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Domestic Greywater Generation Rates in a Tropical Peri-Urban Residential Community: Evidence from the National Water Resources Institute Residential Units, Kaduna, Nigeria

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ABSTRACT

Domestic greywater represents a significant but underutilized fraction of household wastewater in rapidly urbanizing regions, particularly in developing countries where centralized sanitation infrastructure is limited (Eriksson et al., 2002; Oteng-Peprah et al., 2018). This study quantified domestic greywater generation rates and assessed associated influencing factors in a tropical peri-urban residential community using the residential units of the National Water Resources Institute (NWRI), Kaduna, Nigeria, as a case study. Greywater generated from non-toilet household activities (bathing, laundry, dishwashing, and food preparation) was measured through direct field monitoring over 30 consecutive days for a resident population of 50 persons. Daily inflows were corrected for evaporation losses and rainfall contributions using on-site meteorological data, consistent with recommended field measurement practices for household wastewater studies (Abed et al., 2020). Results indicated a total greywater generation of 81,601 L during the study period, corresponding to a mean per-capita generation rate of 54.4 L/person/day, with daily net inflows ranging from 2,550 to 3,005 L/day. The observed generation rate reflects moderate household water use influenced by water availability, infrastructural access and socio-economic conditions typical of peri-urban settlements in sub-Saharan Africa (Ahmad & Daura, 2019; Pinto et al., 2021). Comparative analysis showed that the measured values align with reported ranges for similar tropical residential contexts (Oteng-Peprah et al., 2018; Abed et al., 2020). The findings provide robust, site-specific design inputs for optimizing small-scale constructed wetlands for domestic greywater treatment and reuse, particularly regarding hydraulic loading rates, retention time, wetland sizing and macrophyte selection, which supports decentralized sanitation planning in line with Citywide Inclusive Sanitation principles (WHO, 2017; UN-Water, 2023).

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INTRODUCTION

Growing freshwater scarcity, driven by population growth, urbanization and climate variability, has intensified interest in alternative water sources such as greywater (UN-Water, 2021). In many tropical developing regions, limited wastewater infrastructure results in the discharge of untreated domestic wastewater into the environment, exacerbating water pollution and public health risks (WHO, 2017).

Greywater which is wastewater generated from household activities excluding toilet effluent typically accounts for 60–85% of total domestic wastewater (Eriksson et al., 2002;

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Abed et al., 2020). Compared to blackwater, greywater generally contains lower concentrations of organic matter and nutrients, making it more amenable to decentralized treatment and reuse for non-potable applications such as landscape irrigation and toilet flushing (Ghaitidak & Yadav, 2013; Langergraber & Dotro, 2019).

Consequently, the design of effective decentralized treatment systems requires site-specific data on greywater generation rates and quality. Despite the growing global literature on greywater reuse, studies from tropical Sub-Saharan African residential communities remain limited (Bakare et al., 2017; Pinto et al., 2021). This knowledge gap constrains the development of appropriate low-cost treatment solutions.

This study therefore assesses domestic greywater generation in a tropical residential community, providing baseline data to support decentralized treatment system design and sustainable water reuse planning.

MATERIALS AND METHODS

Study Area Description

The study was conducted in a tropical peri-urban residential community located within the residential units of the National Water Resources Institute (NWRI), Kaduna, Nigeria. The area experiences a tropical savannah climate, characterized by a warm temperature regime and distinct wet (April–October) and dry (November–March) seasons, which influence household water-use patterns and wastewater generation.

Residential housing units are supplied with potable water through a centralized water supply system, primarily serving institutional staff and their households. Household wastewater generated from domestic activities is typically discharged without prior segregation or on-site treatment, reflecting sanitation practices common in many urban and peri-urban residential settings in developing countries (UNEP, 2016; WHO, 2017). Greywater and blackwater are commonly combined and conveyed through informal drainage channels or septic systems, resulting in limited opportunities for wastewater reuse or environmental protection.

