Journal of Energy and Natural Resource Management (JENRM), Vol. 11, No. 1, 27-38, 2025
Received: May 16, 2025; Revised: August 19, 2025.; Accepted: August 25, 2025

Sanitation Management Practices and Treatment Of Greywater Using a Simple Filtration System

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Abstract
Greywater is a type of wastewater generated from bathrooms, handwashing basins, kitchens, laundry, and related sources, excluding wastewater from toilets. Its management is essential to prevent public health and environmental risks. This study assessed sanitation management practices in three communities in the Sunyani West District of Ghana and investigated greywater treatment using a simple filtration system. A cross-sectional household survey, greywater sampling, laboratory analyses, and filtration treatment were employed. Less than half of respondents reported access to household toilet facilities, of which about 60% were wet sanitation systems. Over 50% of households relied on the Ghana Water Company Limited's piped-water supply. Greywater reuse, assessed from bathrooms, car washing bays, laundries, and salons, was most common in laundry services. Raw greywater quality analysis revealed that nearly all physicochemical parameters and total coliforms (3.9–7.4 log10 CFU/100 mL) exceeded the Ghana Environmental Protection Agency (EPA) limits, while heavy metals were within permissible levels. E. coli and Salmonella spp. loads were absent in the car washing bay and salon greywater and within the EPA regulatory limits of 1.0 and 0 log10 CFU 100 mL-1, respectively. Microbial removal by the filtration system was highly efficient, with E. coli and Salmonella spp. completely eliminated and total coliform reduced by 76–100% across sources. Physicochemical removal was also substantial (up to 97% for TSS, turbidity, and COD), but most parameters remained above EPA standards. These findings indicate that the low-cost system can improve microbial safety of greywater for restricted reuse, though further treatment is needed for full compliance with physicochemical guidelines.

Keywords
Charcoal, Filtration, Greywater, Micropollutant, Moringa, Water Quality

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DOI: 10.26796/jenrm.v11i1.295
Received: May 16, 2025; **Received in revised form:** August 19, 2025; **Accepted:** August 25, 2025; **Published:** August 30, 2025

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1. Introduction

Water scarcity is a global challenge that poses adverse health and environmental threats. This predicament is aggravated by population growth, urbanisation, and climate change, with concomitant stress on water resources. The inability of some developing countries to treat wastewater to tolerable levels further increases contaminant loads in the receiving environment, thereby worsening the crisis of freshwater availability and quality (Travis et al., 2010). The demand for water worldwide calls for sustainable management of this scarce resource, including the safe treatment and reuse of wastewater, particularly greywater (Abdel-Shafy et al., 2014). Greywater is a type of wastewater generated from bathrooms, handwashing basins, kitchens, laundry, and related sources, excluding wastewater from toilets (Eriksson et al., 2002). Its quantity and characteristics vary across countries depending on climate, water availability, lifestyle, and population structure (Oteng-Peprah et al., 2018). Greywater often contains high concentrations of surfactants and heavy metals (Eriksson & Donner, 2009; Mohamed et al., 2013), but comparatively lower pathogen loads (Mandac et al., 2014). Nevertheless, pathogen presence means prolonged exposure can still increase mortality and morbidity risks (Ottoson & Stenström, 2003). In Ghana, although greywater is widely generated, only about 6% is properly managed (Dwumfour-Asare et al., 2018). The indiscriminate disposal of untreated greywater into drains and the environment not only creates local problems such as odour and mosquito breeding but also contributes to global water quality deterioration and loss of opportunities for water reuse. Studies in Ghana have shown that greywater contains micropollutants (Dwumfour-Asare et al., 2017), which have been detected in surface waters (Azanu et al., 2021), posing risks to human health and aquatic ecosystems. These micropollutants are potential health risks to humans and aquatic organisms (Backhaus, 2014). Linking this local challenge to the broader global scarcity crisis underscores the urgency of finding affordable, sustainable greywater treatment solutions. Many approaches have been explored, including physical, chemical, and biological systems (Abdel-Shafy et al., 2014; Abu-Zreig et al., 2003). Each has strengths and limitations, with adoption often constrained by costs, contaminant load, and intended end-use. For instance, hybrid integrated systems can achieve unrestricted reuse but are costly (Abdel-Shafy et al., 2014), while granular activated carbon biofilters are effective but require long operational times (Sharaf et al., 2020). These constraints highlight the need for simple, eco-friendly, low-cost technologies suitable for households in resource-limited settings. In this study, a simple filtration system comprising gravel, sand, moringa seeds, and charcoal was evaluated for greywater treatment. Such low-cost systems can maximize reuse potential, improve microbial safety, and reduce environmental risks (Arifin et al., 2020). The specific objectives of this study were to (i) assess the sanitation facilities and greywater management practices in three communities in Sunyani West District of Ghana and (ii) investigate the treatment of greywater using a simple filtration system with charcoal, moringa, gravel, and sand for reuse. Charcoal has a large surface area and can trap many micropollutants and chemical contaminants due to its adsorptive characteristics (Bernal et al., 2018). Charcoal is readily available and can effectively reduce the levels of organic compounds, odour, and taste from contaminated water (Dvorak & Skipton, 2013). Moringa seeds are natural coagulants that attract pollutants in wastewater to enhance removal efficiency and improve colour (Madrona et al., 2012).

