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Low-Cost Domestic Greywater Filtration Using Coconut Coir and Activated Charcoal: A Review of Performance and Design

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ABSTRACT

Households in water-stressed regions discharge large volumes of lightly polluted water every day. Greywater from bathrooms, laundry and kitchens makes up roughly 50–80% of domestic wastewater and, with suitable treatment, can be reused for toilet flushing, gardening and vehicle washing. This paper reviews low-cost, decentralised filtration systems built from coconut coir, charred coconut husk powder, coconut-shell activated charcoal, sand and gravel. We first summarise how greywater quality varies between household sources, then explain how each medium works, and finally compare removal efficiencies reported in published column and pilot studies. Coir is effective at catching suspended solids, with reported removals of 80–92%, while activated charcoal handles dissolved organics and surfactants; in several studies it removed more than 90% of BOD_5 and COD and more than 99% of anionic surfactants. Layered beds that combine the two media consistently outperformed single-medium filters, and in the studies reviewed their effluent met CPCB and WHO limits for non-potable reuse. We also discuss clogging, biofouling and the uneven flow typical of households, and propose practical design and maintenance guidelines for household units. Most of the evidence comes from laboratory and small pilot studies, so field validation is still needed.

Keywords: greywater characterisation, coconut coir, activated charcoal, decentralised filtration, water reuse, non-potable standards

1. INTRODUCTION

1.1 Background

Water scarcity is now one of the defining environmental and social problems of this century. According to WHO and UN-Water assessments, more than 2.3 billion people live in water-stressed countries, and inadequate access to safe water and sanitation is linked to over 1.6 million deaths each year. Urbanisation, population growth, industrial demand and a changing climate are all pulling down conventional freshwater supplies. In many cities of South Asia, Africa and Latin America, piped supply is available for only a few hours a day.

Because of this gap between demand and supply, water engineers have started to move away from the traditional "use and dispose" model towards circular approaches in which water is recovered and reused. A key step in this shift is separating household wastewater at source into two streams. Blackwater is the discharge from toilets and urinals; it carries excreta, pathogens and concentrated nitrogen and phosphorus. Greywater is everything else: water from showers, wash basins, washing machines, laundry troughs and kitchen sinks. By volume, greywater is the larger stream, making up 50–80% of household wastewater depending on consumption patterns, plumbing and lifestyle [1], [7], [28]. Table 1 shows the typical contribution of each household source.

Table 1. Domestic water use and greywater generation by household source

Household source	Share of water use (%)	Greywater class	Main pollutants
Bathroom (shower and basin)	40–55	Light greywater	Soaps, body fats, hair; low organics; moderate pathogens
Laundry (washing machine)	20–35	Light/medium greywater	Surfactants, phosphates, lint; high pH, alkalinity and TSS
Kitchen sink and dishwashing	10–25	Dark greywater	Food particles, oil and grease; high COD/BOD and turbidity
Toilet (blackwater)	20–30	Excluded	High nitrogen, faecal pathogens, organic matter

1.2 Why decentralised treatment?

For decades, urban sanitation has depended on centralised sewers that carry mixed wastewater to a sewage treatment plant. This model is expensive: laying and maintaining sewer networks can take up to 70% of a municipal sanitation budget, and treatment plants use a lot of energy and are easily upset by storm flows or industrial spills. Decentralised treatment is a more flexible alternative [25]. Greywater has a much lower organic and pathogen load than combined sewage, so it can be treated at or near the point of use with low-energy, simple systems. Reusing treated greywater for flushing, irrigation, vehicle washing, dust control or concrete curing can cut household freshwater demand by 30–50%, and it also reduces the volume sent to storm drains, which helps to limit urban flooding and eutrophication [18], [19].

1.3 Scope and objectives

Coconut husk and shell are abundant agricultural wastes in coastal India and other tropical regions, which makes them attractive and cheap filter materials. This review looks at household-scale filters that use raw coconut coir, charred coconut husk powder (CCHP) and coconut-shell activated charcoal together with graded sand and gravel. The objectives are:

- to summarise the physical, chemical and microbiological quality of greywater from bathrooms, laundry and kitchens;
- to explain how coir, CCHP and activated charcoal remove suspended solids, dissolved organics, surfactants and pathogens;
- to compare single-layer and multi-layer filters across different bed depths and hydraulic loading rates; and
- to check reported effluent quality against CPCB (India) and WHO limits for non-potable reuse and to derive practical design and maintenance guidelines.

