Investigating the viability and performance of the Pilot Scale Fly Ash/Lime Filter Tower for Onsite Greywater Treatment.

S. Nondlazi, N.P. Ngqwala*, B. Zuma and R. Tandlich,

Environmental Health and Research Group, Division of Pharmaceutical Chemistry, Faculty of Pharmacy, Rhodes University, Grahamstown, 6140

*Corresponding author (E-mail: *n.ngqwala@ru.ac.za*)

Abstract

The re-use of greywater has the potential to reduce the demand for water supply caused by an increase in urbanisation, reduce energy demands and carbon footprint of water services, and more importantly reduce the demand for costly quality potable water for non-potable use. South Africa is a water scarce country. Other parts of the world are on the verge of water scarcity; therefore decentralised wastewater treatment systems are an attractive option in trying to mitigate the on-going water demand. The Fly Ash/Lime Filter Tower (FLFT) is an example of a decentralised wastewater treatment system, which treats domestic greywater. The system was investigated on its treatment efficiency for the removal of microbial and physico-chemical constituents of the greywater. The results were that phosphate, chloride, nitrate, ammonium, COD and faecal coliforms content of the greywater were efficiently removed by the FLFT tower with the average removal efficiency of 51%, 40%, 52%, 50%, 85% and 60% respectively and the tower was proved to reduce the microbial content of the greywater. The pH and turbidity of the treated greywater samples shows a tremendous decrease from an alkaline to a more neutral pH. The average pH, COD, Nitrate, Phosphate, Cloride and Ammonium of the treated greywater samples was obtained to be 7.1, 369.2, 36.3, 2.14, 7.8 and 2.0 mg/L which is within the guideline for greywater reuse which indicate that the acceptable pH of greywater intended for re-use in irrigation. The chemical concentrations of the effluent comply with greywater quality guidelines for small scale irrigation in South Africa issued by the Department of Water and Sanitation. The greywater effluent from the FLFT system was evaluated for reuse in irrigation and the technology is efficient and reliable.

Keywords

Greywater, Fly Ash, Water Hyacinth, Irrigation

INTRODUCTION

The increase in urbanisation and the constant growth in the population in many instances causes the rise in water demand, which has caused some areas to be classified as water scarce regions (Ruhiiga, 2014; Friedler and Hadari, 2005). This rise in water demands has led to the exploitation of other water sources for examples distant surface water and deeper groundwater and seawater desalination (Ilemobade *et al.,* 2011)., which may lead to the exhaustion of these water sources (Friedler and Hadari, 2005). The utilization of these water sources comes at high operational and maintenance costs therefore finding cheaper alternative water sources like the reuse of greywater for non-potable purposes will help in alleviating the demand for freshwater in these already stressed water sources (Ilemobade *et al.,* 2009). Globally, the reuse of water is supported because of its economic viability

(Ilemobade *et al.,* 2011). In countries such as the USA and Australia the reuse of greywater is an acceptable practise with the water reuse applications requiring little to no human contact, for example flushing and irrigation (Albalawneh and Chang, 2015; Sameer and Younus, 2015; Radcliffe, 2003). Using domestic greywater for irrigation has become increasingly common in developed and developing countries, and this has allowed countries to cope with water scarcity (Albalawneh and Chang, 2015). The government and water government gencies have developed regulations and guidelines for the reuse of domestic greywater for irrigation, however, there are still are issues related to human, soil and plant health risks and environmental pollution due to the reuse (Ukponng and Agunwamba, 2010). As a result, there are often community concerns towards the reuse of greywater for irrigation (Pinto *et al.,* 2010). These health risks include the spread of pathogenic organisms

Greywater reuse has a wide range of social and economic advantages (Carden, *et al*, 2007; Rodda *et al,* 2011) If greywater is to be appropriately handled, disposed of or reused, then its treatment is therefore essential to reduce the microbial and chemical concentrations, and reduce health risks and the consequences on the economy and society (Carden, *et al,* 2007). The re-use of greywater has the potential to reduce the demand for water supply, reduce energy demands and carbon footprint of water services, and more importantly reduce the demand for costlier high quality potable water for non-potable use (Rodda *et al.,* 2010). Africa is a water scarce country and also has limited freshwater sources (Ngqwala, 2015). Therefore, innovative approaches are required to conserve the quality of water in these already strained water sources by using alternative water sources e.g. greywater for non-potable water uses.

Decentralised systems

Onsite treatment of greywater using decentralised systems has become one of the important sector in water re-use. This particularly important in arid regions (Yu *et al.,* 2013; Maimon *et al.,* 2010). The use of greywater in such regions can therefore be used to mitigate the freshwater demand for non-portable uses in these areas. In areas where greywater reuse is vital, minimizing human exposure to pathogens (Shamabadi *et al.,* 2015), which are found in greywater, is of outmost importance that the greywater be treated before reuse (Yu *et al.,* 2013). A greywater treatment system consists of different treatment steps that may be considered (Maimon *et al.*, 2010) depending on the required quality of the effluent. Several treatment technologies are used in each step and the treatment of greywater involves removal of phosphorus, nitrogen, chemical oxygen demand (COD)/ biological oxygen demand (BOD) and some biological matter (Leal *et al,* 2007; Finch *et al.,* 2003). According to Morel and Diener (2006) different treatment processes such as disinfection and chemical removal can be combined sequentially to obtain the required effluent standards for reuse or disposal and these greywater treatment systems are reviewed based performance, operation and problems encountered with the system (Pinto *et al.,* 2007)

In countries like South Africa which are on the verge of water scarcity, decentralised systems are an attractive option in trying to alleviate the water demand. These systems are easy to operate by the local population and even in remote location (Ngqwala, 2015). Ahmed and Arora (2012) suggest that a more suitable water practice involves moving away from the incompetence of a single potable water supply for all uses some of which do not necessarily require high quality drinking water. Barton and Argue (2009) suggest that in order for such practises to be implemented then decentralization of system and better application of local treatment and storage measures need to be emphasized. Centralized wastewater systems usually have high operational and maintenance costs due to longer sewer networks and treatment plants; therefore, moving towards decentralised systems is a viable option (Barton and Argue, 2009). According (van Zyl *et al.,* 2007) the average water consumption of water is a South African household is 200 L per day. Decentralised wastewater treatment systems usually operate at a smaller scale which is the suitable for households, (Ahmed and Arora, 2012), especially if the water is intended for reuse, as the treated wastewater does not have to be stored which may create health risks. An example of such a decentralised system is the Fly Ash/Lime Filter Tower (FLFT), which was, developed form the Mulch Tower.

