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Greywater treatment by vermifiltration for sub-Saharan urban poor

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ABSTRACT

The treatment of greywater collected from an urban slum area of Ouagadougou, Burkina Faso, by vermifiltration (VF) was investigated using locally available sawdust as bedding material and *Eudrilus eugeniae* earthworm. The filtration system was made up of layers of sand, and fine and coarse gravel from the top to the bottom, which was spread inside a cylindrical DN200-PVC pipe. The fine sawdust and density of 6370 worms/m^2 were added while the same filtration system without earthworms was used as an experimental control. Batch experiments were conducted at ambient temperature, with hydraulic loading rate of 64 and 191 L m^{-2} d^{-1}. The raw greywater was highly concentrated with biochemical oxygen demand (BOD_5) varying from 690 to 2200 mg/L and pH varying from 4.37 to 7.32. The results showed that *Eudrilus eugeniae* were able to tolerate temperatures above 40 °C and avoided odour and clogging problems inside the filter. The removal efficiencies of BOD_5, chemical oxygen demand, total suspended solid, *E. coli* and thermotolerant coliforms were better in the vermifilter than in the control system. Moreover, the pH at the exit of the system was close to neutral. Therefore, VF could be applied as an alternative low-cost technology to treat greywater for the urban poor in hot climate areas.

Key words | earthworms, *Eudrilus eugeniae*, greywater treatment, vermifiltration

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INTRODUCTION

In developing countries, the greywater generated from an urban slum area is not properly collected and treated. It is usually disposed of on roads or open spaces near houses. The greywater is concentrated with pollutants and pathogens, which become a threat to the environment and human health, especially for the low income urban poor (Mara 1996). The existing low-cost sanitation options are not solving the problems. For instance, intermittent sand filters were proven to be a cost effective option to treat domestic and industrial wastewaters but clogging is the most common problem (Netter 1992; Healy *et al.* 2004). Lagoons also require large areas of land and a sewer system (Pattarkine *et al.* 2006). The septic tank has low treatment efficiency and emits foul odours (Imhof & Muhlemann 2005). Therefore, it is necessary to develop technologies, which are relatively low-cost and low-energy consumption, need little maintenance and are environmentally friendly.

Vermifiltration (VF) is a recently developed technology to process organically polluted wastewater using earthworms with bedding materials on top of a filter media. Different researches have been conducted in China, India, Australia, France and other countries on VF for treatment of domestic wastewater mostly at a laboratory scale; on the other hand, little effort has been done to use it at small- and medium-scale levels in the field (Taylor *et al.* 2003; Li *et al.* 2009; Kharwade & Khedikar 2011).

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The bedding material type, the filter media design and earthworm species affect the efficiency of the system. The most commonly tested bedding materials are clay soil, fine sawdust, compost and different animals' dung. They are selected based on the following characteristics: high absorbency, good bulking potential and low protein and/or nitrogen content (Mahmoud 2011). It has been reported that newspaper bedding is more influential in worm biomass production and growth rate, whereas sawdust bedding is better for cocoons and the number of earthworms' production (Manaf *et al.* 2009).

Regarding the filter media, sand, coarse sawdust and gravel have been widely tested with various depths and compositions (Taylor *et al.* 2003; Li *et al.* 2009; Kharwade & Khedikar 2011). As far as earthworm species are concerned, the most commonly utilised in wastewater treatment are *Eisenia fetida*, *Eisenia andrei*, *Lumbricus rubellus*, *Perionyx excavatus* and *Eudrilus eugeniae* (Bajsa *et al.* 2003). In their research, Kharwade & Khedikar (2011) found that the use of *Eudrilus eugeniae* on a filtration system increased the overall removal efficiency of biochemical oxygen demand (BOD_5), chemical oxygen demand (COD) and total suspended solids (TSS) by an average of 10% for 2 – 3 h of the retention time. The vermifilter was filled with 4 cm of 20 mm size gravel, 3 cm of 10 mm size gravel, 3 cm of sand and 12 cm of soil from the bottom to the top, respectively.

