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Research article

Assessing greywater characteristics in the sahel region and perception of the local population on its reuse in agriculture

Cheik Omar Tidiane Compaoré [a,*], Amidou S. Ouili [a], Sandrine G. Zongo [a], Djamilatou Dabré [a], Ynoussa Maiga [a], Iliassou Mogmenga [b], Dagoro Palé [a], Raogo Guy Noel Tindouré [c], Mahamadi Nikiema [d], Cheik Amadou Tidiane Ouattara [a], Aboubakar Sidiki Ouattara [a]

[a] *Laboratoire de Microbiologie et Biotechnologies Microbiennes, Université Joseph KI-ZERBO, Ouagadougou, Burkina Faso*
[b] *Centre Universitaire de Banfora, Université Nazi BONI, Bobo Dioulasso, Burkina Faso*
[c] *Institut International d'Ingénierie de l'Eau et l'Environnement, Ouagadougou, Burkina Faso*
[d] *Institut Supérieur de Développement Durable, Université Yembila Abdoulaye TOGUEYENI, Fada N'Gourma, Burkina Faso*

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ABSTRACT

Research on greywater reuse in water stressed areas is in full swing. However, the perception of greywater reuse is one of the least researched areas in West Africa, particularly in Sahelian countries. This study aimed to fills a significant gap in the existing literature, which has largely ignored the specific socio-demographic contexts of developing countries in the Sahelian regions. The study involved in-depth interviews with 240 rural households and the collection of 40 greywater samples in four locations for laboratory analysis. The survey focused on greywater management and household perceptions of greywater reuse in agriculture. The analyses focused on determining the physico-chemical and microbiological parameters of greywater collected from households. The results showed that over 80 % of households discharged greywater into the natural environment without prior treatment. The majority of respondents were aware that poor greywater management poses a health risk. The results also showed an association between locality, gender, education level and perceptions of poor grey water management. Respondents were willing to accept the reuse of greywater in agriculture, to consume irrigated vegetables and to install a greywater treatment system. The quality analysis showed that the greywater was not in compliance with the legal discharge limits. This study highlights that in order to promote sustainable greywater management practices within households, it is important to design effective greywater treatment systems that meet the needs of the target population. Awareness campaigns, education and training programmes on wastewater management could also be established.

1. Introduction

Greywater is wastewater generated by domestic activities such as laundry, dishwashing and shower [1]. It accounts for between 65 and 100 % of the wastewater discharged by households [2]. In developing countries, the inadequate management of greywater is a

* Corresponding author.
E-mail addresses: cheick.compaore@ujkz.bf, compaomar91@yahoo.com (C.O.T. Compaoré).

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major public health and environmental problem. The lack of a proper greywater management system is a public health problem in developing countries because greywater is discharged directly into the environment [3,4]. In addition, direct discharge of greywater can affect soils and plants due to the presence of high concentrations of surfactants [5,6] and heavy metals [6,7]. Furthermore, the accumulation of nutrients in surface waters as a result of greywater discharges can lead to eutrophication, which is detrimental to the aquatic environment [6,8]. It is therefore important that researchers and decision-makers pay greater attention to greywater so that these challenges can be better explored and the implications better understood. A great deal of work has been done worldwide on the characteristics and treatment options for greywater. However, most of this work has been carried out in developed countries [9,10]. Greywater studies in Africa are few [2,11,12] and concentrated in urban areas [13,14], but greywater management in peri-urban areas remains poorly studied. Where studies on greywater management exist in developing countries, most are from coastal African countries, particularly Ghana, Nigeria, Zimbabwe and South Africa [13,15–17], and focus on single or combined factors related to quantity, quality and cost of greywater treatment [18]. These previous studies have shown that these factors may predispose individuals to reject greywater treatment and reuse, especially for individuals who have no prior knowledge or experience of greywater treatment and reuse [19]. Therefore, this question is relevant and highlights the need to investigate individuals' perceptions of greywater management, as negative individual perceptions may affect the implementation of policies aimed at providing adequate and sustainable greywater management [13].

In addition, climate change and population growth are the main causes of water scarcity in the world's arid regions [20]. In addition, unsafe wastewater disposal contributes to water quality scarcity [21], directly affecting water supply for human consumption, industry and agricultural irrigation in many regions [22]. In sub-Saharan Africa, this scarcity is one of the major constraints to agricultural development in semi-arid and arid areas [23]. In view of this situation, it is necessary to find alternative sources of water for irrigation. Previous research has shown that although greywater poses a potential risk to the environment and public health due to its contaminant content, it can be treated and beneficially used in agriculture. Previous work has shown that irrigation with treated greywater can improve plant growth and increase crop yields [1,24,25]. In addition, research by Ref. [26] has shown that the use of greywater for irrigation helps to conserve freshwater resources, which is particularly important in arid and semi-arid regions. However, despite the potential benefits, greywater reuse remains limited by public perception and socio-demographic barriers. Previous studies have shown that public perception of greywater reuse varies considerably depending on cultural, educational and economic factors [15,27,28]. For example, a study by Ref. [29] found that reluctance to use greywater is often related to concerns about the safety and cleanliness of treated greywater. The work of [30,31] focused on attributes related to the cost of implementing technologies and found that this may lead individuals to reject water reuse because of the economic costs involved, particularly among individuals with limited knowledge of water reuse [19].

Greywater management and reuse in agriculture is an active research topic, with particular emphasis on technical and environmental aspects in developed countries [32,33]. However, in developing countries, particularly in West Africa, there is a lack of documentation on the subject. The available literature on greywater reuse focuses mainly on technical aspects [24,25], while a coherent analysis of the socio-demographic factors influencing the possibility and likelihood of success of these technologies is scarce. However, in the context of the implementation of greywater treatment techniques for reuse, knowledge of the population's acceptance of greywater reuse in agriculture is crucial to guide public policy and decision making by public officials [34,35]. In addition, the perception of greywater reuse is one of the least researched areas in the Sahelian countries.

The novelty of this study lies in its focus on the Sahelian region, specifically Burkina Faso, a geographical area that has been little explored in previous studies on greywater reuse. This study fills a significant gap in the existing literature, which has largely ignored the specific socio-demographic contexts of developing countries in the Sahelian regions, by examining the perceptions of rural Sahelian populations. Furthermore, by combining an analysis of public perceptions with technical assessments of greywater characteristics, this study provides a holistic understanding of greywater management in a peri-urban context. This integrated approach is essential for developing greywater management strategies that are both technically feasible and socially acceptable. It also makes an important contribution to the greywater management literature by exploring a unique geographical and socio-demographic context and by highlighting the importance of understanding public perceptions for the success of greywater reuse projects.