We reviewed peer-reviewed papers, theses and regulatory documents on greywater characterisation and on filtration with coir, biochar, activated carbon and sand. Values in the tables are those reported by the original authors. Because experimental conditions differ between studies, comparisons should be read as indicative rather than exact.

1.4 Link to the Sustainable Development Goals

This work mainly supports SDG 6 (Clean Water and Sanitation), in particular Target 6.3 on halving untreated wastewater and increasing safe reuse, and Target 6.4 on water-use efficiency. It also relates to SDG 11 (decentralised urban sanitation) and SDG 12 (making use of agricultural waste such as coconut husk). The evidence reviewed here suggests that household filters can cut freshwater demand and keep coconut waste out of landfills; however, the real impact depends on field-scale performance, flow buffering and regular maintenance.

2. CHARACTERISTICS OF HOUSEHOLD GREYWATER

A good filter design starts with a clear picture of what is in the water. Published studies agree that greywater quality varies a great deal with time, place and source, depending on how many people live in the house, their habits, the products they use and the quality of the supply water [8], [20], [27]. Researchers usually split greywater into “light” greywater from showers, baths and hand basins, and “dark” greywater, which includes kitchen sinks, dishwashers and washing machines and carries more organics, grease and surfactants [7].

Temperature is typically 18–35 °C. Warm water speeds up microbial activity, so stored greywater can use up its dissolved oxygen quickly and turn anoxic. pH depends strongly on the source: kitchen water is often mildly acidic (pH 5.8–6.8) because food residues ferment, whereas laundry water is strongly alkaline (pH 8.0–10.5) because of the builders and carbonates in washing powders. Suspended solids range from about 33 mg/L in light bathroom streams to more than 1,800 mg/L in raw kitchen and laundry discharges (Table 2).

A notable chemical feature, highlighted by Bakare and Mtsweni [1] and Jefferson et al. [7], is the high COD:BOD_5 ratio of greywater, commonly 2.5–6.4 compared with about 1.8–2.2 for domestic sewage. This means that a large share of the organic load is slowly biodegradable or non-biodegradable, for example linear alkylbenzene sulfonates (LAS), optical brighteners, EDTA, bleaching agents and fragrances. Greywater is also short of nitrogen and phosphorus relative to carbon (a COD:N:P ratio of about 100:2.25:0.06 in bathroom greywater), which slows biological treatment. For these reasons, physical filtration and adsorption are often more dependable than purely biological processes.

Table 2. Physicochemical and microbiological profile of raw greywater reported in the literature

Parameter	Unit	Bathroom	Laundry	Kitchen	Combined
pH	–	6.4–8.2	7.3–10.5	5.8–7.0	6.1–8.4
Electrical conductivity	µS/cm	156–680	450–1,830	320–1,270	190–1,500

Parameter	Unit	Bathroom	Laundry	Kitchen	Combined
Turbidity	NTU	17–120	39–444	133–375	20–619
Total suspended solids	mg/L	25–183	68–465	134–1,800	23–1,140
BOD_5	mg/L	85–253	154–600	320–812	14–1,240
COD	mg/L	367–1,800	509–3,672	1,200–8,071	25–2,878
COD:BOD_5 ratio	–	2.8–3.6	2.5–6.1	2.9–4.9	2.5–6.4
Anionic surfactants (MBAS)	mg/L	0.5–12.0	10.0–120.0	1.0–25.0	1.0–48.0
Total coliforms	CFU/100 mL	10^2–10^5	10^2–10^6	10^5–10^8	10^3–10^7
Faecal coliforms / E. coli	CFU/100 mL	10^1–10^3	10^1–10^4	10^3–10^6	10^1–10^5

Microbiologically, greywater is far from sterile. Although urine and faeces are excluded in principle, bathing, washing of soiled clothes and raw-food preparation introduce faecal coliforms, enterococci and opportunistic bacteria. Thermotolerant coliform counts of 10^2 to 10^7 CFU/100 mL have been reported in laundry and shower water, with Escherichia coli, Salmonella spp., Staphylococcus aureus and Pseudomonas aeruginosa frequently detected [28]. These organisms can survive and even regrow in stored greywater, so treatment should have more than one stage before reuse.

