Pilot study of a horizontal roughing filtration system treating greywater generated from a peri-urban community in Durban, South Africa

B. F. Bakare, S. Mtsweni and S. Rathilal

ABSTRACT

There is a growing pressure on the available freshwater resources in South Africa and many other countries around the world. This has led to a large scale of interest in the application of water reclamation and reuse of wastewater as alternative water supply sources. This is becoming critical to sustain development and economic growth in the southern Africa region. This study investigated the performance of a horizontal roughing filtration system treating greywater generated from a peri-urban settlement in Durban, South Africa. The horizontal roughing filtration system consists of three compartments containing different sizes of gravels that serve as the filter media. The horizontal roughing filter was operated at a filtration rate of 0.3 m/hr for 90 days. The results indicated that at this low filtration rate, effective reduction in turbidity, conductivity, chemical oxygen demand and total solids can be achieved. Overall average removal efficiencies of 90% turbidity, 70% chemical oxygen demand, 86% conductivity, and 84% total solids were obtained for the entire duration of operation of the horizontal roughing filtration system. Thus, it was concluded that the horizontal roughing filtration system is suitable for the treatment of greywater for non-potable reuse applications although further investigation needs to be conducted for the microbial removal during the treatment.

Key words | filter media, filtration rates, greywater, horizontal roughing filter, reuse application, water reclamation

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INTRODUCTION

South Africa is a water scarce country and is currently facing its worst drought in decades. The demand for fresh water in the country is rising quickly due to increasing population growth, industrialization and mechanization. According to Van Staden (2014), quite a number of researchers have stated that water demand in South Africa will exceed the supply between 2015 and 2033, due to anticipated population growth, consumption and other needs for water, thus the supply will not be able to cope with this demand. This pressure is triggered by the fact that South Africa is associated with low rainfalls and a high evaporation rate in most parts of the country (Adewumi *et al.* 2010; Bakare *et al.* 2016). Although issues around water scarcity are not only associated with South Africa, it is recognised as a major challenge facing many countries on a worldwide scale (Tiruneh 2014; Tsoumachidou *et al.* 2017).

Given the worldwide water scarcity and future demands, this has forced water resource managers and planners, as well as scientist and researchers, to look at other unconventional water sources such as desalination, water reuse and rain harvesting (Bakare *et al.* 2017; Tsoumachidou *et al.* 2017). Water reuse has become an attractive option for

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water augmentation, the reason being that this water source is usually readily available and in close proximity to the point of application.

In South Africa, there has also been a lot of interest recently in the reuse of greywater; however, greywater contains pollutants that could pose public health and environmental risks if not properly treated before reuse or disposal. Many qualitative greywater characterization studies have been conducted and several pollutants have been identified such as chemical oxygen demand (COD), biological oxygen demand (BOD), solids (total solids, volatile solids, total suspended solids, and volatile suspended solids), nitrogen, phosphorus, surfactants, heavy metals and even emerging contaminants that require the identification of appropriate treatment technology for the removal of these pollutants before direct potable reuse and in some cases before non-potable reuse (Eriksson & Donner 2009; Bakare *et al.* 2017; Noutsopoulos *et al.* 2017). There is a wide variation in the physicochemical characteristics reported by many of these studies, which could be attributed to the quality of the greywater generated from households, the greywater source (bath, laundry, or kitchen), household lifestyles and/or major activities taking place in the households considered for the studies. Thus the intensity and method of treatment will largely depend on the characteristics of the greywater.

The acceptance and attitude of the public towards the idea of reusing water which they believe is unsafe or unhealthy has been a major challenge for the success of any greywater reuse projects. However, some studies have revealed that public acceptance of greywater reuse for certain activities can be quite high. Several factors, which may include issues related to perceived risks, political issues and degree of human contact, have contributed to the lack of general public acceptance of greywater reuse projects (Po *et al.* 2005; Bakare *et al.* 2016). The willingness to reuse greywater for non-potable purposes that involve low human contact, such as toilet flushing and irrigation, has been found to be generally acceptable by individuals compared to the reuse of greywater for potable purposes with a high likelihood of human contact, such as swimming (Hurlimann & Dolnicar 2010; Dolnicar *et al.* 2011; Bakare *et al.* 2016). Thus it is of great importance that prior investigation into public acceptance be taken into consideration when undertaking any form of greywater reuse projects.