It is therefore necessary to study how peri-urban Sahelians perceive reusing treated greywater in agriculture. The main objective of this study is to assess the characteristics of greywater in the Sahel region and to understand local people's perceptions of its reuse in agriculture. The study focuses specifically on a peri-urban area in Burkina Faso. The research aims to (i) understand public perceptions of greywater management, (ii) determine the physico-chemical and microbiological characteristics of greywater in a peri-urban area in Burkina Faso. The methodology used in this study involved a survey of the peri-urban population and analysis of greywater parameters collected from the surveyed households.

2. Material and methods

2.1. Study area

The study was carried out between Mars and May 2022. To have a global view of the perceptions and characteristics of greywater, 4 municipalities around Ouagadougou, namely "Saaba" (12°22′59″N 1°25′01″W), "Koubri" (12°10′N 1°24″W), "Pabré" (12°30′00″N 1°34′01″W) and "Komki-ipala" (12°11′27″N 1°48′14″W) in the central region of Burkina Faso (see Fig. 1). The region is located in the Sudano-Sahelian zone. The area is dominated by a Sahelo-Soudanese climate, haracterized by a long dry season from November to May, alternating with a short rainy season from May/June to October, with water depths between 600 and 900 mm and an average annual temperature of 28 °C.

2.2. Household survey

The production and management of greywater, as well as the perception of the population on its reuse in market gardening, were determined through a survey carried out in the four peri-urban municipalities. A questionnaire designed using Sphinx plus V5 software was administered to respondents. The survey data were collected from 240 households. The number of households was determined using the following formula [36]:

$$N = \frac{(84.5).(1-r)}{r.p} \tag{1}$$

With: N: number of households to be interviewed.

r: estimation of the key indicator to be measured in the survey: in this study, the key indicator is considered to be equal to the rate of access to sanitation in rural areas in Burkina Faso, 19 %);

p: proportion of the total population represented by the target population on which is based the parameter r.

The structure of the survey questionnaire and the questions used for the present study were developed based on a review of similar greywater questionnaires in the literature [27]. The specially designed survey consisted of 79 questions, divided into five groups [27]. The first group (Q 1–16) concerned the socio-demographic characteristics of the respondents, such as gender, age group, education level and household size. The second group (Q 17–50) focused on questions related to the sources of drinking water for different household activities, the amounts of water consumed in the household and the types of products (soaps and detergents) used to perform the greywater generating activities. The third set of questions (Q 51–59) focused on greywater management practices, including the main disposal routes. The fourth group of questions (Q 60–62) concerned the population's perception of hygiene. Finally, the fifth set of questions (Q 63–79) collected data on the recovery of sanitation by-products. Respondents were asked about their knowledge of the concept of treated greywater, hygienised urine and feces and their perceptions of the reuse of these sanitation by-products in market gardening.

2.3. Assessment of greywater characteristics in peri-urban areas

2.3.1. Greywater sample collection

Greywater was collected from households during the survey in the four zones ("Saaba", "Koubri", "Pabré" and "Komki Ipala"). Greywater samples were randomly collected from 10 households in each peri-urban area, for a total of 40 samples for analysis.

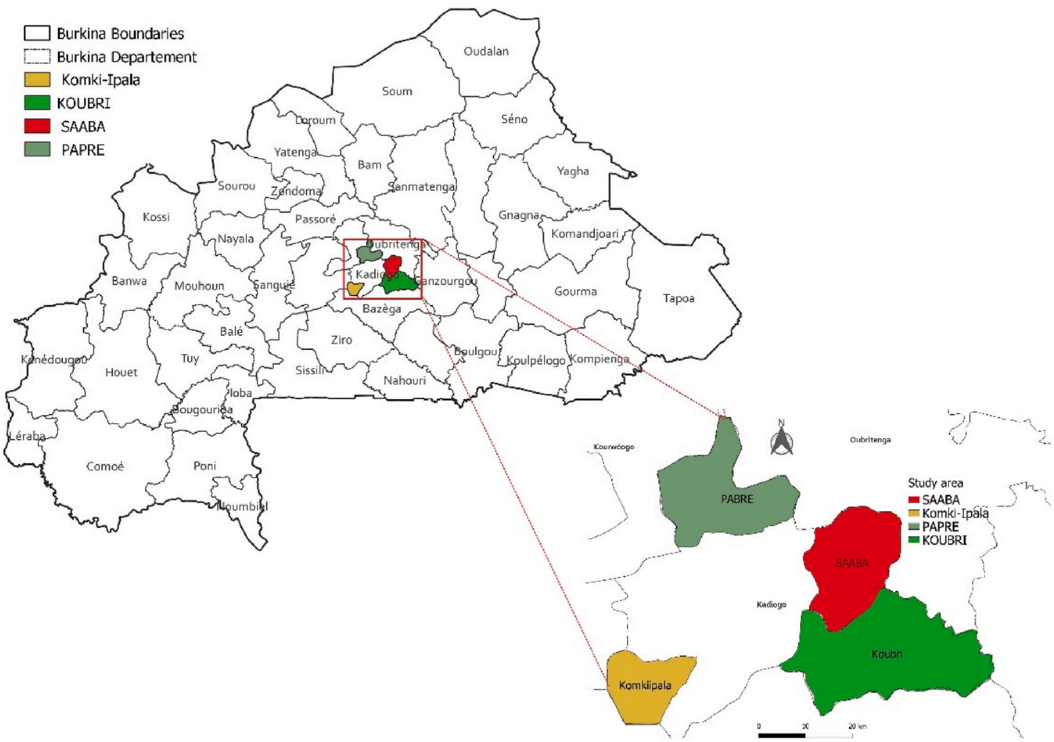

Fig. 1. Study area.

2.3.2. Greywater analysis

Physico-chemical parameters such as pH and electrical conductivity (EC) were measured *in situ* from the greywater using a portable pH/EC/TDS/Temperature (Hanna instrument, Romania) [30,37]. Organic parameters such as 5-day biological oxygen demand (BOD_5), chemical oxygen demand (COD), suspended solids (SS) were determined according to standard methods [37].