2. Materials and Methods

2.1 Description of the study area

The study was conducted at Fiapre, Odumase, and Chiraa communities in the Sunyani West District in the Bono Region of Ghana (Figure 1). These communities were purposively selected because they are the most populous in the district, with relatively high population densities that generate greater volumes of greywater and present diverse sanitation practices. Their size, therefore, made them representative of the greywater management challenges in the district. According to the 2010 Population and Housing Census, the populations of Fiapre, Odumase, and Chiraa were 11,986, 16,542, and 16,348, respectively (Ghana Statistical Service, 2012). 2.2 Data collection A cross-sectional study was employed for the study. The data collection involved household surveys, greywater sampling, and laboratory analyses. One hundred participants from each of the three communities (a total of 300 participants) were randomly selected for the administration of the questionnaires. The sample size (n) was calculated from the equation, $n = N/(1 + N(e^2))$, (Yamane, 1967) N= total population of the community; e=margin of error (10Household survey data included access to water, sanitation facilities, household expenditure, demography, and greywater management practices. Greywater samples were collected from four sources: bathrooms, car washing bays, commercial laundry services, and hairdressing salons, and all four sources were subjected to the filtration treatment experiment. Electrical conductivity and pH of greywater were measured in situ. For each of the greywater generation sites, in each community, a 1-L narrow-mouth low-density polyethylene (LDPE) bottle with leak-proof polypropylene closure was used to sample greywater from storm drain or PVC pipe outfall. The samples were transported on ice to the laboratory for analyses within 2 to 4 hours after collection. Physical and microbial analyses were carried out at the University of Energy and Natural Resources (UENR) laboratories, Sunyani, Ghana while heavy metals were analysed at the Environmental Quality Laboratory at Kwame Nkrumah University of Science and Technology (KNUST), Kumasi, Ghana. Raw greywater samples were characterised using Standard Methods for the Examination of Water and Wastewater (APHA, AWWA, 2005) (Table 1).

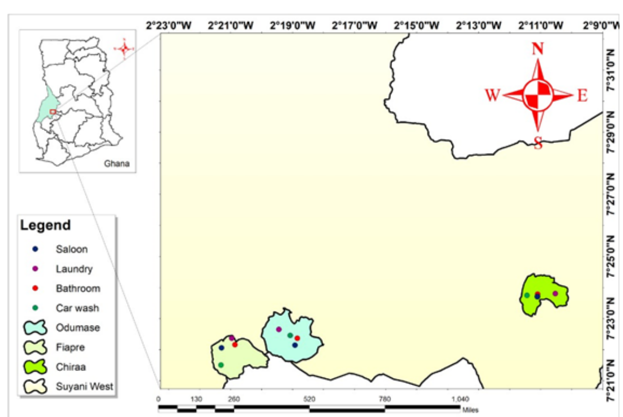

Figure 1. Map of the study area

2.2 Filtration system

The filtration system was constructed with a 20-L plastic bucket connected with a 102 mm diameter inlet PVC pipe (705 mm long); about 50 mm below the top of the plastic bucket. The filter bed comprised multiple layers arranged from the bottom upwards: a 60-mm layer of 40-mm diameter coarse gravels, a 40-mm layer of 20-mm diameter fine gravels, a 20-mm thick layer of cotton wool, a stratum of dried coconut husks (depth: 40 mm), an 80-mm fine sand layer (2-mm diameter), and a 100-mm layer of charcoal mixed with Moringa oleifera seed powder (Suhartini et al., 2013) . On top of this mixture was a 100-mm layer of 20-mm diameter coarse gravel. A 25-mm PVC outlet pipe was connected from the base of the filtration bucket to a 20-L storage container equipped with a tap for easy access to the treated effluent. A schematic diagram of the constructed system has been provided (Figure 2) to illustrate the layering, dimensions, and flow path.