The study area is representative of planned institutional residential developments in Nigerian cities, where relatively reliable water supply contrasts with limited decentralized wastewater management infrastructure. This context provides a suitable case study for assessing domestic greywater generation and its implications for decentralized sanitation planning and treatment system optimization in tropical urban environments.

Greywater Source Identification

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 from the study due to its substantially higher organic load, pathogen content and grease concentration, which fundamentally distinguish it from greywater in terms of composition and treatment requirements. This source segregation was necessary to ensure consistency with widely accepted definitions of greywater and to avoid 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 in the study area and contributes significantly to overall greywater volume. Source identification and segregation were carried out at designated household outlets to enable accurate quantification of greywater generation from non-toilet activities and to support subsequent analysis of design implications for decentralized treatment systems.

Assessment of Greywater Generation

A short-term longitudinal field monitoring study with descriptive analysis was adopted, incorporating both quantitative measurement and household survey components. The study population comprises households within the NWRI catchment area which amounted

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50 persons from the three blocks of flats with three households in each block.. A sampling frame was developed from the NWRI household registry which adopted single-family homes, reflecting the local demographic and socio-economic mix. A stratified random sampling method was to ensure representation across household types and sizes. Field data collection involved two complementary approaches: a household survey and direct measurement of greywater generation. The survey instrument was to collect data on household composition, daily water-use activities (such as bathing, laundry, dishwashing). Parallel to the survey, direct measurement was undertaken by installing calibrated collection devices on designated greywater outlets over a consecutive 30day period, (Figure 1) capturing daily variability in greywater volumes, Daily losses due to evaporation and increased volume due to rainfall for the month of April were obtained from the metrological station (Figure 2). Temporal variations were evaluated to capture daily and seasonal fluctuations, as recommended for decentralized wastewater planning (Oteng-Peprah et al., 2018).

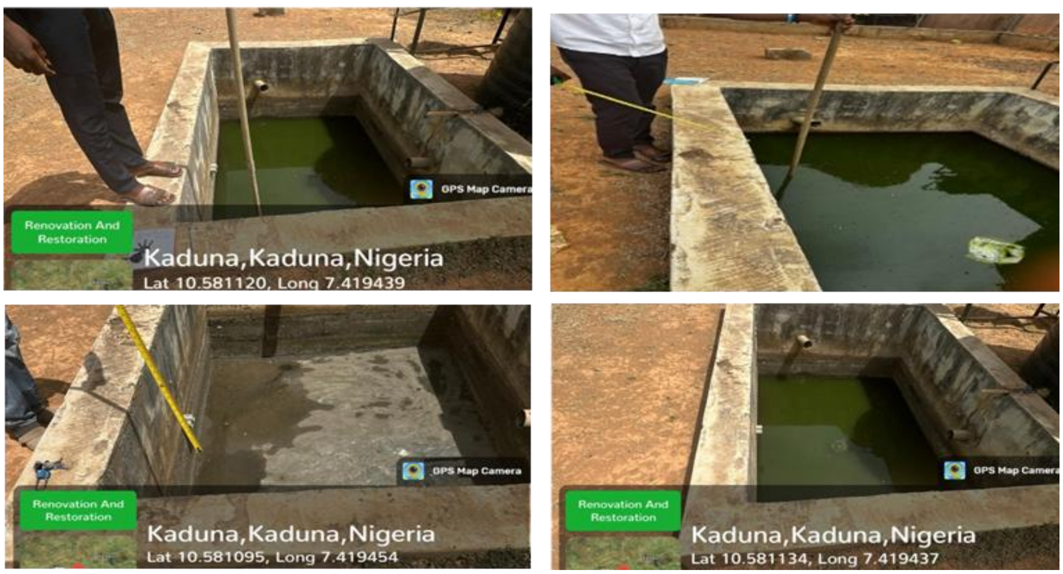

Figure 1: Daily Direct Measurement of Generated Domestic Greywa

Figure 2: NWRI Metrological Station

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Data Analysis

Greywater generation data were analyzed using descriptive statistical methods to characterize daily and per-capita generation patterns. Total daily greywater volumes were aggregated over the monitoring period to determine cumulative generation, mean daily flow and per-capita generation rates. Measures of central tendency (mean) and dispersion (minimum–maximum ranges) were used to capture temporal variability in household greywater production.