The Fly Ash/Lime Filter Tower (FLFT)

The Mulch Tower Treatment system (MTTS) developed by Zuma *et al*. (2009) is a biological greywater treatment system consisting of mulch, coarse sand, fine and coarse grave, and these materials serves to filter to remove suspended solids in the greywater and also allows the biodegradation of the filtrate by aerobic microorganisms (Zuma *et al.,* 2009). However, the system did not perform as anticipated. The system was unable to remove faecal coliforms and total microbial indicators, phosphates, chlorides, ammonia and sulphates. This led to the system being modified into the Flyash/Lime Filter Tower (FLFT), which is a cheap, easy to operate system designed to treat greywater. The system was developed for the sterilisation of greywater (elimination of indicator microorganism) and also the removal of phosphates, nitrates and other chemical constituents. The development of an on-site greywater treatment system like the FLFT which informal and rural settlements can use directly in schools, houses help in reducing the inappropriate disposal of greywater. This system consists of Fly Ash, Lime, sand, water hyacinth and gravel that are responsible for the treatment of biological and physiochemical components in the greywater (Zuma, 2012; Ngqwala *et al.*, 2015). Water hyacinth was incorporated into the system to buffer the pH of the system. Description of the system can be seen in Figure 1.

MATERIALS AND METHODS

The influent and effluent samples collected from the Flyash/Lime Filter Tower were analysed for concentrations of ammonium (NH_4^+), phosphate (PO_4^{3-}), nitrate (NO_3^-), chloride (Cl^-), chemical oxygen demand (COD) (test kit number: solution A; 1.14679.0495 and solution B; 1.14680.0495) which were purchased from Merck Millipore Ltd, South Africa. Faecal coliforms (FC). Turbidity (Tur), and pH of the samples were also determined. The membrane filters; Pall corporation GN-6 Metricel sterile, grid 0.45 µm 47 mm were purchased from from Spellbound Labs (Port Elizabeth, South Africa), the Hanna Comb pH meter from Sigma-Aldrich, South Africa) and the Lutron TU-2016 portable turbidity meter was purchased from Lutron Electronic Enterprise (Taipen, Taiwan). The m-FC agar and Nutrient agar were obtained from Biolab (Spellbound, South Africa). All incubations were done in the Labcon incubator Model FSIM B (Labmark, Johannesburg, South Africa), and the Labcon low temperature incubator LTIE 10 (Labmark, Johannesburg, South Africa). Sterile petri dishes (90 mm) and 40 ml urine jars were purchased from Spellbound Labs (Port Elizabeth, South Africa). All microbial enumerations were performed in a LabEair fume hood purchased from Vivid Air (Durban, South Africa). Absorbance was measured using Shimadzu UV-18 1240 spectrophotometer (Shimadzu, Johannesburg, South Africa). All other consumables were purchased from Sigma-Aldrich (Johannesburg, South Africa) and Spellbound (Port Elizabeth, South Africa).

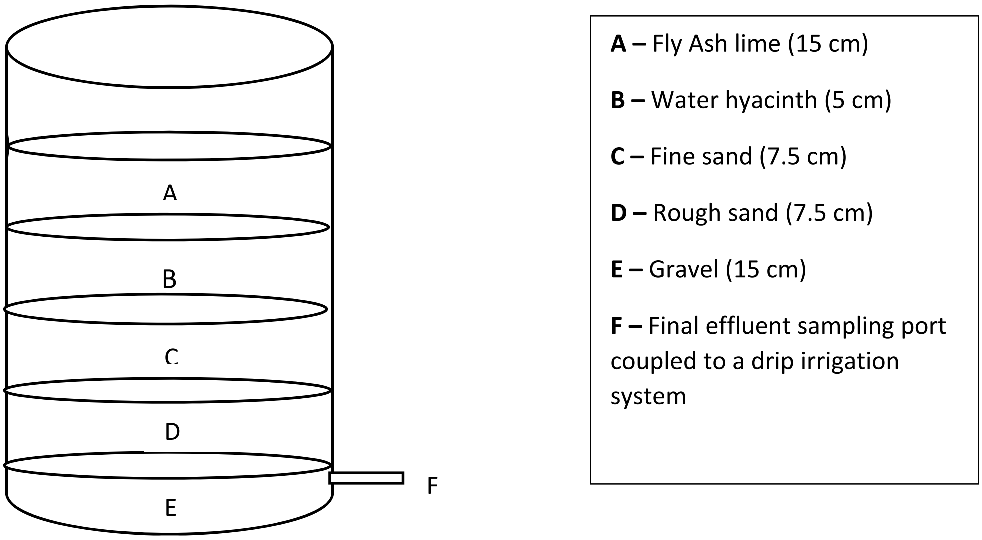

Image adapted from (Ngqwala , 2015)

Figure 1: A representation of the Fly Ash/Lime Filter Tower greywater treatment reactor

Sampling

The Fly Ash/Lime Filter Tower takes up to 30 L of water at a single time with the hydraulic retention time of 1 hour and 150 ml of the influent and effluent were collected in sterile sampling bottles (plastic sample bottles were sterilised using 70% ethanol) and the samples were analysed in triplicates for microbial and physico-chemical parameters. Soil samples were also collected and analysed for microbial constituents, bulk density, particle size density, loss on ignition, pH and Metal analysis.

