

# Assessment of Recycled Brick and Concrete Aggregate as Filter Media for Laundry Wastewater Treatment for Irrigation Purposes

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## Research Article

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# Abstract

Untreated laundry greywater and mismanaged construction and demolition waste (CDW) represent two linked environmental burdens in rapidly urbanising areas. This study valorises CDW by evaluating broken brick and crushed concrete, sourced locally in Ogbomoso, Nigeria, as low-cost filter media for treating laundry greywater for irrigation reuse. Six laboratory-scale vertical-flow column filters (three brick, three concretes; media depths of 700, 800 and 900 mm) were packed with graded, washed and oven-dried aggregate and dosed with raw laundry greywater generated using a homemade liquid soap. Raw and treated effluent were characterised for pH, temperature, turbidity, electrical conductivity (EC), total dissolved solids (TDS), calcium, magnesium, sodium, nitrate, surfactant and chloride, and the sodium adsorption ratio (SAR) of each configuration was compared with FAO/Ayers–Westcot irrigation guidelines. Hydraulic conductivity and clogging behaviour were assessed using the constant-head method across three successive wastewater application cycles. Both media reduced turbidity (60–80%), surfactant (30–50%), sodium, nitrate and chloride, with performance improving at greater bed depth; crushed concrete achieved marginally higher turbidity and surfactant removal but leached calcium and raised pH, EC and TDS above raw-water levels, whereas broken brick removed pollutants without leaching. Broken brick effluent (900-mm bed) gave the closest overall compliance with irrigation guidelines, though chloride remained in the slight-to-moderate restriction category throughout. Hydraulic conductivity declined by 26.5–31.0% after three filtration cycles, with only partial recovery during rest periods, confirming that both media would require periodic maintenance. The results demonstrate that recycled brick aggregate is a chemically stable and practically viable low-cost medium for decentralised greywater treatment in resource-constrained settings.

## 1. Introduction

Rapid urbanisation and population growth are placing sustained pressure on freshwater resources, particularly in developing regions, while the construction sector simultaneously generates growing volumes of construction and demolition waste (CDW) that is frequently discarded without further use [1, 2]. Greywater, wastewater from bathing, laundry and kitchen activities, excluding toilet waste, can constitute 50–80% of total domestic wastewater and represents a substantial, largely untapped source of non-potable water for irrigation and other reuse applications [3, 4]. Recent field and modelling studies continue to confirm that laundry greywater specifically is amenable to low-cost, decentralised treatment and reuse: Cardoso and Bodnar [5] demonstrated that a simple coagulation–flocculation and sand filtration sequence could bring synthetic laundry greywater within the sodium adsorption ratio (SAR) threshold recommended for safe irrigation, while a field assessment of thirty operating laundry-to-landscape greywater systems in California found that most systems, even decades-old and unmaintained, produced water with acceptable reuse-quality parameters [6]. In Vietnam, a six-layer physical filtration and disinfection train achieved over 60% removal of turbidity, biochemical oxygen demand and chemical oxygen demand from household greywater destined for irrigation reuse [7], underscoring that simple filtration remains a technically credible and economically attractive treatment route for this waste stream in resource-constrained settings [8, 9].

At the same time, the valorisation of CDW as a filtration medium has attracted growing research attention as a means of simultaneously addressing solid-waste accumulation and water treatment needs. Haiyan et al. [10] showed that recycled concrete and brick aggregates used as constructed-wetland substrates achieved total phosphorus and chemical oxygen demand (COD) removal efficiencies of up to 87.1% and 74.9% respectively, performance that in several cases exceeded that of conventional natural substrates such as limestone and zeolite. Verma et al. [2], working with small-scale decentralised filtration units built entirely from CDW aggregates, reported turbidity and total-solids removals of up to 98% and 86% respectively from river water, concluding that recycled aggregate can fully substitute for fresh aggregate in gravity-fed filtration systems intended for resource-poor communities. More recently, Aguirre Alvarez et al. [11] combined CDW substrates with vascular plants in a nature-based system for greywater treatment, reporting that CDW fractions selected for their affinity for organic matter and nutrients performed comparably to conventional wetland media. Collectively, these studies establish that CDW-based filter media are technically capable of substantial pollutant removal; however, comparatively little of this literature evaluates mixed brick and concrete rubble specifically against laundry greywater, and fewer studies still report the hydraulic conductivity and clogging behaviour of these media under repeated wastewater dosing, a gap also noted in earlier low-cost filter studies using brick as a supporting rather than primary medium [12, 13].

A further consideration specific to laundry greywater is the fate of anionic surfactants derived from detergent formulations. Recent reviews confirm that surfactant concentrations in greywater vary widely (7–436 mg/L) and that simple physicochemical filtration alone does not completely remove them, since surfactant molecules tend to adhere to solid surfaces within the filter matrix rather than degrade [14, 15]. Because surfactant residues can alter soil wetting behaviour and contribute to sodium loading if discharged untreated, their removal is an important secondary performance indicator for any low-cost greywater filter intended for irrigation reuse. Likewise, the long-term hydraulic performance of granular filter media, governed by progressive pore clogging from trapped solids and biofilm accumulation [16–18], has been shown in recent intermittent sand-filter studies to be a major determinant of a filter's operational lifespan and maintenance burden, with one study reporting an 85% loss of infiltration capacity in a conventional sand filter after 280 days of continuous dairy-wastewater dosing [19]. Despite this, hydraulic conductivity decline is rarely reported alongside pollutant removal efficiency in studies of recycled-aggregate filters, making it difficult for practitioners to judge the practical durability of these systems.