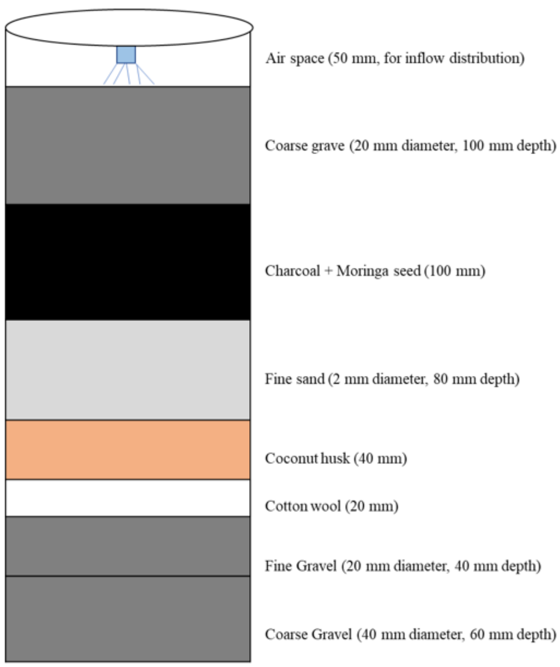

Figure 2. Greywater Treatment Steps

Only greywater from the hairdressing salon was subjected to a simple pre-treatment step, where 2.5 L of raw greywater was left to stand for 30 minutes to allow oil and grease to float and then skimmed off to prevent fat blockage and filter fouling. Other sources were used without pre-treatment because they did not exhibit the same visible oil and grease layer. Although laundry greywater contained high organic loads, its composition was dominated by surfactants and suspended solids rather than floating oils, and therefore did not require the same skimming process (Mandac et al., 2014). For each greywater source in each community, equal volumes of raw greywater were introduced into the filtration unit via the inlet pipe and allowed to percolate through the layers for treatment. Treated effluents were sampled directly from the storage container for physicochemical and microbiological analyses using the same protocols applied to raw samples. This procedure ensured a consistent comparison of raw and treated water quality across all four greywater sources. 2.4 data analysis Data were analysed with SPSS (IPM 21) and Microsoft Excel 2019. All laboratory analysis was done using the appropriate standard methods (Table 1)

Table 1. Laboratory analysis of water parameters

Parameters	Unit	Analytical Techniques (Method Used)
pH		Electrochemical Method Using pH Meter
Turbidity	NTU	Hanna turbidimeter (HI 93414)
Electrical Conductivity	μS cm-1	Electromagnetic Induction Method
Magnesium	mg L-1	Gravimetric Method
TSS	mg L-1	Gravimetric method by the filtration process
Phosphorus	mg L-1	Spectrometric methods
Nitrogen	mg L-1	Spectrometric methods
COD	mg L-1	Open reflux titrimetric
BOD	mg L-1	Dilution methods
Total Hardness	mg L-1	Ethylenediaminetetraacetic acid (EDTA) Titration with Eriochrome Black T (EBT) as Indicator
Pb	mg L-1	Iodometric Method
Fe	mg L-1	Spectrophotometric Method
Zn	mg L-1	Atomic absorption spectroscopy (Agilent 200 Series).
E. coli	CFU 100 mL-1	Most Probable Number method
Salmonella	CFU 100 mL-1	Salmonella detection method
Total Coliform	CFU 100 mL-1	Most Probable Number method

CFU= colony formation unit, COD= chemical oxygen demand, TSS= total suspended solids, BOD=biochemical oxygen demand

3. Results and Discussion

3.1 Characteristics of respondents

The average respondents for the study constituted 36.3% and 63.7% males and females respectively (Table 2). The high percentage of females was preferred because issues of water usage and sanitation are generally considered as women's responsibilities (Antwi-Agyei et al., 2020). All respondents in the study were adults within an average age of 42-45 years for the three communities. This corresponds with the study by Dwumfour-Asare et al. (Dwumfour-Asare et al., 2020), although their study area was in Kumasi, Ghana. The result shows that the respondents were people capable of giving useful answers to the survey questionnaires. The overall mean household size recorded was 4. This was slightly below the national average of 4.5 people (Ghana Statistical Service, 2012). However, Fiapre and Odumase recorded the same average household size of 5. About 47% of all the households used household toilet facilities while 53% accessed public toilets (Table 2). About 60% of the household toilet facilities are classified as wet sanitation systems (i.e., water closet with septic tank); which has the potential for greywater reuse for toilet flushing. The remaining 40% used Kumasi Ventilated Improved Pit (KVIP) latrines (a dry sanitation option) (Thrift, 2007).

The majority of the respondents (56%) used onsite Ghana Water Company Limited (GWCL) piped-water supply for domestic purposes. The average daily per capita water consumption was approximately 124 L for Fiapre and Odumase which is about 30% higher than that of Chiraa. Per capita water consumption may be influenced by individuals' income levels, lifestyle, and needs requiring water usage. Water consumption expenditure did not show any consistent trend with the quantities of water used by the households. This could be due to the differences in water pricing for private and commercial services. The highest average expenditure on water was recorded at Odumase (¢36 per month or $6.28 per month). This amount was relatively higher compared to studies by Dwumfour-Asare et al. (¢25 or $4.36 per month) (Dwumfour-Asare et al., 2020) because respondents in their study used only onsite privately-owned GWCL pipe supply.