Microbiological parameters*:*

Faecal coliforms (FC)***:*** Membrane filtration of the water samples was performed by allowing 100 ml of the sample to pass through sterile nylon membrane filters under vacuum filtration and the membranes were then enumerated onto MF-C agar and incubated at 44.5±0.2 °C for 24 hours. Faecal coliforms were enumerated as an indicator for faecal contamination

Total bacteria (TB) the method of Whittington-Jones (2011)*:* The enumeration of total coliforms was done by performing serial dilutions of the water samples using sterile physiological saline (10^{-1} - 10^{-5}) and 100 µl of each of the dilutions (10^{-0} - 10^{-5}) were spread plated onto Nutrient agar plates and incubated at 37±0.2 °C for 24 hours.

Physico-chemical parameters:

pH and Turbidity: The pH of the water samples was measured using the Hanna Comb pH and CE meter and the turbidity of the samples was measured using the Lutron TU-2016 portable turbidity meter.

Chemical Oxygen Demand: Chemical oxygen demand (COD) was measured using the closed-reflux colorimetric method (APHA, 1998). In COD tubes, 3 ml of the samples is mixed with 0.3 ml of COD solution A, then 2.85 ml of COD solution B was added and mixed gently. The tubes were placed in a preheated thermoreactor. The samples were allowed to digest at 148 °C for 120 min. Thereafter the samples were allowed to cool at room temperature for 10 min and the absorbance of the samples was read at 610 nm. Potassium Hydrogen Phthalate (KHP) was used as the standard to prepare solutions and the COD values were converted into KHP concentrations (mg KHP eq/L) where eq/L refers to equivalent per litre based on equation 1 and the wavelength was measured at 610 nm

$$KC_8H_5O_4 + 7.5\,O_2 \rightarrow KOH + 8CO_2 + 2H_2O \ldots \textit{(1)}$$

Nitrate test (US EPA Method 353.2): In concentrated sulphuric acid nitrates an ion reacts with benzoic acid derivatives and forms a red nitro compound which is determined spectrophotometrically. The method is analogous to DIN 38405 D9, equation 2

$$R{-}NH_2 + N0_2\,R \quad \rightarrow N_2 + R'{-}NH_2\,R \quad \rightarrow N{=}N{-}R'{-}NH_2\,(red) \ldots \textit{(2)}$$

Potassium nitrate was used in the construction of the calibration curve. The quantitative analysis of nitrates, a calibration curve at 540 nm was constructed between 2 and 20 mg/L with three replicates each measured.

*Phosphates test (US EPA Method 365.2)****:*** In sulphuric solution the orthophosphate ions react with the molybdate ions to form molybdophosphoric acid. Ascorbic acid reduces this to phosphomolybdenum blue (PMB) that is determined spectrophotometrically. The method is analogous to EPA 365.2+3, APHA 4500-P E, and DIN EN ISO 6878, equation 3

$$H_3PO_4 + 6(VI)\ 12(dark\ blue) + 9H^+ \cdots \textit{(3)}$$

Potassium orthophosphate was used in the construction of the calibration curve. Analysis of Phosphate-P, a calibration curve at 650 nm was constructed 11 between 1 and 10 mg/L with three replicates each measured to construct the calibration curve.

Ammonium test (US EPA Method 350.1): Ammonium nitrogen (NH4-N) occurs partly in the form of ammonium ions and partly as ammonia. A pH-dependent equilibrium exists between the two forms. In strongly alkaline solution ammonium nitrogen is present almost entirely as ammonium, which reacts with a chlorinating agent to form monochloramine. This in turn reacts with thymol to form a blue indophenol derivative that is determined photometrically. The method is analogous to EPA 350.1, APHA 4500-NH3 D, ISO 7150/1, and DIN 38406 E5, equation 4

$$NH_3 + OCl^- + 2C_6H_5OH\ OC_6H_8NC_6H_6O^-\ (blue) \ldots \textit{(4)}$$

Ammonium chloride was used in the construction of the calibration curve. A calibration curve at 660 nm wavelength, was constructed between 1 and 10 mg/L with three replicates each measure

Chlorides (US EPA 325.1): Chloride ions react with mercury(II) thiocyanate to form a slightly dissociated mercury (II) chloride. The thiocyanate released in the process in turn reacts with iron(II) irons to form a red iron (II) thiocyanate that is determined spectrophotometrically. This method is analogous to EPA 325.1 APHA 4500-Cl^- E. The chemical reaction ofchloride ions with the reagents is presented below; calcium chloride was used when preparing the calibration curve and the chemical reaction is presented in equation

$$(SCN)_2 + 2Cl^- \rightarrow HgCl_2 + 2SCN^- \rightarrow 3SCN^- + Fe^{3+} \rightarrow Fe(SCN)_3 \quad \text{... } (5)$$

The absorbance was read using the Shimadzu UV-18 1240 spectrophotometer

Soil analysis

Microbial analysis: The extraction of the bacterial colonies from the soil was achieved using sterile physiological saline. Extractions were achieved by mixing 1 g of soil with 100 ml of physiological saline, vortexting (MT19 Deluxe Vortex Mixer, Chiltern Scientific, Australia) performing the necessary serial dilutions and plating the fraction of bacteria, which are loosely attached to the soil particles and can be detached when the soil received the fly ash lime tower effluent.

pH - Measurement were done using the methods of Sikora and Kissel (2000). The standard methods for leaching protons form the soil using calcium chloride (0.01M $CaCl_2$) and 1M potassium chloride (KCl). The pH of the soil samples was measured using 0.01 M $CaCl_2$, 1M KCl and dH2O (at different ratios). Each of the samples was mixed with the solution at different volumes: 1:3 [sludge: water]; 1:6 [sludge: water]; 1: 3 [sludge: 0.1 M $CaCl_2$]; 1: 3 [sludge: 1 M KCl]. The samples were stirred vigorously at room temperature and the suspension was allowed to stand for 20 minutes and the pH of each sample was measured the Hanna Combo pH and CE meter.