Fecal coliforms, *Escherichia coli* and enterococci were used as indicators of fecal contamination to assess the bacterial contamination of greywater. The spread plate method according to APHA method 9215 was used to evaluate the thermotolerant coliforms and *E. coli* using Chromocult Coliform Agar ES medium (Merck KgaA, Allemagne) (44 °C for 24 h) and enterococci using Slanetz and Barthley agar medium (Liofilchem srl, Italie) (37 °C for 48 h) [37].

2.4. Analysis of data

The survey data were analysed using Sphinx plus V5 software in order to identify the main trends and examine the relationship between socio-demographic characteristics and the responses to the different survey questions in the form of mean and median percentages. The Sphinx Plus V5 software starts with the creation of a questionnaire by choosing from the different types of questions available (open questions, multiple choice, Likert scale, etc.). Once the questionnaire has been created, users can distribute it online or offline and collect the responses. The data collected can then be analysed using the analysis tools built into Sphinx Plus V5, which can be used to generate detailed reports and graphs to interpret the survey results. The input data to Sphinx Plus V5 is the responses of the participants to the surveys.

Data were analysed using XLSTAT version 2016 software. Descriptive analyses were used to present the frequency and percentage of socio-demographic characteristics, and household perceptions. Chi-square correlation tests were performed to observe correlations between respondents' socio-demographic characteristics and their perceptions of greywater management, health risks and valorisation of treated greywater [38,39].

The statistical processing of physicochemical and microbiological parameters of the greywater was carried out in XLSTAT software version 2016. Independent t-tests ($\alpha = 0.05$) were used to determine the statistical significance of the measured parameters between the different types of greywater.

3. Results and discussion

3.1. Perceptions of peri-urban households on greywater

3.1.1. Socio-demographic characteristics of the population surveyed

The average household size was 6 persons. The majority of the respondents were aged between 30 and 50 years (58.7 %) and had a low level of education (58.4 %). This could have a negative impact on their perceptions and practices regarding greywater management. In addition, the majority of respondents (70.83 %) were male, while 29.17 % were female (see Fig. 2).

3.1.2. Relationship between socio-demographic characteristics of respondents and household greywater management practices

Chi-square analysis was performed to determine the factors contributing to greywater management practices of peri-urban households (see Table 1). The results of this analysis indicate that greywater management practices for shower ($\chi2 = 82.851$, $p < 0.0001$), dishwashing ($\chi2 = 65.898$, $p < 0.0001$) and laundry ($\chi2 = 62.324$, $p < 0.0001$) are strongly associated with location (see

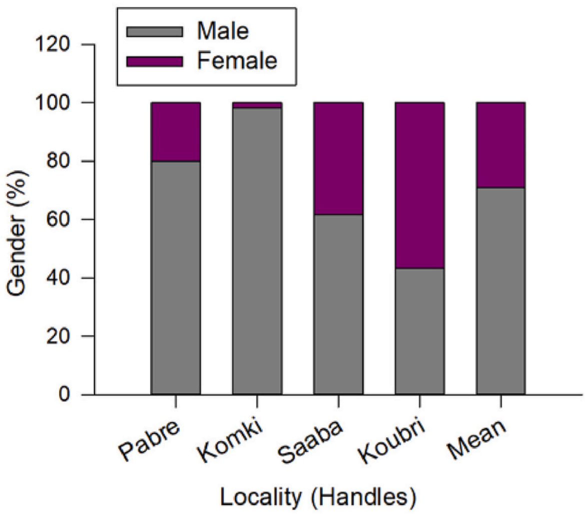

Fig. 2. Gender profile of households surveyed in peri-urban localities.

Table 1). For example, of the 60 respondents in "Komki Ipala", 95 %, 96.67 % and 96.67 % respectively, discharged shower, dishwashing and laundry greywater outside the household without prior treatment. This trend was also observed in "Koubri", where most of the respondents discharged their shower and dishwashing greywater outside the household (80 and 96.67 % respectively for shower and dishwashing greywater). In "Saaba", on the other hand, most of the respondents do not discharge their greywater outside their households, but rather into sump discharge (see Table 1). For example, of the 60 respondents in "Saaba", 71.67 % and 43.33 % respectively discharge their shower and dishwashing greywater into sump discharge, while 28.33 % and 56.67 % do not discharge at all (see Table 1).

Gender showed no significant correlation with shower greywater management practices ($\chi2 = 1.628$, $p = 0.202$). However, the results showed that dishwashing ($\chi2 = 11.356$, $p = 0.001$) and laundry ($\chi2 = 12.550$, $p < 0.0001$) greywater management practices were strongly related to gender (see Table 1). Indeed, 91.77 % and 92.35 % of male respondents discharged dishwashing and laundry greywater outside their households, respectively, compared to only 8.24 % and 7.65 % who discharged to the Sump discharge. Females, on the other hand, were more likely to discharge dishwashing greywater (24.29 %) and laundry greywater (24.29 %) into the Sump (see Table 1).

A significant correlation was found between level of education and greywater management practices for shower ($\chi2 = 38.051$, $p < 0.0001$), dishwashing ($\chi2 = 12.282$, $p = 0.006$), laundry ($\chi2 = 10.044$, $p = 0.018$) and level of education (see Table 1). On the basis of respondents' level of education, respondents with an elementary level or who were illiterate were those who discharged greywater outside their households without treatment (see Table 1). On the other hand, those with secondary or higher education were more likely to discharge greywater from domestic activities into Sump (see Table 1).

3.1.3. Relationship between socio-demograhic characteristics of respondents and household perceptions of risk related to greywater and its valorisation

Analysis of the $\chi2$ correlation between gender and respondents' perception of poor greywater management as a health risk contributor revealed no significant correlation between the two variables ($p = 0.792$). Indeed, males (96.47 %) and females (97.14 %) recognised the existence of a health risk due to poor greywater management within households (see Table 2). This poor greywater management practice is due to the lack of adequate greywater management infrastructure in the study areas. However, a significant correlation was found between gender and respondents' perception of the possibility of treating greywater to eliminate the risk ($\chi2 = 13.159$, $p < 0.0001$) and also the possibility of reusing greywater in agriculture ($\chi2 = 4.906$, $p = 0.027$). Considering both genders, the majority of male respondents thought that greywater could be treated to eliminate health risks (78.82 %) and reused in agriculture (70.58 %) (see Table 2).