This study addresses these gaps by evaluating broken brick and crushed concrete, both sourced from local CDW, as filter media for the treatment of real laundry greywater collected from a commercial laundry service in Ogbomoso, Nigeria. The specific objectives were to: (i) characterise the raw greywater; (ii) design, fabricate and physically characterise laboratory-scale vertical-flow filter columns using each medium at three bed depths; (iii) determine the pollutant removal efficiency of each configuration; (iv) assess the suitability of the treated effluent for irrigation against FAO/Ayers–Westcot guidelines; and (v) quantify the hydraulic conductivity and clogging behaviour of each medium across repeated filtration cycles. By evaluating chemical performance and hydraulic durability together, the study aims to provide

practical, decision-relevant evidence for the use of recycled CDW aggregate in decentralised greywater treatment.

## **2. Materials and Methods**

### **2.1 Greywater collection**

Laundry greywater was collected as a single batch of approximately 20 L from HARFO Laundry Service, Adenike Street, Ogbomoso, Nigeria, on 18 August 2026 and transported to the University of Ibadan, Department of Agronomy, for physicochemical analysis on 19 August 2026. The wash water was generated using a homemade liquid soap rather than a commercial powder detergent; liquid soap formulations are typically based on saponified fatty-acid salts with comparatively lower quantities of the sodium-based builders and phosphates used in powder detergents, a consideration relevant to interpreting the raw-water quality reported in Section 3.1.

### **2.2 Filter media sourcing and preparation**

Two filter media were evaluated, both recovered from local CDW: (i) crushed concrete, obtained from demolished reinforced-concrete structural elements and composed primarily of calcium silicate hydrate phases, residual calcium carbonate and quartz aggregate; and (ii) broken brick, obtained from demolished fired-clay brick masonry and composed of kaolinite and illite clay minerals, quartz and iron oxides. Both materials were size-reduced by hammer crushing, sieve-fractionated (broken brick: 6.3–13.2 mm; crushed concrete: 13.2–25.0 mm), washed in repeated changes of clean water until visually clear, and oven-dried at 105°C for 24 h before storage in sealed containers. Figure 1 shows the aggregate at this preparatory stage, before washing and sieve fractionation into the size ranges used for column packing and Fig. 2 provides a close-up view of the broken brick and concrete rubble, showing the fired-clay masonry material later crushed and sieved to the 6.3–13.2 mm fraction used in the brick columns.

### **2.3 Column design and physical characterisation of media**

Six vertical-flow columns were fabricated from Schedule 4 inches PVC pipe (101.6 mm internal diameter), packed with either broken brick or crushed concrete at media depths of 700, 800 or 900 mm (overall column heights of 800, 900 and 1000 mm), giving six treatment combinations (Table 1). Each column comprised a base drainage layer of coarse gravel, a 150 µm nylon mesh separation layer, the primary filter medium (packed in three tamped sub-layers), a second mesh layer, and an inlet fitting; columns were pre-saturated by upward flow before being returned to downflow operation. Bulk density was determined by the standard cylinder method, particle density by the pycnometer (water-displacement) method, and porosity ( $n$ ) calculated using Eq. (1):

$$n (\%) = \left[ 1 - \frac{\rho_{\text{bulk}}}{\rho_{\text{particle}}} \right] \times 100$$

1

where  $\rho_{\text{bulk}}$  and  $\rho_{\text{particle}}$  are the bulk and particle densities ( $\text{g/cm}^3$ ). The laboratory filtration setup, comprising the three PVC columns packed with graded media and connected to a common outlet manifold, is shown in Fig. 3, and a schematic of the six columns is given in Fig. 4.

Table 1  
Column configurations and codes

| Column code | Medium           | Size range (mm) | Grades (mm)    | Media depth (mm) | Column length (mm) |
|-------------|------------------|-----------------|----------------|------------------|--------------------|
| B700        | Broken brick     | 6.3–13.2        | 13.2, 9.5, 6.3 | 700              | 800                |
| B800        | Broken brick     | 6.3–13.2        | 13.2, 9.5, 6.3 | 800              | 900                |
| B900        | Broken brick     | 6.3–13.2        | 13.2, 9.5, 6.3 | 900              | 1000               |
| C700        | Crushed concrete | 13.2–25.0       | 25, 19, 13.2   | 700              | 800                |
| C800        | Crushed concrete | 13.2–25.0       | 25, 19, 13.2   | 800              | 900                |
| C900        | Crushed concrete | 13.2–25.0       | 25, 19, 13.2   | 900              | 1000               |

Codes are B (broken brick) or C (crushed concrete) followed by the media depth in mm. Media porosity is given in Section 3.2 (brick 49.5%, concrete 47.5%).

## 2.4 Filtration experiment and water quality analysis

Each column was dosed with raw laundry greywater under gravity flow, and effluent samples were collected and analysed for pH, temperature, turbidity, electrical conductivity (EC), total dissolved solids (TDS), calcium, magnesium, sodium, nitrate, anionic surfactant and chloride, using standard methods consistent with those applied to the raw water. Removal efficiency (RE) for each parameter was calculated using Eq. (2):

$$RE (\%) = \frac{C_{\text{in}} - C_{\text{out}}}{C_{\text{in}}} \times 100$$

2

where  $C_{in}$  and  $C_{out}$  are the influent and effluent concentrations respectively; a negative value indicates a net increase (leaching). The sodium adsorption ratio (SAR) was calculated from the sodium, calcium and magnesium concentrations of each sample and compared against FAO/Ayers–Westcot [20] threshold values for irrigation water quality.

## 2.5 Irrigation suitability

The sodium adsorption ratio was calculated from Eq. (3), with concentrations converted from mg/L to meq/L using equivalent weights of 23, 20 and 12.15 g/eq for  $Na^+$ ,  $Ca^{2+}$  and  $Mg^{2+}$ .

$$SAR = \frac{Na^+}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}}$$

3

where  $Na^+$ ,  $Ca^{2+}$  and  $Mg^{2+}$  are in meq/L.

