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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

This study quantified domestic greywater generation rates in a tropical peri-urban residential community to provide strong engineering design inputs for decentralized wastewater treatment systems. The National Water Resources Institute (NWRI) residential units in Kaduna, Nigeria, served as a representative case. Greywater generated from non-toilet household activities, namely bathing, laundry, dishwashing and food preparation were quantified through direct field monitoring over a continuous 30-day period for a resident population of 50 persons. Daily greywater inflows were measured at source outlets and corrected for evaporation losses and rainfall contributions using on-site meteorological observations to obtain accurate net generation values suitable for hydraulic analysis. The total greywater volume recorded during the monitoring period was 81,601 L, corresponding to a mean per-capita generation rate of 54.4 L/person/day. Daily net inflows ranged from 2,550 to 3,005 L/day, with an average flow of approximately 2,720 L/day. These values indicate moderate household water-use patterns typical of peri-urban residential settings and exhibit limited temporal variability, supporting their applicability for steady-state and conservative design assumptions. The findings provide reliable, site-specific greywater generation data essential for decentralized sanitation planning and non-potable reuse assessment and offer a robust empirical basis for future decentralized wastewater treatment design studies.

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INTRODUCTION

Growing freshwater scarcity driven by population growth, rapid urbanization and increasing climate variability has intensified the need for alternative and sustainable water sources, particularly in water-stressed tropical regions. In Sub-Saharan Africa, the combined pressures of unreliable water supply systems and expanding peri-urban settlements have increased interest in wastewater reuse as a strategic component of integrated water resources management (UN-Water, 2023; Mekonnen & Hoekstra, 2020). Greywater reuse, in particular, offers significant potential to augment non-potable water supply while reducing pollutant loads discharged into the environment.

Despite this potential, wastewater management infrastructure in many tropical developing countries remains inadequate. Large proportions of domestic wastewater are discharged untreated into surface drains, soils and nearby water bodies, contributing to environmental degradation and public health risks (WHO, 2022; Adindu, 2023). Decentralized wastewater treatment systems are increasingly promoted as technically appropriate and economically viable alternatives to centralized

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sewerage in peri-urban and low-density residential settings.

Greywater which is defined as wastewater generated from household activities excluding toilet effluent constitutes the dominant fraction of domestic wastewater, typically accounting for 60–80% of total household wastewater volume (Abed et al., 2020; Pinto et al., 2021). Compared to blackwater, greywater generally contains lower concentrations of nutrients, organic matter and pathogens, making it more amenable to decentralized treatment and reuse. This characteristic underpins the growing application of nature-based treatment technologies, particularly constructed wetlands, for greywater management in tropical environments (Langergraber & Dotro, 2019; Vymazal, 2021).

The effective planning of decentralized sanitation systems requires accurate, site-specific data on greywater generation rates. However, despite growing global interest in greywater reuse, empirical data from tropical peri-urban residential communities in Sub-Saharan Africa remain limited (Bakare et al., 2017; Asare et al., 2023). This data gap constrains evidence-based sanitation planning and leads to reliance on generalized assumptions that may compromise system performance.

This study therefore quantifies domestic greywater generation rates in a tropical peri-urban residential community in Kaduna, Nigeria, using direct field measurements to provide empirical data for decentralized sanitation planning and greywater reuse assessment.

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 lies within the Northern Guinea Savannah ecological zone and experiences a tropical savannah climate characterized by a pronounced wet season (April–October) and dry season (November–March). Mean daily temperatures remain relatively high throughout the year, while seasonal rainfall patterns strongly influence household water-use behavior and wastewater generation dynamics (Nigerian Meteorological Agency [NiMet], 2021; World Bank Group, 2023).

The residential units comprise planned institutional housing occupied primarily by NWRI staff and their households. Potable water is supplied through a centralized borehole water supply system; however, wastewater management infrastructure remains limited. Household wastewater generated from domestic activities is typically discharged without prior segregation or on-site treatment, reflecting sanitation practices common in many Nigerian peri-urban settings (WHO, 2022; Adindu, 2023). This context provides a suitable case study for assessing domestic greywater generation and its implications for decentralized sanitation planning.

Greywater Source Identification

Greywater was defined in this study as wastewater generated from non-toilet household activities, including bathing, handwashing, laundry, dishwashing and food preparation. Accordingly, greywater was collected exclusively from bathrooms, wash basins, kitchen sinks and laundry outlets. Blackwater (toilet effluent) was deliberately excluded due to its substantially higher organic load and pathogen content, which fundamentally distinguish it from greywater in terms of composition and management requirements (Eriksson et al., 2002; Ghaitidak & Yadav, 2013).

The inclusion of kitchen greywater, despite its relatively higher grease and organic content, was intentional, as it reflects realistic household wastewater generation patterns and contributes significantly to total greywater volume in the study area. Source identification and segregation were carried out at designated household outlets to enable accurate quantification of greywater generated from non-toilet activities.