A correlation analysis was also carried out to determine the relationship between level of education and respondents' perception of the risk associated with poor greywater management of greywater and the possibility of reusing this water (see Table 2). The results showed no significant correlation between level of education and respondents' perception of the health risks associated with poor greywater management ($\chi2 = 2.178$, $p = 0.536$). However, the results showed that the level of education and the respondents' perception of the possibility of treating greywater were significantly correlated ($\chi2 = 49.868$, $p < 0.0001$). In addition, similar results were obtained between the level of education and the respondents' perception of the possibility of reusing treated greywater in agriculture ($\chi2 = 46.470$, $p < 0.0001$). For example, 100 % of people with a higher level of education thought that greywater could be treated to eliminate health risks, but also for reuse in agriculture. On the other hand, more than 50 % of illiterate persons did not think it was possible to treat greywater to eliminate risks and reuse it in agriculture. This reluctance could be explained by the lack of concrete examples of greywater treatment and reuse in West Africa. This may reinforce the perception that it's a difficult practice.

Table 1

Correlation between respondent's socio-demographics characteristics and greywater discharge practices in households.

Variables	Description	Greywater management practice								
		Shower greywater			Dishwater			Laundry greywater		
		ED	SD	X^2 (Pvalue)	ED	SD	X^2 (Pvalue)	ED	SD	X^2 (Pvalue)
		Rate (%)	Rate (%)		Rate (%)	Rate (%)		Rate (%)	Rate (%)	
Peri-urban locality	Koubri	80	20	82.851 (<0.0001)	96.67	3.33	65.898 (<0.0001)	96.67	3.33	62.324 (<0.0001)
	KomkiIpala	95	5		96.67	3.33		96.67	3.33	
	Pabré	33.33	66.67		98.33	1.67		98.33	1.67	
	Saaba	28.33	71.67		56.67	43.33		58.33	41.67	
Gender	Male	61.77	38.23	1.628 (0.202)	91.77	8.24	11.356 (0.001)	92.35	7.65	12.550 (<0.0001)
	Female	52.86	47.14		75.71	24.29		75.71	24.29	
Education level	Illiterate	73.68	26.32	38.051 (<0.0001)	89.47	10.53	12.282 (0.006)	89.47	10.53	10.044 (0.018)
	Elementary	78.72	21.27		97.87	2.13		95.75	4.25	
	High school	35.44	64.56		77.22	22.78		78.48	21.52	
	Senior	36.84	63.16		89.47	10.53		94.74	5.26	

Legend: ED: External discharge; SD: Sump discharge.

Table 2
Correlation between socio-demographic characteristics and respondents' perception of risks associated with untreated greywater and its valorisation.

Variables	Description	Untreated greywater represente a health risk			Greywater can be treated to eliminate the risk			Treated greywater can be reused in agricultural		
		Yes (%)	No (%)	X^2 (Pvalue)	Yes (%)	No (%)	X^2 (Pvalue)	Yes (%)	No (%)	X^2 (Pvalue)
Gender	Male	96.47	3.53	0.070 (0.792)	78.82	21.18	13.159	70.58	29.42	4.906 (0.027)
	Female	97.14	2.86		55.71	44.29	(<0.0001)	55.71	44.29	
Education level	Illiterate	97.90	2.10	2.178 (0.536)	49.48	50.52	49.868	44.21	55.79	46.470
	Elementary	93.62	6.38		70.21	29.79	(<0.0001)	61.70	38.30	(<0.0001)
	High school	97.47	2.53		93.67	6.33		87.34	12.66	
	Senior	94.74	5.26		100	0		100	0	

3.1.4. Relationship between respondents' socio-demographic characteristics and their perception of reusing the greywater treated in agriculture, installing a greywater treatment system and consuming vegetables irrigated with treated greywater

The influence of gender on the acceptance of treated greywater was determined using the Chi square test. The results show that the perception of reuse treated greywater in this study was not significantly related to gender ($p > 0.05$) (see Table 3). Indeed, regardless of gender, more than 50 % of males and females were more likely to reuse greywater in agriculture ($\chi 2 = 1.778$, $p = 0.182$), consume vegetables irrigated with treated greywater ($\chi 2 = 2.197$, $p = 0.138$) and install a greywater collection and treatment system ($\chi 2 = 1.789$, $p = 0.181$).

Previous studies have shown that education-related factors can influence the acceptance of treated wastewater for various uses [40]. Similar results were obtained in the present study. Indeed, the results of the Chi-square ($\chi 2$) analysis in see Table 3 show that there is a statistically significant correlation ($p < 0.0001$) between the educational level of the respondents and their perception on the acceptance of treated greywater reuse in agriculture with $\chi 2$ values ranging from 30.149 to 35.394. Furthermore, people with at least an elementary level of education were more inclined to reuse treated greywater, consume vegetables irrigated with treated greywater and install a treatment system than illiterate people. For example, the majority respondents with a higher level of education agreed to reuse greywater for irrigation (78.95 %), consume vegetables irrigated with treated greywater (89.47 %) and install a greywater treatment system (100 %). On the other hand, illiterate people were less interested in reusing treated greywater for agriculture (38.95 %), consuming vegetables irrigated with treated greywater (37.89 %) and installing a greywater treatment system (38.95 %). This is clearly shown in see Fig. 3, which shows a positive correlation between people with secondary education and perception of treated greywater ($R^2 > 0.61$). However, there is a negative correlation between illiterate people and perception of treated greywater (see Fig. 3).

3.2. Greywater characterization

The aim of this section was to investigate the physico-chemical and microbiological characteristics of greywater discharged by the peri-urban households studied. In addition, the biodegradability potential and the compliance of the greywater discharged by the households with the standards in vigour in Burkina Faso were assessed. The average characteristics of the physico-chemical and microbiological parameters and the biodegradability potential of greywater are presented in Tables 4 and 5.

4. Discussion

4.1. Public perception of greywater management

This study attempts to (i) understand the public perception of greywater management and (ii) determine the characteristics of

Table 3
Correlation between socio-demographic characteristics and respondents' perceptions of the reuse of treated greywater in agriculture, the installation of a greywater treatment system and the acceptance of consuming vegetables irrigated with treated greywater.