3. FILTER MEDIA AND HOW THEY WORK

3.1 Coconut coir and charred husk powder

Coconut coir is the fibrous husk of Cocos nucifera L. Millions of tonnes are produced every year in tropical regions, where disposal is often a problem. Chemically it consists of about 40–45% lignin, 30–35% cellulose and 10–15% hemicellulose and pectin. The high lignin content gives the fibre strength and resistance to enzymatic breakdown, which makes it more durable than straw, cotton or bagasse. Table 3 compares coir with its charred form and with two other common media.

Table 3. Properties of natural fibre media compared with river sand

Property	Raw coir fibre	Charred coir (CCHP)	Luffa sponge	River silica sand
Lignin content (%)	41.5–45.0	Carbonised	8.0–12.0	0 (inorganic)
Cellulose content (%)	32.0–36.0	Rearranged matrix	55.0–62.0	0 (inorganic)
Bulk density (g/cm³)	0.08–0.12	0.22–0.35	0.02–0.05	1.45–1.65
Porosity (%)	88–94	75–85	92–96	35–42
Specific surface area	1.2–3.5 m²/g	150–450 m²/g	0.8–1.8 m²/g	0.02–0.15 m²/g
C/N ratio	300:1–500:1	Stable carbon	120:1–200:1	Not applicable
Main mechanism	Straining, depth capture	Micropore adsorption	Coarse straining	Granular interception

Raw coir acts as an open, three-dimensional fibre network. It strains particles at the surface and traps more of them inside its large voids. Its porosity of 88–94% gives a large void volume for holding lint, grease droplets and particulate organic matter without causing sudden head loss or surface blinding. The high C/N ratio (300:1–500:1) also slows bacterial attack on the fibre itself, so coir beds keep their structure for a long time. Under intermittent flow,

aerobic biofilms grow on the fibres and break down some of the captured organic matter. Together, straining and biofilm activity are reported to reduce influent suspended solids by up to 92.3% and COD by around 51–63% before any polishing step [3], [6].

Charring changes the material considerably. Taylor et al. [3] showed that slow pyrolysis of coconut husk at 600 °C produces CCHP, in which loss of the hemicellulose fraction opens up a network of micropores (<2 nm) and mesopores (2–50 nm) and raises surface area from about 2.5 m^2/g to over 350 m^2/g. SEM and FTIR analyses indicate that pyrolysis removes unstable hydroxyl groups and exposes stable aromatic carbon, which improves adsorption. In that study, CCHP columns removed 88.4% of nitrate and about 2.9 log of faecal coliforms. Wider reviews of biochar-based water treatment point the same way [29], [31], and coconut husk has also been used in full-scale decentralised systems [32].

3.2 Coconut-shell activated charcoal

Coconut-shell activated carbon is widely regarded as one of the best adsorbents for liquid-phase treatment. Compared with wood- or coal-based carbons it is harder, has lower ash content and a denser microporous structure [14], [24]. It is produced by steam activation at 800–1000 °C or by chemical activation with agents such as $ZnCl_2$, H_3PO_4 or $FeCl_3$, and the result is a very large internal surface of roughly 1,000 to over 3,100 m^2/g, with pore volumes up to 1.5 mL/g [30]. Table 4 lists typical properties.