3.2 Greywater generation and management practices

The main sources of greywater used in this study included wastewater generated from the bathroom, car washing bay, laundry, and saloon; these are used to define greywater (Wilderer, 2004). The primary source of greywater generation in the households was from the bathroom (52%) (Figure 2). It was noted that greywater reuse practices were common with respondents at the laundry services (85%) compared to the households (15%) and other sources. The high reuse rate at laundry services can be attributed to the large volumes of wastewater generated daily, the high cost of fresh water for repeated washing cycles, and the immediate economic benefit of reusing water within their business operations. By contrast, households generate smaller volumes of greywater, and the incentive to reuse is weaker since the cost of piped-water supply is relatively lower for domestic use.

This suggests that economic drivers and perceived utility strongly influence the adoption of greywater reuse. This result agrees with other studies where greywater from car washing bay was not reused (Dwumfour-Asare et al., 2017). Specific household reuse of greywater (3%) included mopping or scrubbing, flushing toilets, and watering lawns (Figure 3). None of the households practiced greywater vegetable irrigation farming since about 96% perceive it as an unsafe method with public health implications. The predominant greywater disposal practice was disposal into stormwater drains (88%). The disposal practices among households are similar to the reports from

Table 2. Respondents Demographic Characteristics

Variable	Items of measurement	Fiapre (N=100)	Chiraa (N=100)	Odumase (N=100)	Average
Gender	Male, (%)	34	30	45	36.33±7.77a
	Female, (%)	66	70	55	63.67±7.77
Age	Average (years)	45 ± 10	43 ± 12	42 ±15	43 ± 14
Household size	Average	5 ± 2	4 ±1	5 ± 3	4 ± 3
Household income	Average (USD month-1)	261.61±55.85	271.03±67.71	261.08±50.26	264.57±57.94
Access to toilet facility	Household toilet, (%)	46	39	56	47.00±8.54
	Public facility, (%)	54	61	44	53.00±8.54
Source of potable water	GWCL pipe supply, (%)	64	47	57	56.00±8.54
	Public standpipe, (%)	15	22	23	20.00±4.36
	Borehole, (%)	9	22	14	15.00±6.56
	Hand-dug well, (%)	12	7	6	8.33±3.21
	River/Stream, (%)	0	2	0	0.67±1.15
Water consumption	Average (Lpcd)	123±14	88±21	124±24	111±20
Amount spent on water	Average (USD month-1)	4.54±1.13	5.06±1.06	6.258±2.27	5.24±1.48

[a] $\pm SD$ represent standard deviation USD: United States Dollar ($) GWCL: Ghana Water Company Limited Lpcd: Litre per capita per day Exchange rate for May 2021: $1.00 = ¢5.73

the 2010 National Population and Housing Census which indicated that most people practice unimproved methods of disposal (Ghana Statistical Service, 2012). This situation can partly be attributed to the non-existence of sewerage systems in the localities as the entire nation has poor sewerage coverage of less than 5% (Murray & Drechsel, 2011).

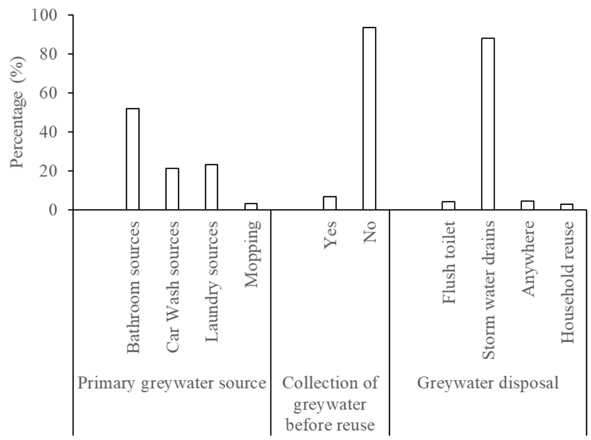

Figure 3. Greywater source and management practices

Studies have suggested that frequent education helped increase the perceptions on the need to treat greywater water and appreciate its association with water-borne diseases (MacAfee, 2017). It was evident that after explaining the importance of the greywater treatment, some respondents (6.7%) considered adopting greywater treatment in the future. However, the majority rejected adoption, citing high costs (96.3%) and the perception that treatment should be the responsibility of the government (3.7%). This is a critical social finding, highlighting financial and institutional barriers to household adoption. Strengthened community education could play a pivotal role in shifting perceptions, reducing reliance on government, and building willingness to adopt affordable household-scale treatment options (Carden et al., 2007).