Variables	Description	Greywater management practice								
		Acceptance to reuse treated greywater in agriculture			Acceptance of consuming vegetables irrigated with treated greywater			acceptance to install a system for collecting, treating and reusing treated greywater		
		Yes (%)	No (%)	X^2 (Pvalue)	Yes (%)	No (%)	X^2 (Pvalue)	Yes (%)	No (%)	X^2 (Pvalue)
Gender	Male	63.53	36.47	1.778 (0.182)	65.88	34.12	2.197 (0.138)	79.41	20.59	1.789 (0.181)
	Female	54.28	45.72		55.71	44.29		71.43	28.57	
Education level	Illiterate	38.95	61.05	35.394	37.89	62.11	47.652	38.95	61.05	30.149
	Elementary	63.83	36.17	(<0.0001)	65.96	34.04	(<0.0001)	74.67	25.53	(<0.0001)
	High school	81.01	18.99		84.81	15.19		92.41	7.59	
	Senior	78.95	21.05		89.47	10.53		100	0	

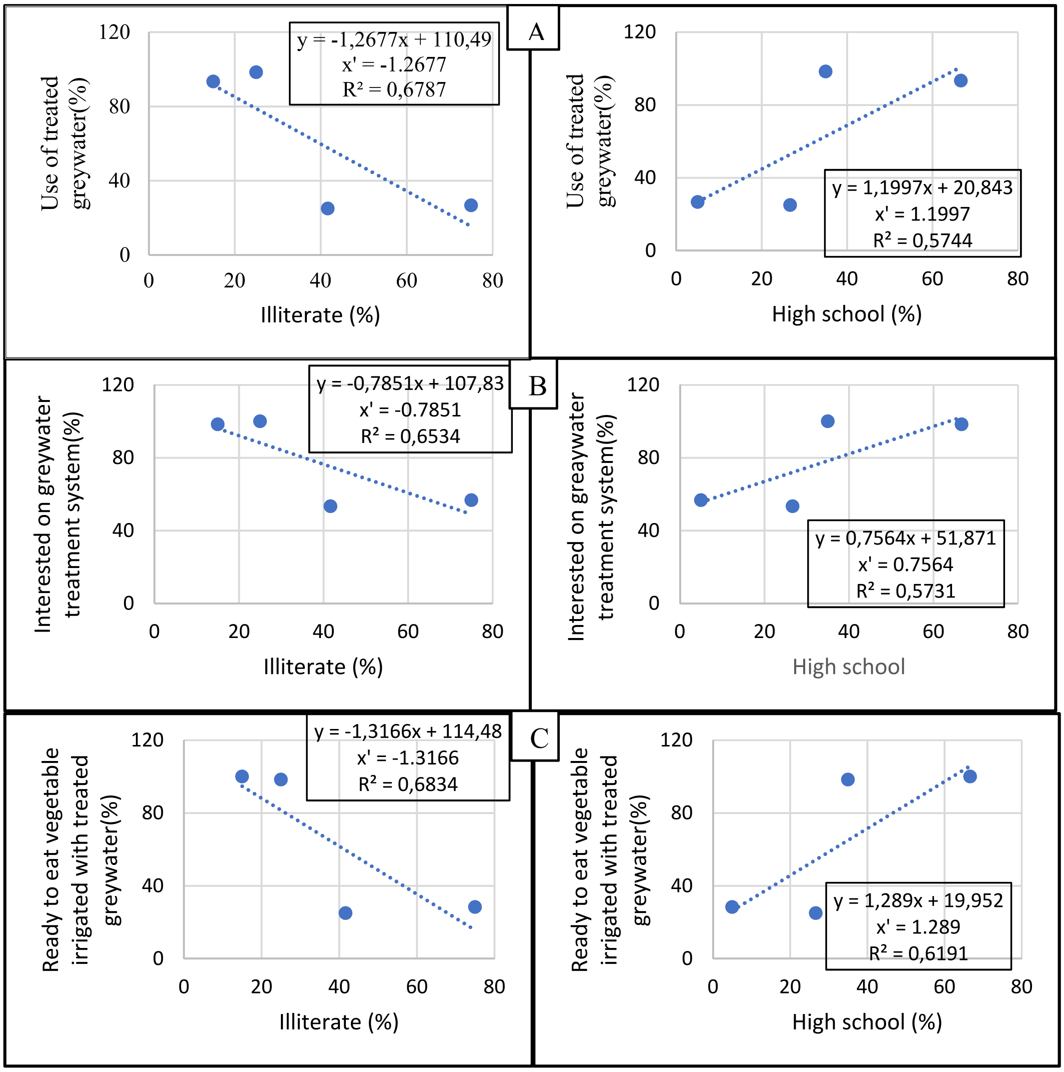

Fig. 3. Correlation analysis illustrating the relationship between respondents' level of education and their acceptance of reusing treated greywater in agriculture (A), installing a greywater treatment system (B) and consuming vegetables irrigated with treated greywater (C).

Table 4
Average concentrations and standard deviations of raw greywater characteristics (values are in mg/L, except for pH, EC (mS/cm) and indicators of fecal contamination (CFU/100 mL) sampled in peri-urban area.

	Variables							
	chemical parameters		Organic parameters			Microbial parameters		
Localities	pH	EC	SS	COD	BOD	TC	*E. coli*	Enterococci
Koubri	7.4 (0.87)^{a}	1.5 (0.90)^{a}	1371 (1181.16)^{a}	1696.2 (391.96)^{a}	1112.8 (587.02)^{a}	2.75×10^{5} (0.95 $\times 10^{1}$)^{ab}	8.51×10^{4} (0.81 $\times 10^{1}$)^{ab}	7.24×10^{4} (0.85 $\times 10^{1}$)^{a}
Pabré	5.5 (0.98)^{b}	1.6 (1.57)^{a}	2602.41 (2314)^{a}	1683.5 (346.23)^{ab}	1128.4 (722.03)^{a}	3.63×10^{6} (1.40 $\times 10^{1}$)^{a}	3.39×10^{5} (1.58 $\times 10^{1}$)^{a}	2.69×10^{5} (1.2 $\times 10^{1}$)^{a}
Saaba	7.2 (0.82)^{a}	1.0 (0.22)^{a}	3528 (1643.05)^{a}	1946 (46.71)^{a}	1182.2 (587.02)^{a}	9.55×10^{6} (0.38 $\times 10^{1}$)^{a}	2.19×10^{4} (0.32 $\times 10^{1}$)^{ab}	9.55×10^{4} (0.85 $\times 10^{1}$)^{a}
Komki Ipala	6.3 (1.80)^{a}	1.2 (1.10)^{a}	1704 (1446.11)^{a}	1274.2 (682.68)^{b}	819.3 (640.52)^{a}	2.75×10^{5} (1.23 $\times 10^{1}$)^{ab}	1.02×10^{5} (0.91 $\times 10^{1}$)^{ab}	1.32×10^{5} (10^{1})^{a}

E. coli: Escherichia coli; EC: electrical conductivity; TC: Thermotolerant coliforms; ^{a,b,c} For a given parameter, the values with different letters are significantly different at $p < 0.05$.
(): standard deviations.

