Scientific Research Publishing

Journal of Agricultural Chemistry and Environment, 2022, 11, 117-131
https://www.scirp.org/journal/jacen
ISSN Online: 2325-744X
ISSN Print: 2325-7458

Purification Potential of Local Media in the Pre-Treatment of Greywater Using Vertical Biofilters under Sahelian Conditions

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How to cite this paper: Compaoré, C.O.T., Maiga, Y., Ouili, A.S., Nikiema, M. and Ouattara, A.S. (2022) Purification Potential of Local Media in the Pre-Treatment of Greywater Using Vertical Biofilters under Sahelian Conditions. *Journal of Agricultural Chemistry and Environment*, **11**, 117-131.
https://doi.org/10.4236/jacen.2022.112008

Received: March 12, 2022
Accepted: May 7, 2022
Published: May 10, 2022

Abstract

Several on-site greywater treatment systems are under development including biofiltration, whose efficiency is influenced by the filter media. Therefore, the main objective of this study was to evaluate the influence of the type of filter media and their grain size in the removal of organic and microbial pollutants from greywater. Hence, three types of local filter media of different grain size were used for the pre-treatment of greywater. Their removal potential and clogging time were evaluated and compared. The results indicated that the type of filter media and the grain size have an influence on the elimination of organic and microbial pollution from greywater. Indeed, sand of 1 - 2 mm in size obtained the highest removal efficiencies of organic pollutants (67.35% and 78.04% for COD and BOD_5 respectively) and microbial indicators (2.07, 1.77 and 2.27 log. units for *E. coli*, fecal coliforms and enterococci respectively). Although media of fine texture enhanced the removal efficiencies, they experienced significant clogging problems. To overcome these limitations while enhancing the removal efficiency, 1) pre-treatment stage with coarse materials followed by a treatment with finer materials or 2) the use of a combination of fine and coarse materials should be considered.

Keywords

Biofiltration, Fecal Indicators, Granitic Gravel, Greywater, Lateritic Gravel, Sand

1. Introduction

According to the joint report of World Health Organization (WHO) and UNICEF [1], in 2017, 55% of the world's population *i.e.* 4.2 billion people, did not have access to safely managed sanitation services. In addition, in some developing countries, up to 95% of wastewater is discharged into the environment without treatment [2]. The situation in Burkina Faso is similar, with almost 85% of domestic wastewater discharged untreated into the environment according to the Ministry of Water and Sanitation. The major consequence of this lack of sanitation is the persistence of diseases such as diarrhea [3] and malaria [4], responsible of more than 90% of deaths of children under 5. Furthermore, due to climate change and population growth [5], the arid and semi-arid regions are facing increasing water scarcity which is one of the major constraints to the development of agriculture [6]. In rural area, greywater is the main source of domestic wastewater and its reuse could be an alternative for crop production. However, it contains organic and microbial pollutants that could compromise its reuse potential. Hence, the development of efficient and affordable onsite treatment systems is essential to overcome these challenges. Recently, biofilter systems using various filter materials such as granite and sand have been tested in Burkina Faso [7] and elsewhere [8] [9] with promising results. However, the pollutant removal efficiency (*RE*) of the biofilters varies considerably depending on the type and particle size of the filtering materials, the depth of the biofilter, the feed interval of the wastewater etc. [10] [11]. Therefore, it is important to test locally available filter materials in order to improve the treatment and reuse of greywater in rural areas.

Consequently, in this study, four locally available filter media of different particle size (sand: 1 - 2 mm and 2 - 4 mm in size; granitic gravel: 1 - 2 mm, 2 - 4 mm and 4 - 6 mm in size; lateritic gravel: 2 - 4 mm and 4 - 6 mm) were used to compare their ability in reducing organic and microbial pollution from household greywater while allowing a longer clogging time. The objectives of this study were to identify 1) the most efficient biofilter media and 2) the best particle size in terms of pollutants removal with a longer clogging time.

2. Material and Methods

2.1. Greywater Collection and Experimental Setup

Mixed laundry and dishwashing greywater were collected from five households located in "Zogona" and "Wentenga" districts of Ouagadougou (Burkina Faso) and used for the treatment. The experimental device consisted of seven cylindrical polyvinyl chloride (PVC) columns with internal diameter of 16 cm and a height of 1 m in which were distributed different layers of filter media (**Figure 1**). Each column was filled from the bottom to top with a drainage layer (10 cm of granitic gravel with a size of 11 - 25 mm), a transition layer (10 cm of granitic gravel with a size of 4 - 10 mm) and a varying filtration layer consisting of either sand, granitic gravel or lateritic gravel (**Figure 1**). The columns were equipped with a PVC pipe at their base to allow the collection of the treated greywater.

2.2. Filtration Tests

In order to simulate household greywater production and discharge, the biofilters