Effluent quality was compared with the FAO guidelines of Ayers and Westcot [20] for pH (normal range 6.5–8.4), EC, TDS, SAR, chloride and nitrate-nitrogen, each classified as no restriction, slight-to-moderate restriction or severe restriction. Nitrate was converted to nitrate-nitrogen with a factor of 0.2259.

Microbial quality, COD, BOD and heavy metals were not measured.

## 2.6 Hydraulic conductivity and clogging assessment

Hydraulic conductivity ( $K$ ) was measured using the constant-head method: a fixed 1000 mL volume of water was passed through each column and the drainage time recorded, with  $K$  calculated from Darcy's law, as given in Eq. (4):

$$K = \frac{Q \times L}{A \times \Delta H}$$

4

where  $K$  = hydraulic conductivity (m/s),  $Q$  = flow rate ( $m^3/s$ ),  $L$  = media depth (m),  $A$  = column cross-sectional area ( $m^2$ ) and  $\Delta H$  = head difference (m).

A hydraulic gradient of  $i = \Delta H/L = 1.0$  was applied. A baseline conductivity ( $K_0$ ) was measured on each freshly packed column using clean water. Each column was then dosed with raw laundry wastewater and conductivity re-measured ( $K_{post}$ ), and this cycle was repeated over three successive wastewater applications, each separated by a 1-hour rest period during which a pre-run conductivity ( $K_{pre}$ ) was measured to assess hydraulic recovery. Overall percentage reduction in conductivity was calculated using Eq. (5):

$$\Delta K (\%) = \frac{K_0 - K_n}{K_0} \times 100$$

where  $K_n$  = hydraulic conductivity at stage  $n$  (m/s).

## 3. Results and Discussion

### 3.1 Raw greywater characteristics

The raw greywater was moderately alkaline (pH 8.8) and moderately saline (EC 650  $\mu\text{S}/\text{cm}$ ; TDS 350 mg/L), with turbidity of 35 NTU, sodium of 75 mg/L, surfactant of 15 mg/L and chloride of 250 mg/L (Table 2). The alkalinity and moderate surfactant loading are consistent with the use of a homemade liquid-soap detergent rather than a phosphate-rich commercial powder detergent, and the overall profile confirms that the raw water was unsuitable for direct irrigation without treatment, chiefly on account of its chloride and pH levels.

Table 2  
Raw greywater quality

| Parameter               | Unit                    | Value 1 | Value 2 | Mean |
|-------------------------|-------------------------|---------|---------|------|
| pH                      | –                       | 8.7     | 8.9     | 8.8  |
| Temperature             | $^{\circ}\text{C}$      | 26.8    | 27.2    | 27.0 |
| Turbidity               | NTU                     | 34.7    | 35.3    | 35.0 |
| Electrical conductivity | $\mu\text{S}/\text{cm}$ | 648     | 652     | 650  |
| Total dissolved solids  | mg/L                    | 348     | 352     | 350  |
| Calcium                 | mg/L                    | 34.8    | 35.2    | 35   |
| Magnesium               | mg/L                    | 5.8     | 6.2     | 6.0  |
| Sodium                  | mg/L                    | 74.7    | 75.3    | 75   |
| Nitrate                 | mg/L                    | 9.8     | 10.2    | 10   |
| Surfactant (MBAS)       | mg/L                    | 14.7    | 15.3    | 15   |
| Chloride                | mg/L                    | 248     | 252     | 250  |

### 3.2 Physical properties of filter media

Broken brick had a lower average bulk density ( $\approx 1.11 \text{ g}/\text{cm}^3$ ) and higher porosity ( $\approx 49.5\%$ ) than crushed concrete ( $\approx 1.26 \text{ g}/\text{cm}^3$ ;  $\approx 47.5\%$ ; Table 3), while particle density was constant within each material ( $2.20 \text{ g}/\text{cm}^3$  for brick;  $2.40 \text{ g}/\text{cm}^3$  for concrete). The more open pore structure of brick favours sustained permeability, whereas the denser, less porous concrete provides a more tortuous flow path that promotes particulate straining but, as discussed below, was also associated with greater chemical reactivity.

Table 3  
Summary physical properties of the two filter media

| Parameter                             | Broken brick | Crushed concrete |
|---------------------------------------|--------------|------------------|
| Bulk density (g/cm <sup>3</sup> )     | ≈ 1.11       | ≈ 1.26           |
| Particle density (g/cm <sup>3</sup> ) | ≈ 2.20       | ≈ 2.40           |
| Porosity (%)                          | ≈ 49.5       | ≈ 47.5           |

### 3.3 Pollutant removal efficiency

Both media reduced turbidity, surfactant, sodium, nitrate and chloride relative to the raw greywater (Table 4), with removal improving consistently as bed depth increased from 700 to 900 mm (Table 5). Turbidity removal reached 77.1% in the deepest brick column and 80.0% in the deepest concrete column, broadly consistent with the 86–98% turbidity and solids removals reported for CDW-based decentralised filters treating river water [2], and with the strong particulate-removal performance reported for recycled aggregates used as constructed-wetland substrates [10]. Surfactant removal reached 46.7% (brick) and 50.0% (concrete), a magnitude consistent with the 22–99% range reported across physicochemical greywater treatments in a recent review of surfactant removal technologies, which also notes that low-cost adsorbent-based systems commonly plateau below complete removal because surfactant molecules partition onto solid surfaces rather than being degraded [14, 15].