Table 5
Values for the BOD_5/COD ratio of greywater.

Greywater sources	BOD_5/COD Ratio		
	Minimum	Maximum	Average
Saaba	0.29	0.89	0.60[a]
Pabré	0.32	0,99	0.70[a]
Koubri	0.35	0,98	0.66[a]
Komki Ipala	0.36	0,93	0.89[a]
Biodegradability criteria*	>0,6		

[a,b,c] For a given parameter, values followed by different letters are significantly different at $p < 0.05$, *.

greywater in peri-urban area in Burkina Faso. As indicated in section 3.1.1, the majority of respondents (70.83 %) were male, while 29.17 % were female. This contrast could be explained by hierarchy and traditional family values, which prevent women from interacting freely with male strangers. Men are responsible for making decisions on behalf of the family [13]. Similar findings were reported in a survey of peri-urban communities' attitudes and perceptions towards greywater management in India [41].

The Chi-square analysis shows a strong correlation between greywater management practices and the location of peri-urban households, with significant differences observed between the "Komki Ipala", "Koubri" and "Saaba" locations, particularly in terms of greywater discharge outside the house or into sump. These results highlight the importance of local characteristics in the greywater management practices of peri-urban households in Africa. Our results corroborate those of [2] who showed that greywater has traditionally received the least attention in Africa. The greywater management practices of peri-urban households are similar to those reported by the General Population and Housing Census of Burkina Faso's 2019, in that more people practice haphazard and unimproved disposal methods [42]. Our results are consistent with the work of [16], who reported that over 90 % of household wastewater in Ghana is discharged untreated into the street. This is also similar to the findings of [13] who showed that in the Central Region of Ghana, households discharge greywater into open sewers (67 %), nearby water bodies (17 %), directly into the ground (9 %) or to decentralised treatment systems (7 %). These different findings highlight poor greywater disposal practices and call for solutions to be found for a healthier living environment. The lack of adequate greywater management in peri-urban areas of developing countries could contribute to public health concerns and threats [4]. However, they also show the availability of greywater that could be collected for possible use in market gardening. These results suggest that location has a significant impact on greywater management practices, highlighting the importance of taking local characteristics into account when implementing greywater management strategies.

Our results showed no significant correlation between gender and shower greywater management practices, but we did observe a strong association between gender and dishwashing and laundry greywater management practices, with male respondents more likely to discharge greywater outside, while female respondents were more likely to discharge it into a sump. This situation can be explained by the perception of laundry and dishwashing as predominantly female household activities. Consequently, females are more likely to opt for septic tank disposal. Research conducted by Ref. [43] on domestic waste management in India showed that females have a better understanding and knowledge of waste management because they are more involved in waste management at the household level [44]. In contrast, males may be more likely to dispose of greywater in the open, as they often have more limited access to appropriate treatment facilities, or simply because of cultural norms or pre-existing practices in their community. These findings highlight the importance of considering gender differences when planning greywater management interventions to ensure an inclusive and equitable approach. This study showed a significant correlation between education level and greywater management practices for shower, dishwashing and laundry. Indeed, people with higher levels of education were more likely to adopt more responsible management practices. Educated people are better informed about the health risks associated with discharging untreated greywater, which encourages them to use latrines [45].

The lack of a significant correlation between gender and respondents' perception that poor greywater management contributes to health risks, as both male and female respondents largely recognised the existence of such risks (96.47 % and 97.14 % respectively). These results may be explained by a similar awareness in both genders of the potential risks associated with poor greywater management, possibly as a result of a general knowledge of the health risks associated with exposure to water. However, the results showed a significant correlation between gender and respondents' perceptions of the possibility of treating greywater to eliminate risks ($\chi2 = 13.159$, $p < 0.0001$) as well as its reuse in agriculture ($\chi2 = 4.906$, $p = 0.027$). The majority of male interviewed thought that greywater could be treated to eliminate health risks (78.82 %) and reused in agriculture (70.58 %). Our results can be explained by the fact that male respondents have a better understanding of the potential benefits of greywater for agriculture, such as providing additional nutrients to crops, than female respondents. Contrary results have been reported by Ref. [15] on the perception of reuse of treated greywater according to gender. Indeed, these authors observed that female respondents were more likely than males to disagree with the idea that greywater reuse could have a negative impact on public health. In addition, they observed that female respondents were more likely than males to believe that greywater reuse could be beneficial in reducing water demand within the community and would have a positive impact on the environment. As females are responsible for household chores and family health, they may be more attentive to health impacts and have specific concerns related to the use of greywater in the domestic context (see Table 2).

Many recent studies on the influence of gender on the acceptance of treated wastewater have found no significant relationship [28,40,46], although our study has shown that males are more likely than females to accept reuse options. In addition, a survey by Ref. [47]

showed that both males and females found treated wastewater to be highly acceptable for firefighting, agriculture, lawn watering and car washing. However, in Brazil, a similar study of agricultural technicians showed that female agricultural technicians were more accepting of the use of greywater in agriculture than male technicians [48]. The results of this study are a good indication of the willingness of the peri-urban population to accept the reuse of treated greywater.

Several studies have examined public perceptions of treated wastewater and come to different conclusions [27,28]. These conclusions are generally based on demographic information for the community or country under consideration. For example, in developed countries, some work has shown a general reluctance of the population to reuse treated wastewater [34]. In their study [34], females with lower levels of education were more likely to be uncomfortable with treated wastewater and unwilling to reuse treated wastewater for food crops. However, perceptions in arid countries are different. Indeed, a perception study conducted in Tunisia and Jordan showed that farmers were very much in favour of using treated wastewater for food production [49]. However, a study conducted in Israel found that only 49 % of respondents were in favour of reusing treated wastewater for irrigation orchard. Similarly, respondents to another study in sub-Saharan Africa indicated that they favoured the reuse of treated wastewater for non-drinking purposes only [8].