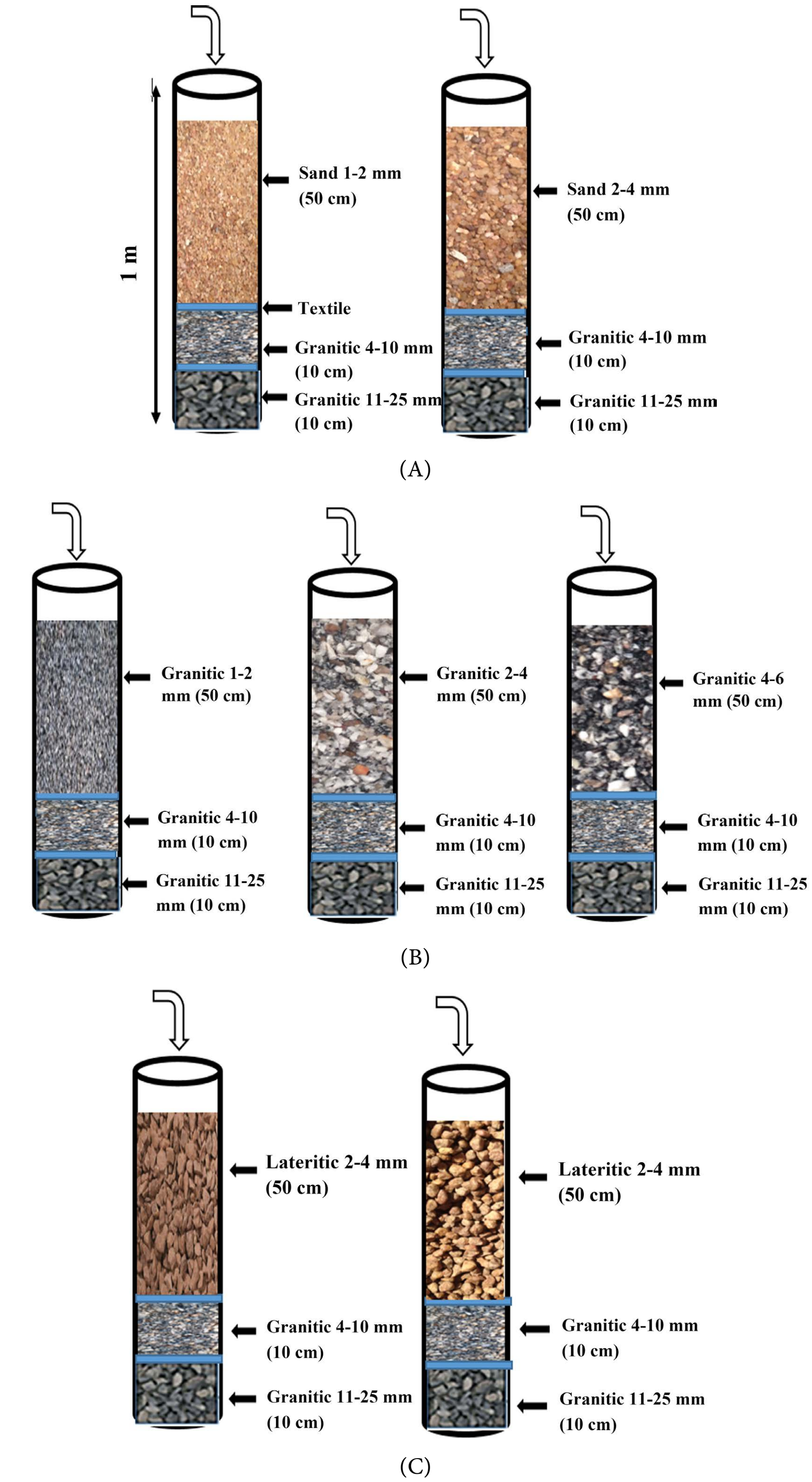

Figure 1. Configuration of the biofilters and the arrangement of the different layers (drainage, transition, filtration and their corresponding heights) (A) sand; (B) granitic gravel; (C) lateritic gravel. ⤵: greywater.

were fed at 8 am, 1 pm and 6 pm on Saturday, Sunday and Monday and left to stand the rest of the time. A total of 4 L/d (1.5, 1 and 1.5 L at 8 am, 1 pm and 18 am respectively) corresponding to a hydraulic load of 200 L/m^2/d was distributed into each biofilter.

Greywater samples (raw and pretreated) were collected during the second feeding period (1 pm) for analysis. During sampling, the pH was measured *in situ* from the effluent and influent using a pHmeter multi-340 (WTW GmbH, Germany). Some important physico-chemical parameters (5-day biological oxygen demand [BOD_5], chemical oxygen demand [COD], suspended solids [SS] were measured. The SS were determined by a gravimetric method using glass microfiber filters Whatman (porosity 1.5 µm). The BOD_5 was determined by the respirometric method using an Oxitop placed in an incubator set at 20˚C and operating in the dark for five (5) days. The COD was determined by the acidic oxidation method in an excess of potassium dichromate, at a temperature of 150˚C.

Escherichia coli and fecal coliforms were assessed as indicator bacteria. We used Chromocult Coliform Agar ES as culture medium for both bacteria. For enterococci, we used M-*Enterococcus* Agar as culture medium. The spread plate method was used after appropriate dilutions of the samples. All parameters were determined in accordance with the procedure described in standard methods for the examination of water and wastewater [12].

2.3. Evaluation of the Clogging Time

Since, maintenance is an important factor influencing the success and acceptability of a treatment system, the infiltration time of each treatment unit was measured and used as a basis to estimate the clogging level of the different biofilters. This infiltration time was measured as the time necessary for the greywater to pass throughout the system.

2.4. Determination of the Removal Efficiency and Statistical Analysis

For each biofilter, we evaluated the removal efficiency (*RE*) of physico-chemical parameters and bacteria using equation 1 and 2 respectively.

$$RE(\%) = \left(\frac{X_0 - X}{X_0}\right) * 100 \tag{1}$$

$$RE(\log.\text{u}) = \log(X_0) - \log(X) \tag{2}$$

where X_0 and X = concentration of a considered parameter in the raw greywater and the effluent respectively.

For all parameters, the *RE* was determined using Excel software. The effects of media type and particle size on the efficiency of the biofilters were compared using the t-test ($\alpha = 0.05$).

3. Results and Discussion

3.1. Characteristics of the Household's Greywater

The raw greywater showed high concentrations of organic matter and fecal indicators (**Table 1**). The pH values were slightly alkaline (7.47 and 8) with an average of 7.69. Similar results were reported by [7] in their work on the design of a "slanted soil" system for greywater treatment in rural Burkina Faso. The alkaline pH of greywater is related to the use of soaps and detergents in dishwashing and laundry activities [13] [14]. The concentration of organic matter (BOD_5, COD, SS) was high in the raw greywater. Similar results were obtained by [14] who found DCO value of up to 1120 mg/L on urban greywater in Lagos (Nigeria). The high concentration of organic matter observed in greywater could be explained by the presence of food residues from dishwashing, but also clothing fibers that could also be found in laundry greywater. However, our results are higher than those from developed countries like France where values of 110, 398 and 196 mg/L were reported for SS, COD and BOD respectively [15]. The low concentration of organic matter in the greywater from developed countries compared to that of developing countries could be the consequence of the dilution, owing to the large quantity of water used in domestic activities in developed countries.