A clear divergence between the two media emerged for the dissolved and cationic parameters. Broken brick reduced pH, EC, TDS and calcium at every bed depth, with no parameter exceeding its raw-water value, indicating a chemically stable, non-leaching medium. Crushed concrete, in contrast, increased pH (to 9.0–9.5), EC (to 715–800  $\mu\text{S}/\text{cm}$ ), TDS (to 375–420 mg/L) and calcium (to 44–55 mg/L) above raw-water levels at every depth, consistent with dissolution of calcium hydroxide and other cementitious hydration products from the concrete matrix. This leaching behaviour explains why, despite its marginally superior turbidity and surfactant removal, crushed concrete cannot be regarded as an unqualified improvement over broken brick: its particulate-removal advantage is achieved at the cost of introducing new dissolved-ion loading into the treated water.

Table 4  
Raw and treated water quality for each column (mean of duplicates)

| Parameter                                                                                                                                                                 | Raw  | Brick<br>700<br>mm | Brick<br>800<br>mm | Brick<br>900<br>mm | Concrete<br>700 mm | Concrete<br>800 mm | Concrete<br>900 mm |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|
| pH                                                                                                                                                                        | 8.8  | 8.7                | 8.6                | 8.5                | 9.5                | 9.2                | 9.0                |
| Temperature<br>(°C)                                                                                                                                                       | 27.0 | 26.9               | 26.9               | 26.8               | 26.9               | 26.9               | 26.8               |
| Turbidity (NTU)                                                                                                                                                           | 35   | 14                 | 11                 | 8                  | 13                 | 10                 | 7                  |
| Electrical<br>conductivity<br>( $\mu$ S/cm)                                                                                                                               | 650  | 625                | 610                | 595                | 800                | 755                | 715                |
| Total dissolved<br>solids (mg/L)                                                                                                                                          | 350  | 340                | 330                | 325                | 420                | 395                | 375                |
| Calcium (mg/L)                                                                                                                                                            | 35   | 34                 | 33                 | 32                 | 55                 | 49                 | 44                 |
| Magnesium<br>(mg/L)                                                                                                                                                       | 6.0  | 5.8                | 5.6                | 5.5                | 6.0                | 5.8                | 5.6                |
| Sodium (mg/L)                                                                                                                                                             | 75   | 68                 | 64                 | 60                 | 72                 | 68                 | 64                 |
| Nitrate (mg/L)                                                                                                                                                            | 10.0 | 7.0                | 6.5                | 6.0                | 7.2                | 6.7                | 6.2                |
| Surfactant<br>(MBAS) (mg/L)                                                                                                                                               | 15.0 | 10.5               | 9.0                | 8.0                | 10.0               | 8.5                | 7.5                |
| Chloride (mg/L)                                                                                                                                                           | 250  | 225                | 210                | 200                | 230                | 215                | 205                |
| <i>Note: column heights of 800, 900 and 1000 mm correspond to media (bed) depths of 700, 800 and 900 mm respectively, after accounting for the gravel drainage layer.</i> |      |                    |                    |                    |                    |                    |                    |

Table 5  
Removal efficiency (%) of each pollutant for each filter column relative to the raw greywater

| Parameter  | Brick<br>700 mm | Brick<br>800 mm | Brick<br>900 mm | Concrete<br>700 mm | Concrete<br>800 mm | Concrete<br>900 mm |
|------------|-----------------|-----------------|-----------------|--------------------|--------------------|--------------------|
| Turbidity  | 60.0            | 68.6            | 77.1            | 62.9               | 71.4               | 80.0               |
| Surfactant | 30.0            | 40.0            | 46.7            | 33.3               | 43.3               | 50.0               |
| Nitrate    | 30.0            | 35.0            | 40.0            | 28.0               | 33.0               | 38.0               |
| Sodium     | 9.3             | 14.7            | 20.0            | 4.0                | 9.3                | 14.7               |
| Chloride   | 10.0            | 16.0            | 20.0            | 8.0                | 14.0               | 18.0               |
| Magnesium  | 3.3             | 6.7             | 8.3             | 0.0                | 3.3                | 6.7                |
| EC         | 3.8             | 6.2             | 8.5             | -23.1              | -16.2              | -10.0              |
| TDS        | 2.9             | 5.7             | 7.1             | -20.0              | -12.9              | -7.1               |
| Calcium    | 2.9             | 5.7             | 8.6             | -57.1              | -40.0              | -25.7              |

*Negative values indicate an increase relative to the raw greywater (leaching).*

### 3.3.1 Turbidity and surfactants

Turbidity removal rose almost linearly with media depth, by about 8.5 percentage points for each additional 100 mm, from 60.0% to 77.1% in brick and from 62.9% to 80.0% in concrete (Fig. 5a), leaving 14, 11 and 8 NTU in brick effluent and 13, 10 and 7 NTU in concrete effluent (Table 4). These removals are within the range reported for lab-scale greywater filters [7, 21] and below the up to 98% obtained with CDW filters treating river water [2] and the roughly 97% achieved by crushed brick above sand [13], which is expected given the single-medium beds and the colloid- and surfactant-laden influent used here. Effluent turbidity also remained well above the 2 NTU value that only a few greywater filtration studies have met [22]; a polishing layer of sand, as in the dual-layer arrangement of Acharya and Parajuli [13], could be considered where lower turbidity is required. Concrete removed 2.8–2.9 percentage points more turbidity than brick at every depth, a difference of about 1 NTU that should be treated as a tendency rather than a demonstrated effect because the duplicate readings were identical and no replicate columns were run.