3.3 Characteristics of greywater and treatment efficiency

The greywater characterisation involved the assessment of greywater quality in terms of physicochemical, microbial, and heavy metal concentrations from all the greywater sources in the three communities. Water quality was monitored for both the raw and treated greywater (Tables 3-5). Generally, it was observed from Tables 3-5 that except for pH, all the physicochemical concentrations of the raw greywater in all three communities at all four-generation points (that is bathroom, car washing bay, laundry, and saloon) were above the Ghana Environmental Protection Agency (EPA) discharge limit (EPA, 2007). The result supports earlier findings that raw greywater generated in Ghana does not satisfy the required discharge limit set by the Ghana EPA (Dwumfour-Asare et al., 2018). For treated greywater, most of the physicochemical characteristics were above Ghana EPA standard except for saloon greywaters which were generally treated to, below the discharge limit. In general, the concentrations of total suspended solids (TSS), turbidity, biochemical oxygen demand (BOD), and chemical oxygen demand (COD) in raw greywater generated from the laundry were up to about an order of magnitude higher than the greywater generated from the bathroom and saloon. Also, the nutrients (nitrogen and phosphorus) in the raw greywater from the laundry were relatively higher than greywater from the bathroom and saloon but approximately equal to greywater from the car washing bay. Reports from other studies showed that the concentrations of nutrients, BOD, and COD in laundry greywater are higher (Sumisha et al., 2015). This can be attributed to differences in the type of soaps, detergents, chemicals, as well as personal care and beauty products used for bathing and hairdo. Chaillou et al. noted that solid soaps usually produce higher levels of TSS, turbidity, BOD, and COD (Chaillou et al., 2011). The high levels of electrical conductivity in greywater from the laundry and car wash may be from the groundwater used for these activities. Interestingly, in a few treated samples, concentrations of Magnesium, Iron, and Zinc were observed to increase rather than decrease. This could be attributed to leaching or dissolution from the filter media (such as sand, gravel, or charcoal), residual impurities in the moringa seeds, or possible desorption of metals already bound to particulate matter. While the increases were not consistent across all samples, this finding highlights a limitation of natural-material filtration systems and warrants further research to optimise the choice of media and prevent secondary contamination. The persistence of most physicochemical parameters above EPA discharge limits after treatment has important implications for reuse. For instance, elevated turbidity, COD, and nutrient concentrations could restrict direct application of the treated effluent for agricultural irrigation of edible crops, laundry reuse, or discharge into sensitive water bodies. However, the significant microbial reductions achieved make the treated greywater potentially suitable for restricted uses such as flushing toilets, landscape irrigation, or cleaning, provided additional polishing steps are incorporated for physicochemical quality.

Increasing concentrations of the nutrients uncontrollably is a threat to receiving water bodies; as it can result in algal bloom. The concentrations of COD in the greywaters from all the sources in all the communities were between 2-12 times more than BOD_5 because of the probable presence of xenobiotic organic compounds in chemicals and surfactants used in cleaning, laundry, and saloon services (Oteng-Peprah et al., 2018). The higher BOD and COD levels of the untreated greywater may challenge biodegradation especially under natural

Table 3. Characteristics of untreated and treated greywater from Fiapre, Ghana

Parameter	Laundry		Bathroom		Car Wash		Salon		Ghana EPA guidelines[a]
Physicochemical parameters	Raw	Treated	Raw	Treated	Raw	Treated	Raw	Treated	
pH	8.9	8.7	6.8	7.2	8.4	7.9	6.35	7.5	9-Jun
EC (μS cm-1)	2,871	2010	1,230	1,345	2,989	2,980	298	299	1,500
TSS (mg L^{-1})	2,987	80	500	63	3,430	488	288	150	50
Turbidity (NTU)	820	90	540	72	470	98	480	69	75
BOD (mg L^{-1})	280	85	133	60	264	64	204.5	50	50
COD (mg L^{-1})	1948	400	388	236.5	2,020	300	612	243	250
Nitrogen (mg L^{-1})	13.3	3.4	6.8	3.6	13.5	9.4	7.6	5.6	1
Magnesium (mg L^{-1})	0.5	0.5	1.93	0.94	4.34	1.34	1.67	1.63	-
Phosphorus (mg L^{-1})	12.6	3	11	4.8	12.8	6.9	21.5	12.8	2
Heavy metals									
Fe (mg L^{-1})	0.136	0.128	0.222	0.212	0.344	0.342	0.476	0.54	10
Pb (mg L^{-1})	0.1	0.1	0.09	0.01	0.1	0.01	0.05	0.01	0.1
Zn (mg L^{-1})	0.039	0.048	0.067	0.03	0.046	0.02	0.001	0.04	10
Microbial Parameters									
Total Coliforms (Log10 CFU 100 mL^{-1})	6.4	0.8	5.8	0.8	6.5	1.1	6.2	<DL	2.6
E. coli (Log10 CFU 100 mL^{-1})	4.7	<DL	4.6	<DL	<DL	<DL	<DL	<DL	1
Salmonella spp. (Log10 CFU 100 mL^{-1})	5	<DL	4.8	<DL	<DL	<DL	<DL	<DL	0

[a]EPA (2007); <DL = Below Detection Limit.