Loss on ignition (LOI) - The soil samples were sieved through a 2 mm sieve and air-dried to and. The crucibles were dried in a drying oven at 105 °C for 24 hours and allowed to cool in a desiccator for 1 hour. About 5 g soil sample was placed in the porcelain crucible and dried at 105 °C for 24 hours and then ignited at 400°C in muffle furnace for 24 hours, with the resultant mass weighed to 4 decimal points on the Pioneer PA214 analytical balance. The LOI was be calculated using the following equation:

$$\text{Loss Of Ignition}(\%) = \left(\frac{\Delta m(g)/}{ms(g))}\right) x\ 100 \quad \text{... } (6)$$

Δm *(g* (Loss of mass after ignition) = Mass of soil dried at 105°C (m_s) – mass of soil ignited at 400°C (m_c)

m_s Mass of soil dried at 105°C

m_c Mass of soil ignited at 400°C

Bulk density - A 100 ml beaker was filled to the brim with soil and weighed to 4 decimal points, this was done at 25 °C. Then the contents of the beaker were decanted into an aluminium can (of which the weight was known). The aluminium can with lid was weighed out on the Pioneer PA214 analytical balance; recorded; and kept in the UFE 700 oven (Memmert, Schwabach, Germany) at 105 °C until a constant weight was achieved. The beaker was then filled to the brim with deionised water and weighed. Everything was recorded in a table. The bulk density was calculated using the formula,

$$\text{Bulk density} = \frac{mass\ of\ dry\ soil\ (g)}{volume\ of\ solids\ (cm^3)} \qquad \ldots\ (7)$$

Particle size density - Water was slowly added to the soil and mixed thoroughly and vigorously shaken until the flask is full and weighed out on the Pioneer PA214 analytical balance. The entire content was then descanted into a waste bucket and rinse flask. The flask was refilled weighed and the results will be recorded.

Metal analysis: Sample preparation – Heavy metals were extracted from sludge using 1 M HCl (Tuin and Tels, 1990). Five grams (5 g) of soil samples were weighed using Pioneer™ PA2102 analytical balance and transferred into 250 mL Erlenmeyer flasks. Using a 50 mL graduated measuring cylinder, 50 mL of 1 M HCl was transferred into each Erlenmeyer flask. The flasks were sealed with Parafilm™ and aluminium foil. The Erlenmeyer flasks each containing soil and 1 M HCl, were placed in the Mechanical orbital shaker and shaken at 150 rpm at 20 ºC for 24 h. The samples were left to stand for 15 min, after which the supernatant was pipetted into 5 mL glass vials. The heavy metal composition of samples was determined using inductively coupled plasma/optical emission spectrometry (ICP/OES) at Bemlab (Pty) Ltd, Cape Town, South Africa.

RESULTS AND DISCUSSION

According to Pinto *et al* (2010), water is becoming a scarce resource and to try and ensure a sustainable water supply and mitigate the water demand, alternative water supplies are required for non-potable uses. Greywater is considered a valuable resource for nutrients, which such nitrogen and phosphates, which are required for plant growth, which makes greywater suitable alternative water source for irrigation. When greywater is recycled, particularly for garden irrigation, considerable volumes of high quality water could be saved. The effluent collected from the FLFT was analysed for microbial and chemical constituents to investigate whether the effluent is within the water quality guidelines for the re-use of greywater for small-scale irrigation in South Africa provided by the Department of Water Affairs and Forestry (2010). Faecal coliforms are indicators of water contamination and according to Rodda *et al.* (2010).

The project was part of a civic engagement to address the community's urgent needs, such as food security and improvement of sanitation and aimed at the development of a socially responsive biotechnology and healthcare professional. In the establishment of the sites used in the project, existing contacts from NGO. These contacts were used based on their understanding of the community needs. All the sites had the tower system installed, and were offered a remuneration of $35 and offered the installation of a garden, which seedling of vegetables were provided. Informed consent was obtained verbally and it was obtained after the participants were clearly informed about project and the parameters to be investigated (Table 1) (Shahnazarian *et al* (2001)). According to Shahnazarian *et al* (2001) Research subjects must be informed fully about the purpose of the study, methods to be utilised and possible outcomes of the project. The 1964 Helsinki Declaration stipulated that valid consent is properly informed and also freely given without pressures such as coercion, threats or persuasion. The gardens that were installed were left in a good condition for the benefit of the participants.

The collection of the greywater samples was performed after a period of 4 weeks. This was to allow for the stabilisation of the systems. Faecal coliforms ranging from 65-100 CFU/ 100 ml were obtained in the effluent and 20-60 CFU/ 100 ml were obtained for the in the treated greywater which shows a removal efficiency of about 67.7%. These results obtained from the analysis of the effluent comply with the water quality guidelines for re-use of greywater for small irrigation issued by the Department of Water Affairs (Rodda *et al*, 2010).

It is stipulated that the acceptable faecal contamination should be 1 -1000 CFU/100 ml, this greywater should be used in restriction, because if it is used unrestricted then it causes an increase to human health, plants and soil. Since toilet water waste is not included in greywater, faecal contamination should be minimal, however some household activities such as washing contaminated laundry (i.e. diapers), and occasionally gastro-intestinal bacteria such as *Salmonella* and *Campylobacters* may be introduced due to food handling in the kitchen hence these factors may influence in the faecal contamination of greywater (Ottoson, 2003). Therefore, the faecal contamination in the treated greywater could attributed to the quality of water that the user subjects to the tower, because some bacterial communities are persistent, and therefore are left untreated which will end in the effluent.

There is a significant decrease in the microbial and chemical constituents (Table 1) of the treated greywater rendering the water suitable for re-use. Based on the analysis of the sample collected from the system, the FLFT has shown to be relatively efficient, producing effluent of good quality when related to the guidelines for small- scale irrigation. The FLFT system has an average COD removal efficiency (Figure 2) of about 85%, which is relatively high when compared to the removal efficiency of the other components.

Table 1: The physico-chemical components of the greywater before and after treatment with the FLFT.