Table 4. Structural and adsorptive characteristics of coconut-shell activated carbon

Parameter	Typical range	Dominant pore type	Target pollutants / role
Specific surface area (BET)	1,000–3,100 m^2/g	Micropores (<2 nm)	Dissolved organics, surfactants
Total pore volume	0.85–1.50 mL/g	Micro/mesopore mix	Low-molecular-weight organics
Bulk density	0.45–0.55 g/mL	Granular matrix	Resistance to bed attrition
Iodine number	950–1,250 mg/g	Micropore indicator	Small organic molecules
Methylene blue number	180–320 mg/g	Mesopore indicator	Dyes, surfactants, colour
Fixed carbon	74.5–82.0%	Aromatic carbon	Chemical stability, regeneration

Adsorption on activated charcoal involves both physisorption (weak van der Waals forces) and chemisorption (interaction with surface functional groups). The dissolved molecules that cause most of the BOD_5 and COD in greywater, such as residual soap, LAS, fragrances, lipids and phenolics, are attracted to the hydrophobic carbon surface, diffuse into the pores and become trapped. The carbon also acts as a support for aerobic biofilms (bio-activated carbon), which keep degrading adsorbed material and so extend the life of the bed.

Adsorption capacity is normally described with isotherm models. The Langmuir model assumes monolayer adsorption on uniform sites:

$$q_e = (q_{max} K_L C_e) / (1 + K_L C_e) \qquad (1)$$

where q_e is the amount adsorbed per unit mass of carbon at equilibrium (mg/g), C_e is the equilibrium concentration in the water (mg/L), q_{max} is the maximum monolayer capacity (mg/g) and K_L is the Langmuir constant (L/mg). The Freundlich model allows for heterogeneous surfaces and multilayer adsorption:

$$q_e = K_F C_e^{1/n} \qquad (2)$$

where K_F is the capacity factor and 1/n is the adsorption intensity. Coconut-shell carbon is reported to fit the Freundlich model very well ($R^2 > 0.98$) for anionic surfactants and hard-to-remove COD, which indicates good affinity for complex organic molecules even at low concentrations.

3.3 Multi-media filter arrangement

Each medium has a weakness when used alone. Coarse fibres remove solids but not dissolved organics; fine sand captures colloids but clogs quickly with grease; and activated carbon removes dissolved organics but is easily blinded by suspended solids. Layering them in sequence lets each one do what it does best. A typical gravity column, from top to bottom, has: a gravel layer (20–60 mm stone) to spread flow and catch coarse grit; a raw coir (or luffa) layer, 10–15 cm deep, to strain lint, hair and solids; a fine river sand layer (0.5–1.0 mm, 10–18 cm) for finer clarification and biofilm attachment; and a granular activated charcoal (GAC) layer, 5–15 cm deep, for organics, colour, odour and surfactants. Many designs add an anaerobic baffled reactor (ABR) or septic pre-settling tank upstream to even out flow and digest settleable solids.

3.4 Comparison with other media

Several studies have compared coir and charcoal with other natural and mineral media. Dalahmeh [17] and Adelodun [6] found that coconut coir retained 78–92.3% of total solids, more than loofah (56–84.6%) and other plant-based media. In column trials that compared bark, charcoal, foam and sand, activated charcoal reduced COD by 94% and BOD_5 by 97%, whereas a conventional sand filter reached only about 72% and 75%, and a foam filter removed less than 37% of BOD_5 [5]. Sand [11], natural zeolite [23] and Moringa seed powder combined with sand [22] have also been tested as low-cost alternatives, and submerged membrane bioreactors can deliver high-quality effluent but at higher cost and complexity [33]. Overall, coir paired with coconut-shell charcoal is a good balance of performance, cost and local availability.

4. OPERATIONAL CHALLENGES AND REUSE STANDARDS

4.1 Clogging and biofouling

Natural-media filters perform well in the laboratory, but in the field the main cause of failure is gradual clogging. Lint, hair, food particles and insoluble calcium–soap complexes build up in the pores of the sand and charcoal beds, which reduces hydraulic conductivity and increases head loss. The Ergun equation is commonly used to describe head loss through packed beds:

$$\Delta P / L = [150\,\mu\,(1-\varepsilon)^2\,v] / (d_p^2\,\varepsilon^3) + [1.75\,\rho\,(1-\varepsilon)\,v^2] / (d_p\,\varepsilon^3) \qquad (3)$$

where $\Delta P/L$ is the pressure drop per unit bed length, μ is the dynamic viscosity of water, ε is bed porosity, v is the superficial velocity (the hydraulic loading rate), d_p is the equivalent grain diameter and ρ is the fluid density. As solids and biofilm fill the voids, ε falls and head loss climbs steeply. For example, if porosity drops from 0.40 to 0.32 (a 20% loss), the viscous term of the equation rises by about 150%, which is enough to cause ponding or overflow in a gravity filter.