Table 4. Characteristics of untreated and treated greywater from Chiraa, Ghana

Parameter	Laundry		Bathroom		Car Wash		Salon		Ghana EPA guidelinesa
Physicochemical parameters	Raw	Treated	Raw	Treated	Raw	Treated	Raw	Treated	
pH	8.6	8.98	6.9	7	9.5	7.9	6.28	6.3	9-Jun
EC (μS cm^{-1})	3,071	3114	1,530	1,145	1,654	1,584	189	160	1,500
TSS (mg L^{-1})	2,005	1202	485	83	3,630	1000	222	50	50
Turbidity (NTU)	600	98	420	83	240	49	520	60	75
BOD (mg L^{-1})	234	72	120	66	202	48	205	67	50
COD (mg L^{-1})	2880	300	298	230	780	289	912	240	250
Nitrogen (mg L^{-1})	10.8	4.4	7.4	6.6	23.5	12.3	6.6	4.6	1
Magnesium (mg L^{-1})	0.55	0.56	1.63	0.34	0.29	1	1.89	1.53	-
Phosphorus (mg L^{-1})	10.6	4	9	4.87	9.87	5.6	23.5	11.8	2
Heavy metals									
Fe (mg L^{-1})	0.126	0.138	0.233	0.342	0.344	0.442	0.376	0.67	10
Pb (mg L^{-1})	0.1	0.01	0.01	0.01	0.1	0.01	0.06	0.04	0.1
Zn (mg L^{-1})	0.044	0.04	0.073	0.06	0.046	0.03	0.034	0.03	10
Microbial Parameters									
Total Coliforms (Log10 CFU 100 mL^{-1})	7.4	0.2	6.1	0.2	6.5	1.5	3.9	<DL	2.6
E. coli (Log10 CFU 100 mL^{-1})	5.9	<DL	3.6	<DL	<DL	<DL	<DL	<DL	1
Salmonella spp. (Log10 CFU 100 mL^{-1})	6.1	<DL	5.8	<DL	<DL	<DL	<DL	<DL	0

[a]EPA (2007); <DL = Below Detection Limit.

Table 5. Characteristics of untreated and treated greywater from Odumase, Ghana

Parameter	Laundry		Bathroom		Car Wash		Salon		Ghana EPA guidelines[a]
Physicochemical parameters	Raw	Treated	Raw	Treated	Raw	Treated	Raw	Treated	
pH	8	8.09	6.5	6.8	8.2	8	6.23	6.5	9-Jun
EC (μS cm^{-1})	1,671	1,114	890	745	2,007	1,930	280	257	1,500
TSS (mg L^{-1})	2,287	1,256	480	73	3,423	588	168	150	50
Turbidity (NTU)	420	88	350	64	300	66	340	67	75
BOD (mg L^{-1})	380	67	130	62	273	44	136	54	50
COD (mg L^{-1})	1448	250	400	220	2,080	340	531	235	250
Nitrogen (mg L^{-1})	10.3	4.44	7.8	4.6	11.5	6.4	4.8	2.6	1
Magnesium (mg L^{-1})	1.5	0.42	1.76	0.04	1.35	1.37	2.6	1.65	-
Phosphorus (mg L-1)	12.6	5	12.1	6.8	10.5	7.9	12.3	11.8	2
Heavy metals									
Fe (mg L^{-1})	0.137	0.228	0.345	0.312	0.15	0.44	0.56	0.61	10
Pb (mg L^{-1})	0.1	0.01	0.001	0.01	0.09	0.01	0.04	0.01	0.1
Zn (mg L^{-1})	0.078	0.04	0.043	0.03	0.054	0.04	0.03	0.03	10
Microbial Parameters									
Total Coliforms (Log10 CFU 100 mL^{-1})	6.5	0.3	4.1	0.3	5.7	1	4.2	<DL	2.6
E. coli (Log10 CFU 100 mL^{-1})	4.9	<DL	3	<DL	<DL	<DL	<DL	<DL	1
Salmonella spp. (Log10 CFU 100 mL^{-1})	6	<DL	3.6	<DL	<DL	<DL	<DL	<DL	0

[a]EPA (2007); <DL = Below Detection Limit.