Besides, the hydraulic loading rates (HLRs), the pH from raw wastewater and environmental temperature have an effect on the vermifilter performance. The growth of earthworms is best in the temperature range of 25 – 30 °C but above 35 °C they will die (Dominguez & Edwards 2011). For a VF experiment conducted in Shanghai, the HLR was increased to keep the temperature below 35 °C inside the filter to avoid the death of the earthworms (Li *et al.* 2009).

However, as far as VF for treating domestic wastewater is concerned, no specific research has been done in sub-Saharan countries, particularly in the Sahelian area. The objective of this research was to test the potential of VF in removing organic pollutants and coliforms from concentrated greywater in a hot climate region, using locally available earthworm species, bedding materials and filter media. Attention was given to the effects of pH, temperature and HLR on removal efficiency of the system. The sources for domestic greywater were kitchen and laundry wastewater.

MATERIALS AND METHODS

Earthworms

A stock of earthworms was collected from a moistened bank of a lake in Ouagadougou, Burkina Faso. The stock was cultured in the research site and fed with kitchen wastes, soil and cow dung, while being watered every day. Physical and macroscopic identification of the earthworm species was done using a magnifying glass. The method allows identification of the species based on counting the segments above the clitellum (Vijaya *et al.* 2012).

Greywater

The greywater was collected daily in a 60 L plastic container from an urban poor household near the research site. Upon arrival, it was thoroughly mixed and then supplied to the system in accordance with the selected HLR. The characteristics of the raw greywater, showed a high concentration of organic matter, chemicals, solids and microbial indicators when compared to the wastewater tested for VF by other researchers (Table 1). The greywater was highly concentrated because in the Sahelian region, where water shortage is an issue, water is used several times before final disposal.

Research site

The experiment was conducted outdoor in Ouagadougou, Burkina Faso. A shade was constructed to protect the system from direct sunlight and rainfall. The average temperature is about 24.8 °C in January, the coldest season and 33.6 °C in April, the warmest one. The average daily minimum and maximum temperatures are 16–32 °C, and 26.5–42 °C, in January and April, respectively (Konate *et al.* 2013).

Filtration system

The filtration system was made up of a cylindrical PVC pipe with a diameter of 200 mm and depth of 70 cm, in which the filter media, bedding material and earthworms were added. The same system without earthworms was

Table 1 | Characteristics of the raw greywater

Parameters	Present finding Range (min–max)	Average (SD)	Li *et al.* 2009	Xing *et al.* 2005	Taylor *et al.* 2003
BOD_5 (mg/L)	690–2200	1,598 (429)	160	297	23 ± 9
COD (mg/L)	1505–2744	2,049 (430)	324	409	83 ± 23
TSS (mg/L)	710–2340	1,501 (630)	189	187	–
pH	4.37–7.23	5.73 (0.79)	–	–	–
Conductivity (μS/cm)	830–2520	1,635 (681)	–	–	–
Escherichia coli (CFU/100mL)	$(6–30) \times 10^3$	18×10^3 (12,342)	–	–	–
Thermotolerant coliforms (CFU/100mL)	$(2.1–620) \times 10^3$	535×10^3 (3322)	–	–	–
Temperature (°C)	28.2–20.9	26.06 (2.24)	–	–	–

used as a control unit. The filter media was made up of one layer of sand (40 cm thickness, particles size 0.08–16 mm), one layer of medium-sized gravel (5 cm thickness, grain size 20–40 mm) and one layer of coarse gravel (5 cm thickness, grain size 10–20 mm), from the top to the bottom (Figure 1). The sand has a uniformity coefficient of 1.36, effective size of 0.118 and density of 1517.6 kg/m^3. To remove the dust and other materials, the filter media was washed with tap water before it was introduced into the PVC pipe. The fine sawdust, composed of *Khaya ivorensis*, *Mansonia altissima*, *Milicia excelsa* tree species, was collected from the nearby woodwork shop. The average pH was 6.47 with a density of 96 kg/m^3.