Chemical components	**Fingo**		**Extension 1**		**Extension 9**		**Town 1**		**Town 2**	
	Influent	***Effluent***	***Influent***	***Effluent***	***Influent***	***Effluent***	***Influent***	***Effluent***	***Influent***	***Effluent***
pH	8.92 ± 0.5	6.87 ± 0.5	7.63 ± 0.7	6.91 ± 0.5	7.22 ± 0.6	7.19 ± 0.5	7.23 ± 0.6	6.94 ± 0.5	9.44 ± 0.9	7.47 ± 0.5
Turbidity	748 ± 213.4	430 ± 411.1	691 ± 98.8	368 ± 97.3	1032 ± 55.5	598 ± 276.9	986 ± 282.6	26.2 ± 6.5	334 ± 258.2	29.1 ± 10.7
COD (mg/l)	2116.2 ±1018.1	392.2 ±23.0	2994.5± 653.3	411.7 ±69.5	2978.3 ±1295.2	376.5 ±96.4	1509.7 ±260.9	291.3 ±95.1	3046±1083.7	351.5±91.3
NO_3^- (mg/l)	96.54 ± 87.9	45.58 ± 21.9	71.61 ± 50.8	24.43 ± 17.4	78.95 ± 7.4	44.84± 10.8	35.10 ± 10.7	23.40 ± 8.4	55.43 ± 5.2	17.98 ±8.1
PO_4^- (mg/l)	1.87 ± 0.6	0.78 ± 0.7	8.08 ± 3.2	2.14 ± 1.8	3.71 ± 2.2	2.45 ± 1.9	1.60 ± 0.6	0.88 ± 0.2	1.47 ± 0.7	0.58 ± 0.4
NH_4^+ (mg/l)	3.25 ± 1.9	1.73 ± 1.4	6.93 ± 3.1	3.392 ± 2.6	2.55 ± 1.8	1.30 ± 1.8	2.95 ± 1.7	1.53 ± 1.6	4.70 ± 1.6	2.18 ± 1.6
Cl^- (mg/l)	7.80 ± 3.1	4.43 ± 2.0	15.15 ± 6.3	7.9 ± 3.1	6.0 ± 3.1	3.86 ± 1.9	3.31 ± 1.7	1.9 ± 0.8	5.63 ± 3.2	3.84 ± 2.2
Aerobic (CFU/ml) 10^{-5}	2x10^{7}±8.7x10^{6}	2.5x10^{6}±8.4x10^{5}	2x10^{7}±5.9x10^{6}	3.8x10^{6}±1.73x10^{6}	5.2x10^{7}±2.3x10^{6}	4.1x10^{7}±1.5x10^{7}	3.0x10^{7}±1.4x10^{7}	3.8x10^{6}±8.1x10^{6}	2.9x10^{7}±1.7x10^{7}	2.0x10^{7}±8.9x10^{6}
Anaerobic (CFU/ml)	1.9x10^{7}±8.1x10^{6}	2.3x10^{7}±6.1x10^{6}	2.9x10^{6}±1.7x10^{6}	1.1x10^{7}±8.9x10^{6}	3.3x10^{6}±8.8x10^{7}	1.2x10^{7}±5.2x10^{6}	1.6x10^{7}±3.0x10^{7}	1.9x10^{7}±5.4x10^{6}	1.9x10^{7}±5.4x10^{6}	2.1x10^{7}±5.9x10^{6}

Efficiency of treatment was assessed by calculating the percentage of removal for each parameter as defined in equation 8. The percentage (%) removal efficiency was calculated as follows:

$$\text{Removal efficiency (\%)} = \frac{[influent] - [effluent]}{[influent]} \times 100 \qquad \ldots(8)$$

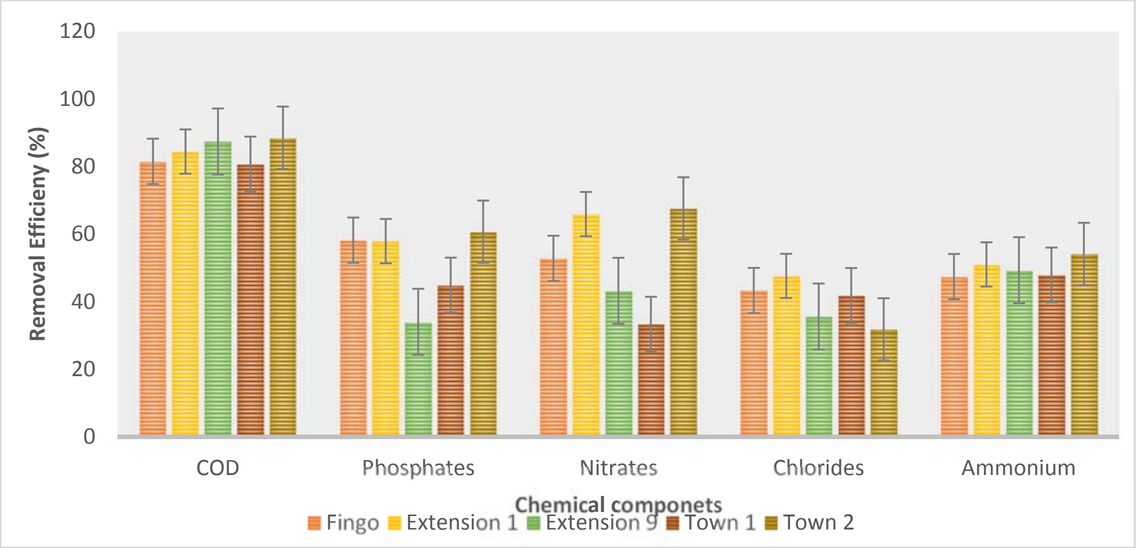

Figure 2: Percentage removal of the chemical content of the greywater after treatment with the Fly Ash/Lime Filter Tower treatment system to check the efficiency of the system with respect