Observed generation rates were evaluated in relation to household water-use behavior, population size and daily activity patterns. To place the findings within a broader contextual framework, the measured values were compared with reported greywater generation ranges from similar tropical and peri-urban residential settings documented in the literature. This comparative approach enabled assessment of the representativeness of the study area and facilitated interpretation of site-specific variability.

In addition, the quantified greywater generation rates were assessed against relevant guideline thresholds and planning benchmarks to infer implications for decentralized treatment system design, including hydraulic loading estimation and system sizing. Although the present study focused on generation rather than treatment performance, the analysis provides foundational input for evaluating treatment requirements and reuse potential in accordance with established sanitation and water reuse guidance (WHO, 2017; Tilley et al., 2022).

RESULTS AND DISCUSSION

Domestic Greywater Generation Rates

Greywater constituted a substantial fraction of household wastewater Table 1, consistent with findings reported for domestic settings globally (Eriksson et al., 2002; Abed et al., 2020). Per capita generation rates reflected household water-use behavior and availability, emphasizing the importance of incorporating variability into decentralized treatment system design (Oteng-Peprah et al., 2018).

Table 1: Daily Net Inflow, Evaporation and Precipitation Records (Extracted from field measurements, April 2025)

Greywater Rate of Generation							
S/N	Date	Day	Net Inflow (L/day)	evaporation rate (mm/day)	evaporation rate (m/day)	Losses due to evaporation (L/day)	precipitation rate (mm/day)
1	01-04-25	Tuesday	2,753	4.2	0.0042	22.0248	0
2	02-04-25	Wednesday	2,685	4.8	0.0048	25.1712	0
3	03-04-25	Thursday	2,785	4.4	0.0044	23.0736	0
4	04-04-25	Friday	2,784	4.6	0.0046	24.1224	0
5	05-04-05	Saturday	3,053	4.6	0.0046	24.1224	0
6	06-04-25	Sunday	2,930	4.8	0.0048	25.1712	0
7	07-04-25	Monday	2,645	4.6	0.0046	24.1224	0
8	08-04-25	Tuesday	2,830	4.9	0.0049	25.6956	0
9	09-04-25	Wednesday	2,755	5	0.005	26.22	0
10	10-04-25	Thursday	2,820	5.1	0.0051	26.7444	0
11	11-04-25	Friday	2,810	4.7	0.0047	24.6468	0
12	12-04-25	Saturday	2 920	4.9	0.0049	25.6956	0
13	13-04-25	Sunday	2,835	5.2	0.0052	27.2688	0
14	14-04-25	Monday	2,750	5.1	0.0051	26.7444	0
15	15-04-25	Tuesday	2,680	5.3	0.0053	27.7932	0
16	16-04-25	Wednesday	2,800	4.9	0.0049	25.6956	0