Surfactant removal followed the same pattern, increasing from 30.0% to 46.7% in brick and from 33.3% to 50.0% in concrete (Fig. 5b), and leaving 7.5–10.5 mg/L in the effluents. Removals that stop well short of complete removal are typical of adsorbent-based greywater systems, because surfactant molecules partition onto solid surfaces rather than being degraded [14, 15]. In freshly packed columns operated for only three runs, biodegradation in a mature biolayer, which contributes to organic removal in granular filters [22], would have been limited. Because filtration alone leaves residual surfactants and salts [23], and surfactant-rich greywater adsorbs onto soil surfaces and can promote water repellence at high

concentrations [24], the effect of the 7.5–10.5 mg/L remaining here should be checked in longer-term soil trials; the concentrations examined in that soil study (0.26–0.442 g/L) were far higher. Calcium released by concrete could contribute to its slightly higher turbidity and surfactant removal by destabilizing anionic colloids and precipitating soap-derived anions, but this mechanism was not tested.

### **3.3.2 Nitrate, sodium, magnesium and chloride**

Nitrate fell from 10.0 mg/L to 6.0–7.2 mg/L (28–40% removal), sodium from 75 to 60–72 mg/L (4.0–20.0%), and chloride from 250 to 200–230 mg/L (8.0–20.0%), with brick performing slightly better than concrete for each (Fig. 5c–e). Magnesium changed little, from 6.0 mg/L to 5.5–6.0 mg/L (0–8.3%; Fig. 5f). Nutrient removal by CDW substrates has been reported in wetland studies [10, 11], but the mechanism for nitrate was not investigated here, and adsorption, entrapment with particulates and limited biological activity are all possible. The greater sodium removal in brick may reflect cation exchange on clay minerals in fired brick, with  $\text{Ca}^{2+}$  released by concrete competing for exchange sites, although exchange capacity was not measured. Chloride is highly soluble and poorly retained by simple granular filtration [23], so the 8–20% reductions, which also increased with depth, may partly reflect dilution or displacement by water retained in the bed after pre-saturation and draining rather than true retention; the applied volume relative to the bed pore volume (2.7–3.6 L, calculated from the bed volume and the porosity in Table 3) would show whether this applies.

The duplicate range was largest for brick sodium (6 mg/L), nitrate (0.8 mg/L) and chloride (6 mg/L), and for each of these parameters, and for surfactant, the ranges for brick and concrete overlapped or just touched at every depth (Fig. 5). The differences between the media for these parameters should therefore be regarded as indicative, whereas the increase in removal with depth was consistent in both media.

### **3.3.3 pH, EC, TDS and calcium**

Broken brick lowered pH slightly (8.7, 8.6 and 8.5 against 8.8 in the raw water) and reduced EC by 3.8–8.5%, TDS by 2.9–7.1% and calcium by 2.9–8.6%, whereas crushed concrete raised pH to 9.5, 9.2 and 9.0 and increased EC by 10.0–23.1%, TDS by 7.1–20.0% and calcium by 25.7–57.1% (Figs. 6a–d and Table 5). This is the expected signature of dissolving cement hydration products, which produce high-pH, calcium-rich leachate in contact with water [25], and it means that crushed concrete cannot be regarded as an unqualified improvement. The concrete effluent pH of 9.0–9.5 is lower than the pH above 10 typical of laboratory column leaching tests on recycled concrete aggregate [25]; contact time, carbonation and particle abrasion strongly influence leachate pH, and the short contact time and the composition of greywater relative to clean water may both contribute.

The extent of leaching also decreased with media depth (calcium increase from 57.1% to 25.7%; Fig. 6c), the opposite of what greater media mass and contact time would suggest. Possible explanations include dilution by water retained in the larger deeper beds, progressive carbonation, or precipitation of calcium carbonate along the flow path, but the present data cannot discriminate between them. Field studies show that initially high leachate pH approaches neutral within one to two years [25], which

suggests that pre-washing or pre-conditioning could reduce the initial alkaline and calcium pulse; whether this would remove the difference between the media over longer operation should be tested. Trace metals were not measured, and their release from recycled concrete aggregate has been reported [26], so they should be checked before field use.

### 3.4 Irrigation suitability

The sodium adsorption ratio declined with increasing bed depth in both media, from 3.08 in the raw water to as low as 2.58 (brick, 900 mm) and 2.41 (concrete, 900 mm) (Table 6). This places every configuration below the SAR = 3 threshold identified as the boundary for safe irrigation reuse of treated laundry greywater in a comparable modelling and seed-germination study [5], and is broadly consistent with SAR values reported for well-managed laundry-to-landscape greywater systems in the 0.8–4.3 range [6]. However, as with the removal-efficiency results, the numerically favorable SAR values recorded for crushed concrete are partly an artefact of the elevated calcium concentration introduced by leaching rather than evidence of genuinely improved water quality, since SAR is calculated from the ratio of sodium to calcium and magnesium and therefore falls when calcium rises even without any true reduction in sodium hazard.

Table 6  
Comparison of raw and treated water quality with FAO/Ayers–Westcot irrigation guideline values [20]

| Configuration     | pH  | EC (dS/m) | TDS (mg/L) | SAR  | Cl <sup>-</sup> (mg/L) | Overall classification                        |
|-------------------|-----|-----------|------------|------|------------------------|-----------------------------------------------|
| Raw greywater     | 8.8 | 0.650     | 350        | 3.08 | 250                    | Slight-to-moderate (Cl <sup>-</sup> , pH)     |
| Brick – 900 mm    | 8.5 | 0.595     | 325        | 2.58 | 200                    | Slight-to-moderate (Cl <sup>-</sup> , pH)     |
| Concrete – 900 mm | 9.0 | 0.715     | 375        | 2.41 | 205                    | Slight-to-moderate (EC, Cl <sup>-</sup> , pH) |

Overall, broken brick at 800–900 mm bed depth produced the effluent most compatible with irrigation reuse, combining lower pH, EC, TDS and sodium with a stable ionic composition. Chloride remained the principal limiting parameter for both media, falling within the FAO slight-to-moderate restriction category (142–355 mg/L) in every configuration tested; because chloride is a highly soluble, conservative ion, it is not efficiently removed by simple granular filtration, and this finding is consistent with the general expectation that physical filtration alone is insufficient to achieve full salinity control in treated greywater [7, 22].

