



CHARACTERIZATION OF DOMESTIC GREYWATER FOR CONSTRUCTED WETLAND TREATMENT AND NON-POTABLE REUSE IN A TROPICAL PERI-URBAN RESIDENTIAL COMMUNITY

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ABSTRACT

Increasing freshwater scarcity and rapid urbanization in tropical regions have intensified interest in greywater reuse as a sustainable water management strategy. Constructed wetlands offer a low-cost, nature-based solution for decentralized treatment; however, their effective design and optimization depend on a detailed understanding of influent greywater characteristics. Comprehensive characterization is therefore essential to guide system configuration, pretreatment requirements, and reuse risk assessment. This study characterized the physicochemical, nutrient, microbiological and trace-metal properties of domestic greywater generated from residential units at the National Water Resources Institute (NWRI), Kaduna, Nigeria, representing a tropical peri-urban environment. Composite samples were collected from bathrooms, kitchen sinks, wash basins and laundry outlets. Laboratory analyses were conducted using standard methods to determine organic strength indicators, solids content, nutrient levels, microbial loads, and selected heavy metals relevant to treatment design and reuse suitability. Greywater exhibited near-neutral pH (7.8) and moderate salinity (EC 2008 $\mu\text{S}/\text{cm}$). Organic pollution was high, with BOD₅ and COD concentrations of 286.45 mg/L and 537.42 mg/L, respectively and a BOD₅/COD ratio of 0.53, indicating good biodegradability. Suspended solids (237 mg/L) and turbidity (113 NTU) were elevated, suggesting pretreatment needs. Nutrient concentrations were appreciable, while sodium levels indicated potential irrigation constraints. Microbial indicators exceeded reuse limits, whereas trace metals remained low. The findings confirm that the greywater characteristics are suitable for treatment using small-scale Free Water Surface constructed wetlands, provided adequate pretreatment and post-treatment safeguards are incorporated to ensure safe non-potable reuse in tropical peri-urban communities.

Keywords: Domestic greywater, Greywater characterization, Constructed wetland treatment, Free water surface wetlands, Non-potable reuse

INTRODUCTION

Greywater constitutes a substantial fraction of domestic wastewater, accounting for approximately 50–80 % of total household wastewater generation and represents a promising alternative water source for non-potable reuse when adequately treated, particularly in water-stressed regions experiencing rapid urbanization and infrastructure deficits (Van de Walle et al., 2023). Greywater originates from household activities such as bathing, laundry, handwashing and kitchen operations and is increasingly recognized for its reuse potential in applications such as landscape irrigation and toilet flushing, thereby reducing freshwater demand and wastewater discharge volumes.

In many tropical developing regions, however, greywater is commonly discharged untreated into open drains, surrounding land, or surface water bodies, leading to environmental pollution and increased public health risks (Gyapong-Korsah et al., 2026). Recent studies demonstrate that mixed-source domestic greywater can contain substantial organic and microbial loads, with reported biochemical oxygen demand (BOD₅) and chemical oxygen demand (COD) values far exceeding typical discharge limits, particularly where laundry and kitchen wastewater are included (Gyapong-Korsah et al., 2026). Elevated electrical conductivity and sodium concentrations associated with detergent use further raise concerns regarding soil degradation and crop sensitivity when greywater is reused for irrigation without adequate treatment (Van de Walle et al., 2023).

Constructed wetlands have gained increasing attention as low-cost, low-energy and environmentally sustainable

systems for decentralized greywater treatment, especially in warm climates where microbial activity and plant growth enhance treatment performance (Masoud et al., 2025). When appropriately designed, constructed wetlands can effectively reduce organic matter, nutrients, suspended solids and microbial contaminants, making them suitable for small-scale and peri-urban applications. However, the performance and reliability of constructed wetlands are strongly influenced by influent greywater characteristics, including organic load, solids content, nutrient concentrations, salinity and microbial contamination, as these parameters directly determine hydraulic loading rates, required retention times, substrate configuration, vegetation selection, and the need for pretreatment to prevent clogging and performance deterioration (Van de Walle et al., 2023; Masoud et al., 2025). Despite the growing body of greywater research, most existing studies focus on bathroom-only greywater, post-treatment performance, or temperate-region case studies, with limited emphasis on comprehensive influent characterization for reuse-oriented wetland design in tropical peri-urban contexts (Van de Walle et al., 2023; Masoud et al., 2025). In Nigeria, in particular, there remains a scarcity of quantitative data on mixed-source domestic greywater quality, including kitchen contributions, salinity and sodium levels, microbial indicators and trace metals relevant to irrigation reuse and environmental protection. This study addresses this gap by providing a detailed, design-enabling characterization of domestic greywater generated within a tropical peri-urban institutional residential community. The findings generate baseline data essential for constructed wetland sizing,