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Greywater Rate of Generation								
S/ N	Date	Day	Net Inflow	evaporation rate	evaporation rate	Losses due to evaporation	precipitation rate
			(L/day)	(mm/day)	(m/day)	(L/day)	(mm/day)
17	17-04-25	Thursday	2,550	5.3	0.0053	27.7932	0
18	18-04-25	Friday	2,600	5.5	0.0055	28.842	0
19	19-04-25	Saturday	2,950	5.6	0.0056	29.3664	0
20	20-04-25	Sunday	3,005	5.2	0.0052	27.2688	0
21	21-04-25	Monday	2,780	4.7	0.0047	24.6468	0
22	22-04-25	Tuesday	2,760	4.9	0.0049	25.6956	0
23	23-04-25	Wednesday	2,745	5.1	0.0051	26.7444	0
24	24-04-25	Thursday	2,850	5.3	0.0053	27.7932	0
25	25-04-25	Friday	2,890	5.5	0.0055	28.842	0
26	26-04-25	Saturday	2,920	5.2	0.0052	27.2688	0
27	27-04-25	Sunday	2,975	5.6	0.0056	29.3664	0
28	28-04-25	Monday	2,650	5.1	0.0051	26.7444	8.9
29	29-04-25	Tuesday	2,750	4.8	0.0048	25.1712	5
30	30-04-25	Wednesday	2,550	4.6	0.0046	24.1224	0
		TOTAL	**80,890**			**783.978**	**13.9**

The average daily flow rate calculated from the net inflow considering losses due to evaporation and the input from precipitation using excel resulted in 2720 L/day

Retention Basin Design and Input Data

The retention basin was designed based on the estimated greywater load from the study population. A total of 50 persons were identified within the selected households, with an average daily greywater generation rate of 2,720 L. The basin was constructed with external dimensions of 2.76 m × 1.90 m × 1.17 m, yielding a gross volume of 6.14 m³ (6,135 L) table 3.2, calculated as the product of length, breadth and depth (Metcalf & Eddy, 2014).

To ensure operational safety and avoid overflow, a freeboard of 10% was applied, reducing the usable storage volume to 5,522L. Freeboard allowances of 10–20% are commonly recommended in small-scale wastewater treatment systems to accommodate wave action and unexpected inflow variations (Crites & Tchobanoglous, 1998; Tchobanoglous, Burton, & Stensel, 2003).

A factor of safety (FoS) of 1.5 was incorporated into the design to account for variability in household water use and potential peak inflows. Safety factors in the range of 1.2–2.0 are widely applied in constructed wetlands and retention basin designs to increase reliability under fluctuating hydraulic and pollutant loads (Kadlec & Wallace, 2009; Vymazal, 2011). With the applied FoS, the required storage volume was 4,080 L, which is comfortably below the basin's effective capacity.

The hydraulic retention time (HRT) was estimated by dividing the working volume by the daily greywater flow, giving 2.03 days (≈48.7 hours). This exceeds the 24-hour design target typically recommended for retention basins serving as equalization and primary treatment units prior to wetland application (UN-HABITAT, 2008). The basin design is therefore sufficient to meet both volumetric and operational requirements.

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Table 2: The Retention Basin Design Calculations and Input Data

Parameter	Value	Units	Basis / Reference
Population size	50	Persons	Field survey (structured questionnaire & key informant interviews)
Greywater generation rate	54.4	L/person/day	Field measurement; consistent with ranges in Metcalf & Eddy (2014)
Daily greywater load (Q)	2,720	L/day	50 × 54.4 L/person/day
Basin dimensions	2.76 × 1.90 × 1.17	m	Field design
Gross volume (V)	(≈ 6,135)	m³ (L)	V = L × B × D (Metcalf & Eddy, 2014)
Freeboard allowance	10% of gross volume (≈ 614)	m³ (L)	Typical design allowance 10–20% (Crites & Tchobanoglous, 1998; Tchobanoglous et al., 2003)
Working (usable) volume	5,522	L	Gross volume – 10%
Factor of safety (FoS)	1.5 (conservative)	Dimensionless	Common range 1.2–2.0 (Kadlec & Wallace, 2009; Vymazal, 2011)
Required storage with FoS	4,080	L	Q × FoS = 2,720 × 1.5
Hydraulic retention time (HRT)	2.03 (≈ 48.7)	Days (hours)	HRT = Working volume ÷ Q
Design target HRT	24	Hours	UN-HABITAT (2008); Crites & Tchobanoglous (1998)
Design outcome	Basin capacity exceeds required volume and HRT even under FoS = 1.5	—	Demonstrates adequacy of design