Various forms of greywater treatment technologies have been used and developed over the past decades. The selection of a typical technology for greywater treatment depends largely on a number of factors which may include, but are not limited to: greywater quality, human capacity and availability of financial resources, reuse application, specific guidelines and standard requirements of the country (Friedler *et al.* 2006; Pidou *et al.* 2007). Specific guidelines and standard requirements differ from country to country but they are used to govern and monitor the identified reuse purposes. In South Africa, the national legislation does not prohibit the reuse of greywater; however, its use must not contravene the National Health Act 61 (2003) by allowing greywater to create a nuisance, which is defined as fly/mosquito breeding, objectionable odours, the surface ponding of water and/or the entry of polluted water onto a neighbouring property.

The existing treatment technologies can be categorized into natural treatment processes, biological treatment processes, chemical treatment processes and physical treatment processes. According to Al-Zou'by *et al.* (2017), the treatment technologies for greywater that are currently preferred are the physical, biological and natural systems such as sand filtration, constructed wetlands and membrane bioreactors; however, certain chemical treatment technologies such as coagulation and adsorption have recently been shown to be effective for the treatment of low-moderate strength greywater by effectively removing suspended solids, organic materials and surfactants from greywater (Boyjoo *et al.* 2013; Al-Zou'by *et al.* 2017).

This paper mainly focuses on the performance of a horizontal roughing filtration system for the treatment of greywater generated from a peri-urban community in Durban, South Africa. Roughing filtration systems have been shown to be effective for the removal of suspended solids, turbidity, organic contaminants and pathogenic materials in wastewater (Galvis *et al.* 1998; Wegelin & Sommer 1998; Al-Bayati & Habeeb 2009). This has been ascribed to the ability of the filter media to physically retain or adsorb contaminants which could be enhanced by operating the filtration system at a low filtration rate. The roughing filtration systems are also preferred in certain applications because of their relatively low operation and maintenance costs as compared to other wastewater treatment technology (Clarke *et al.* 1996). Previous studies that have been conducted on the application of horizontal roughing filtration systems have largely focused on the use of synthetic greywater. In the current study, the performance of the horizontal roughing filtration system treating raw greywater generated from households is investigated.

MATERIALS AND METHODS

Greywater source

The overall aim of this study was to evaluate the performance of a horizontal roughing filter system for the treatment of greywater generated from a peri-urban community in Durban, South Africa. A mixture of greywater from the kitchen, laundry, and bathing were collected from 30 different households within the community for the entire duration of operation of the horizontal roughing filter system. On each occasion, over 500 L of greywater was collected and supplied to the horizontal roughing filter.

Experimental set-up and procedures

A pilot scale horizontal roughing filtration unit was designed and fabricated for this study. The horizontal roughing filtration system used in this study was designed in accordance with the design guidelines, principles and concepts as presented in Wegelin (1996) and Galvis *et al.* (1998). Table 1 summarizes the design guidelines, principles and concept and this was adopted for the fabrication of the horizontal roughing filtration system used for the present study.

The system was fabricated from polyethylene plastic and metal frames. The horizontal roughing filtration system comprises three compartments with a total length of 3 m and a depth of 1 m. Each compartment was partitioned using perforated PVC material which prevents the mixing of the gravel in different compartments and allows the greywater to trickle at minimum flow velocity across the entire length of the filtration system. The lengths of the compartments were 1.5, 1 and 0.5 m respectively. Each compartment was packed with washed gravels of different sizes. The gravel size in the first compartment was 12.2–15 mm, while the second compartment was packed with gravel sizes of 9.5–12.2 mm and the third compartment contained the finer gravel sizes of 6.7–8 mm. This arrangement was done so that the flow across the filter system followed the direction of decreasing filter media sizes and allowed for the operation of the filter in series.

The horizontal roughing filtration system was connected to a 1,000 L PVC tank via a pipe and pump. The feed tank was used to store greywater generated from the households before the operation of the filtration system. The flow of greywater from the storage tank into the horizontal roughing filtration system was kept constant under a variable head using a flow control device with a pre-calibrated valve. All