### 3.5 Hydraulic conductivity and clogging behavior

Hydraulic conductivity declined progressively in every column across the three successive wastewater application cycles, falling by 26.5–29.6% in the brick columns and 29.9–31.0% in the concrete columns (Table 7). A small, incomplete recovery in conductivity was observed during each 1-hour rest period, but every recovered (Kpre) value remained below the preceding baseline, confirming that clogging

accumulated progressively rather than being reversed between cycles. This pattern mirrors that reported for intermittent sand filters treating dairy wastewater, where clogging driven by suspended-solids and organic-matter accumulation reduced infiltration capacity by up to 85% over an extended dosing period, with only a fraction of that decline attributable to reversible, rather than permanent, pore blockage [19]. The marginally faster clogging observed in the concrete columns is consistent with their denser, less porous structure, which favors particulate capture (and hence the slightly higher turbidity and surfactant removal reported in Section 3.3) at the cost of a more rapid loss of hydraulic capacity, the same trade-off between removal efficiency and clogging rate noted for fine-pored recycled-aggregate and glass filter media used in reclaimed-water drip-irrigation systems.

Table 7  
Overall hydraulic conductivity reduction after three filtration cycles

| Media    | Bed depth (mm) | K0 (m/s) | Kpost3 (m/s) | Reduction (%) |
|----------|----------------|----------|--------------|---------------|
| Brick    | 700            | 0.00348  | 0.00252      | 27.6          |
| Brick    | 800            | 0.00324  | 0.00238      | 26.5          |
| Brick    | 900            | 0.00294  | 0.00207      | 29.6          |
| Concrete | 700            | 0.00439  | 0.00305      | 30.5          |
| Concrete | 800            | 0.00411  | 0.00288      | 29.9          |
| Concrete | 900            | 0.00394  | 0.00272      | 31.0          |

These results indicate that both media would require a defined maintenance regime, periodic backwashing, replacement of the upper filter layer, or pre-screening of highly turbid influent, for sustained field operation, and that filter-medium selection should not be based on removal efficiency in isolation, since the medium with marginally superior pollutant capture (crushed concrete) also clogs marginally faster and simultaneously introduces chemical leaching.

## 4. Conclusions

This study evaluated recycled broken brick and crushed concrete aggregate as low-cost filter media for laundry greywater treatment intended for irrigation reuse. Both media achieved measurable improvements in turbidity, surfactant, sodium, nitrate and chloride, with performance improving at greater bed depth, and both reduced the sodium adsorption ratio of the treated water below the threshold associated with safe irrigation reuse. However, chemical stability distinguished the two media more decisively than removal efficiency: broken brick removed pollutants without leaching, whereas crushed concrete leached calcium and raised pH, EC and TDS above raw-water levels, and its apparently favorable SAR values were partly an artefact of this leaching. Hydraulic conductivity declined by 26.5–31.0% across three filtration cycles in both media, with concrete clogging marginally faster than brick, consistent with its denser, more particulate-retentive structure. Broken brick at 800–900 mm bed depth is therefore recommended as the preferable medium where treated-effluent quality is the primary

concern, while chloride remains a parameter that filtration alone cannot adequately address and would require a supplementary polishing step for chloride-sensitive irrigation applications. These findings support the practical viability of recycled CDW aggregate as a decentralized, low-cost greywater treatment option in resource-constrained settings, while underscoring the need to evaluate chemical stability and hydraulic durability alongside pollutant removal efficiency when selecting recycled materials for water treatment applications.

## Declarations

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**Data availability:** The datasets generated and analyzed during the current study are available from the corresponding author on reasonable request.

**Author contributions:** Olatunbosun Oluwaferanmi and Bamigboye Favour Ayomide conceived and designed the study. Olatunbosun Oluwaferanmi and Bamigboye Favour Ayomide fabricated the six vertical-flow filter columns, sourced and characterised the broken brick and crushed concrete media, and conducted the greywater dosing, effluent sampling and hydraulic conductivity testing. Olatunbosun Oluwaferanmi analysed and interpreted the water quality and hydraulic conductivity data, compared the findings against the literature and FAO irrigation guidelines, and wrote the main manuscript text. Bamigboye Favour Ayomide prepared the figures. Rebecca Adepte Olaoye and Stephen Akinola Olaiya reviewed the manuscript for intellectual content. All authors read and approved the final manuscript.

**Ethics approval:** Not applicable, this study did not involve human participants, human data or animals.

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## Figures



**Figure 1**

Crushed aggregate being sorted and shovelled prior to washing and sieve fractionation



**Figure 2**

Close-up view of broken fired-clay brick and concrete fragments recovered from demolished masonry.



**Figure 3**

Laboratory setup of the vertical-flow PVC filter columns (101.6 mm internal diameter), packed with graded filter media and mounted on a wooden support stand with a common effluent collection manifold.