Assessment of Greywater Generation

A short-term longitudinal field monitoring approach was adopted, combining

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quantitative measurement with a structured household survey. The study population comprised households within the NWRI residential unit, with a total resident population of 50 persons distributed across three blocks of flats, each containing six households. A sampling frame was developed using the NWRI household registry and the housing units were classified as single-family residences. Stratified random sampling was applied to ensure representation across household sizes and occupancy patterns.

Primary data collection involved two complementary methods. First, a structured household survey was administered to collect information on household composition, daily water-use activities (such as bathing frequency, laundry practices and dishwashing routines) and general water-use behavior. Second, direct measurement of greywater generation was undertaken by installing calibrated collection devices at designated greywater outlets (into a retention basin). Greywater volumes were measured daily over a continuous 30-day monitoring period Figure 1 to capture short-term temporal variability.

Meteorological data for the monitoring period were obtained from the NWRI on-site Meteorological Station. Daily evaporation rates and rainfall depths were used to correct measured greywater volumes for losses due to evaporation and gains due to precipitation Figure 2, ensuring accurate estimation of net greywater generation. This correction is particularly important in open or semi-open collection systems in tropical climates, where evaporation and rainfall can significantly influence measured volumes. Ethical approval was not required as the study involved no human subjects, personal identifiers or invasive procedures.

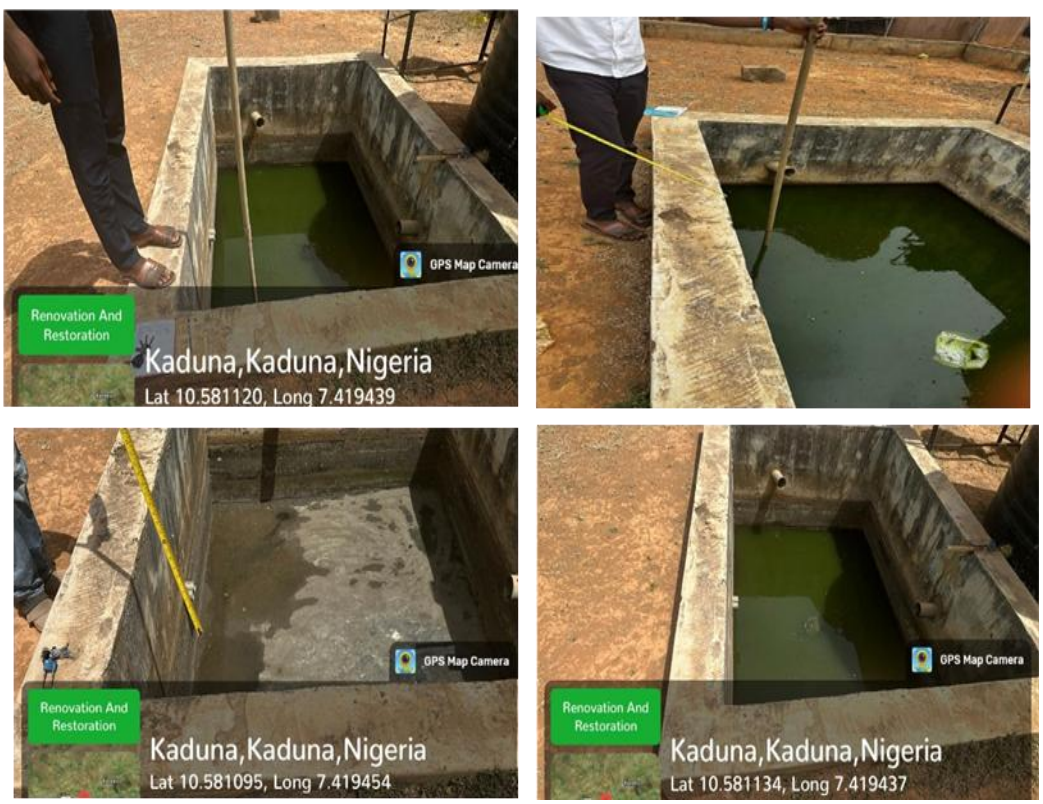

Figure 1 Daily Direct Measurement of Generated Domestic Greywa

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Figure 2 NWRI Metrological Station

Data Analysis

Greywater generation data were analyzed using Microsoft Excel to characterize daily, cumulative and per-capita generation patterns (Abed et al., 2020; Pinto et al., 2021). Daily volumes were aggregated to determine total greywater generation, mean daily flow and per-capita generation rates expressed in litres per person per day (L/person/day). Measures of central tendency (mean) and dispersion (minimum and maximum values) were used to assess temporal variability.