In our study, we also found high contents of fecal bacteria in the raw greywater with values of 1.05×10^7, 2.75×10^8 and 7.35×10^6 CFU/mL for *E. coli*, fecal coliforms and enterococci respectively. This finding shows that, greywater could be a risk for human health and must be treated before being reused. Previous studies have reported high contents of *E. coli*, ranging from 10^1 to 10^8 CFU/100 mL in greywater in urban and peri-urban environments [16] [17]. These concentrations of fecal bacteria remain lower than those of greywater in rural areas, which are of the order of 10^8 CFU/100 ml for *E. coli* and 10^9 for fecal coliforms [7]. However, the values obtained in our study are higher than those reported by the [15], which were in the order of 2.6×10^6 and 3×10^5 respectively for Enterococci and E. coli obtained from raw greywater from French cities.

The variations observed between the concentrations of fecal bacteria in urban and rural areas on the one hand, and in an African city and an European city, on the other hand, suggest that the behaviour of the inhabitants has an important influence on the characteristics of the greywater.

All treated greywater exhibited slightly neutral mean pH values compared to the raw greywater (**Table 2**). These values are in compliance with the WHO reuse in irrigation standards (pH of 6.5 to 8) [18]. Based on these values, if reused in irrigation, the treated greywater could promote bacterial growth in the soil since most bacteria prefer neutral or slightly alkaline conditions, around 6.5 to 8.5 [19]. The contents of organic matter from the biofilters using sand and granitic

Table 1. Characteristics of raw greywater.

Parameters	pH	BOD_5	COD	SS	*E. coli*	FC	Enterococcci
Units	-	mg/L	mg/L	mg/L	CFU/mL	CFU/mL	CFU/mL
Raw greywater	7.69 (0.39)	862.25 (302.32)	1377.33 (308.66)	1131.20 (572.98)	1.05×10^7 (2.86×10^6)	2.75×10^8 (5.72×10^7)	7.35×10^6 (1.21×10^6)

Table 2. Characteristics of greywater treated.

Biofilter	Units	Sand 1 - 2 mm	Sand 2 - 4 mm	Lateritic gravel 2 - 4 mm	Lateritic gravel 4 - 6 mm	Granitic gravel 1 - 2 mm	Granitic gravel 2 - 4 mm	Granitic gravel 4 - 6 mm
pH	-	7.21 (0.38)	7.29 (0.52)	7.19 (0.31)	7.26 (0.37)	7.16 (0.32)	6.99 (0.36)	7.25 (0.34)
COD	mg/L	577.5 (204.85)	1015.86 (474.14)	1248.25 (317.42)	1325.58 (241.11)	777.5 (319.03)	1144.25 (326.86)	1335.5 (257.84)
BOD5	mg/L	215 (109.20)	360 (173.29)	593.75 (152.47)	695 (263.04)	267.5 (68.63)	475 (136.17)	551.67 (302.32)
SS	mg/L	170.14 (152.83)	143.90 (95.10)	357.42 (158.22)	532.56 (210.38)	245.5 (221.41)	342.92 (188.01)	654.41 (250.60)
E. coli	CFU/mL	8.91×10^4 (1.08×10^3)	1.47×10^6 (1.43×10^6)	3.02×10^5 (7.96×10^4)	7.76×10^5 (5.63×10^4)	4.36×10^4 (2.65×10^2)	4.17×10^5 (1.62×10^4)	7.24×10^5 (5.20×10^4)
FC	CFU/mL	4.67×10^6 (1.45×10^6)	2.88×10^7 (2.85×10^7)	5.37×10^7 (3.00×10^7)	4.26×10^8 (5.72×10^7)	6.91×10^7 (4.03×10^7)	2.57×10^7 (2.21×10^7)	9.12×10^7 (5.72×10^6)
Enterococcus	CFU/mL	3.98×10^4 (4.86×10^3)	4.26×10^4 (8.12×10^3)	2.57×10^5 (7.57×10^4)	8.12×10^6 (7.59×10^6)	9.12×10^4 (3.90×10^3)	2.09×10^5 (4.49×10^4)	2.34×10^6 (1.21×10^6)

( ) = standard deviation.

gravel of (1 - 2 mm) were the lowest. Low concentrations were also obtained in many studies using sand (1 - 4 mm) and gravel (2 - 4 mm) biofilters for greywater treatment in Palestine [20] [21] and Jordan [22]. From the organic matter point of view, sand (1 - 2 mm) and granitic gravel (1 - 2 mm) biofilters produced treated greywater with high reuse potential.

3.2. Treatment Performance

3.2.1. Removal Efficiency of Organic Pollutants (BOD_5, COD and SS)

Figure 2 shows the average values of the removal efficiency of organic pollutants obtained with the different biofilters. The average *RE* ranged from 18.16% (lateritic gravel 4 - 6 mm) to 78.04% (sand 1 - 2 mm) for BOD_5 and from −2.23% (lateritic gravel 4 - 6 mm) to 67.35% (sand 1 - 2 mm) for COD; regarding the SS removal, the highest and the lowest *RE* values (87.53% and 34.97%) were obtained with the sand 2 - 4 mm and the granitic gravel 4 - 6 mm in size respectively (Figure 2). The highest *RE* for BOD_5 and COD were observed with sand having a particle size of 1 - 2 mm with values of 78.04% and 67.35% respectively. Similar trends of 76% for BOD_5 and 74% for COD were reported by [21] using sand biofilters with a particle size of 1 - 2 mm treating greywater. [21] also reported efficiencies of 97% and 94% for BOD_5 and COD respectively, after passing synthetic greywater through a series of three drawers filled with gravel and silica operating as a vertical filter.