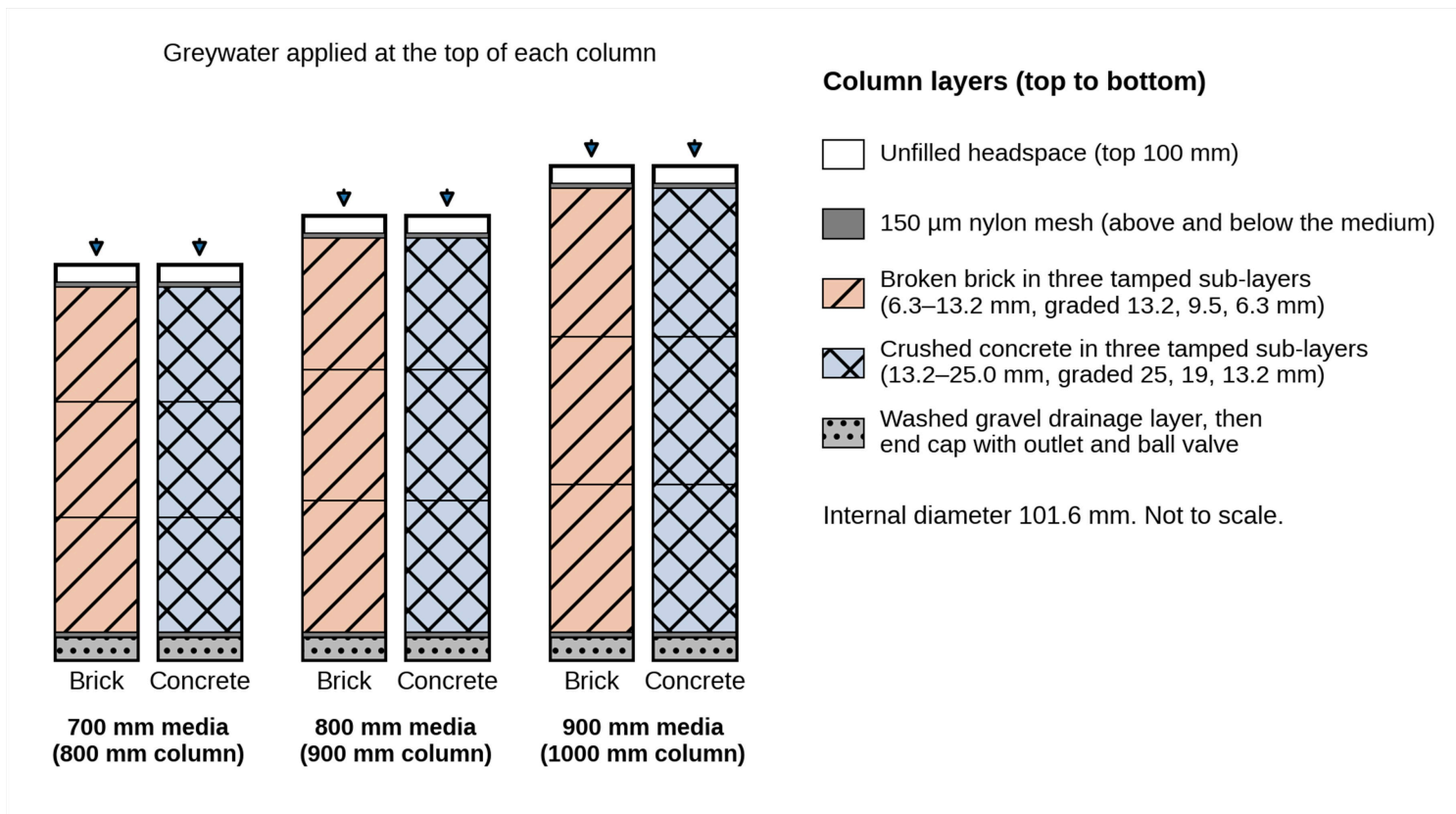


**Figure 4**

Schematic of the six filter columns showing media depths, layers and fittings.