Net daily greywater generation was calculated by adjusting measured volumes for evaporation losses and rainfall contributions. The corrected daily volumes were aggregated over the monitoring period and normalized by the resident population to derive per-capita greywater generation rates expressed in litres per person per day.

To contextualize the findings, the derived per-capita values were compared with reported greywater generation ranges from similar tropical and peri-urban residential settings documented in recent literature (Asare et al., 2023; UN-Water, 2023). The analysis focused exclusively on quantifying greywater generation rates; therefore, treatment unit design and detailed hydraulic calculations were outside the scope of this paper.

RESULTS AND DISCUSSION

Domestic Greywater Generation Rates

Greywater constituted a substantial fraction of total household wastewater generated during the monitoring period (Table 1), confirming its dominance as the primary domestic wastewater stream in the study area.

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

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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)
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
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

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			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)
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 observed daily net greywater inflows, which ranged from 2,550 to 3,005 L/day over the 30-day monitoring period, demonstrate relatively stable generation patterns with moderate day-to-day variability. This stability reflects regular household water-use activities such as bathing, laundry, dishwashing, and food preparation, which tend to follow predictable daily routines in institutional residential settings.

Based on a mean daily greywater generation of 2,720 L/day and a resident population of 50 persons, the per-capita greywater generation rate was estimated as 54.4 L/person/day. The mean per-capita greywater generation rate of 54.4 L/person/day observed in this study is indicative of moderate domestic water use typical of peri-urban residential communities in Sub-Saharan Africa. This value aligns closely with recent findings from comparable settings, where per-capita greywater generation rates generally fall within the range of 30–70 L/person/day, depending on water availability, infrastructure, and household practices (Abed et al., 2020; Asare et al., 2023; Mathew et al., 2023). The agreement between the present results and those reported in the literature suggests that the NWRI residential units provide a representative case for peri-urban institutional housing in Nigeria.

Temporal variability in daily greywater generation, although limited, was evident across the monitoring period. Such variability is commonly attributed to fluctuations in household activity intensity, including laundry frequency and weekend versus weekday water-use behavior. Similar short-term variations have been reported in recent greywater generation studies and highlight the importance of accounting for daily fluctuations when assessing greywater reuse potential and planning decentralized sanitation systems (Pinto et al., 2021).

Overall, the findings confirm that greywater represents a significant and recoverable wastewater stream in peri-urban residential communities. The relatively predictable nature of greywater generation observed in this study supports its consideration in decentralized sanitation planning and non-potable reuse assessments. Importantly, the use of direct field measurement combined with climatic corrections enhances the reliability of the reported generation rates and addresses a key data gap for peri-urban residential settings in Nigeria.

Comparative Analysis of Greywater Generation Rates

The comparative analysis presented in Table 3.3 further supports the representativeness of the greywater generation rate obtained in this study. The mean per-capita generation rate of 54.4 L/person/day observed in the Mando, Kaduna peri-urban residential community is comparable to values reported for similar peri-urban and urban contexts in Ghana. In particular, the measured value closely aligns with greywater generation rates of approximately 53.7 L/person/day reported for low-income urban

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households in the Oforikrom Municipal Assembly and 61.2 L/person/day for peri-urban households with in-house water supply in Ghana.

Table 2: 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)

The lower greywater generation rate of approximately 32.5 L/person/day reported for peri-urban households relying on external water sources highlights the strong influence of water access and supply reliability on household water-use behavior. Similarly, the intermediate value of about 43 L/person/day reported for the Kumasi Metropolis reflects the moderating effects of urban density and water-use restrictions. These variations underscore that differences in greywater generation across settings are primarily driven by water availability, infrastructure, and socio-economic conditions rather than climatic factors alone.

Overall, the close agreement between the present study and recent empirical findings from comparable West African peri-urban and urban residential settings strengthens the validity of the measured greywater generation rate. The results confirm that the value of 54.4 L/person/day represents a realistic and defensible estimate for peri-urban residential communities with relatively reliable water supply in Nigeria.

CONCLUSION

This study quantified domestic greywater generation rates 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 fraction of household wastewater in the study area. The observed values align with reported ranges from similar tropical residential contexts, supporting their representativeness. By providing site-specific greywater generation data from a Nigerian peri-urban setting, the study addresses a critical data gap and supports evidence-based decentralized sanitation planning and greywater reuse assessment in rapidly urbanizing communities.

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 by:

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1. Site-specific greywater generation rates should be used for decentralized sanitation planning rather than generalized assumptions.
2. Greywater reuse assessments in peri-urban areas should account for observed daily variability in generation.
3. Similar generation studies should be extended to other residential typologies to improve national and regional planning benchmarks.
4. Future research should integrate greywater quality characterization with generation data to support treatment system optimization.
5. Consistent with Citywide Inclusive Sanitation principles (WHO, 2022; UN-Water, 2023).

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