pretreatment selection, and reuse risk screening, thereby supporting the sustainable implementation of decentralized greywater reuse systems in similar settings.

MATERIALS AND METHODS

Study Area

The study was conducted within the residential units of the National Water Resources Institute (NWRI), located in Kaduna State, north-western Nigeria. The area represents a planned institutional peri-urban residential community and is characterized by a tropical savannah climate with clearly defined wet (April–October) and dry (November–March) seasons. Mean daily temperatures typically range between 25 and 35 °C, conditions that favor enhanced biological activity in natural treatment systems (Varma et al., 2021).

Residential units within the study area are supplied primarily through borehole and centralized potable water systems, while household wastewater is discharged without prior segregation or treatment. Greywater and blackwater are commonly combined and conveyed through informal drainage channels or septic systems, reflecting sanitation practices typical of many peri-urban communities in Nigeria and other developing regions. This setting provides a representative case for assessing domestic greywater characteristics relevant to decentralized treatment and reuse using constructed wetlands.

Greywater Source Segregation and Sampling

Greywater was collected exclusively from bathrooms, wash basins, kitchen sinks and laundry outlets, representing wastewater streams generated from routine non-toilet household activities. Blackwater (toilet effluent) was deliberately excluded due to its substantially higher organic load, pathogen concentration and nutrient strength, which fundamentally distinguishes it from greywater in terms of composition and treatment requirements. This segregation ensured consistency with widely accepted greywater definitions and avoided confounding effects associated with mixed domestic wastewater (Eriksson et al., 2002; Ghaitidak & Yadav, 2013).

The inclusion of kitchen greywater, despite its relatively higher grease and organic content compared to bathroom and

laundry streams, was intentional, as it reflects realistic household wastewater generation patterns and significantly contributes to overall greywater pollutant loads. Composite greywater samples were obtained by collecting grab samples from a retention Basin to represent average household discharge conditions. Sampling was conducted during active water-use periods to capture typical daily variability.

Analytical Methods

Collected greywater samples were analyzed for a comprehensive set of physicochemical, nutrient, microbiological and trace-metal parameters to evaluate treatment requirements and reuse suitability. Laboratory analyses followed procedures outlined in Standard Methods for the Examination of Water and Wastewater (APHA, 2022). The following parameters were determined:

- i. Physicochemical parameters: pH, Electrical Conductivity (EC), turbidity, Total Suspended Solids (TSS), and Total Dissolved Solids (TDS).
- ii. Organic strength indicators: Biochemical Oxygen Demand (BOD₅) and Chemical Oxygen Demand (COD), used to assess biodegradability and suitability for biological treatment.
- iii. Nutrients: Total Nitrogen (TN), Ammonium (NH₄⁺), Nitrate (NO₃⁻) and Total Phosphorus (TP), reflecting detergent use, food residues and human activity inputs.
- iv. Major cations: Sodium (Na⁺), Calcium (Ca²⁺), and Magnesium (Mg²⁺), relevant for irrigation reuse and soil structure considerations.
- v. Microbiological indicators: Total Coliforms and Fecal Coliforms, used to evaluate public health risks and the need for pathogen removal prior to reuse.
- vi. Trace metals: Lead (Pb), Zinc (Zn), and Cadmium (Cd), analyzed to assess potential long-term environmental and health implications of reuse.

All analyses were performed on composite samples to reduce short-term variability and to provide representative influent characteristics for constructed wetland design, optimization, and performance evaluation.