The main mechanism contributing to the removal of organic matter in biofilters is stratification [8], where particles larger than the pores between the granular

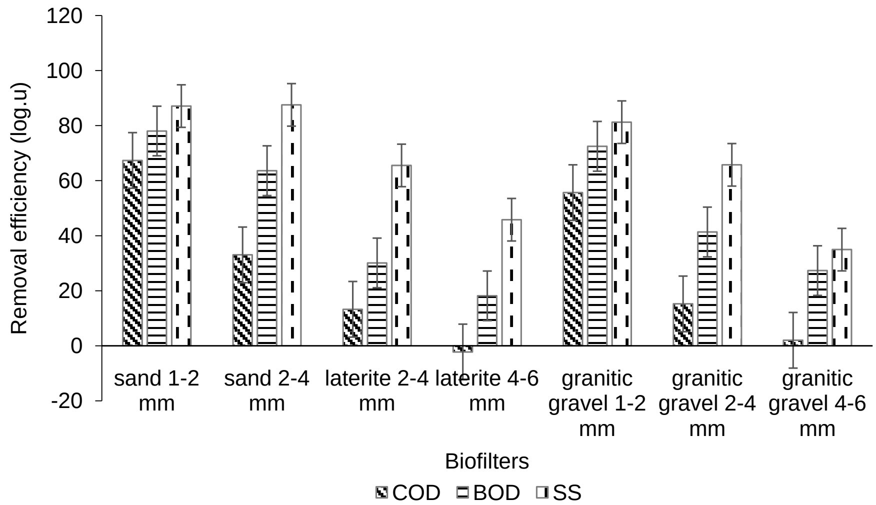

Figure 2. Average values of the removal efficiency of organic pollutants obtained with different biofilters.

media become trapped. Indeed the ability of sand to remove pollutants has been widely discussed in [23], who attributed this ability to physical processes such as stratification and sedimentation, and to a biological process through the formation of a biofilm layer on the top surface of the sand.

3.2.2. Removal Efficiency of Fecal Bacteria (*E. coli*, Fecal Coliforms and Enterococci)

The average *RE* of fecal bacteria ranged from 0.85 (sand 2 - 4 mm) to 2.38 $\log_{10}$ units (log.u) (granitic gravel 1 - 2 mm) for *E. coli* and from 0.80 (lateritic gravel 4 - 6 mm) to 1.77 log.u (sand 1- 2 mm) for fecal coliforms (**Figure 3**). With enterococci, the *REs* exhibited the same trends with values varying from 0.96 (lateritic gravel 4 - 6 mm) to 2.27 log.u (sand 2 - 4 mm).

Apart from *E. coli*, the highest *REs* for fecal coliforms and enterococci were observed using sand with a grain size of 1 - 2 mm. Indeed, the maximum values achieved were 1.77 log.u for fecal coliforms and 2.27 log.u for enterococci (**Figure 3**). Similar results in *E. coli* removal were reported by [24] using compacted drawer sand biofilters with a particle size of 1.3 mm when treating greywater onsite in Jordan. Further, [25], using a horizontal biofilter filled with sand of 1 - 2 mm in size, reported *REs* of 2.66 and 2.56 log.u for fecal coliform and enterococci respectively.

However, the maximum *REs* we obtained are lower than the 3 log.u reported by [24] in a Drawer Compacted Sand Filter system. These differences in the removal of microbial pollution depend on several parameters including the nature of the filter materials, the adsorption and the absorption in the biofilm [26] [27]. Indeed, [28] showed the treatment of artificial greywater, that the *RE* of *E. coli* decreased drastically in carbon and sand filters, but increased by 2 log.u in bark filters. Furthermore, [8] obtained better *RE* of *E. coli*, *Salmonella* spp. and total coliforms with crushed lava rock (1.18 - 2.56 mm in size) than with silica sand of the same particle size. [29] reported an average attachment of 8×10^6 bacterial

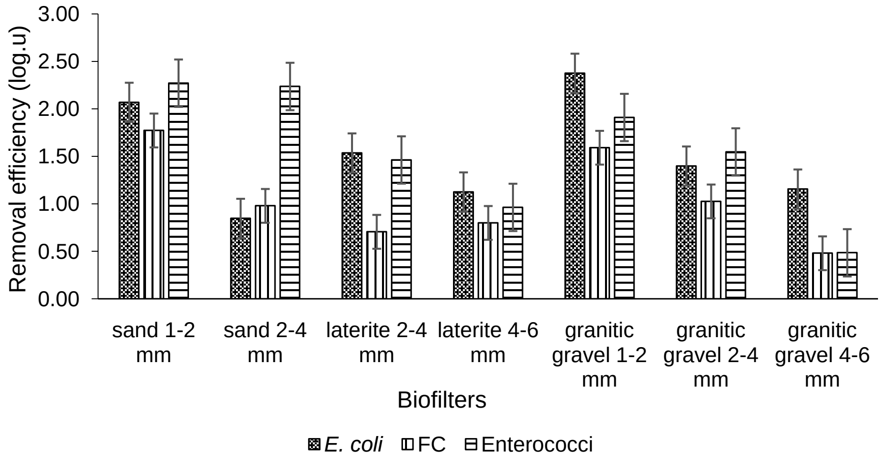

Figure 3. Average removal efficiencies of fecal indicators using different filter materials.

cells per gram of sand in a column study simulating a vertical flow constructed wetland. This suggests that retention by absorption could be the main mechanism of bacterial removal in a vertical flow wetland.

3.3. Influence of Filter Media and Particle Size on the Removal of Organic Pollutants

The effect of the type of filter media on the *RE* of organic pollutants was evaluated by considering the data obtained with sand (particle size of 1 - 2 mm, 2 - 4 mm), granitic gravel (particle size of 1 - 2, 2 - 4 and 4 - 6 mm) and lateritic gravel (particle size of 2 - 4 and 4 - 6 mm). The results obtained with the different type of biofilters operating at the same particle size were compared. It appeared that sand and granitic gravel of 1 - 2 mm in size significantly reduced BOD_5, COD and SS compared to the other filter materials used in this study. In most cases, the sand obtained the highest *REs* (for example, for sand and granitic gravel at the particle size of 1 - 2 mm, COD removal was 67.35% and 55.67% respectively) (**Table 3**). However, the statistical analysis showed that there was no

Table 3. Comparison of the efficiency of local filter media in the removal of organic matter.