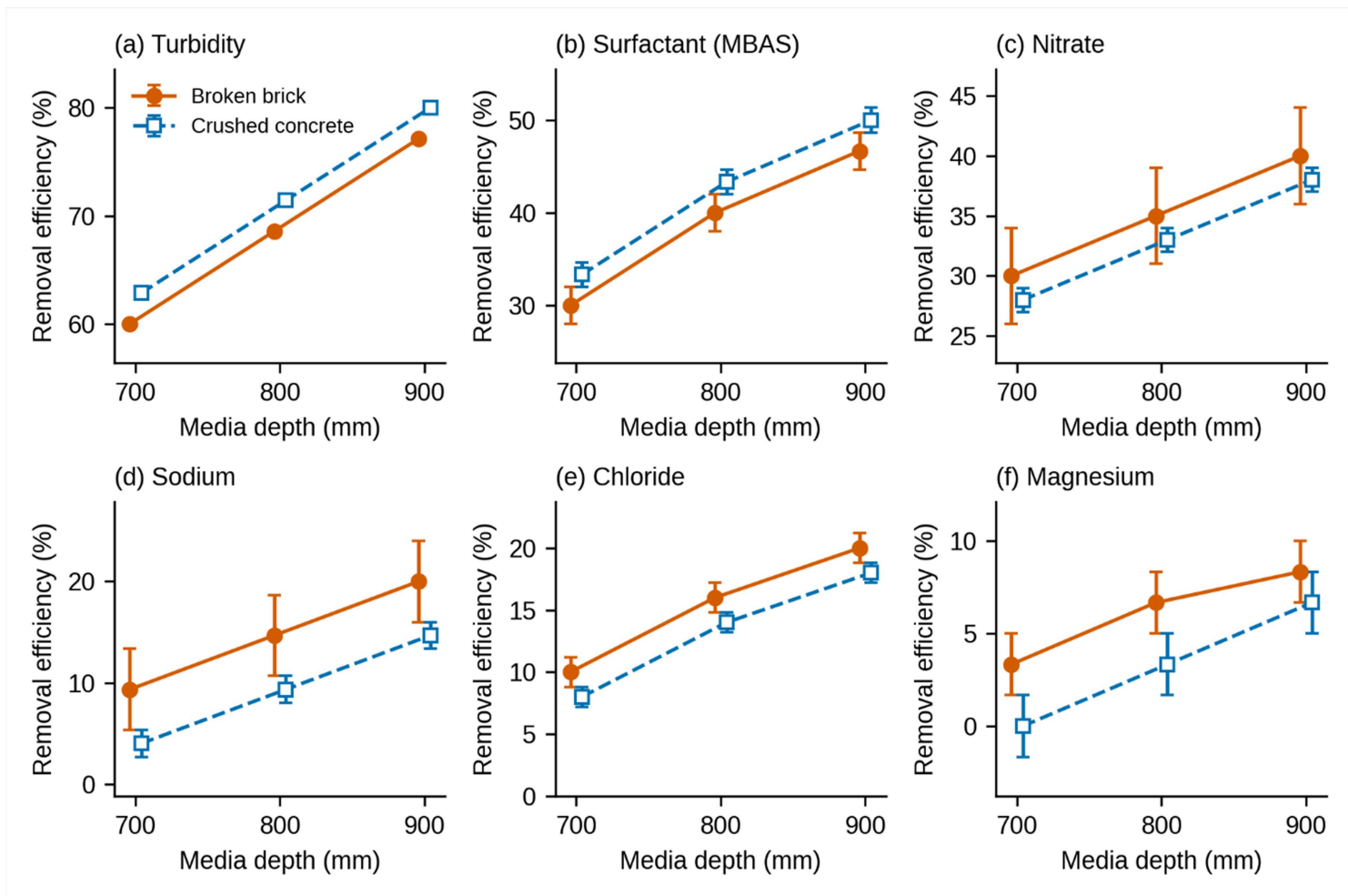


**Figure 5**

Removal efficiency against media depth for broken brick and crushed concrete. Error bars show the range of the duplicate measurements.

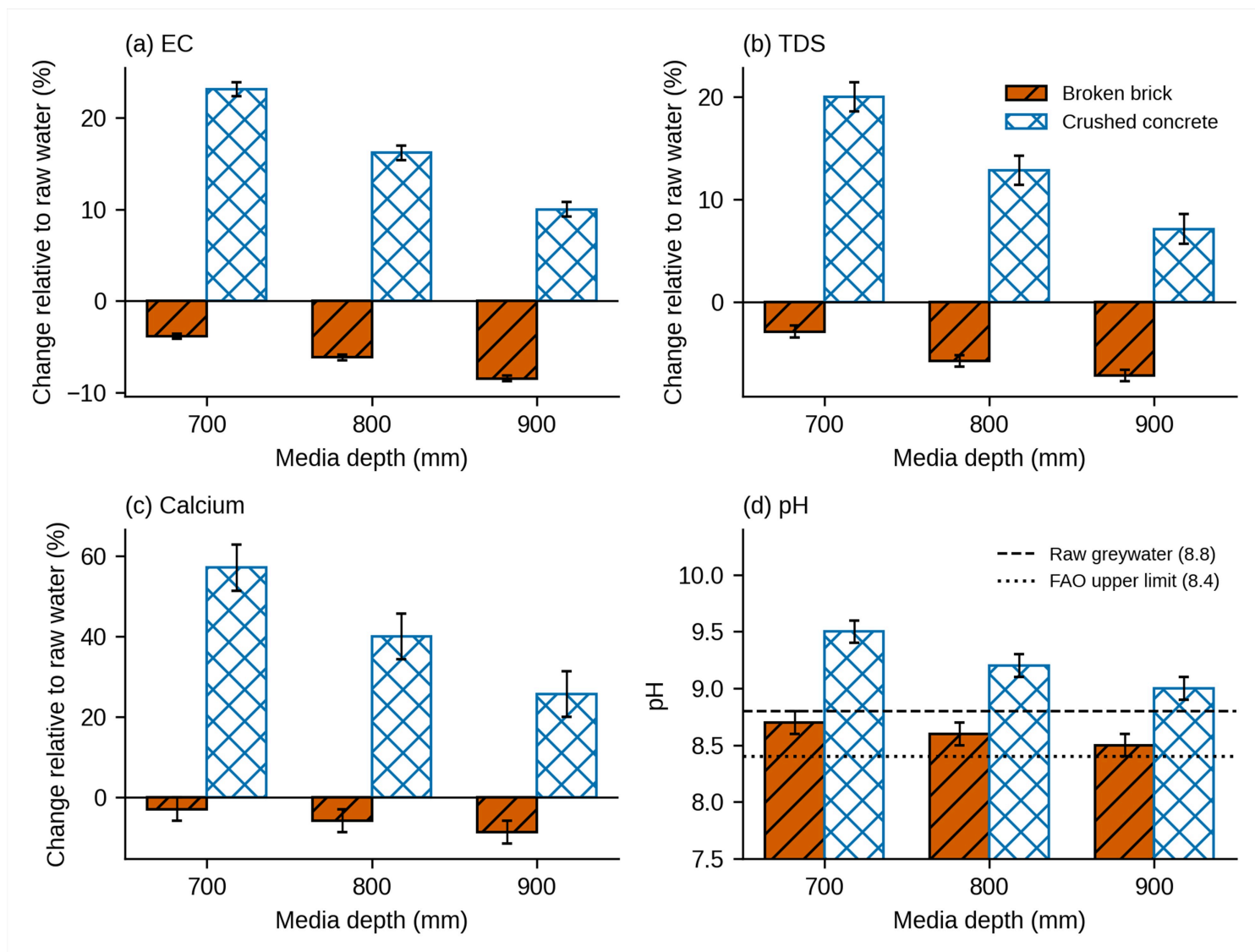


**Figure 6**

Change in (a) EC, (b) TDS and (c) calcium relative to the raw greywater, and (d) effluent pH, for broken brick and crushed concrete. Error bars show the range of the duplicate measurements.