The retention basin dimensions are;
1. Length = 276 cm = 2.76 m
2. Breadth = 190 cm = 1.90 m
3. Depth =117cm=1.17m

The Surface Area:

A = 2.76×1.90=5.244 m^2

Daily Evaporation Volume Loss

Total volume loss due to evaporation (Liters/day) =
Evaporation (m/day) ×Surface Area (m^2) ×1000 (L/m^3) = 783.978 l/day

Calculate rainwater volume (V_r) entering the basin:

V_r = Rainfall (mm) ×Basin Area (m²) ×0.001
V_r = 13.9 x 5.244 x 0.001
= 0.07289m^3/ 72.9liters

Total wastewater generated = (total volume measured + losses due to evaporation – rainwater volume)

= (80,890 + 783.978 – 72.9)
= 81,601.078

Per Capita Generation = $\frac{\text{Wastewater Volume}}{no\ of\ persons\ x\ no\ of\ days}$

$$\frac{81{,}601.078}{50x30}$$

= 54.40liters per capita per day

The assessment of greywater generation in NWRI in Mando, a peri-urban settlement in Kaduna State, Nigeria, revealed a mean value of 54.40litres per capita per day (L/c/d). This figure encompasses wastewater generated from non-toilet household activities, including bathing, laundry, dishwashing and food preparation with boreholes as the source of water

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supply. The observed generation rate is indicative of moderate water use, shaped by household income levels, water availability, infrastructural access and cultural habits which are factors often identified in greywater generation studies (Li *et al*., 2019; Otieno & Omole, 2017).

This value aligns with previous research conducted in urban and peri-urban areas across sub-Saharan Africa Table 3. For instance, Mathew *et al*. (2023) reported greywater generation rates ranging from 30 to 70 L/c/d in Ibadan, Nigeria, while Oke *et al*. (2016) found a similar range (40–60 L/c/d) in peri-urban Lagos. These figures suggest that water consumption patterns in Nigerian cities, particularly in low and middle-income households, tend to result in moderate greywater production, limited primarily by water access and cost (Ahmad & Daura., 2019).

Regionally, greywater generation in East African contexts shows comparable trends. Otieno and Omole (2017) reported greywater flows ranging between 35 and 60 L/c/d in informal settlements of Nairobi, where most households depend on communal or irregular water supplies. Similarly, Mekonnen et al. (2018) estimated per capita greywater production of 50–65 L/c/d in Addis Ababa, Ethiopia. These findings highlight the strong influence of water supply infrastructure and socio-economic conditions on household water use and subsequent wastewater generation.

Average greywater generation in urban households has been reported at 50–80 L per capita per day in Australia (Oteng-Peprah, Acheampong, & Gyeabour, 2018), while values of 50–70 L/c/d have been observed in Jordan, a water-scarce country where reuse is highly prioritized (Al-Hamaideh & Bino, 2010). The significance of greywater in the total volume of household wastewater is substantial. According to (Oteng-Peprah et al., 2018), greywater accounts for approximately 60–75% of total domestic wastewater in most households. However, despite the significant volume of greywater generated, most households in Mando axis practice informal disposal, such as channeling greywater to open drains or surrounding land surfaces. Similar disposal practices have been reported in other Nigerian cities, where untreated greywater is commonly released into drainage channels and surrounding environments due to inadequate decentralized treatment facilities and poor public awareness of reuse opportunities (Adelekan & Ogunsola, 2012; Adindu, 2023).

The average figure of 54.45 L/c/d supports the design and feasibility of decentralized greywater treatment systems, especially constructed wetlands, which are suitable for small to medium household clusters. Gross *et al*. (2015) demonstrated the applicability of Free Water Surface (FWS) constructed wetlands for treating greywater in semi-arid rural and peri-urban environments. Maimon *et al*. (2010) also confirmed that such systems can reduce pollutants while producing water safe for non-potable reuse, particularly for irrigation or flushing.