The tower shows to decrease the chemical and microbial constituents of the greywater rendering it suitable for reuse. Based on the analysis of greywater samples that have been collected so far from the system, its removal efficiency on average for COD, Phosphates, Nitrates, Chlorides and Ammonia are 85±3%; 51±11%; 53±15%; 40±6% and 50±3% respectively (Figure 1). However, for the FLFT system in the Fingo site, its removal efficiency for Ammonia was 82.5% and 66.87 for Phosphate and 60.6% removal efficiency for COD. This is a significant improvement when compared to the Mulch Tower from which the FLFT tower developed from (Tandlich *et al.,* 2009; Zuma *et al,* 2009) where the removal efficiency for the chemical and microbial constituents for the Mulch tower was obtained to be 70%, 30%, 61%, 24% and 41% for COD, Phosphates, Nitrates, Ammonium Chlorides (Zuma *et al.,* 2009)

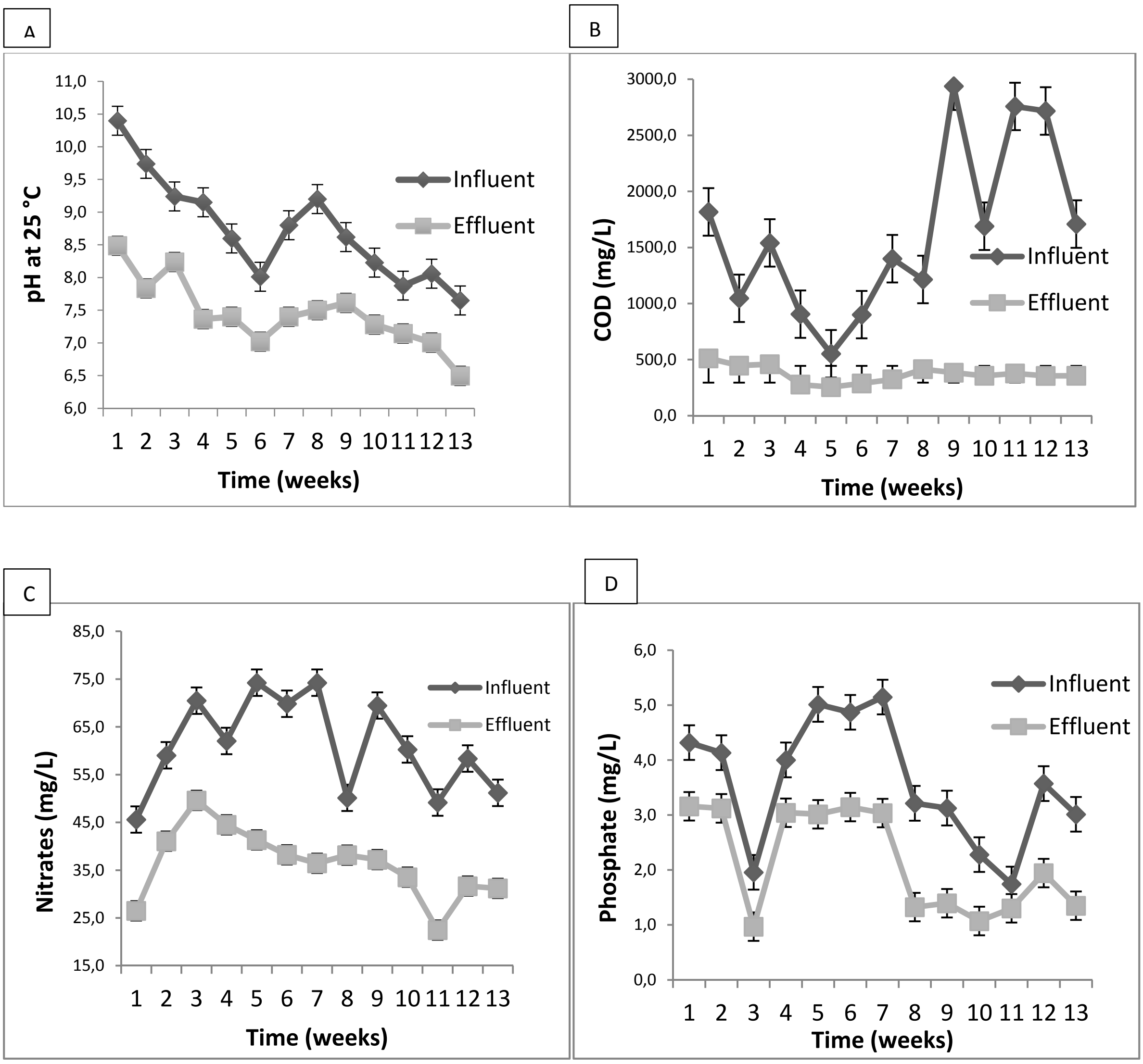

Figure 3 (A-D): pH and chemical constituents of the greywater samples (influent and effluent) over a period time

Table 2: Statistical significance of the different parameters at the tabulated 5% level of significance (average *p*-values for all the systems for the respective parameters)

Parameter	***Statistical Analysis p = 0.05***
	***p*- value**
COD	0.0000039
Nitrates	0.005452
Phosphate	0.000097
Chloride	0.005452
Ammonium	0.000097
pH	0.01243
Turbidity	0.01219
Faecal Coliforms	0.01193
Aerobic Bacteria	0.01218
Anaerobic Bacteria	0.01219

Soil pH is known to have a substantial effect on the activities of microbial communities and the biochemical processes which they mediate (Nicol *et al.,* 2008). Soil pH will affect the chemical form, concentration and availability of substrates (Kemmitt *et al.,* 2006) and will influence cell growth and activity. There is also strong evidence that soil pH is an important determinant of bacterial diversity and community structure on a global scale (Fierer and Jackson, 2006). The pH of the effluent will affect the soil pH, which will ultimately affect the fertility of the soil.

The filter tower shows a significant reduction in the chemical constituents, pH (Figure 3) and turbidity The decrease in the pH is caused due to the water hyacinth incorporated into the tower, the flyash/lime combination increases the pH and this is for sterilization purposes as this is component of the tower that does the most treatment and therefore to the water hyacinth stabilizes the pH decrease from alkaline to a pH closer to neutral pH.