Biofilter	Removal efficiencies (%)		
	COD	BOD_5	SS
Sand 1 - 2mm	67.35^{a}	78.04^{a}	87.10^{a}
Sand 2 - 4 mm	33.05^{ab}	63.62^{a}	87.53^{a}
Lateritic gravel 2 - 4 mm	13.26^{bc}	30.12^{ab}	65.53^{ab}
Lateritic gravel 4 - 6 mm	−2.23^{c}	18.16^{b}	45.82^{bc}
Granitic gravel 1 - 2 mm	55.67^{a}	72.48^{a}	81.26^{a}
Granitic gravel 2 - 4 mm	15.25^{bc}	41.36^{ab}	65.77^{ab}
Granitic gravel 4 - 6 mm	2.03^{c}	27.33^{ab}	34.97^{c}

For a given parameter, values with different letters are significantly different.

significant difference between the *REs* of the organic pollutants by the different filter media (sand, granitic and lateritic gravel) operating at the same particle size (1 - 2 mm, 2 - 4 mm or 4 - 6 mm) for all of the tested parameters (COD, BOD_5 and SS).

The effect of the variation of the particle size for a given filter media was evaluated using the granitic gravel (particle size of 1 - 2 mm, 2 - 4 mm and 4 - 6 mm), sand (particle size of 1- 2 mm, 2 - 4 mm) and lateritic gravel (particle size of 2 - 4 mm, 4 - 6 mm). For all of the tested parameters (COD, BOD_5, SS), the biofilters using particle size of 1 - 2 mm mainly obtained the highest *REs* regardless of the filter media (sand, granitic or lateritic gravel). For BOD_5, the statistical analysis showed that, within a given biofilter media, the variation in particle size did not have a significant effect on the *RE* of the different biofilters. For COD, when granitic gravel was used as filter materials, it appeared that the decrease in particle size had a significant effect on the *REs*. Indeed, the value obtained with the smallest particle size (1 - 2 mm) was significantly higher than that of 2 - 4 mm and the largess particle size (4 - 6 mm). For SS, granitic gravel with a particle size of 1 - 2 mm on the one hand and 2 - 4 mm on the other hand obtained significantly higher organic pollutants *REs* than that of 4 - 6 mm in size.

When we consider the effect of the combination of the type and size of the filter media, some significant differences appeared. For BOD_5, the *REs* of sand biofilters 1 - 2 mm in size in the one hand and 2 - 4 mm in size in the other hand were significantly higher than that of lateritic gravel biofilter 4 - 6 mm in size. Regarding COD removal, the results obtained with sand biofilter 1 - 2 mm in size were significantly higher than that obtained with granitic gravel biofilters 2 - 4 mm and 4 - 6 mm in size. In addition, the sand biofilter of 2 - 4 mm in size exhibited significantly higher *REs* compared to the granitic and lateritic gravel biofilters, both of 4 - 6 mm in size. For SS, the *REs* of sand biofilters 1 - 2 mm and 2 - 4 mm in size and granitic gravel biofilter 1 - 2 mm in size were significantly higher than that of lateritic and granitic gravel biofilters, both of 4 - 6 mm in size.

Our results are in compliance with those of [30] who demonstrated that the particle size affects the optimal absorption of pollutants when wood chip and peanut shell biofilters were used to remove organic matter from domestic wastewater. The differences in *RE* between the same media filters of different particle sizes could mainly be attributed to the heterogeneous shape and compaction, with unpredictable particle size organization and distribution leading to preferential pathways [31]. The *RE* of sand biofilter (1 - 2 mm) and granitic gravel (1 - 2 mm) were directly related to their particle sizes but also to their long infiltration time. Indeed, according to [11], if a fine material is used, the retention time of wastewater in the filter is longer, which often leads to higher *REs*; however, the water takes longer time to infiltrate and the potential for clogging increases as shown in our study where after four weeks, both sand 1 - 2 mm and 1 - 2 mm granitic gravel biofilters were clogged. These results could be explained by a significant reduction in the porosity of the filter media due to organic loading [32] and biofilm formation [33]. The opposite effect is observed when coarser filter media are used: it leads to late clogging but lower *RE*s. Indeed, with lateritic and granitic gravels (4 - 6 mm in size) any clogging was noticed, but the *REs* obtained were low (**Table 3**).

3.4. Influence of Filter Media and Particle Size on the Removal of Fecal Indicators

The assessment of the influence of the type of filter media and particle size on the removal of the microbial pollution was conducted based on the determination of the contents of *E. coli*, fecal coliforms and enterococci in the raw and pre-treated greywater.

When *E. coli* was considered, we noticed that whatever the type of the filter media, we obtained a decrease in the *RE* if the particle size was increased. The highest *RE* was observed using granitic gravel of 1 - 2 mm in size with a value of 2.38 log.u (**Table 4**). Overall, granitic gravel (1 - 2 mm) seemed to show better *E. coli* removal compared to sand (1 - 2 mm). However, the statistical analysis did not show any significant difference between the filter media when compared to each other, nor between the particle sizes of the same filter media.

For fecal coliforms, it is noted that an increase in the particle size of the filter materials resulted in a decrease in the *RE*. From 1 to 4 mm in size, the *REs* obtained by the different materials were sand > granitic gravel > lateritic gravel. The highest *RE* was obtained with sand at 1 - 2 mm in size with a value of 1.77 log.u. The *REs* obtained with sand and granitic gravel of 1 - 2 mm in size were both significantly higher than that of granitic gravel of 4 - 6 mm in size.

With enterococci, regardless of the type of the filter material, we noticed an increase in the *REs* when the particle size of the filter media was decreased. The highest *RE* was obtained with sand of 1 - 2 mm in size. The *REs* obtained with sand of 1 - 2 and 2 - 4 mm in size were both significantly higher than that of lateritic and granitic gravels of 4 - 6 mm in size.

Table 4. Comparison of the efficiency of local filter media in the removal of fecal bacteria.