Biofouling is just as important. Greywater carries dissolved organics and nutrients that encourage microbial growth, and the microbes secrete extracellular polymeric substances (EPS), a sticky mix of polysaccharides, proteins and lipids. EPS glues grains together, forms a slime layer on the surface, and causes channelling and further clogging. In raw coir there is an extra problem: fungi and bacteria slowly break down the pectin and hemicellulose, which weakens the fibre, lets the bed compact, and releases humic and fulvic acids that add colour and COD to the effluent.

4.2 Uneven household flows

Unlike a municipal plant that benefits from the averaging effect of thousands of connections, a single home produces sharp peaks and long gaps. Flows peak in the morning (about 7–9 AM, with showers and laundry) and again in the evening (about 6–8 PM, with cooking and washing), and may drop to zero for hours in between. This causes shock loading in the peaks and drying in the gaps. Dry spells can kill the biofilm and crack sand or coir beds, leading to short-circuiting when flow returns. Chemical strength also swings: laundry discharge can briefly push pH up to 10.5 and anionic surfactants up to 120 mg/L, which can inhibit nitrifying bacteria and overload the charcoal if there is no equalisation tank.

4.3 Reuse standards

Another barrier to wider adoption is that reuse standards are missing or poorly enforced in many developing regions. In India, the Central Pollution Control Board (CPCB) sets discharge and reuse limits under the Environment (Protection) Rules [15], [35], while WHO provides health-based guidelines for the safe use of greywater [16]. Table 5 compares the main limits with the effluent quality reported for the filters reviewed here. Washing, irrigation and other reuse should also consider possible effects on soil and plants [21], and sampling and analysis should follow standard methods [34].

Table 5. Water quality limits for non-potable reuse and typical treated-greywater range

Parameter	Unit	CPCB (India)	WHO	Reported treated range
pH	–	5.5–9.0	6.0–9.0	6.8–7.8
Total suspended solids	mg/L	< 30	< 30	6.0–26.0
Turbidity	NTU	10–50	< 5	1.0–4.5
BOD_5	mg/L	< 30	< 30	2.4–19.4
COD	mg/L	< 100	< 100	11.0–95.0
Oil and grease	mg/L	< 10	< 10	Below detection limit

Parameter	Unit	CPCB (India)	WHO	Reported treated range
Faecal coliforms / E. coli	CFU/100 mL	< 100	< 100	< 10–89

To meet these limits, a decentralised system has to bring BOD_5 below 30 mg/L, COD below 100 mg/L, TSS below 30 mg/L, turbidity below 5–10 NTU and faecal coliforms below 100 CFU/100 mL. Doing this reliably with passive, low-cost filtration and no chlorine or UV disinfection is the main design challenge; it depends on getting bed depth, retention time and backwashing right.

5. PERFORMANCE OF REPORTED SYSTEMS

5.1 Removal of BOD, COD, solids and microorganisms

Table 6 summarises influent and effluent values from representative studies of coir, biochar, charcoal and sand–charcoal filters.

Table 6. Removal efficiencies reported for different filter configurations

Study and media	Parameter	Influent	Effluent	Removal
Sabara et al. [2]: activated carbon + coir + ABR	BOD_5 (mg/L)	54.88	17.80	67.6%
	COD (mg/L)	655.00	152.00	76.8%
	TSS (mg/L)	464.65	59.68	87.2%
	Turbidity (NTU)	313.00	16.25	94.8%
Taylor et al. [3]: pyrolysed coir (CCHP)	COD (mg/L)	380.00	110.20	71.0%
	Turbidity (NTU)	85.00	4.25	95.0%
	Nitrate (mg/L)	45.00	5.23	88.4%
	Faecal coliforms	10^5 CFU	10^2 CFU	2.87 log
Tusiime et al. [4]: sand + GAC, column B	BOD_5 (mg/L)	75.25	2.35	96.9%
	COD (mg/L)	123.50	4.40	96.4%
	Turbidity (NTU)	257.50	2.00	99.2%
	Total coliforms	6.95×10^7	4.30×10^3	99.9%
Vinnerås et al. [5]: activated charcoal filter	BOD_5 (mg/L)	425.00	12.75	97.0%
	COD (mg/L)	890.00	53.40	94.0%
	MBAS surfactant (mg/L)	30.00	< 0.30	> 99.0%
	Total phosphorus (mg/L)	15.00	1.35	91.0%
Adelodun [6]: coir filter	Total solids (mg/L)	3,980.00	796.00	80.0%