environmental self-purification conditions (Varkey, 2020). The ratio of BOD_5/COD which determines the biodegradability of greywater is usually in the range of 0.31-0.71 (Halalsheh et al., 2008). The BOD_5/COD ratio range for this study was 0.08-040, an indication that biological treatment can be limited. Thus, the study employed the integrated filtration treatment method to reduce or eliminate contaminants in the greywater for reuse purposes. Also, all the detected heavy metals in the raw and treated greywater in the 3 communities at all the generation points were below the Ghana EPA discharge limit. The metal contamination could originate from detergents and personal care products (Dwumfour-Asare et al., 2018). While the concentrations of total coliform detected in all the communities at all the generation points were above the Ghana EPA limit, they were below the limit after treatment. On the contrary, *E. coli* and *Salmonella spp* were only observed in laundry and bathroom greywaters in all the 3 communities at concentrations above the Ghana EPA limit but the filtration-adsorption system produced concentrations below the limit. Excreta-related pathogens have been detected in greywater generated from the laundry and bathroom due to poor hygienic practices, and napkins and clothes soiled with faeces (Eriksson et al., 2002; O'Toole et al., 2012). The filtration system showed substantial treatment of greywaters from all the 3 communities at all 4 greywater generation points; although most treatment levels especially physicochemical parameters were above the required Ghana EPA limit for disposal of wastewater into the environment. The highest removals of laundry greywater physicochemical characteristics were 97.3, 83.7, and 82.7%; representing TSS, turbidity, and COD at Fiapre, Chiraa, and Odumase respectively. For bathroom greywater, removal of physicochemical contaminants in all greywater from the 3 communities was between 16 and 98%. Furthermore, greywater treatment levels from the car washing bay and saloon respectively ranged from 0.3-98% and 2-89% in all the communities. Reduction in the concentrations of TSS, turbidity, BOD, COD, nitrogen, and phosphorus in the treated greywater was observed in all generated greywater in all the 3 communities. The other physicochemical parameters did not show noticeable trends. Heavy metals removal from greywater ranged from 0.5 to 91% across communities and greywater generation points. Lead (Pb) was the heavy metal predominantly removed in all greywaters (33-91%). Total coliform removals in greywater generated in the 3 communities were 87-98%, 86-97%, 76-84%, and 100% at the laundry, bathroom, car washing bay, and saloon respectively. Contrarily, 100% *E. coli* and *Salmonella spp.* were removed from laundry and bathroom greywaters generated in the 3 communities. High microbial removal in the studies could be attributed to straining on organisms in the filter media. The filtration system gained a cumulative reduction in the contaminants in the effluent through physical and biochemical processes. This could be explained as, after the greywater enters the system, a biological slime layer known also as a biofilm is formed around the surface of the top particles in the filter bed over a period. This layer of slime consists of both inorganic and organic materials and microorganisms such as bacteria, fungi, protozoa, etc. As the greywater passed through this layer, some soluble and insoluble substances were trapped between the particles of the filter bed. Organic substances were broken down or degraded by the microorganisms in the layer while some contaminants were metabolized by the presence of the biofilm formed on the surface of the particles to make them less toxic. The inclusion of charcoal provided a large surface area for the adsorption of organic matter present in the greywater and also helped in the removal of contaminants such as phosphorus, BOD, and Total Coliforms. Charcoal has exhibited a high capacity to reduce BOD5, COD, and heavy metals in greywater (Ahsan et al., 2001; Babel & Kurniawan, 2004). Also, moringa seed acted as a coagulant to bind the pollutants in wastewater thus improving the removal efficiency of pollutants and the colour of the greywater (Madrona et al., 2012). According to Suhartini et al., an improved water quality is achieved by increasing the dose of *Moringa oleifera* seed coagulant (Suhartini et al., 2013). Thus, using the filtration system (with moringa and charcoal) resulted in the efficient removal of contaminants in the greywater. These findings confirmed with other studies that used Moringa seeds as a natural coagulant to treat wastewater (Suhartini et al., 2013; Varkey, 2020). Despite the considerable microbial reductions achieved, the persistence of physicochemical parameters above Ghana EPA limits presents a major barrier to unrestricted reuse or safe discharge. To address this, future designs should integrate simple, low-cost "polishing steps" that enhance removal efficiency without undermining affordability. Options such as small constructed wetlands, soil or sand infiltration trenches, biochar-amended filters, and solar disinfection have shown promise in household and community contexts and could complement the tested system. These additions would provide further reductions in turbidity, nutrients, and COD at relatively low capital and maintenance costs, making the effluent safer for broader reuse. Another important limitation observed was the occasional increase in magnesium, iron, and zinc in treated samples. Although these concentrations remained within permissible limits, their presence indicates potential leaching from filter media. This underlines the importance of careful material selection and periodic monitoring to prevent secondary contamination during long-term operation. Finally, the consistently low BOD_5/COD ratio (0.08–0.40) demonstrates that the greywater matrix is poorly biodegradable, dominated by recalcitrant compounds from detergents and surfactants. This suggests that biological processes alone are insufficient and that media clogging and performance decline are likely over time. Periodic replacement or regeneration of filter media, combined with adsorption or coagulation steps, will therefore be essential to maintain treatment efficiency and ensure system sustainability.