Table 1 | Summary of the design guidelines adopted for this study

Design parameter		Recommended literature value	Design parameter (Present study)
Gravel media	Compartment 1 (mm)	20–12[a]	15–12.2
	Compartment 2 (mm)	12–8[a]	12.2–9.5
	Compartment 3 (mm)	8–4[a]	8–6.7
Gravel type		(granite. quartz, local)[a]	Quartzite
Filter depth (m)		0.2–0.3[b]	0.3
Area of the filter (m^2)			1
Hydraulic velocity (m/hr)		0.3–1.5	0.3
Uniformity coefficient		<2[a]	
Filter length (m)	Compartment 1 (m)		1.5
	Compartment 2 (m)		1
	Compartment 3 (m)		0.5
Filter width (m)		1–2.3[a]	1
Filter material			Steel and PVC (internals)

[a]Wegelin (1996); [b]Galvis *et al.* (1998).

the materials used for the fabrication of the filtration system were selected considering aspects of availability, cost, ease of use and reliability. Figure 1 is a pictorial view of the horizontal roughing filtration system used in this study.

In order to explore the overall aim of this study, the pilot horizontal roughing filtration unit was operated for 12 weeks. Samples were collected for analysis twice a week and the sampling points were from the inlets and outlets of the horizontal roughing filtration unit. The sampling process was conducted in order to be able to ascertain the characteristics of the greywater prior to and after the treatment had occurred using the horizontal roughing filtration unit. The horizontal roughing filter was operated at a very low filtration rate of 0.3 m/hr because it had been largely documented from previous studies that filtration rate has a significant influence on the removal efficiency. High removal efficiency in horizontal roughing filtration units has been achieved at low filtration rates (Boller 1993). Analysis of the samples was carried out on the same day immediately after the sampling.

Analytical methods

The performance monitoring parameters that were considered in this study for the evaluation of the treatment efficiencies of the horizontal roughing filtration unit are turbidity, COD, conductivity, and total solids. *Standard Methods for the Examination of Water and Wastewater* according to American Public Health Association (2012) were adopted for the analysis of the selected performance monitoring parameters where possible.

Turbidity

The measurement of turbidity is a key parameter for water quality which depends on the presence of suspended insoluble particles in the water. Higher turbidity values are associated with bad water quality and its removal is often required for any reuse purposes. The turbidity of the influent and effluent greywater from the horizontal roughing filter was measured using a calibrated TB300 IR Orbeco Hellige turbidity meter.

Chemical oxygen demand

COD is the amount of oxygen required to oxidize the organic matter in the greywater sample by use of dichromate in an acid solution to convert it to carbon dioxide and water. Many organic substances can be oxidized chemically rather than biologically and as such the value of COD is always higher than that of BOD. COD is an indication of the polluting potential of the greywater sample. In order to determine the COD in this study, the open reflux procedure was followed according to *Standard Methods for the Examination of Water and Wastewater* (American Public Health Association 2012).

Conductivity

The conductivity of the influent and effluent greywater was measured immediately using a calibrated Orion Star A215 conductivity meter. The conductivity of the greywater is an indication of the quantities of the soluble salts present in the greywater. High conductivity is an indication of the presence of a high quantity of soluble salts in the greywater.

Total solids

Total solid is a measure of all the suspended, colloidal, and dissolved solids present in the greywater. The total solids present in the greywater were measured before and after

Figure 1 | Pictorial view of horizontal roughing filtration system (Mtsweni 2016).

treatment. The total solids were measured by evaporating the greywater sample to dryness in crucibles in an oven at 103–105 °C and weighing the residue. The weight of the residue is the total solids present in the greywater sample in mg/L. This can be an approximate indication of the amount of organic matter present in the greywater.

RESULTS AND DISCUSSION

The findings of the investigation conducted to evaluate the performance of the designed and fabricated laboratory scale horizontal roughing filtration system to reduce the physicochemical characteristics of greywater are discussed in this section. The investigation involved monitoring greywater physicochemical characteristics before and after treatment using the horizontal roughing filtration system over a period of 90 days.

Figure 2 presents the turbidity results. As shown, the influent greywater turbidity into the horizontal roughing filtration system over the 90 days of operation fluctuated considerably. High values of influent greywater turbidity in the range of 156–420 NTU were observed. The high value could be attributed to the fact that the influent greywater into the horizontal roughing filtration system was from a mixed source containing greywater from the kitchen, laundry and bath. However, after treatment, the effluent from the horizontal roughing filters showed a consistent reduction in turbidity when compared with the influent over the entire duration of 90 days in the range of 14–53 NTU. Statistical analysis conducted using a matched-pair *t*-test indicated that there was a significant reduction ($P < 0.05$) of the influent greywater when compared to the effluent from the horizontal roughing filtration system.