[50] concluded that education influences people's perceptions of greywater reuse. Indeed, the lack of knowledge and campaigns on greywater reuse is also recognised as the main limiting factor [51,52]. Although lack of education is often at the root of peri-urban populations' reluctance to accept greywater reuse, a lower level of education does not necessarily mean an unwillingness to accept greywater reuse, to consume vegetables irrigated with treated greywater (see Fig. 3). Indeed, this behaviour can be considered natural [48], given that even treated greywater, like other wastewater, can have harmful effects on human health [53,54]. However, despite this knowledge, some people were unwilling to reuse greywater and consume vegetables irrigated with treated greywater (see Table 3), probably because they had less confidence in the greywater treatment system [55]. reported that student respondents in South Africa preferred to reuse greywater for toilet flushing rather than for garden irrigation because they were afraid of coming into contact with diseases. These results are similar to those of [48], who found that agricultural technicians were less likely to consume vegetables irrigated with greywater. This contrasts with our results regarding the acceptance of consuming vegetables irrigated with treated greywater. This difference with our results could be explained by the fact that more developed countries may have stricter sanitary standards for irrigation water supply. Indeed, their intellectuals may be more concerned about meeting these high standards and therefore oppose the use of treated greywater, even if it is considered safe. Consumers have been shown to be more or less accepting of greywater reuse systems depending on a variety of factors [56]. According to these authors, one of the main factors influencing public acceptance of greywater reuse is the degree of human contact with the recycled water, as consumers are most reluctant to accept potable reuse [57]. This is why we often speak of the 'disgust factor' [57]. This factor describes the instinctive reaction of disgust associated with recycled water, regardless of the actual quality of the water [58]. The results of this study, carried out in peri-urban areas, are in line with those obtained in the United States, where suburban residents were more favourable to the reuse of recycled water for irrigation than their urban and rural counterparts [59]. Furthermore, our results were in line with those of [60], who showed that low-income populations were more likely to consume produce irrigated with treated greywater. In a similar study, the same situation was found when assessing attitudes towards for greywater reuse in a low-cost housing estate in South Africa [15]. The reasons that motivate these inclined populations to reuse greywater may be economic motivation and climatic conditions. For example, according to Refs. [34,61] economic incentives, such as savings on water expenditure, can lead to a higher level of acceptance of water reuse practices. In addition, research by Ref. [34] suggests that regions that have recently experienced drought have a higher percentage of water reuse advocates.

In Sahelian countries, and particularly in peri-urban areas, although the problem of water scarcity is serious and is expected to worsen with climate change, there is a need to experiment with treated greywater and its reuse in order to establish a scientifically sound and safe basis for reuse. One of the interesting findings of this study was that the majority of respondents were interested in a treatment system to collect, treat and reuse greywater (see Table 3). Despite this encouraging result for the continuation of the study in its greywater treatment system proposal component, this result suggests the need to implement an appropriate awareness programme in the study area to encourage the implementation of the greywater reuse concept within households. This can be achieved through awareness campaigns, site visits, workshops, regular meetings and group discussions as suggested by Ref. [62].

4.2. Characteristics of greywater parameters

4.2.1. Physicochemical characteristics of greywater

The main physical characteristics of greywater are presented in see Table 4. According to our results, the average pH of greywater in "Koubri" and "Saaba" was in the neutral range with values of 7.4 and 7.2 respectively, while greywater in "Pabré" and "Komki Ipala" was acidic with average values of 6.3 and 5.5 respectively. Overall, the average pH of the greywater from the different locations was within the acceptable range of 6–9, with the exception of "Pabré". The pH of greywater is highly dependent on the pH and alkalinity of the feed water and is usually in the range of 5–9 [62]. It has also been shown that the pH of greywater is highly dependent on the standard of living of the country [6]. Indeed, it has been found that greywater in developed countries has a neutral pH, whereas in developing countries it varies from less than 6 as reported in Bangladesh, Jordan, Brazil and Ghana [8,63,64] to more than pH 9 as reported in India [65]. The extreme pH of 5 recorded in some of our samples could be attributed to organic acids produced by edible organic compounds while the high pH of 8 could be partly attributed to the use of sodium hydroxide soaps [8,66]. However, the results showed a significant difference between the pH recorded in the different locations ($P = 0.004$). This indicates that the location influences the pH of the greywater produced especially as households in different locations do not have exactly the same practices.

The electrical conductivity (EC) values of the greywater were high in all areas with values ranging from 1 to 1.6 mS/cm (see

Table 4). Similar conductivity values ranging from 0.52 to 1.27 mS/cm have been reported for greywater in Hungary [67]. There was no significant difference (P = 0.652) between the different locations. These values are above the WHO non-restrictive reuse limit (>700 μS/cm) for wastewater [68]. This could be due to the excessive use of the same water for several washing cycles, especially for dishwashing. The massive accumulation of ions dissolved in water by this practice leads to an increase in electrical conductivity [8]. In addition, the high EC could also originate from the water sources, which could largely be groundwater sources such as boreholes and wells, as observed in the study area. Indeed, [62] reported that groundwater sources and water scarcity areas are mainly associated with high electrical conductivity due to dissolved matter.

4.2.2. Organic matter composition of household greywater in peri-urban areas

The mean SS concentration of domestic greywater in peri-urban areas varied between 1375 ("Komki Ipala") and 3528 mg/L ("Koubri") (see Table 4). There is no statistically significant difference between these values (P = 0.221). Lower SS concentrations ranging from 190 to 537 mg/L have been reported in Ghana [8]. The high SS concentration found in greywater from different locations may be due to the small amount of water used for greywater production or the repeated use of water for different activities before its final disposal [69]. On the other hand, the fact that greywater is largely derived from dishwashing and laundry could explain its relatively high SS concentrations. Indeed, [62] have shown that the washing of clothes, shoes, vegetables, fruit, tubers and many other items, which may contain sand, clay and other materials, can contribute to increased SS in greywater. The consequence of greywater with a high SS concentration is that the receptor water masses become turbid, visibility is impaired and dissolved oxygen in the receptor water mass is reduced [8].

Average BOD_5 concentrations of domestic greywater in the study area ranged from 819.3 mg/L ("Komki Ipala") to 1182.2 mg/L ("Saaba"), while COD concentrations varied from 1274.2 mg/L ("Komki Ipala") to 1946.2 mg/L ("Saaba") (see Table 4). In a rural study in Burkina Faso [11], reported similar results from greywater with BOD_5 ranging from 848 to 1330 mg/L and COD from 1800 to 6300 mg/L. Furthermore, [70] reported high COD values of 2210 mg/L for domestic greywater in Ghana. However, many studies have reported significantly lower concentrations of BOD_5 and COD in greywater. For example, [71] reported BOD_5 ranging from 5 to 431 mg/L and COD ranging from 38 to 1843 mg/L for greywater in Cairo (Egypt). Similarly, in Chennai (India) [72], reported COD values ranging from 254 mg/L to 618 mg/L and BOD from 120 mg/L to 350 mg/L in greywater. Comparing the concentration range of BOD_5 and COD in greywater from different localities, it can be seen that all concentrations are above the wastewater discharge standards in force in Burkina Faso. These high COD and BOD_5 concentrations could be explained by the successive reuse of greywater in domestic activities before its final disposal. It could also be attributed to the excessive input of biodegradable and non-biodegradable materials in greywater from dishwashing and laundry activities. Indeed, it has been reported that the main contributors to BOD in greywater are dissolved organic matter and suspended food particles [62]. Discharging of such greywater with high BOD_5 and COD concentrations into surface waters could lead to oxygen depletion and harm aquatic life [8].