The aim of the study was to establish the extent to which the FLFT could reduce the values of measured parameters. Statistically significant differences, mentioned below, refer to cases when the *p*-value for a particular case was equal to or smaller than the particular level of significance.

A statistically significant removal of the chemical and microbial constituents in Figure 3 shows the parameters pH, nitrates, phosphates and COD as a function of time, showing the removal of efficiency of the FLFT. Paleontological Statistics software for education (PAST) version 2.17c (Hammer, *et. al.*, 2013), Mann-Whitney statistical analysis was used to conduct the statistical analysis of the data, where the influent was measured against the effluent for each of the sites (Table 2). The filter tower shows a significant difference in the concentration of ammonium, nitrates, phosphates, COD, chlorides, faecal coliforms in the influent with respect to the effluent. On week 10, concentrations of nitrate, COD, Chlorides were obtained to be 60.3±5. 58 mg/l, 1688.9±43.02 mg/l, 9.85±6.8 mg/l respectively while the concentrations of the effluent were obtained to be 33.52±10.94 mg/l, 355.63±49.13 mg/l and 1.01±0.081 mg/l and a statistically significant removal efficiency of the constituents was observed. This resulted on the removal efficiency of 40%, 78.9%; and 89.1% of nitrates, COD and chloride respectively. A statistically significant removal for pH, turbidity and faecal coliforms and total bacteria was observed throughout the duration of the 13 weeks (sampling and analysis). The results show that at all the p-values were below the 5% level of significance, which shows an effective removal of all the parameters analysed.

Table 3: Soil analysis of the initial samples (untreated) and treated samples (irrigated with greywater treated using the FLFT system over a period of time

	Fingo		***Extension 1***		***Extension 9***		***Town 1***		***Town 2***	
	Initial	***After***	***Initial***	***After***	***Initial***	***After***	***Initial***	***After***	***Initial***	***After***
pH	6.50±0.3	7.53±0.16	5.76±0.02	7.16±0.14	7.16±0.03	7.15±0.08	6.60±0.04	7.38±0.14	6.13±0.02	7.31±0.20
Bulk density (g/cm^3)	0.79±0.01	0.81±0.12	0.84±0.01	1.02±0.08	0.11±0.02	0.64±0.02	0.15±0.002	0.75±0.02	0.116±0.004	0.89±0.03
Particle size density(g/cm^3)	2.10±0.1	2.11±0.03	2.2±0.2	2.00±.0.02	2.35±0.2	2.05±0.01	2.48±0.02	2.23±0.06	2.31±0.1	2.27±0.06
Loss on ignition (%)	10.81±0.02	13.95±1.32	11.33±0.03	13.27±1.68	11.03±0.01	15.84±1.2	13.05±0.04	14.52±3.79	13.89±0.02	15.33±1.19

Table 4: Metal analysis of soil after irrigation with greywater from the Fly Ash/Lime Filter Tower

	Metal Concentration *(mg/l)*							
Sites	***Mn***	***Cu***	***Pb***	***Cd***	***Mg***	***K***	***Al***	***Fe***
Fingo	8.4	0.63	3.22	0.0	75.18	45.34	142.70	133.90
Ext 1	20.60	0.73	2.10	0.0	31.38	25.18	139.52	182.80
Ext 9	32.30	1.12	2.29	0.0	41.48	71.00	149.02	222.24
Town 1	18.59	0.41	0.40	0.0	34.20	31.29	168.15	207.00
Town 2	18.69	0.42	0.0	0.0	82.99	23.02	134.20	174.22

Soil microorganisms help in the decomposition of organic matter which has an immense influence on soil fertility, plant growth, soil structure, and carbon storage. They play a role in nitrification (aerobes) and denitrification (anaerobes), and nitrogen fixation (Le Roux *et al.,* 2013). Faecal and total coliforms of the soil were analysed and according to Travis et al. (2010) faecal coliforms are measured as a surrogate for pathogen persistence in soil. The soil was analysed for faecal coliforms present in the samples before and after treatment as they were calculated to be on average 550 ±332 CFU/100 ml. According to (Chaudhari *et a.l,* 2013) bulk density is an indicator of soil compaction and soil health. Typically, bulk density increases with soil depth since subsurface layers are more compacted and less organic matter

Sharvelle *et al* (2012) investigated the effects of irrigation with greywater on a long term bases on landscapes. It was observed that over a long period there was an accumulation of salts in the soil, which then poses a risk of leaching down to the water table. Travis et al (2010) discovered that the pH of the soil irrigated with greywater was significantly low over that of the soils irrigated with potable water. Traveis *et al* (2010) and Sharvelle (2012) hypothesised that this is due to the microbial community in the soil and the enhanced bacterial activities such as respiration. Al-Hamaiedeh and Bino (2010) suggest that gardens that are often irrigated with greywater should be periodically watered with tap water to prevent the build-up of harmful substance that could be introduced with prolonged greywater use.

According to Wuana and Okieimen (2011) Copper and Zinc are two essential elements for plants, microorganisms, animals, and humans. Kootbodien *et al.* (2012) suggest that the connection between soil and water contamination and metal uptake by plants is determined by many chemical and physical soil factors as well as the physiological properties of the crops. Soils contaminated with trace metals may pose both direct and indirect threats: direct, through negative effects of metals on crop growth and yield, and indirect, by entering the human food chain with a potentially negative impact on human health (Kootbodien *et al*., 2012; Mthunzi *et al.,* 2015). Different countries have different guidelines when it comes to heavy metal contamination in soil (Mthunzi *et al.,* 2015). The average Cu was calculated to be 0.662±0.290 mg/l and the concentration of Pb was obtained to be 1.602±1.36 mg/L with the limit od detection (LOD) OF 0.001 mg/l (Table 3).