3.4 Environmental implication

Generally, the water quality parameters of the raw greywater used in the study exceeded the Ghana EPA limit for disposal into the environment. Most physicochemical qualities were not reduced to tolerable concentrations for direct environmental release. Of concern are nutrients, which are primary sources of eutrophication in receiving waters when greywater is indiscriminately discharged, often triggering algal blooms. However, the treatment system demonstrated high microbial removal efficiency, with 76–100% reduction of bacterial indicators, making the effluent suitable for restricted reuse in line with (WHO, 2006) guidelines. An added advantage of the treated greywater is the retention of nitrogen and phosphorus at levels beneficial for crop growth. These nutrients can supplement synthetic fertilizers, improve soil fertility, and support vegetable irrigation, thereby lowering input costs for farmers. This nutrient enrichment highlights the potential of the treated greywater as a dual-purpose resource, providing both water and essential plant nutrients. Although slight increases in magnesium, iron, and zinc were detected in some treated samples, these concentrations remained well below Ghana EPA permissible limits. Such increases may result from minor leaching of ions from the filter media (e.g., sand, gravel, or charcoal) or desorption of metals bound to suspended solids. Importantly, these observations did not compromise the overall safety of the effluent and instead point to opportunities for optimising filter design to minimise secondary release. The apparent lack of consistent trends in certain physicochemical parameters can be attributed to variations in greywater composition across households and activities. Further statistical analysis would be required to determine whether such fluctuations reflect real differences or normal variability. Nonetheless, the persistence of elevated turbidity, COD, and nutrient levels above EPA discharge limits suggests that the effluent is more appropriate for restricted reuse applications (e.g., toilet flushing, landscape irrigation, or cleaning) rather than direct discharge into sensitive water bodies. The study also observed inconsistencies between water consumption expenditure and reported quantities used. This may be explained by differing pricing structures, where commercial users such as laundries and car washes are charged higher tariffs than households, thereby weakening the direct relationship between expenditure and consumption. A key social finding was that 96.3% of respondents cited high treatment costs as a barrier to adoption, despite the system being promoted as "low-cost." This reflects a difference in perception: while the system is inexpensive relative to advanced technologies, it may still be beyond the immediate affordability of low-income households. This disconnect suggests the need for policy interventions, such as subsidies, community-level systems, or microfinance options, to enhance uptake. The low BOD_5/COD ratio (0.08–0.40) observed in this study further indicates the limited biodegradability of the greywater, largely due to recalcitrant organic compounds present in detergents and cleaning chemicals. This finding implies that while biological treatment alone may be insufficient, the integration of simple physical-chemical methods (e.g., adsorption, coagulation, or constructed wetlands) with the tested filtration system could significantly improve overall performance. A further consideration is the disconnect between the technical framing of the system as "low-cost" and community perceptions of affordability. Nearly all respondents (96.3%) cited cost as a barrier, even though the system is considerably less expensive than advanced treatment options. This indicates that while the design may be inexpensive in absolute terms, it remains beyond the immediate financial capacity of many low-income households. Bridging this perception gap requires both economic and social strategies. At the household level, cost–benefit analyses that compare treatment expenses against water purchase and health cost savings could help demonstrate value. Community-level systems managed collectively may further reduce the burden on individual households. In addition, innovative financing approaches, including microcredit schemes, subsidies, or pay-as-you-go models, could make adoption more realistic. By situating the system within a supportive policy and financing environment, the affordability barrier could be substantially reduced, improving the likelihood of adoption at scale.

4. Conclusion

This study assessed sanitation facilities and greywater management practices in three communities in the Sunyani West District of Ghana, as well as the performance of a simple low-cost filtration system for greywater treatment. About 47% of respondents used household toilet facilities, of which 60% were wet sanitation systems with potential for greywater reuse, particularly for toilet flushing. More than half of respondents relied on piped water supply from the Ghana Water Company Limited. Greywater reuse was observed from four generation points, bathroom, laundry, car washing bay, and hair salon, with reuse most common at laundry services (85%), highlighting institutional and commercial settings as key adoption points. The study found that while all raw greywater samples exceeded Ghana EPA discharge limits for most physicochemical parameters, heavy metal concentrations were consistently below the limits. Microbial quality varied across sources, with total coliforms detected in all samples, though E. coli and Salmonella spp. were absent in greywater from car washing bays and salons. Treatment through the simple filtration system achieved excellent microbial removal (76–100% reduction in total coliforms, and complete elimination of E. coli and Salmonella spp. in bathroom and laundry greywater). However, a major limitation was that key physicochemical parameters, including TSS, turbidity, BOD, COD, nitrogen, and phosphorus, remained above the Ghana EPA disposal limits after treatment. These findings imply that while the treated greywater is suitable for restricted applications such as toilet flushing, lawn watering, and vegetable irrigation under WHO guidelines, it is not yet appropriate for unrestricted reuse or direct environmental discharge. To achieve broader and safer reuse, secondary treatment processes are required to further reduce physicochemical loads. Conventional disinfection can be effective but may generate harmful by-products, making alternatives such as membrane filtration, advanced adsorption media, or constructed wetlands more ecologically sustainable. Despite the technical limitations, the study demonstrates the feasibility of simple, low-cost systems for significantly improving microbial safety in greywater and highlights the added benefit of retained nutrients that can support agricultural reuse. However, adoption remains a challenge, as less than 20% of respondents expressed willingness to use greywater treatment due to perceived high costs and a reliance on government interventions. Targeted education, incentives, and community-level systems could help overcome these barriers and enhance the adoption of safe greywater reuse, thereby contributing to water conservation, reduced fertiliser use, and improved environmental health in Ghana.

5. Acknowledgment

The authors would like to thank the Technicians at the Chemistry Laboratory of the University of Energy and Natural Resources for their support during the laboratory analysis.

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