Study and media	Parameter	Influent	Effluent	Removal
	Total solids, well/borehole water (mg/L)	2,600.00	200.20	92.3%

The studies in Table 6 point to a clear division of labour between the media:

- **pH.** Alkaline laundry water (pH 9.2–10.5) is buffered as it passes through charcoal, because carbonate and hydroxide ions react with acidic carboxylic and phenolic groups on the carbon surface. Effluent pH settles at about 6.8–7.8, inside the CPCB and WHO range.
- **Solids and turbidity.** Coir acts as a coarse strainer, removing 80–92.3% of suspended or total solids. The sand and charcoal layers below it capture finer colloids and emulsified soap, taking turbidity from over 300 NTU to about 2 NTU in the best cases.
- **Organics.** Sand–GAC and charcoal columns brought BOD_5 from 75–425 mg/L down to about 2–13 mg/L (about 97%) and COD from 124–890 mg/L to about 4–53 mg/L (94–96%). The coir–ABR–carbon system, which received a heavier solids load, reached lower values (67.6% BOD_5 and 76.8% COD).
- **Surfactants, colour and odour.** Coconut-shell charcoal removed more than 99% of anionic surfactants (LAS). Its high methylene blue capacity also explains the good removal of dyes and odour reported in these studies.
- **Microorganisms.** CCHP and sand–charcoal columns reduced coliforms by roughly 2.9 to 4.2 log in the studies in Table 6. The likely mechanisms are straining in the dense coir matrix, adsorption onto hydrophobic biochar surfaces and natural die-off in the nutrient-poor biofilm.

5.2 Effect of bed depth and hydraulic loading

Treatment performance and filter life depend strongly on bed thickness, hydraulic retention time (HRT) and hydraulic loading rate (HLR). Table 7 compiles results from studies that varied these parameters [4].

Table 7. Effect of charcoal bed thickness and HRT on effluent quality

Configuration	Charcoal depth (cm)	HRT	COD removal (%)	TDS removal (%)	Effluent turbidity (NTU)
Sand + charcoal, layer 1	5.0	12 h	92.8	30.8	2.0
Sand + charcoal, layer 2	10.0	24 h	97.8	64.7	0.0
Sand + charcoal, layer 3	14.0	36 h	96.4	75.8	0.3
Raw coir + sand (control)	0 (no charcoal)	12 h	37.8	12.5	12.0
Pyrolysed CCHP column	10.0 (CCHP)	45 min (0.15 m/h)	71.0	45.0	4.2

Increasing the charcoal depth from 5 cm to 14 cm gave more contact time and raised TDS removal from 30.8% to 75.8%, while COD removal rose above 97%. The best HRT was in the range of 12–24 hours. Going to 36 hours added little for TDS, and long stagnation in low-flow periods can create local anaerobic zones that release some organic matter back into the water. Running gravity columns at a modest HLR of 0.15 m/h to 1.58 m^3/m^2/day is reported to balance treatment quality against reasonable run time between backwashes.

5.3 Hybrid treatment trains

To raise performance and extend media life, some researchers have combined the coir–charcoal filter with other units. One arrangement places an ABR upstream of a coir–activated charcoal column and a horizontal-flow constructed wetland (HFCW) planted with Canna indica or water hyacinth downstream [2], [13], [26]. Table 8 compares such trains with single-stage filters.