To access the performance of the horizontal roughing filtration system for turbidity reduction for the entire duration of the 90 days of operation, the quality of the greywater at the inlet of the horizontal roughing filter was compared to that of the outlet and was calculated in terms of percentage reduction. The horizontal roughing filtration system was consistent in the reduction of the greywater turbidity. The percentage turbidity reduction was found to be significantly high throughout the duration of the operation of the horizontal roughing filtration and was found to be within the range of 81–95% with an overall average turbidity percentage reduction of 90%.

The influent and effluent greywater COD results for the entire duration of the operation of the horizontal roughing filtration system are presented in Figure 3. The greywater collected from the household that was used for this study was high in COD, confirming the presence of high organic

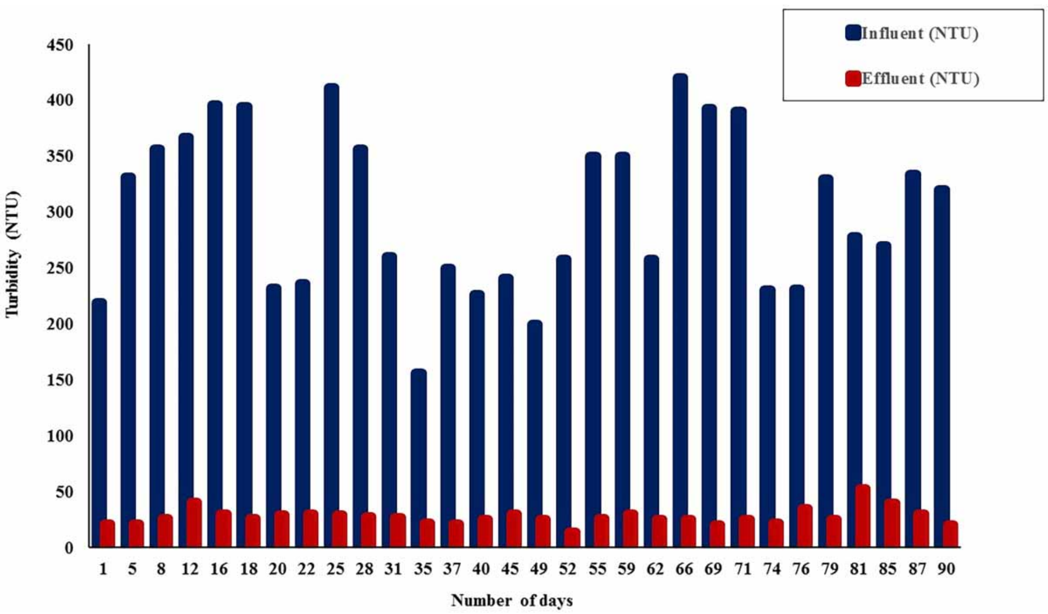

Figure 2 | Greywater influent and effluent turbidity over the 90 days of operation of the horizontal roughing filtration system at a constant filtration rate of 0.3 m/hr.

pollutants in the greywater. The COD ranged between 1,020–2,640 mg/L. Although the difference between the greywater COD before and after treatment was statistically significant using the matched-pair *t*-test ($P < 0.05$), the effluent COD obtained was still significantly high.

The effluent COD value for the entire duration of the operation of the horizontal roughing filter was between 304 and 806 mg/L. The horizontal roughing filtration system was also consistent in the reduction of the greywater COD. The COD percentage reduction was found to be significantly above 50% throughout the duration of the operation of the horizontal roughing filtration and was found to be within the range of 60–88% with an overall average COD percentage reduction of 70%.

Another parameter that was used to evaluate the performance of a horizontal roughing filtration system treating mixed greywater collected from a peri-urban community in Durban is conductivity. As shown in Figure 4, the conductivity of the influent greywater ranged between 1,055 and 2,591 μS/cm over the 90 days of operation of the horizontal roughing filtration system. After treatment, the effluent greywater conductivity from the horizontal roughing filtration system over the 90 days of operation showed a significant reduction ($P < 0.05$) compared to the influent greywater.

The effluent greywater conductivity ranged between 95 and 420 μS/cm. The conductivity percentage reduction was found to be significantly high throughout the duration of the operation of the horizontal roughing filtration and was found to be within the range of 76–94% with an overall average conductivity percentage reduction of 86%.