Experimental set-up

Upon arrival at the experimental site, the greywater was thoroughly mixed before it was supplied into the filtration system, four times a day, at 8:00 am, 11:00 am, 2:00 pm and 5:00 pm. Two feeding rates of 1.5 and 0.5 L per batch were simultaneously tested for each condition (with and without earthworms) for a period of 13 weeks between February and May. Considering the diameter of the pipe, these flow rates will give approximately a daily HLR of 191 and 64 L m^{-2} d^{-1}, respectively for 1.5 and 0.5 L per batch. The pH, water temperature, soil temperature and amount of greywater supplied were checked four times a day on site. The treated

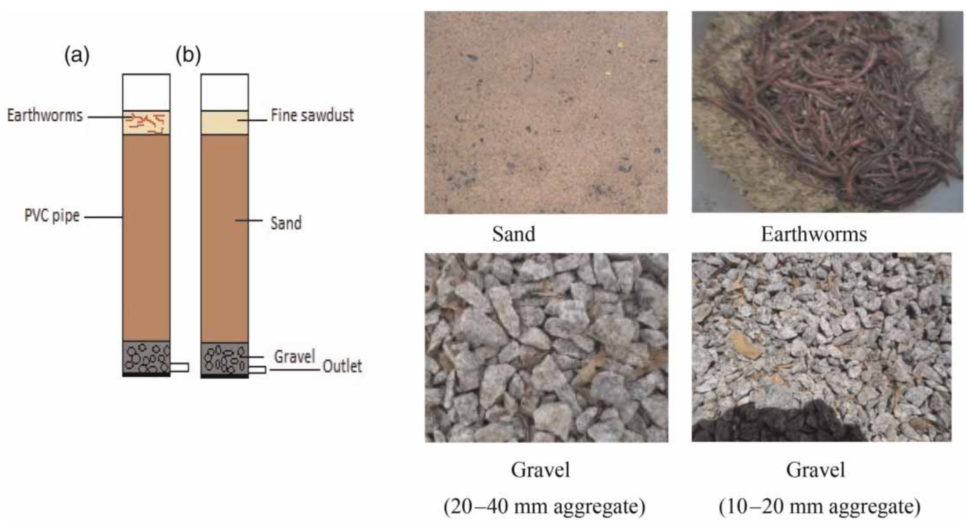

Figure 1 | Filtration system.

water was collected from the system outlet at the bottom with an open container. Samples were collected every week with properly cleaned and dried plastic and sterilised glass containers, and transported to the laboratory for immediate analysis of BOD_5, COD, TSS and coliforms.

Analytical procedures

BOD_5, COD and TSS were analysed according to Standard Methods for the Examination of Water and Wastewater (American Public Health Association [APHA] 1998). The pH was measured with a portable pH meter (WTW 3310) and the temperature with a Digital Thermometer (HI 93522 HANNA). *Escherichia coli* and thermotolerant coliforms were used as microbial indicators for human faecal contamination assessment. The spread plate method was used after an appropriate dilution of the samples in accordance with the procedure in Standard Methods for the Examination of Water and Wastewater (APHA 1998). Chromocult Agar (Merck KGaA 64271, Darmstadt, Germany) was used as the culture medium. Statistical analyses were performed using the Mann–Whitney U-test at 5% significance level.

RESULTS AND DISCUSSION

Earthworm identification

The earthworms were recognised by their two large combined female and spermathecal pores situated laterally on segment 14. All specimens belonged to the well-known African compost worm *Eudrilus eugeniae* (Kinberg 1867) (Figure 2).

Figure 2 | Female and spermathecal pores.

Effect of temperature

Figure 3 shows the average temperature inside the vermifilter (a, c, e) and the ambient temperature outside the vermifilter (b, d, f) at 8:00, 11:00, 14:00 and 17:00 for March, April and May, respectively. The temperature inside the system varied from 26.5 to 41.5 °C and the ambient temperature varied 27 to 42.5 °C. Inside the vermifilter, the highest temperature recorded was 41.5 °C, at 17:00 in the middle of April. The dominantly available *Eudrilus eugeniae* tolerated this temperature well, which was different from the findings of Dominguez & Edwards (2011) that *Eudrilus eugeniae* will die if the temperature is above 35 °C. Usually when the temperature is above 35 °C, the earthworms come to the top and are interwoven with each other, while remaining covered by a tiny layer of the bedding material to avoid dehydration. When it started raining, many cocoons were observed as the temperature decreased to 27 °C, which is within the optimum temperature range reported in the literature (Dominguez & Edwards 2011).