RESULTS AND DISCUSSION

Physicochemical Characteristics

Table 1: Physicochemical Characteristics of Domestic Greywater

Parameter	Obtained Values	Typical Greywater Range
pH	7.8	6.0 – 9.0
Electrical Conductivity (EC, μS/cm)	2008	500 – 2500
Total Suspended Solids (TSS, mg/L)	237	30-330
Total Dissolved Solids (TDS, mg/L)	1006	300 – 1200
Turbidity (NTU)	113	10 – 100
Biological Oxygen Demand (BOD ₅ , mg/L)	286.45	100 – 400
Chemical Oxygen Demand (COD, mg/L)	537.42	250 – 700
Sodium (Na ⁺ , mg/L)	112.45	10– 200
Calcium (Ca ²⁺ , mg/L)	32	5 – 50
Magnesium (Mg ²⁺ , mg/L)	11.4	2 – 20

The physicochemical characteristics of greywater generated from the NWRI residential units are summarized in Table 1. The measured pH value of 7.8 indicates neutral to slightly alkaline conditions, which are favorable for microbial activity and macrophyte growth in constructed wetlands. Such pH conditions support enzymatic processes involved in organic matter degradation and nutrient transformation and are commonly reported for domestic greywater influenced by

detergents and soaps (Kadlec & Wallace, 2009; Vymazal, 2011).

Electrical conductivity (EC) averaged 2008 μS/cm, reflecting a moderate level of dissolved ions derived primarily from household detergents, cleaning agents and laundry wastewater. EC values within this range are typical of mixed-source domestic greywater; however, prolonged reuse for irrigation may pose risks of soil salinization if not adequately

managed, highlighting the need for monitoring and appropriate reuse controls (FAO, 2020).

Total suspended solids (TSS) and total dissolved solids (TDS) were measured at 237 mg/L and 1006 mg/L, respectively, while turbidity reached 113 NTU. These elevated values indicate significant contributions from laundry lint, food particles and other particulate matter, particularly from kitchen and washing activities. Without pretreatment, such solids can cause clogging, short-circuiting and reduced hydraulic conductivity in constructed wetland systems. Therefore, the inclusion of inlet screening, sedimentation, or filtration units is critical to maintain long-term wetland performance (Kadlec & Wallace, 2009).

Major cations such as sodium (112.45 mg/L), calcium (32 mg/L), and magnesium (11.4 mg/L) were present at concentrations consistent with detergent use and domestic water consumption patterns. While calcium and magnesium can contribute to water hardness and influence substrate interactions, elevated sodium concentrations can displace calcium and magnesium on soil exchange sites and deteriorate soil structural stability if greywater is reused for irrigation, reinforcing the need for reuse-oriented design considerations (Hardie et al., 2025; sodium adsorption ratio concept).

Organic Load and Biodegradability

The organic strength of the greywater was characterized by biochemical oxygen demand (BOD₅) and chemical oxygen demand (COD) concentrations of 286.45 mg/L and 537.42 mg/L, respectively as presented in Table 3.1. These values indicate moderate to high organic loading and fall within ranges commonly reported for mixed domestic greywater in tropical residential communities (Eriksson et al., 2002; Abed et al., 2020).

The calculated BOD₅/COD ratio of approximately 0.53 suggests a high proportion of readily biodegradable organic matter. Ratios above 0.4 are generally indicative of wastewater that is amenable to biological treatment, confirming the suitability of this greywater for treatment in biologically driven systems such as free water surface and subsurface flow constructed wetlands (Metcalf & Eddy, 2014; Langergraber & Dotro, 2019). This biodegradability is particularly advantageous in warm tropical climates, where microbial activity is enhanced and treatment efficiency can be optimized through appropriate hydraulic retention times.

Table 2: Trace Metal Concentrations in Domestic Greywater

Parameters	Obtained Values	Typical Greywater Range
Lead (Pb, mg/L)	0.021	<0.01 – 0.05
Zinc (Zn, mg/L)	2.75	0.1 – 5
Cadmium (Cd, mg/L)	0.002	<0.001 – 0.01

Trace metal concentrations in the greywater were low, with measured values of 0.021 mg/L for lead (Pb), 2.75 mg/L for zinc (Zn), and 0.002 mg/L for cadmium (Cd) (Table 2). These concentrations are within ranges reported in the literature for domestic greywater and indicate minimal immediate toxicity risks (Eriksson et al., 2002; Abed et al., 2020).