4.2.3. Biodegradability potential of greywater

The biodegradability potential of greywater is based on the BOD_5/COD ratio. Our results showed ratios ranging from 0.29 to 0.89 (see Table 5). The very low biodegradability (0.29) observed for some greywater is similar to studies conducted in rural Burkina Faso with an average BOD_5/COD ratio of 0.2–0.47 [11], and in low-income communities in Accra, Ghana with a BOD_5/COD ratio of 0.29 [16]. However, the average ratios obtained in the study (0.6–0.89) are within the range of typical BOD_5/COD ratios (0.3–0.8) reported by Ref. [73] who stated that a BOD_5/COD ratio close to or above 0.5 indicates good biodegradability of greywater.

Therefore, based on the average ratios obtained, greywater from peri-urban households can be treated using microbial processes. A number of studies on the biological treatment of greywater have been carried out in West Africa with promising results [14,25]. Confidence in a greywater treatment system can become a critical factor. Indeed, if the population has confidence in a treatment system, they will be more inclined to accept and participate in the reuse of treated greywater in agriculture.

4.2.4. Microbiological characteristics of greywater

Contamination with fecal indicators such as thermotolerant coliforms, *E. coli* and enterococci was detected in all samples analysed with concentrations ranging from 2.75×10^5 to 9.55×10^6 CFU/100 mL for fecal coliforms, from 2.19×10^4 to 3.39×10^5 CFU/100 mL for *E. coli*, and from 7.24×10^4 to 2.69×10^5 CFU/100 mL for enterococci (see Table 4).

Many studies have shown the presence of enteric bacteria in greywater [74,75]. Indeed, bacterial concentrations in the order of 2.51×10^5 to 7.94×10^8 CFU/100 mL for total coliforms, 6.30×10^2–10^7 CFU/100 mL for *E. coli* and 2.51×10^2–10^4 CFU/100 mL for enterococci have been reported in greywater [76,77]. The high presence of contamination indicators may be due to washing clothes and underwear or ablutions in Muslim households [8,11]. There were no significant differences between the bacterial loads found in greywater from different locations (see Table 4) suggesting a possible similar lifestyle of households in the study localities.

Overall, the high presence of fecal contamination indicators in the analysed greywater indicates that this water could pose a health risk. A high concentration of fecal contamination indicator bacteria in greywater can increase public awareness and knowledge of the potential hazards associated with direct discharge or reuse of raw greywater in agriculture. These microbiological results can lead to more cautious attitudes and a better understanding of the management practices needed to minimise risks.

5. Conclusion

The study showed that the majority of households are aware that poor greywater management poses a health risk, highlighting the importance of educating the population on good wastewater management practices to reduce health risks. In addition, over 80 % of households were found to be discharging their greywater into the natural environment without prior treatment. This highlights the urgent need to develop effective greywater treatment systems to reduce environmental pollution and health risks. The results of this study also showed that respondents are willing to accept the reuse of greywater in agriculture, which is a positive indicator as it could help reduce pressure on freshwater resources and improve food security. The results of the quality analyses showed that the physico-chemical and microbiological parameters of the greywater did not comply with the legal discharge limits. However, the BOD_5/DCO ratios are higher than 0.6 which makes it possible to envisage a treatment process that includes a biological stage for the treatment of greywater. The study highlights a positive outlook for the development of water conservation technologies, including the reuse of treated greywater. Raising awareness and educating people about good wastewater management practices is essential to promote sustainable greywater management practices within households. This could include awareness campaigns, training and education programmes on wastewater management.

Although this study is an important contribution to the understanding of greywater management, it has certain limitations that could be considered into account in the design of future research. The study was conducted in four peri-urban locations, which limits the generalisability of the results to the country as a whole or to other similar regions. A more comprehensive study may be required to provide a more complete picture of the greywater management situation and the prospects for reuse. In addition, the study showed a weak correlation between graphs A and B in Fig. 3, representing the percentage of high school students, which could indeed be considered a limitation of the study. This weak correlation could be explained by the small size of the sample of secondary school students studied, which is not representative of the whole population. A study should include a larger number of secondary school students in order to obtain a more representative sample of the total population. Although physico-chemical and microbiological analyses of greywater have been carried out, more in-depth analyses of minerals (N and P) and pathogenic bacteria (*Salmonella typhi*, *Staphylococcus aureus* and *Pseudomonas aeruginosa*) may be required to fully assess water quality and the risks associated with its reuse in agriculture. Although households have expressed a willingness to accept greywater reuse in agriculture, the actual impact of this practice on consumer health and the environment has not been assessed in this study. Future work should focus on soil and crop contamination and quantitative assessment of the microbial risk associated with the reuse of treated greywater in agriculture. This study highlights the need to develop greywater treatment technologies that are effective, affordable and adapted to local conditions and the capabilities of the rural populations. This could include simple treatment systems such as planted filters.

Ethical approval

All respondents gave informed consent for their answers to be used for research.

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Data availability statement

Data will be made available on request.

CRediT authorship contribution statement

Cheik Omar Tidiane Compaoré: Writing – original draft, Methodology, Investigation, Conceptualization. **Amidou S. Ouili:** Writing – review & editing, Formal analysis. **Sandrine G. Zongo:** Investigation. **Djamilatou Dabré:** Formal analysis. **Ynoussa Maiga:** Writing – review & editing, Visualization, Validation, Conceptualization. **Iliassou Mogmenga:** Writing – review & editing, Resources. **Dagoro Palé:** Investigation. **Raogo Guy Noel Tindouré:** Writing – review & editing. **Mahamadi Nikiema:** Writing – review & editing. **Cheik Amadou Tidiane Ouattara:** Writing – review & editing. **Aboubakar Sidiki Ouattara:** Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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