Overall performance of the vermifilter and the control unit

Tables 2–4 present the range, mean and standard deviation (SD) of effluent concentrations, the removal efficiencies and *p*-values of the Mann–Whitney *U*-test, respectively, while comparing effluent concentrations and removal efficiencies of the vermifilter and the control unit at a HLR of 191 and 64 L m^{-2} d^{-1}. From Table 2, with a decrease in the HLR, the effluent concentrations reduced for both the vermifilter and control.

The average removal efficiencies of BOD_5, COD, TSS, *E. coli* and thermotolerant coliforms at HLR of 191 L m^{-2} d^{-1} were 71%, 62%, 91%, 0.95 log units and 0.98 log units for the vermifilter, respectively, and 59%, 56%, 85%, 0.93 log units and 0.90 log units, respectively, for the control unit. At an HLR of 64 L m^{-2} d^{-1}, the removal efficiencies of the same parameters were 96%, 74%, 97%, 1.77 log units and 1.54 log units, respectively, for the vermifilter, and 93%, 66%, 94%, 1.47 log units and 1.22 log units,

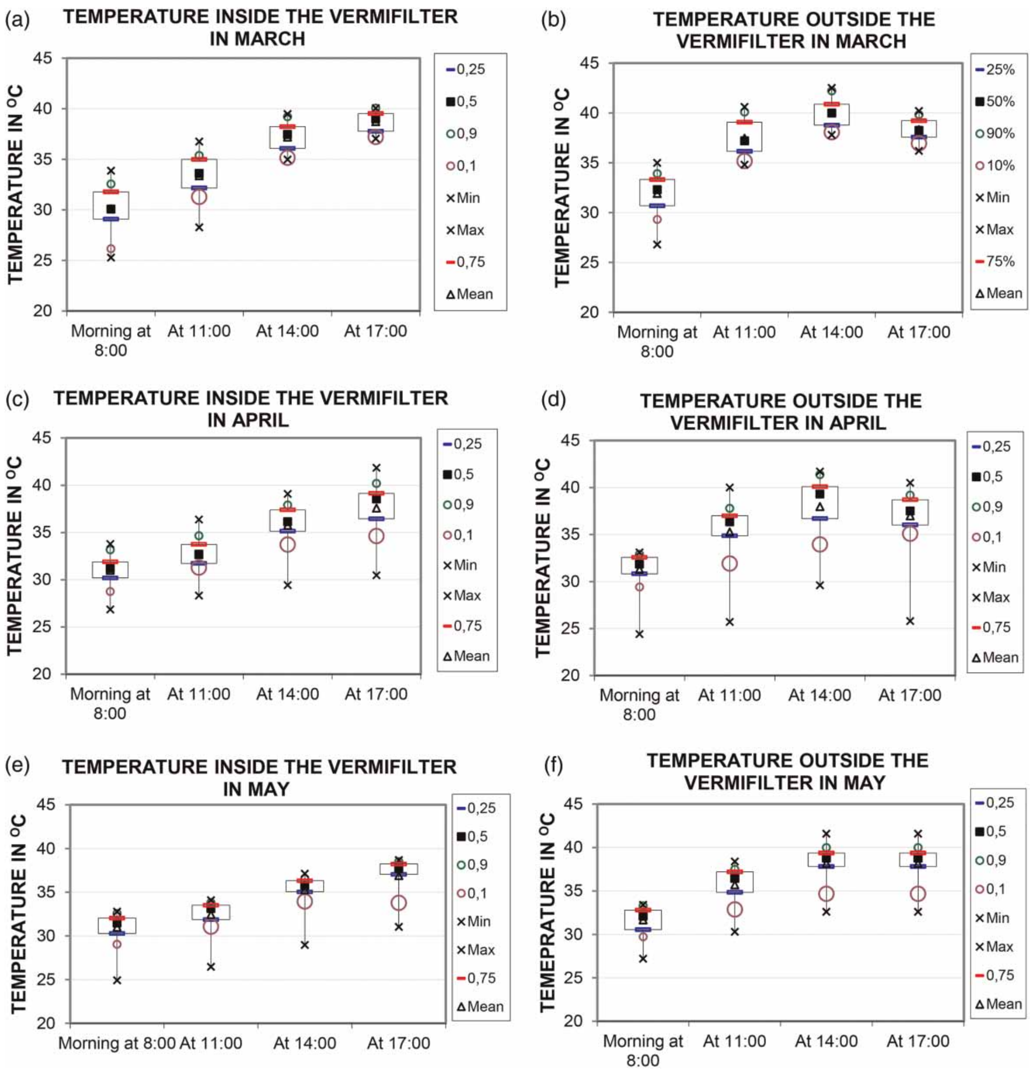

Figure 3 | Average temperature inside the vermifilter (a, c, e) and ambient air temperature outside the vermifilter (b, d, f) in March, April and May.

respectively, for the control unit (see Table 3). For all parameters, higher removal efficiencies were achieved with the HLR of 64 L m^{-2} d^{-1} compared to 191 L m^{-2} d^{-1}.

In their studies, Li *et al.* (2009) and Kharwade & Khedikar (2011) have reported that the removal efficiencies of BOD_5, COD and TSS were 90.6%, 86.8%, 94.7% and 90%, 77%, 75%, respectively, in the vermifilter for the two researches. The results were slightly different from ours, which might be due to difference in the bedding materials, earthworm species, the flow rate and type, the temperature and the characteristics of the wastewater.