Table 8. Removal efficiencies of single-stage, multi-media and hybrid treatment trains

Treatment train	BOD_5 (%)	COD (%)	TSS (%)	Turbidity (%)	Coliform reduction
Single sand filter	75.0	72.0	85.0	82.0	1.0–1.5 log
Single raw coir filter	16.0	37.8	80.0	63.0	0.5–1.0 log
Multi-media (coir + sand + GAC)	96.9	96.4	95.3	99.2	3.0–4.0 log
Hybrid: ABR + coir/GAC	67.6	76.8	87.2	94.8	3.5–4.5 log
Hybrid: GAC + planted wetland (HFCW)	98.2	94.5	96.8	98.5	4.0–5.0 log

In these trains the ABR removes about 40–50% of settleable solids and some organic load. The settled water then passes through the coir–charcoal column for fast clarification and high-capacity adsorption. Finally, in the wetland, plant roots take up residual nitrate and phosphate, and root exudates encourage further biological nitrification. The GAC–wetland train achieved the highest removals (98.2% BOD_5, 94.5% COD), producing water suitable for landscaping and other non-potable uses. The ABR–coir–GAC system in the data of Sabara et al. [2] performed less strongly on organics, but its influent was also heavily loaded with solids (about 465 mg/L TSS).

6. PRACTICAL DESIGN AND MAINTENANCE GUIDELINES

Based on the studies reviewed, the following criteria are suggested for a household-scale gravity filter. They are a starting point for pilot testing and should be adjusted for local water quality and household size.

- **Layering.** From top to bottom: gravel support (10 cm, 20–40 mm), fine river sand (15 cm, 0.5–1.0 mm), raw coir or biochar (12 cm) and coconut-shell activated charcoal (15 cm, 1.5–3.0 mm GAC).
- **Hydraulic operation.** Design for an HLR of 0.15–1.58 m^3/m^2/day, and use intermittent dosing (for example 3 hours of flow followed by 1 hour of rest) to keep the bed aerobic and avoid drying out.
- **Pre-treatment and equalisation.** Fit a grease trap or coarse screen (about 1 mm) and an equalisation tank of around 12 hours' capacity to catch oil and grease and smooth out the morning and evening peaks.
- **Backwashing and replacement.** Backwash (up-flow air/water scouring at about 1.5 times the operating rate) every 14–21 days. Replace raw coir every 6–9 months, and replace or thermally regenerate the activated charcoal (about 400–500 °C) every 12–18 months.

7. FUTURE SCOPE

- **Chemical activation and functionalisation.** Eco-friendly agents such as iron salts or citric acid could be tested to improve the phosphate and heavy-metal uptake of coconut husk biochar.
- **Long-term field trials.** Multi-year pilots in different climates are needed to study bed compaction, biofouling and life-cycle cost under real household conditions.
- **Modular products.** Standard, low-cost prefabricated cartridges, possibly made from recycled polymers, would make installation and replacement easy for households.
- **Policy support.** Building codes and municipal by-laws could encourage dual plumbing for greywater recycling, supported by subsidies and public awareness campaigns.

8. CONCLUSION

This review examined low-cost household greywater filters based on raw coconut coir, charred coconut husk powder and coconut-shell activated charcoal. The main findings are as follows.

- Greywater makes up 50–80% of household wastewater, but its quality varies widely by source. Its high COD:BOD_5 ratio (2.5–6.4) and low nutrient content make purely biological treatment unreliable, so filtration and adsorption are important.
- Raw coir, with 41.5–45% lignin and 88–94% porosity, removed 80–92.3% of solids without immediate clogging in the studies reviewed, which protects the layers below it.

- Coconut-shell activated charcoal (1,000–3,100 m^2/g) removed more than 90% of BOD_5 and COD and more than 99% of anionic surfactants in several studies, and it also neutralised alkaline laundry water to pH 6.8–7.8.
- Layered beds of gravel, coir, sand and GAC outperformed single-medium filters, reaching effluent turbidity of about 2 NTU and a coliform reduction of roughly 3–4 log, and met CPCB and WHO limits for non-potable reuse in the reported tests.

Most of this evidence comes from laboratory columns and small pilot units, so these results should not be assumed to carry over directly to homes. Clogging, uneven flows and maintenance remain the main practical obstacles, and long-term field studies are the most important next step.

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