CONCLUSION

The nutrients found in greywater such as nitrogen and phosphorous are capable of supplementing the nutrients required for plant growth, which makes greywater a suitable alternative water source for irrigation. The tower shows to decrease the chemical and microbial constituents of the greywater when compared to the Mulch tower rendering it suitable for reuse. The greywater effluent from the FLFT system was evaluated for reuse in irrigation and the technology is efficient and reliable. The overall performance of the Fly Ash/Lime Filter Tower was efficient, producing an effluent comply with greywater quality guidelines for small scale irrigation in South Africa issued by the Department of Water and Sanitation

REFERENCES

Carden K., Armitage N., Winter K., Sichone O. and Rivett U. (2007). Understanding the use and disposal of greywater in the South Africa.Water Research Commission Report No. 1524/1/07. Pretoria, RSA.

Casanova, L.M; Gerba, C.P; and Karpiscak, M. (2001), Chemical and microbial characterization of Harrow, D.I; Felker, J.M; and Baker, K.H (2011) Impacts of Triclosan in Greywater on Soil household greywater, and *Journal of Environmental Science and Health Part A*, 36 (4): 395–40

Chaudhari, P.R; Ahire, D.V; Ahire, V.D; Chkravarty, M and Maity, S (2013), Soil bulk density as related to soil texture, organic matter content and availale total nutrient of Coimbatore soil, *Internationa Journal of Scientific and Research Publications,* 3(2), 1-8

Friedler, E and Hadari (2005), Economic feasibility of on-site greywater reuse in multi-storey buildings, *Desalination,* 190: 221-254

Fierer, N., and Jackson, R.B. (2006) The diversity and bio-geography of soil bacterial communities. Proc Natl AcadSci USA 103: 626–631

Illemodabe, A.A; Olanrewuje, O.O and Griffioen, M.L (2013), Greywater reuse for flushing at university academic and residential building, *Water SA,* 39(3): 351-360

IlemobadeA.A., AdewumiJ.R. and van ZylJ.E. (2009).Assessment of the feasibility of using a dual water reticulation system in South Africa.Water Research Commission, Report No1701/1/09. Pretoria, RSA.

Kasak, K; Karabelnik, K; Kõiv, M; Jenssen, P.D and Mander, Ü (2011), Phosphorous removal from greywater in an experimental hybrid compact filter system, *WIT Transaction on Ecology and the Environment,* 145: 649-657

Kemmitt, S.J., Wright, D., Goulding, K.W.T., and Jones, D.L.(2006) pH regulation of carbon and nitrogen dynamics intwo agricultural soils. *Soil Biol Biochem*, 38: 898–911.

Kootbodein, T; Mathee, A; Naicker N and Moodley (2012), Heavy metal contamination in school begetable garden in Johannesburg, *The South African Medical Journal,* 102(4): 214-220

Morel, A. and Diener, S. (2006). Greywater Management in Low and Middle-Income Countries, Review of different treatment systems for households or neighbourhoods. Swiss Federal Institute of Aquatic Science and Technology (Eawag). Dübendorf, Switzerland

Mthunzi, F.M, Dikio, E.D and Moja, S.J (2015) Evaluation of heavy metal pollution on soil in Vaderbijlparl, South Africa, *International Journal of Environmental Monitoring and Analysis,* 3(2): 44-49

Nicol, G.W; Leininger, S; Schleper, C and Posser, J.I (2008) The influence of soil pH on diversity, abundance and transcriptional activity of ammonia oxidizing archaea and bacteria, *Environmental Microbiology,* 10(11): 2966-2978

Ngqwala, N. (2015), Modification and application of the decentralised wastewater treatment technology for greywater treatment to reduce water needs,(PhD thesis), Rhodes University

Pinto U., Maheshwari B. (2010) Reuse of greywater for irrigation around homes in Australia: Understanding community views, issues and practices. *Urban Water Journal*. 7 (2), 141–153.

Prathapar S.A., Jamrah A., Ahmed M., Al Adawi S., Al Sidairi S. and Al Harassi A. (2005). Overcoming constraints in treated greywater reuse in Oman. *Desalination* 186 (1-3): 177 – 186.

Pinto U., Maheshwari B. (2007). Issues and Challenges of Greywater Reuse for Irrigation in Australia—A Case Study of Western Sydney Region; University of Western Sydney: Sydney, Australia.

Rodda, N.; Carden, K.; and Armitage, N. (2010) Sustainable Use of Greywater in Small-scale Agriculture and Gardens in South Africa, Guidance Report, *Water Research Commission,* report TT 496/10

Rodda, N.; Carden, K.; and Armitage, N and du Plessis, H.M, (2011), Development of guidance for sustainable irrigation use og grewater in gardens and small scale agriculture in South Africa, *Water SA,* 37(5); 727-737

Tandlich, R; Zuma, B.M; Whittinhton-Jones, K.J and Burgess, J, (2009), Mulch Tower treatment system Part II: Destructive testing and effluent treatment, *Desalination,* 242: 57-69

Ukpong, E. C ad Agunwamba, J. C (2010), Greywater Re-use for Irrigation, *Interbation Journal of Applied Science and Tehnology,* 2(8): 97-113

Whittington-Jones, K; Tanldich, R, Zuma, B.M; Hoossein, S and Villet, M.H (20110 Performance of the pilot-scale Mulch tower system in treatment og greywater from a low-cost housing development in the Buffalo City, South Afrcia, 1(2): 165-181

Wuana, R.A and Okieinmen (2011), Heavy metal in contaminated soil: A review of Sources, Chemistry, Risks and best available Strategies for remediation, *International Scholarly Research Network Ecology*, 2011: 1-20

Yu, Z.L.T., Rahardianto, A., DeShazo, J.R., Stenstrom, M.K. and Cohen, Y. (2013a) Critical Review: Regulatory Incentives and Impediments for Onsite Graywater Reuse in the United States. Journal of Water and Environment Research 85(7), 650-662

Zuma. B.M; Tandlich, R; Whittinhton-Jones, K.J and Burgess, J (2009), Mulch Tower treatment system Part 1: Overall performance in greywater treatment, *Desalination,* 242: 38-56