As shown in Table 4, in general, there were no significant differences between the vermifilter and the control unit with exception of BOD_5 and TSS when comparing them in terms of effluent concentrations and removal efficiencies for 191 L m^{-2} d^{-1}. For 64 L m^{-2} d^{-1}, both TSS and *E. coli* have significant differences for both effluent concentrations and removal efficiencies. In terms of statistical differences between the vermifilters for HLR of 191 and 64 L m^{-2} d^{-1}, all removal efficiencies are significantly different with the exception of COD and thermotolerant coliforms removal for effluent concentration. Therefore, the removal efficiencies were better for a HLR of 64 L m^{-2} d^{-1}.

Besides the better removal efficiencies, the conditions inside the vermifilter were significantly improved compared

Table 2 | Effluent concentrations of the vermifilter and the control unit

Parameters		Effluent concentrations			
		Vermifilter 191	Control	Vermifilter 64	Control
HLR	(L m^{-2} d^{-1})	191		64	
BOD_5 (mg/L)	Mean (SD)	446 (159)	616 (166)	50 (22)	60 (54)
	Minimum	130	300	20	40
	Maximum	780	960	100	180
	Number of samples	13	13	13	13
COD (mg/L)	Mean (SD)	732 (180)	830 (187)	532 (330)	676 (327)
	Minimum	435	592	435	592
	Maximum	1404	1463	1440	1463
	Number of samples	13	13	13	13
TSS (mg/L)	Mean (SD)	73 (36)	116 (65)	25 (17)	59 (37)
	Minimum	8	6	6	6
	Maximum	100	178	56	128
	Number of samples	13	13	13	13
E. coli (CFU/100 mL)	Mean (SD)	2070 (775)	2440 (1164)	330 (170)	660 (360)
	Minimum	1000	1000	100	300
	Maximum	3000	3500	700	1500
	Number of samples	10	10	10	10
Thermotolerant coliforms (CFU/100 mL)	Mean (SD)	9,025 (10,523)	9,430 (10,541)	3,000 (4428)	5,125 (5618)
	Minimum	1000	1000	500	850
	Maximum	10,100	65,000	11,700	14,000
	Number of samples	10	10	10	10
pH	Mean (SD)	7.27 (0.1)	7.75 (0.2)	7.65 (0.3)	7.87 (0.3)
	Minimum	6	6.1	7.2	7.2
	Maximum	8	8.1	8.1	8.3
	Number of samples	13	13	13	13

to the control unit (see Figure 4). The vermifilter infiltrates the supplied greywater within 1–3 min, but the control unit takes a longer time as the test continued due to the occurrence of clogging mid-way through the testing period. As far as odour is concerned, there were no odour problems in the vermifilter compared to the control unit. Moreover, the bedding material was changed into potentially reusable organic matter.