The total solids result also showed a significant reduction statistically ($P < 0.05$) when the influent greywater total solids was compared with that of the effluent using the matched-pair *t*-test as shown in Figure 5, and the influent greywater total solid ranged between 1,055 and 1,847 mg/L over the entire duration of the operation of the horizontal roughing filtration unit. The effluent greywater total solid ranged between 95 and 350 mg/L. The total solids percentage reduction was found to be significantly high throughout the duration of the operation of the horizontal roughing filtration and was found to be within the range of 74–91% with an overall average conductivity percentage reduction of 84%.

CONCLUSIONS

The purpose of this paper was to investigate the ability of a horizontal roughing filtration system for the treatment

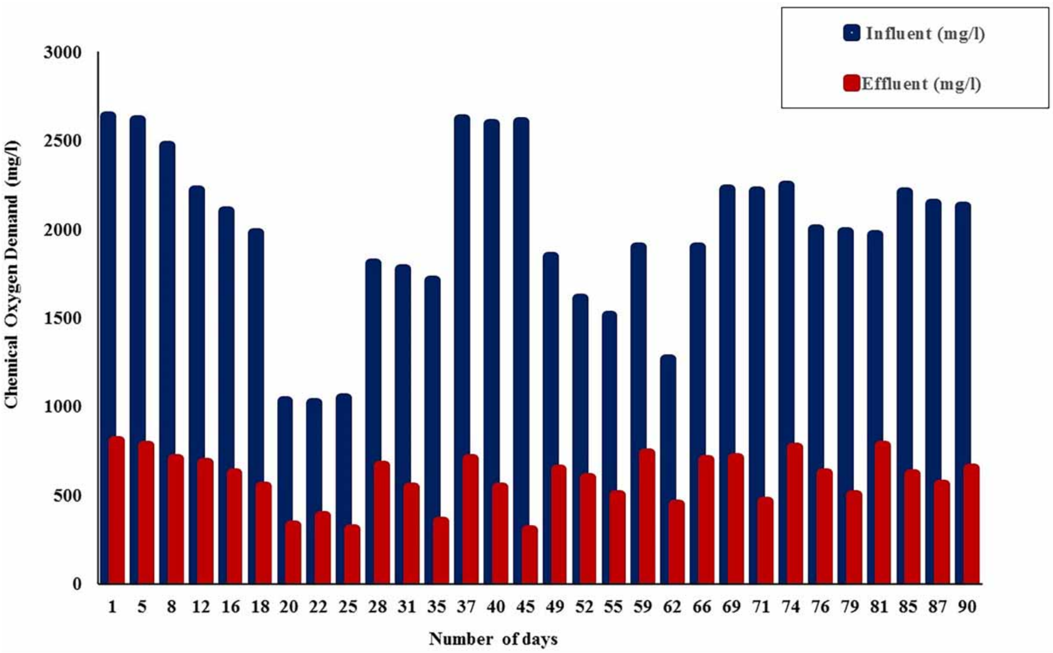

Figure 3 | Greywater influent and effluent COD over the 90 days of operation of the horizonal roughing filtration system at a constant filtration rate of 0.3 m/hr.