Biofilter	Removal efficiencies (log.u)		
	E. coli	Fecal coliforms	Enterococci
Sand 1 – 2 mm	2.07^{a}	1.77^{a}	2.27^{a}
Sand 2 - 4 mm	0.85^{a}	0.98^{ab}	2.24^{ab}
Lateritic gravel 2 - 4 mm	1.54^{a}	0.71^{ab}	1.46^{abcd}
Lateritic gravel 4 - 6 mm	1.13^{a}	0.80^{ab}	0.96^{cd}
Granitic gravel 1 – 2 mm	2.38^{a}	1.59^{a}	1.91^{abc}
Granitic gravel 2 - 4 mm	1.40^{a}	1.03^{ab}	1.55^{abc}
Granitic gravel 4 - 6 mm	1.16^{a}	0.48^{b}	0.49^{d}

For a given fecal indicator, *REs* without any letter in common are significantly different.

From our results, it appeared that:

1) Media of fine texture remove fecal bacteria better than coarse texture media. A similar trend was reported by [34] where unsaturated vertical filters with sand (1 - 4 mm) and gravel (4 - 8 mm) removed 1.9 and only 0.8 log.u of *E. coli* respectively.

2) The removal of fecal bacteria from greywater using biofilters depends on the interaction between the type of the filter media, the particle size and the type of microorganism. The reasons for high bacterial removal in sand biofilters were previously attributed to physical filtration, biofilm growth and accumulation of solids on the top surface which lead to a decrease in pore space, thereby, increasing the removal capacity of bacteria [27] [35].

3.5. Level of Clogging of the Filter Media

The results of the direct observation of the biofilters showed that the early or late clogging depends on the type and the particle size of the filter media (**Figure 4**). Indeed, sand and granitic gravel of 1 - 2 mm in size were clogged the fifth weeks of operation, followed by sand with particle size of 2 - 4 mm the ninth week after operation. The lateritic gravel of 2 - 4 mm in size was clogged after the tenth week. In contrast, the lateritic and granitic gravels with a grain size of 4 - 6 mm, did not show any signs of clogging throughout the study (13 weeks). The clogging of biofilters was previously attributed to the accumulation of organic particles and the microbial growth that lead to the development of biofilms in the filter materials [36]. Indeed, kitchen greywater has the highest levels of organic substances and suspended solids [16]. This explains that the filters of fine to medium texture (1 - 2 mm and 2 - 4 mm) that clogged early, presented the accumulation of organic matter on their surfaces (**Figure 4**). The early clogging could be explained by the fact that fine media pile up and leave less free space for the water to percolate, which increases the time required for infiltration. In addition, organic matter fits into the pores, reducing them, increasing the infiltration time until clogging. In fact, the materials of fine texture showed an increase in

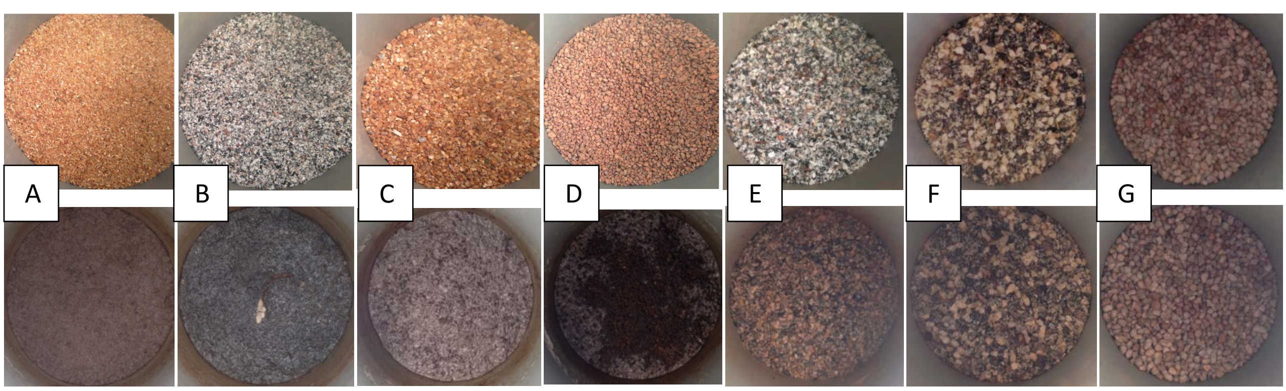

Figure 4. Level of clogging before (top) and after (bottom) pre-treatment with raw greywater. (A) sand 1 - 2 mm; (B) granitic gravel 1 - 2 mm; (C) sand 2 - 4 mm; (D) lateritic gravel 2 - 4 mm; (E) granitic gravel 2 - 4 mm; (F) granitic gravel 4 - 6 mm; (G) lateritic gravel 4 - 6 mm.

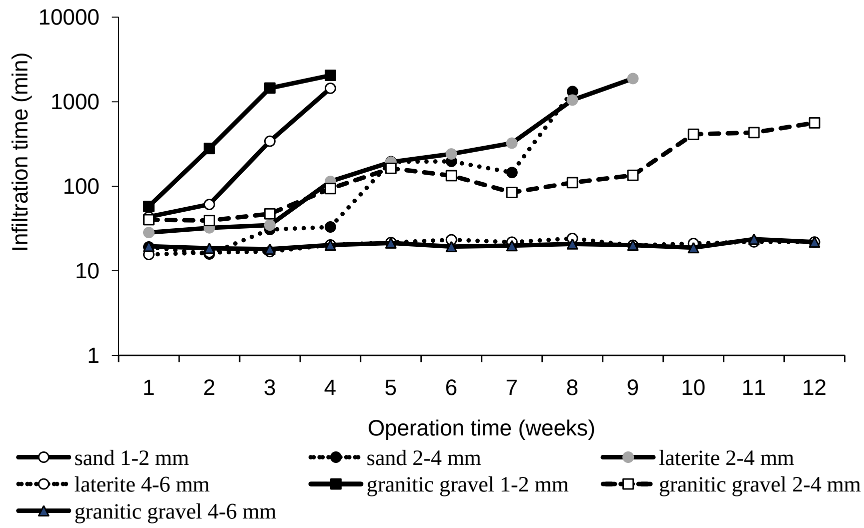

Figure 5. Evolution of infiltration time during the operation of the biofilters

the infiltration time until clogging (33 times *i.e.* from 43 to 1440 min for sand 1 - 2 mm and 35 times *i.e.* from 58 to 2048 min for granitic gravel 1 - 2 mm (**Figure 5**). Besides, the coarse texture materials with grain sizes of 4 - 6 mm had an almost constant infiltration time during the experiment (20 min). The results of direct observation are correlated with the data on infiltration time assessment (**Figure 5**): the longer the infiltration time, the greater the degree of clogging.

