an efficient and sustainable solution by treating wastewater at the source. In this study, a **hybrid filtration system combined with constructed wetland technology** is used to treat greywater. The hybrid filtration unit removes suspended solids, turbidity, and organic impurities using layered media, while the constructed wetland further purifies the water through natural biological and chemical processes.

The filtration media such as sand, gravel, activated carbon, and bio-materials help in physical filtration, whereas wetland plants assist in nutrient uptake and microbial degradation. The combination of these systems improves water quality significantly and makes it suitable for reuse in irrigation and other non-potable applications. This approach is eco-friendly, cost-effective, and suitable for rural and urban areas.

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1.2 METHODS AND OBJECTIVE:

Hybrid Filtration System:

The hybrid filtration system consists of multiple layers of natural and engineered materials arranged in sequence. Common materials used include:

- Gravel
- Coarse and fine sand
- Activated charcoal
- Coconut shell or biochar

These layers perform functions such as:

- Removal of suspended solids
- Reduction of turbidity
- Adsorption of organic pollutants
- Improvement of water clarity

The filtration unit acts as the primary treatment stage, preparing greywater for further purification.

Constructed Wetland System:

Constructed wetlands are engineered systems that mimic natural wetlands to treat wastewater. These systems use vegetation, soil, and microorganisms to remove contaminants.

The materials used in the greywater filtration:

1. Nylon Mesh (Pre-filter)

Purpose: Acts as the first stage of filtration.
Why used: Greywater contains large particles such as hair, lint, and food waste. These materials can clog the system.
Function: The mesh screen traps large solids and protects downstream filter media.
Material details: Typically made of synthetic polymer with 5–10 mm openings, resistant to water and chemicals.

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2. Coarse Gravel (20–40 mm)

Purpose: Flow distribution and structural support.
Why used: Prevents clogging and ensures even distribution of water.
Function: Acts as a drainage layer and supports upper filter layers.
Material details: crushed aggregates with high permeability.

3. Coconut Coir

Purpose: Biological filtration.
Why used: Eco-friendly and locally available material with high porosity.
Function: Traps organic matter and supports microbial growth for biodegradation.
Material details: Fibrous material from coconut husk, high water retention capacity.

4. Sand Layer (Fine to Medium)

Purpose: Physical filtration.
Why used: Effective in removing suspended solids and turbidity.
Function: Filters fine particles through mechanical straining.
Material details: Washed river sand with particle size 0.2–0.5 mm, free from clay.

5. Coconut Charcoal

Purpose: Adsorption of contaminants.
Why used: High adsorption capacity for organic compounds and odor.
Function: Removes color, odor, and dissolved pollutants.
Material details: Activated or crushed coconut shell charcoal, particle size 1–4 mm.

6. Bottom Gravel Layer

Purpose: Drainage support.
Why used: Prevents blockage at the outlet.
Function: Provides free flow of treated water to the outlet pipe.
Material details: Same as coarse gravel, placed around underdrain pipe.

Common plants used include:

- *Canna indica*
- *Typha*
- *Phragmites*

Functions of constructed wetlands:

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- Biological degradation of organic matter
- Removal of nutrients (nitrogen and phosphorus)
- Reduction of BOD and COD
- Improvement of overall water quality

The wetland system acts as a secondary treatment stage, enhancing purification naturally.

Objectives of the Study:

- To develop a **decentralized greywater treatment system**
- To evaluate the efficiency of **hybrid filtration media**
- To analyze the performance of **constructed wetlands**
- To promote **sustainable water reuse practices**
- To reduce environmental pollution and conserve freshwater resources

RESULT AND DISCUSSION:

WATER QUALITY STANDARD

Sl. No	Characteristics / Parameter	BIS	ICMR	WHO
1	Colour	5	2.5	-
2	Odour	Agreeable	Unobjectionable	Unobjectionable
3	Turbidity	10 NTU	5 NTU	2.5 NTC
4	pH	6.5 – 8.5	7.0 – 85	7.0 – 85
5	TDS	500 mgl	500 mgl	500 mgl
6	Hardness	300 mgl	300 mgl	200 mgl
7	Ca	75 mgl	75 mgl	75 mgl
8	Mg	30 mgl	50 mgl	30 mgl
9	CL	250 mgl	200 mgl	200 mgl
10	Sulphate	200 mgl	200 mgl	200 mgl
11	Fe	0.3 mgl	0.1 mgl	0.1 mgl
12	Nitrate	45 mgl	20 mgl	45 mgl
13	Phenolic	0.001 mgl	0.001 mgl	0.001 mgl

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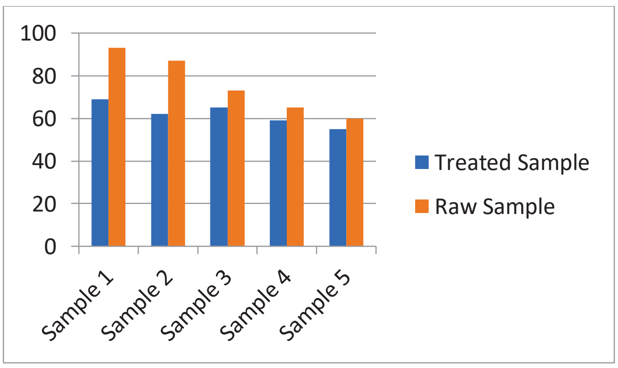
	compounds			
14	Cd. Sc	0.01 mgl	-	0.01 mgl
15	Cu. As	0.05 mgl	0.05 mgl	0.01 mgl
16	Cyanides	0.05 mgl	-	0.01 mgl
17	Pb	0.1 mgl	-	0.01 mgl
18	Anionic detergents	0.2 mgl	-	-
19	PAH	-	-	-
20	Residual Chlorine	0.2 mgl	-	-
21	Pesticides	Absent	-	-

