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A two-step crushed lava rock filter unit for grey water treatment at household level in an urban slum

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ABSTRACT

Decentralised grey water treatment in urban slums using low-cost and robust technologies offers opportunities to minimise public health risks and to reduce environmental pollution caused by the highly polluted grey water i.e. with a COD and N concentration of 3000–6000 mg L^{-1} and 30–40 mg L^{-1}, respectively. However, there has been very limited action research to reduce the pollution load from uncontrolled grey water discharge by households in urban slums. This study was therefore carried out to investigate the potential of a two-step filtration process to reduce the grey water pollution load in an urban slum using a crushed lava rock filter, to determine the main filter design and operation parameters and the effect of intermittent flow on the grey water effluent quality. A two-step crushed lava rock filter unit was designed and implemented for use by a household in the Bwaise III slum in Kampala city (Uganda). It was monitored at a varying hydraulic loading rate (HLR) of 0.5–1.1 m d^{-1} as well as at a constant HLR of 0.39 m d^{-1}. The removal efficiencies of COD, TP and TKN were, respectively, 85.9%, 58% and 65.5% under a varying HLR and 90.5%, 59.5% and 69%, when operating at a constant HLR regime. In addition, the log removal of *Escherichia coli*, *Salmonella* spp. and total coliforms was, respectively, 3.8, 3.2 and 3.9 under the varying HLR and 3.9, 3.5 and 3.9 at a constant HLR. The results show that the use of a two-step filtration process as well as a lower constant HLR increased the pollutant removal efficiencies. Further research is needed to investigate the feasibility of adding a tertiary treatment step to increase the nutrients and microorganisms removal from grey water.

1. Introduction

Grey water is one of the domestic waste streams originating from laundry, bathroom and kitchen activities. In urban slums, it accounts for 65–90% of the domestic wastewater production (Kulabako et al., 2011; Abu Ghunmi et al., 2008; Jamrah et al., 2008; Carden et al., 2007a). Grey water is mainly disposed of in the existing storm water drains and open spaces without treatment because there is no provision for its treatment. Yet, grey water from slums has a high concentration of COD (>2000 mg L^{-1}), *Escherichia coli* (10^4–10^7 cfu (100 $mL)^{-1}$), total phosphorus (5–240 mg L^{-1}), total nitrogen (5–200 mg L^{-1}) and heavy metals (Carden et al., 2007b; Kariuki et al., 2012; Katukiza et al., 2013a; Kulabako et al., 2011). Grey water treatment is therefore driven by the need to reduce environmental pollution from the grey water pollution load and to minimise risks to human health especially in urban slums where sanitary conditions are poor. In areas of water scarcity, treated grey water is used for irrigation to recover nutrients and for artificial aquifer recharge (Abu Ghunmi et al., 2008; Dalahmeh et al., 2011).

Discharge of untreated grey water may lead to pollution of ground water sources by nutrients and micro-pollutants, eutrophication of surface water bodies and soil salinity (Gross et al., 2005; Morel and Diener, 2006; Nyenje et al., 2010). Total suspended solids (TSS) in grey water contribute to the sedimentation and reduction of the hydraulic capacity of drainage channels and surface water reservoirs, and to clogging of media based filter systems (Leverenz et al., 2009). In addition, oil and grease in grey water reduce the soil's ability to transmit water and the grey water treatment efficiency by interfering with the biological, physical and chemical processes (Cammarota and Freire, 2006; Travis et al., 2008). Lastly, grey water contains waterborne viruses, bacteria,

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parasitic protozoa and helminths (Birks and Hills, 2007; Katukiza et al., 2013b; Ottoson and Stenström, 2003), which potentially cause diseases. Hence, for public and environmental health, improved grey water collection and treatment is vital.

Primary, secondary or tertiary treatment of grey water may be achieved by a combination of technologies depending on the discharge and reuse requirements. They include settling tanks, septic tanks, media based (soil, sand, volcanic lava, mulch) filters, constructed wetlands, and oxidation ponds (Dalahmeh et al., 2011; Li et al., 2009; Morel and Diener, 2006; von Sperling and Chernicharo, 2005). Primary treatment of grey water removes oil and grease and reduces the TSS concentration, while tertiary treatment of grey water removes remaining biodegradable and non-biodegradable organics, pathogens, nutrients, and micropollutants after secondary treatment (Campos et al., 2002; Metcalf and Eddy, 2003). Therefore, the quality of grey water influences the choice for the grey water treatment technology.