4. Conclusion

This study compared the purification efficiency of vertical biofilters using three types of local filter media of varying grain size. The results indicated that the type of filter media and their grain size have an influence on the elimination of organic and bacterial pollution from greywater. The use of fine material in the filter layer enhanced the *REs*. Indeed, sand and granitic gravel with a particle size of 1 - 2 mm showed the highest *REs* of organic matter and fecal bacteria. However, fine sand and granitic gravel (1 - 2 mm in size) caused significant clogging issues after five weeks of operation. Although interesting removal of organic and microbial pollutions was achieved with fine filter media, they do not seem to be suitable as filtration material in the greywater pre-treatment stage. Therefore, to overcome these limitations, pre-treatment step with coarse filter media followed by a treatment with finer media could be proposed for greywater treatment. Another alternative to solve the clogging issue while enhancing the removal efficiency could be the use of a combination of fine and coarse media.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] WHO/UNICEF (2019) National Support Systems for Drinking Water, Sanitation

and Hygiene: Global Status Report 2019. UN-Water Global Analysis and Assessment on Sanitation and Drinking Water, GLAAS Report 2019.

[2] WWAP (World Water Assessment Programme) (2017) United Nations World Water Development Report 2017. Wastewater—An Untapped Resource. UNESCO, Paris.

[3] WHO (2013) Water, Sanitation and Hygiene.

[4] WHO (2011) Progress on Sanitation and Drinking Water. WHO/UNICEF Joint Monitoring Program for Water Supply and Sanitation, Geneva, 60 p.

[5] Wu, T.Y., Mohammad, A.W., Lim, S.L., Lim, P.N. and Hay, J.X.W. (2013) Recent Advances in the Reuse of Wastewaters for Promoting Sustainable Development. In: Sharma, S. and Sanghi, R., Eds., *Wastewater Reuse and Management*, Springer, Dordrecht, 47-103. https://doi.org/10.1007/978-94-007-4942-9_3

[6] Jury, W.A. and Vaux Jr., H.J. (2007) The Emerging Global Water Crisis: Managing Scarcity and Conflict between Water Users. *Advances in Agronomy*, **95**, 1-76. https://doi.org/10.1016/S0065-2113(07)95001-4

[7] Maiga, Y., Moyenga, D., Nikiema, B.C., Ushijima, K., Maiga, A.H. and Funamizu N. (2014) Designing Slanted Soil System for Greywater Treatment for Irrigation Purposes in Rural Area of Arid Regions. *Environmental Technology*, **35**, 3020-3027. https://doi.org/10.1080/09593330.2014.929180

[8] Katukiza, A.Y., Ronteltap, M., Niwagaba, C.B., Kansiime, F. and Lens, P.N.L. (2014) Grey Water Treatment in Urban Slums by a Filtration System: Optimisation of the Filtration Medium. *Journal of Environmental Management*, **146**, 131-141. https://doi.org/10.1016/j.jenvman.2014.07.033

[9] Pradhan, S., Helal, M.I., Al-Ghamdi, S.G. and Mackey, H.R. (2019) Performance Evaluation of Various Individual and Mixed Media for Greywater Treatment in Vertical Nature Based Systems. *Chemosphere*, **245**, Article ID: 125564. https://doi.org/10.1016/j.chemosphere.2019.125564

[10] Stefanakis, A.I. and Tsihrintzis, V.A. (2012) Effects of Loading, Resting Period, Temperature, Porous Media, Vegetation and Aeration on Performance of Pilot-Scale Vertical Flow Constructed Wetlands. *Chemical Engineering Journal*, **181-182**, 416-430. https://doi.org/10.1016/j.cej.2011.11.108

[11] Dotro, G., Langergraber, G., Molle, P., Nivala, J., Puigagut, J., Stein, O. and von Sperling, M. (2017) Biological Wastewater Treatment Series Volume 7: Treatment Wetlands. IWA Publishing, London. https://doi.org/10.2166/9781780408774

[12] APHA (1999) Standard Methods for the Examination of Water and Wastewater. 20th Edition, American Public Health Association, Washington DC.

[13] Travis, M.J., Wiel-Shafran, A., Weisbrod, N., Adar, E. and Gross, A. (2010) Greywater Reuse for Irrigation: Effect on Soil Properties. *Science of the Total Environment*, **408**, 2501-2508. https://doi.org/10.1016/j.scitotenv.2010.03.005

[14] Raphael, D.O., Okunade, D.A., Ogedengbe, K. and Adekunle, O.A. (2019) Assessment of a Batch-Flow Free Water Surface Constructed Wetland Planted with *Rhynchospora corymbosa* (L.) Britton for Campus Greywater Treatment. *Environmental Science and Pollution Research*, **27**, 4275-4283. https://doi.org/10.1007/s11356-019-07095-6

[15] Réseau de l'Assainissement Ecologique (RAE) and Pôle Eco Assainissement des Baronnies Provençales (2017) Characterisation of Domestic Wastewater and 3 Associated Treatment Processes. *In Situ* Monitoring Study Report, 140 p.

[16] Li, F., Wichmann, K. and Otterpohl, R. (2009) Review of the Technological Approaches for Greywater Treatment and Reuses. *Science of the Total Environment*,

407, 3439-3449. https://doi.org/10.1016/j.scitotenv.2009.02.004

[17] O'Toole, J., Sinclair, M., Malawaraarachchi, M., Hamilton, A., Barker, S.F. and Leder, K. (2012) Microbial Quality Assessment of Household Greywater. *Water Resource*, **46**, 4301-4313. https://doi.org/10.1016/j.watres.2012.05.001

[18] WHO (2006) Guidelines for the Safe Use of Wastewater, Excreta and Greywater, Vol. 4: Excreta and Greywater Use in Agriculture. WHO Press, Geneva, 204 p.