Despite their low concentrations, long-term reuse of treated greywater particularly for irrigation necessitates periodic

monitoring to prevent gradual accumulation of trace metals in soils and plants. Constructed wetlands can contribute to metal attenuation through adsorption, precipitation, and plant uptake; however, long-term sustainability depends on appropriate design and operational management (Bixio et al., 2006).

Table 3: Nutrient Characteristics of Domestic Greywater

Parameter	Obtained Values	Typical Greywater Range
Nitrate (NO ₃ ⁻ , mg/L)	7.43	0.1 – 10
Ammonium (NH ₄ ⁺ , mg/L)	20.05	1–25
Total Phosphorus (TP mg/L)	6.2	0.4 – 8
Total Nitrogen (TN, mg/L)	36.95	5 – 50

The nutrient levels of the greywater are presented in Table 3. Total nitrogen (TN) concentration was 36.95 mg/L, with ammonium (NH₄⁺) and nitrate (NO₃⁻) levels of 20.05 mg/L and 7.43 mg/L, respectively, while total phosphorus (TP) was measured at 6.2 mg/L. These concentrations are typical of mixed-source domestic greywater and reflect inputs from detergents, food residues, and minor urine contamination, as widely reported in recent greywater characterization studies (Van de Walle et al., 2023; Gyapong-Korsah et al., 2026).

Discharge of untreated greywater containing such nutrient levels can contribute to eutrophication in receiving water

bodies; however, the nutrient content also provides opportunities for effective removal through macrophyte uptake, microbial nitrification–denitrification, and adsorption onto wetland substrates within constructed wetlands (Masoud et al., 2025; Vymazal & Březinová, 2022). Consequently, appropriate wetland design—particularly plant species selection, hydraulic loading control, and sufficient retention time—is essential to achieve efficient nutrient removal while meeting non-potable reuse objectives.

Table 4: Microbiological Characteristics of Domestic Greywater

Microorganism	Obtained Values	Typical Load in Untreated Greywater
Total Coliforms (cfu/100 mL)	14523	10 ³ – 10 ⁶
Fecal Coliforms (cfu/100 mL)	1126	10 ² – 10 ⁴

Microbiological analysis revealed total coliform and fecal coliform concentrations of 14,523 cfu/100 mL and 1,126

cfu/100 mL, respectively (Table 4). These values fall within ranges commonly reported for untreated domestic greywater

and indicate potential health risks if the greywater is reused without adequate treatment (Gyapong-Korsah et al., 2026; Mbiza et al., 2025).

Constructed wetlands can achieve measurable reductions in microbial indicators through physical and biological processes such as sedimentation, filtration, predation, natural die-off and exposure to environmental factors; however, their pathogen removal performance is variable and often insufficient by themselves to meet stringent water reuse standards without adequate hydraulic retention time or integration with post-treatment disinfection to ensure public health protection (Arden, 2024; de Campos, 2024).

CONCLUSION

Domestic greywater generated in the study area exhibits moderate to high organic and nutrient loads, appreciable microbial contamination and low concentrations of trace metals. The physicochemical and biological characteristics observed are representative of domestic greywater reported in the literature and indicate strong suitability for treatment using constructed wetlands under tropical conditions. While untreated discharge poses environmental and public health risks, appropriate system design incorporating pretreatment, adequate hydraulic retention time and post-treatment safeguards can enable safe non-potable reuse.

RECOMMENDATIONS

Based on the greywater characterization and its implications for constructed wetland treatment, it is recommended that:

1. Inlet retention or filtration units be incorporated to reduce suspended solids and turbidity prior to wetland treatment.
2. Constructed wetlands be designed with sufficient hydraulic retention time to enhance organic matter degradation and pathogen reduction.
3. Macrophyte species with high nutrient uptake capacity be selected to optimize nitrogen and phosphorus removal.
4. Salinity and sodium levels be monitored under irrigation reuse scenarios to prevent long-term soil degradation.
5. Periodic monitoring of microbial indicators and trace metals be conducted to ensure compliance with reuse guidelines and protect environmental and public health.

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