Impact of pH

From Table 1, (above) the pH value of raw greywater varied from 4.37 to 7.23, probably due to the variation in concentrations of soap, detergents or type of food prepared in the house. For the HLR of 191 L m^{-2} d^{-1}, the average pH of the effluent in the vermifilter was 7.27 and in the control unit was 7.52 (see Table 2). This result shows that the earthworms helped the treated effluent to approach a neutral pH.

In his study, Edwards (1988) concludes that the earthworms can survive within a pH range of 5–9. However, the earthworms survived at pH value of 4.37 for this research. When the greywater was highly concentrated with soap, salt and other detergents, the earthworms tried to escape from the filter and returned back after few minutes.

CONCLUSIONS

Promising results were obtained during the test of the VF system in hot climate areas. It is suggested that this technology could be an alternative sanitation option for urban poor in these areas. The dominantly available *Eudrilus eugeniae* earthworm tolerated temperatures above 40 °C inside the filter and improved the conditions of the vermifilter. Results showed that the vermifilter was better than the filter without earthworms in removing BOD_5, COD, TSS and coliforms.

Table 3 | Removal efficiencies of the vermifilter and the control unit

Parameters		Removal efficiencies			
		Vermifilter	Control	Vermifilter	Control
HLR	($L\ m^{-2}\ d^{-1}$)	191		64	
BOD_5%	Mean (SD)	71 (8)	59 (8.2)	96 (1.5)	93 (3.9)
	Minimum	59	46	95	87
	Maximum	84	72	98	98
COD%	Mean (SD)	62 (8.6)	56 (9.9)	74 (15.7)	66 (16.6)
	Minimum	49	46	52	45
	Maximum	73	72	93	93
TSS%	Mean (SD)	91 (7.4)	85 (14.3)	97 (1.7)	94 (3.6)
	Minimum	71	47	95	90
	Maximum	99.5	99	99.6	99
E. coli Unit logs	Mean (SD)	0.95 (0.72)	0.90 (0.22)	1.77 (0.29)	1.47 (0.34)
	Minimum	0.70	0.52	1.52	1.10
	Maximum	1.20	1.30	2.40	2.22
Thermotolerant coliforms Unit logs	Mean (SD)	0.98 (0.33)	0.93 (0.31)	1.54 (0.45)	1.22 (0.39)
	Minimum	0.4	0.41	0.92	0.68
	Maximum	1.4	1.34	2.2	1.9

Table 4 | *p*-values of the Mann–Whitney *U*-test comparing effluent concentrations and removal efficiencies

	At loading rate 191 $L\ m^{-2}\ d^{-1}$		At loading rate64 $L\ m^{-2}\ d^{-1}$		The two vermifilters	
Constituent	Vermifilter × control (effluent concentrations)	Vermifilter × control (removal efficiencies)	Vermifilter × control (effluent concentrations)	Vermifilter × control (removal efficiencies)	Vermifilter at 191 $L\ m^{-2}\ d^{-1}$ × at 64 $L\ m^{-2}\ d^{-1}$ (effluent concentrations)	Vermifilter at 191 $L\ m^{-2}\ d^{-1}$ × at 64 $L\ m^{-2}\ d^{-1}$ (removal efficiencies)
BOD_5	0.0133(*)	0.0009(*)	0.0511	0.0530	1.2×10^{-6}(*)	4.7×10^{-8}(*)
COD	0.346	0.112	0.3128	0.2278	0.0525	0.0237(*)
TSS	0.0372(*)	0.1917	0.0077(*)	0.0083(*)	0.0002(*)	0.0102(*)
E. coli	0.4151	0.5812	0.0213(*)	0.0459(*)	4.2×10^{-5}(*)	1.8×10^{-6}(*)
Thermotolerant coliforms	0.9324	0.7432	0.3606	0.0996	0.1208	0.0057(*)

(*) *p*-values $\leq$0.05: sample medians are significantly different.

Figure 4 | Conditions in the vermifilter and control.

Besides, higher removal efficiencies were achieved with the HLR of 64 L m^{-2} d^{-1} compared to 191 L m^{-2} d^{-1} in all parameters. The earthworms were also able to survive at low pH values of 4.37. It is recommended to conduct tests at longer intervals of time for both laboratory and pilot scales, and further studies are also needed for a better understanding of the removal mechanism in this type of filter system.

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