[19] Mara, D. (2004) Domestic Wastewater Treatment in Developing Countries. Earthscan, London, 293 p.

[20] Dalahmeh, S.S., Björn, M.P., Jönsson, V.H., Hylander, L.D. and Lalander, C. (2014) Effects of Changing Hydraulic and Organic Loading Rates on Pollutant Reduction in Bark, Charcoal and Sand Filters Treating Greywater. *Journal of Environmental Management*, **132**, 338-345. https://doi.org/10.1016/j.jenvman.2013.11.005

[21] Abdel-Shafy, H.I., El-Khateeb, M.A. and Shehata, M. (2014) Greywater Treatment Using Different Designs of Sand Filters. *Desalination and Water Treatment*, **52**, 5237-5242. https://doi.org/10.1080/19443994.2013.813007

[22] Albalawneh, A., Chang, T. and Alshawabkeh, H. (2017) Greywater Treatment by Granular Filtration System Using Volcanic Tuff and Gravel Media. *Water Science & Technology*, **75**, 2331-2341. https://doi.org/10.2166/wst.2017.102

[23] Rodgers, M., Mulqueen, J. and Healy, M.G. (2004) Surface Clogging in an Intermittent Stratified Sand Filter. *Soil Science Society of American Journal*, **68**, 1827-1832. https://doi.org/10.2136/sssaj2004.1827

[24] Assayed, A., Chenoweth, J. and Pedley, S. (2014) Drawer Compacted Sand Filter: A New and Innovative Method for On-Site Grey Water Treatment. *Environmental Technology*, **35**, 2435-2446. https://doi.org/10.1080/09593330.2014.909886

[25] Maiga, Y., Ndiaye, A., Sangaré, D., Bitié, E. and Ushijima, K. (2018) Effect of Slanted Soil Design and Filter Media Distribution on the Removal of Fecal Bacteria and Organic Matter from Greywater. *International Journal Current Microbiology Applied Science*, **7**, 2317-2329. https://doi.org/10.20546/ijcmas.2018.707.270

[26] Oakley, S. and von Sperling, M. (2017) Media Filters: Trickling Filters and Anaerobic Filters. In: Rose, J.B. and Jiménez-Cisneros, B., Eds., *Water and Sanitation for the 21st Century: Health and Microbiological Aspects of Excreta and Wastewater Management*, Michigan State University, East Lansing, MI, 11 p. https://doi.org/10.14321/waterpathogens.64

[27] Maiga, Y., Sperling, V.M. and Mihelcic, J.R. (2017) Constructed Wetlands. In: Rose, J.B. and Jiménez-Cisneros, B., Eds., *Water and Sanitation for the 21st Century: Health and Microbiological Aspects of Excreta and Wastewater Management*, Michigan State University, East Lansing, MI, 21 p. https://doi.org/10.14321/waterpathogens.66

[28] Lalander, C., Dalahmeh, S., Jönsson, H. and Vinnerås, B. (2013) Hygienic Quality of Artificial Greywater Subjected to Aerobic Treatment: A Comparison of Three Filter Media at Increasing Organic Loading Rates. *Environmental Technology*, **34**, 2657-2662. https://doi.org/10.1080/09593330.2013.783603

[29] Wand, H., Vacca, G., Kuschk, P., Kruger, M. and Kastner, M. (2007) Removal of Bacteria by Filtration in Planted and Non-Planted Sand Columns. *Water Research*, **41**, 159-167. https://doi.org/10.1016/j.watres.2006.08.024

[30] Tejedor, J., Cóndor, V. and Almeida-Naranjo, C.E. (2018) Performance of Wood Chips/Peanut Shells Biofilters Used to Remove Organic Matter from Domestic Wastewater. *Science of the Total Environment*, **738**, Article ID: 139589. https://doi.org/10.1016/j.scitotenv.2020.139589

[31] Ruiz-Ocampo, H., Paing, J., Molle, P., Chazarenc, F., *et al.* (2021) Effect of Filter Media and Depth on Hydrodynamics and Treatment Performances on a First French Vertical Flow Treatment Wetland Stage Treating Domestic Effluent. *Water*, *Air*, *& Soil Pollution*, **232**, Article No. 282.

[32] Ouattara, J.M.P. and Coulibaly, L. (2019) Effet de la charge hydraulique appliquée sur le fonctionnement d'un marais artificiel à drainage vertical planté avec Panicum maximum traitant des eaux domestiques. *International Journal Biology Chemical Science*, **13**, 24-38. https://doi.org/10.4314/ijbcs.v13i5.2S

[33] Matos, M.P., Sperling, V.M. and Matos, A.T. (2018) Clogging in Horizontal Subsurface Flow Constructed Wetlands: Influencing Factors, Research Methods and Remediation Techniques. *Reviews in Environmental Science and Bio*/*Technology*, **17**, 87-107. https://doi.org/10.1007/s11157-018-9458-1

[34] Headley, T., Nivala, J., Kassa, K., Olsson, L., Wallace, S., Brix, H., Van, A.M. and Mûller, R. (2013) *Escherichia coli* Removal and Internal Dynamics in Subsurface Flow Ecotechnologies: Effects of Design and Plants. *Ecological Engineering*, **61**, 564-574. https://doi.org/10.1016/j.ecoleng.2013.07.062

[35] Arden, S. and Ma, X. (2018) Constructed Wetlands for Greywater Recycle and Reuse: A Review. *Science of the Total Environment*, **630**, 587-599. https://doi.org/10.1016/j.scitotenv.2018.02.218

[36] Licciardello, F., Aiello, R., Alagna, V., Iovino, M., Ventura, D. and Cirelli, G.L. (2019) Assessment of Clogging in Constructed Wetlands by Saturated Hydraulic Conductivity Measurements. *Water Science & Technology*, **79**, 314-322. https://doi.org/10.2166/wst.2019.045