Determination of sodium:

S.NO	CONCENTRATION	ABSORBANCE INTENSITY
1.	Sample 1	93
2.	Sample 2	87
3.	Sample 3	73
4.	Sample 4	65
5.	Sample 5	60
6.	Treated Sample 1	69
7.	Treated Sample 2	62
8.	Treated Sample 3	65
9.	Treated Sample 4	59
10.	Treated Sample 5	55



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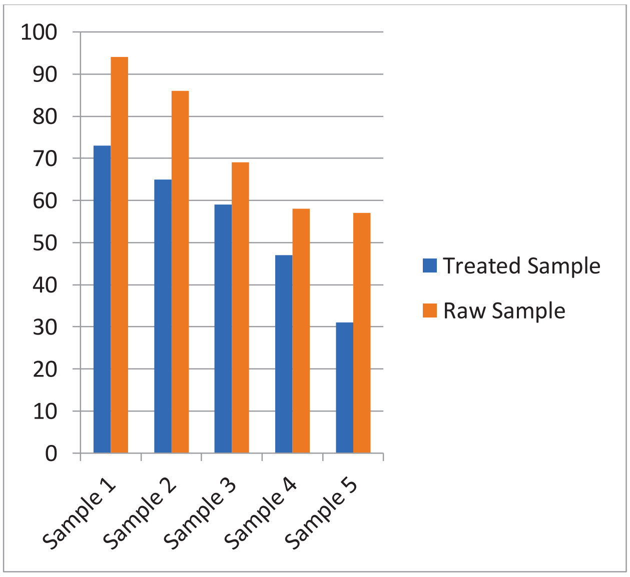
3 Determination of potassium

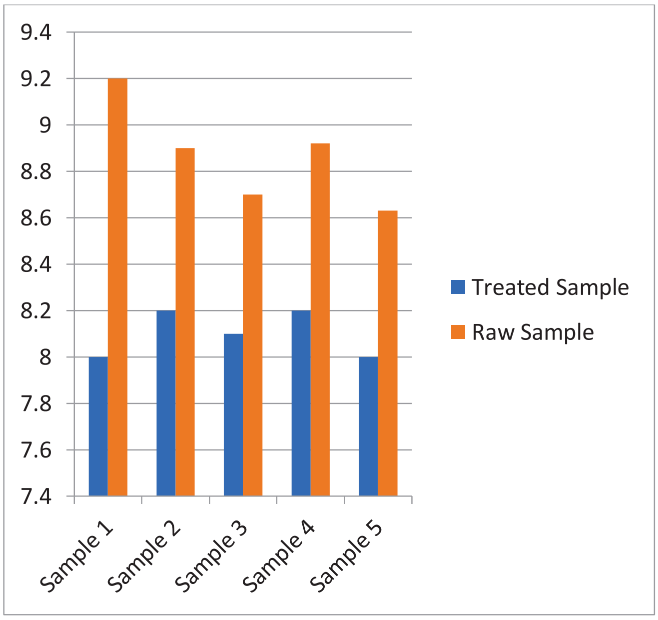
S. N O	CONCENTRATION	ABSORBANCE INTENSITY
1.	Sample 1	94
2.	Sample 2	86
3.	Sample 3	69
4.	Sample 4	58
5.	Sample 5	57
6.	Treated Sample 1	73
7.	Treated Sample 2	65
8.	Treated Sample 3	59
9.	Treated Sample 4	47
10	Treated Sample 5	31



Determination of potassium

Table :Determination of pH

S.No	Sample	Raw Water	Treated Water
1.	Unfiltered sample	9.2	8.0
2.	Sample 1	8.9	8.2
3.	Sample 2	8.7	8.1
4.	Sample 3	8.92	8.2
5.	Sample 4	8.63	8.0



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1.PH

The pH of raw greywater samples ranged between 8.7 and 9.2, indicating alkaline nature due to organic decomposition and detergent presence. After treatment, the pH reduced to around 8.0–8.2.

2. Total Solids (TSS & TDS):

The raw water samples showed high levels of total suspended solids and dissolved solids, which are harmful to reuse applications. After filtration and wetland treatment, a considerable reduction in both TSS and TDS was observehis indicates effective removal of fine particles and dissolved impurities.

3. Nitrate and Phosphate Removal:

Nitrate and phosphate concentrations were initially high due to domestic wastewater contamination.

Post-treatment results show a reduction in these nutrients, which is mainly due to biological uptake by wetland plants and microbial degradation. This helps prevent eutrophication when reused for irrigation.

4. Hardness Reduction:

The hardness of water, mainly caused by calcium and magnesium ions, showed a noticeable decrease after treatment. This indicates that filtration media and wetland processes help in reducing scaling problems in reuse applications.

5. Sodium and Potassium:

The concentration of sodium and potassium ions decreased after treatment. This confirms that the system is effective in reducing dissolved salts and improving water quality for non-potable uses.

6. Overall System Efficiency:

The hybrid filtration system removed coarse and fine impurities, while the constructed wetland provided secondary polishing through natural processes. The combined system achieved significant removal efficiency for pollutants and improved water clarity, odor, and quality.

CONCLUSION:

- Due to damping of waste material in organic and inorganic waste water get polluted.
- Organic matters decomposition pH values are incerased.
- Inorganic matters pollutions chlorine and Magnisium contents are increased.

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- When compare to ground water, surface water pollution is more due to organic decomposition.
- Ground water pollutions, now polluted up to 3km.

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