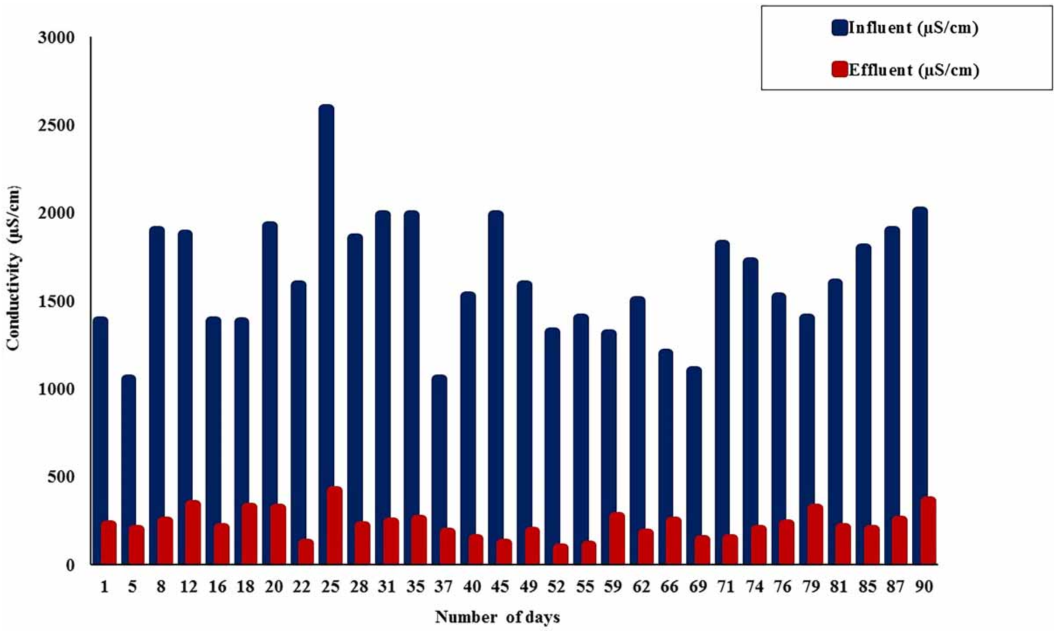

Figure 4 | Greywater influent and effluent conductivity over the 90 days of operation of the horizontal roughing filtration system at a constant filtration rate of 0.3 m/hr.

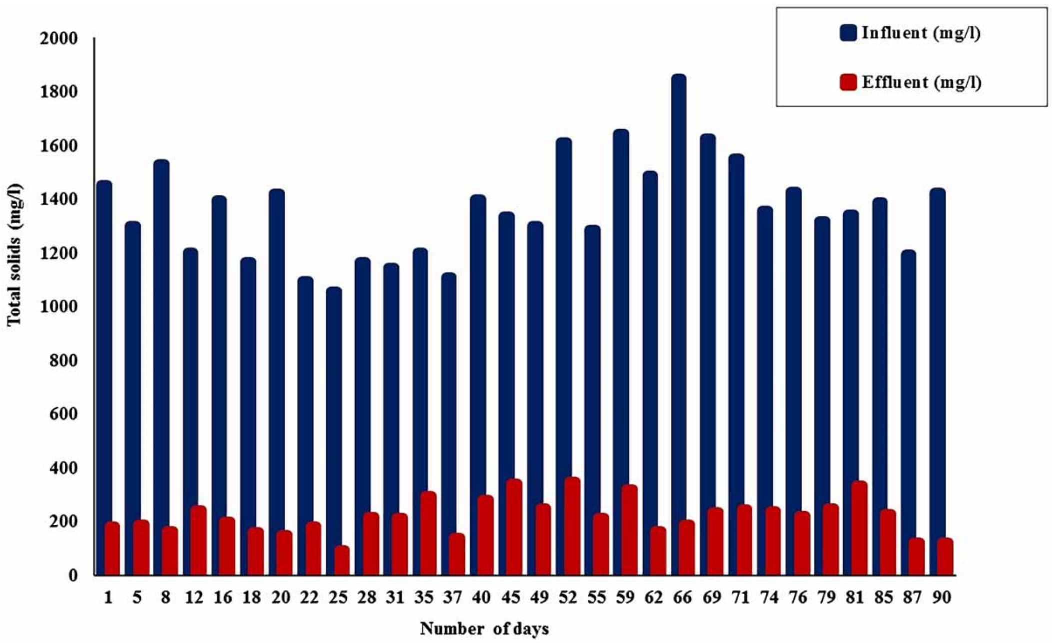

Figure 5 | Greywater influent and effluent total solids over the 90 days operation of the horizontal roughing filtration system at a constant filtration rate of 0.3 m/hr.

and/or reduction of physicochemical pollutant found in greywater. The investigation did not consider the microbial aspect of the performance of the horizontal roughing filtration system. The results obtained from this study showed consistent and significant reductions in all the parameters selected for the investigation when comparing the influent with the effluent quality of the greywater. All parameters investigated in this study had percentage reductions which were significantly greater than 50%. Percentage reduction on average of 90% turbidity, 70%

COD, 86% conductivity, and 84% total solids was obtained for the entire 90 days duration of operation of the horizontal roughing filtration systems. Thus, based on the findings of this study, the fabricated horizontal roughing filtration system can be considered as a viable option for the treatment of greywater for non-potable reuse applications, although further investigation needs to be conducted to evaluate the performance of the horizontal roughing filtration system for microbial removal during the treatment process. The fabricated horizontal roughing filtration unit used in this study is environmentally friendly with no chemical operation, is cost effective and a resourceful pilot plant that can adopted by peri-urban communities for the treatment of greywater for non-potable purposes such as landscaping, irrigations and toilet flushing.

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