A number of low-cost grey water technologies that include horizontal and vertical flow constructed wetlands, grey water tower gardens, and infiltration trenches have been applied in many parts of the world (Li et al., 2009; Masi et al., 2010; Morel and Diener, 2006). However, the existing grey water treatment technologies have neither been adapted to slum conditions nor implemented at the pollution sources (households) for effective control of the pollution load. Moreover, active participation of the slum inhabitants is important for the sustainability of a low-cost household grey water treatment system. There is thus a need for action research to demonstrate the practical application of a media filter unit for grey water treatment at household level in an urban slum. The objective of this study was, therefore, to investigate the potential of a low-cost and robust lava rock filter based on a two-step filtration process to reduce the grey water pollution load in an urban slum. The specific objectives were to implement a crushed lava rock grey water treatment filter unit operated at household level in Bwaise III in Kampala city (Uganda); to determine the removal efficiency of COD, TSS, nutrients (N, P), *E. coli*, *Salmonella* spp. and total coliforms; and to determine the main filter design and operation parameters as well as the effect of intermittent flow on the grey water effluent quality.

2. Materials and methods

2.1. Study area

The Bwaise III slum in Kampala city (Uganda) was selected as the study area for the implementation and monitoring of the performance of the grey water filter unit. It is a typical slum area located in a reclaimed wetland (32° 34′E and 0° 21′N) at an altitude of 1170 m above sea level. There are two dry season periods in the area from January to March and June to August, while during the rainy seasons flooding is usually a problem. Bwaise III is drained by two major open storm water channels into which smaller drains that convey storm water and grey water discharge. Bwaise III is not sewered and the majority of residents use onsite sanitation in the form of elevated pit latrines. There is no grey water management system in place and residents discharge the grey water in nearby open spaces and storm water drains. The water supply sources in the area include contaminated springs and a piped water system that serves the residents who can afford to pay for tap water.

2.2. Household selection

The selection of the household where the grey water treatment filter was implemented in Bwaise III was critical in this study. The majority of the residents (>60%) in the study area are tenants (Isunju et al., 2013). A household was chosen among the 10 households who participated in an earlier study (Katukiza et al., 2013a). The criteria included: availability of space (about 1 m^2 of land), a household with a resident landlord or landlady to ensure the safety of the filter and the presence of the same people throughout the entire study period, a household size of at least 7 (average size in Bwaise III) with children (<3 years) and adults, a per capita water consumption of at least 18 L c^{-1} d^{-1} (average value for Bwaise; Katukiza et al., 2010), the presence of a tertiary drain (defined as a small open drainage channel conveying grey water in the urban slum) nearby to which grey water generated by households would be discharged and the willingness of the household members to use the grey water treatment filter.

2.3. Design and implementation of the crushed lava rock filter in Bwaise III

2.3.1. Design

A pilot onsite grey water treatment unit using crushed lava rock was designed and implemented at a household in Bwaise III parish. The filter unit was composed of two identical filters (R1 and R2 in series) made of plastic material to avoid rusting and a filter support from hollow steel sections of 1.5 mm thickness with a concrete foundation (Fig. 1). The filters were composed of 10 cm of the under-drain of crushed gravel (media size: 5–10 mm), 30 cm of graded crushed lava rock (media size: 2.56–5 mm for the first filter and 1.18–2.56 mm for the second filter; Fig. 1), 170 cm clear space above the media and a perforated plastic diffuser. Sampling points SP1, SP2 and SP3 were provided for the influent, R1 effluent and R2 effluent, respectively.

Crushed lava rock medium was chosen as a filtration medium because it is widely available in south western Uganda in large quantities, has a higher specific surface area and porosity compared to sand and gravel, and its chemical characteristics enhance its suitability as a medium in filter systems for wastewater treatment (Kalibbala et al., 2012; Sekomo et al., 2012). Crushed lava rock has a specific surface area of about 6–8 times that of quartz and gravel (Kalibbala et al., 2012).

The filter was designed in such a way that at least three 200 mL samples can be obtained at anytime regardless of the usage by the household. This was made possible by raising the outlet pipes of both reactors by 10 cm and inserting sampling points about 2–3 cm from the reactor bottom. The elevated outlet allowed the gravel (filter media support) to remain saturated during the filter operation under intermittent flow. A perforated plastic diffuser (with holes about 2 mm diameter) was introduced on top of the reactors to distribute the filter influent uniformly on the media and to prevent scouring of the top biologically active layer. In addition, a perforated Tee-junction with end caps was provided at the end of the outlet pipe from reactor 1 to distribute the effluent of R1 on the diffuser of R2 (Fig. 1).

A two-step design was chosen so that R1 can provide the primary treatment of settled grey water and R2 filled with a smaller grain size of crushed lava can provide secondary treatment. In addition, the highest pollutant removal in the top 10 cm of the infiltration depth for intermittent filters (Campos et al., 2002; Jellison et al., 2000; Rodgers et al., 2005) and thus two separate filters provide a longer aerobic zone than one filter with an equivalent infiltration depth. The filter was designed to serve an average household size of 7 in Bwaise III. The filter design hydraulic loading rate was 1.1 m d^{-1} based on the grey water production in Bwaise III of about 16 L c^{-1} d^{-1} and the filter surface area of 0.102 m^2.

2.3.2. Operational conditions

The crushed lava rock filter was implemented at a household and operated under uncontrolled and then controlled intermittent