In terms of policy implications, the results contribute to ongoing discussions about integrating Citywide Inclusive Sanitation (CWIS) and decentralized wastewater management in Nigerian cities. Accurate data on greywater generation is essential for effective urban water management, as it enables evidence-based planning and the development of appropriate reuse strategies (Van de Walle, 2023). The data from NWRI fills this gap and can support capacity development for agencies involved in sanitation planning and environmental protection.

Although socio-cultural factors were not directly assessed in this study, existing literature indicates that public perception and cultural practices strongly influence greywater reuse adoption.Studies have shown that public perception, cultural practices, and religious beliefs play a significant role in household willingness to reuse greywater. Amoah et al. (2020) highlighted that social acceptance and hygiene concerns strongly influence reuse practices in low- and middle-income settings. Similarly, Rodda et al. (2011) and Malama et al. (2014) demonstrated that cultural perceptions and community awareness directly affect the adoption of greywater reuse in Southern Africa. Therefore, any reuse initiative in Mando must be

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accompanied by community sensitization, hygiene education, and participatory planning.

Table 3: Comparative Greywater Generation Rates

Country / Settlement	Context	Greywater Generation (L/person/day)	Reference
Mando, Kaduna (Nigeria)	Peri-urban residential area	Present Study 54.40	
Ghana (peri-urban households with in-house water supply)	Peri-urban	≈ 61.2	Oteng-Peprah, de Vries, & Acheampong (2018)
Ghana (peri-urban households relying on external water)	Peri-urban	≈ 32.5	Oteng-Peprah, de Vries, & Acheampong (2018)
Ghana – Oforikrom Municipal Assembly	Low-income urban	53.7	Asare, Oduro-Kwarteng, & Donkor (2023)
Ghana – Kumasi Metropolis	Urban	≈ 43	Oduro-Kwarteng, Awuah, & Donkor (2017)

CONCLUSION

This study quantified domestic greywater generation in a tropical peri-urban residential community using direct field measurements over a 30-day period. The mean generation rate of 54.4 L/person/day confirms that greywater constitutes a significant and predictable wastewater stream in the study area. The results align with reported values from similar tropical contexts and provide reliable, site-specific data essential for decentralized sanitation planning.

By addressing a critical data gap on household greywater generation in Nigeria, the study contributes empirical evidence necessary for sustainable urban water management and informed infrastructure design. These generation data provide the quantitative basis for the subsequent optimization of small-scale constructed wetlands evaluated in the companion study.

RECOMMENDATIONS

The quantified domestic greywater generation rates obtained in this study provide a critical empirical basis for translating household wastewater data into effective design and optimization of decentralized treatment systems. To support the optimization of small-scale constructed wetlands for domestic greywater treatment and reuse, the following recommendations are proposed:

1. Use of site-specific generation data: Locally measured greywater generation rates should be adopted as primary design inputs for small-scale constructed wetlands, rather than relying on generalized assumptions, to improve design accuracy and system performance.
2. Hydraulic loading and sizing optimization: Greywater generation data should inform the determination of appropriate hydraulic loading rates, wetland surface area, and basin dimensions, ensuring adequate treatment capacity under variable household water-use conditions.
3. Retention time determination: Accurate estimation of greywater inflow volumes is essential for defining suitable hydraulic retention times, which directly influence pollutant removal efficiency in free water surface and other wetland configurations.
4. Plant species selection and performance: Knowledge of influent greywater volumes should guide the selection and spatial arrangement of

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macrophyte species, enabling optimization of plant uptake capacity, system resilience, and seasonal performance.

5. Scalability and sanitation planning: Incorporating site-specific greywater generation rates into wetland design enhances the scalability and replicability of decentralized sanitation systems and supports evidence-based urban water and sanitation planning consistent with Citywide Inclusive Sanitation principles (WHO, 2017; UN-Water, 2023).

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