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Investigating the viability and performance of the pilot scale fly ash/lime filter tower for onsite greywater treatment

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ABSTRACT

The pilot-scale modified fly ash/lime filter tower (FLFT) was tested for treatment of greywater for reuse in irrigation of gardens in five households in Makana Local Municipality, South Africa. The greywater treatment efficiencies for chemical and microbial indicators stabilised after an initial period of 4 weeks. Then the FLFTs were able to remove 62% of the faecal coliform concentrations in the influent and between 20% and 97% of the influent turbidity values. Results of reuse of the FLFT-treated greywater for irrigation in subsistence agriculture indicates that a chlorinator and a drip filter should be installed at the outflow from the FLFT. The mean removal efficiency for the total aerobic bacteria varied between 21% and 88%. Release of anaerobic bacteria from the FLFTs was recorded at all sampling sites, with the particular average values ranging from 11% to 266%. Irrigation with FLFT effluent resulted in slight increase in the soil pH and loss on ignition, no change or slight decrease in the soil particle density. Bulk density of the soil increased or remained constant as a result of irrigation with FLFT effluent. The microbial indicators of soil were not affected by the irrigation with FLFT effluent. Fate of cadmium and aluminium in the FLFT effluent-irrigated soil and plants grown in this study will have to be examined in more detail. The FLFT should be inoculated with denitrification bacteria and its operation must be further investigated for the optimisation of the nitrate removal.

Keywords: Greywater; Fly ash; Water hyacinth; Decentralised systems

1. Introduction

Water scarcity occurs in a country or region if the renewable/available water volume per capita per year drops below 1,000 m^3 [1]. Increase in urbanisation and population growth has contributed to the increased water demand, which in turn can deepen the water scarcity of a region/country [2]. Parts of the Southern African subcontinent are water-scarce and have experienced increased urbanisation and increased population growth in recent years. Impact of these two factors on water demand and water scarcity in parts of the region can be illustrated on the example of South Africa. The country's population growth rate has increased from 1.192% per annum in 2002 to 1.616% per annum in 2014 [3]. In 2002, 57.898% of the total population of South Africa resided in urban areas, while this figure increased to 64.298% in 2014 [4]. During the same time period, the total volumes of extracted water resources in South Africa increased from 1.279×10^{10} to 1.550×10^{10} m^3/annum [5]. The renewable and available water volume per capita per annum was equal to 976.982 m^3 in 2002 and dropped to 827.381 m^3 in 2014 [6].

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Since the 1980's, all South African governments have put in place policies and programmes to increase the sustainability of water supply to the population, industry and agriculture. Particular examples include the Lesotho Highlands Water Project [7], initiatives related to implementation of rainwater harvesting systems [8] and desalination [9]. All of these initiatives have contributed to the mobilisation of additional freshwater resources for South Africa and have led to significant improvements in the (drinking) water supply across the country. However, practical challenges remain. First type of challenge involves the need to plan and negotiate transnational agreements and the related projects that can run into delays [10]. Next type of challenge is that the intensity of rainfall and volumes of potable water produced from rainwater harvesting can decrease due to the climate change–related phenomena, such as the 2015 El Niňo drought [11,12]. With desalination, careful management of the operational costs of desalination plants is required [9]. These challenges are not insurmountable, but implementation of additional strategies to deal with water scarcity in South Africa should be encouraged.

One additional strategy to decrease the volumes of freshwater/potable water needed in South Africa is to put in place onsite wastewater reuse programmes. If this is done close to the source of wastewater production, then the demand for potable water can be decreased by recycling the treated wastewater in activities such as toilet flushing and irrigation of ornamental gardens. One practical example is the reuse of greywater, which is domestic wastewater without any inputs from toilets [13]. The greywater reuse strategies and programmes have been implemented in developed countries such as USA and Australia [14]. They have been tested [15] and/or implemented practically in developing countries such as South Africa [16]. Potential of greywater reuse in decreasing the volumes of potable water that are necessary at the local level can be illustrated with the following calculations.

The study site in the current article was Makana Local Municipality in the Eastern Cape Province of South Africa. Monthly volumes of drinking water which is supplied by the municipality and that is used by a household of three was monitored and averaged over a 3-month period. Monitoring consisted as following water consumption via municipal statements at the home of the fourth author during the preparation of this article. The resulting point estimates show that a family of three used on average between 144.4 and 233.3 L/cap/d for domestic uses (75% of the total volume) and watering of an ornamental garden (25% of the total volume). Therefore between 108.3 and 175.0 L/cap/d was used for domestic uses.

The overall literature estimate of the percentage of the daily drinking water volumes used by a household for domestic uses that is converted into greywater vary, but a good estimate is in the range of about 60%–70% [13,17]. This excluded the irrigation of ornamental gardens with potable water in the authors' understanding. Taking these figures into account, the daily production of greywater in a Makana household of three can be expected to range from 65.0 to 105.0 L/cap/d. If 50% of the produced greywater was reused, then said household of three members could decrease their potable water consumption for domestic uses by between 13.9% and 36.4% per capita per day. If the entire volume of greywater was to be reused onsite, then the same household could decrease their domestic use of municipal potable water by between 27.8% and 72.7% per capita per day. This point estimate is not representative of the production of greywater in the entire Makana Local Municipality, but the numbers indicate tremendous potential for greywater reuse in improving water security of the Makana Municipality's population at the household level.

Implementation of greywater reuse strategies has become even more urgent as South Africa has been plagued by a drought since 2015, and Makana Local Municipality has recently been declared a water disaster area [18]. However, automatic implementation of greywater reuse projects is not possible, as the greywater management and reuse carry certain risks. If untreated greywater is used in irrigation, then this can lead to the degradation in soil conditions onsite [19]. On the other hand, greywater contains faecal contamination as indicated by the finite concentrations of faecal coliforms (FCs) in it [13,15,17,20]. Thus if greywater is reused without treatment, then this practice can negatively impact on the public health, for example, through triggering an outbreak of an infectious disease in the community where reuse takes place and the community members come into contact with untreated greywater [21].

As a result, treatment of greywater is required before reuse to comply with regulatory guidelines [22]. This can become a challenge in South Africa where many urban areas are un-sewered as suggested by Carden et al. [21]. Therefore greywater treatment in South Africa can be expected to take place in settings where reticulation and collection of sanitation wastes such as greywater do not exist. Under these field conditions, the decentralised treatment systems can be used for greywater treatment at the site of production. An example of such a decentralised system is the modified fly ash/lime filter tower (FLFT) and its schematic representation is shown in Fig. 1. The system was developed at Rhodes University in South Africa based on previously designed international systems as a starting point [13,15,22,23].

The fly ash–lime layer is mixed in a ratio of 5:3 and the layer provides the following function in the FLFT: precipitation of phosphorus, removal of COD through straining and sorption and sterilisation of greywater by the increased pH in the layer. The water hyacinth layer decreases the highly alkaline pH of the greywater to neutral values after it has passed through the fly ash–lime layer. Sand layers and

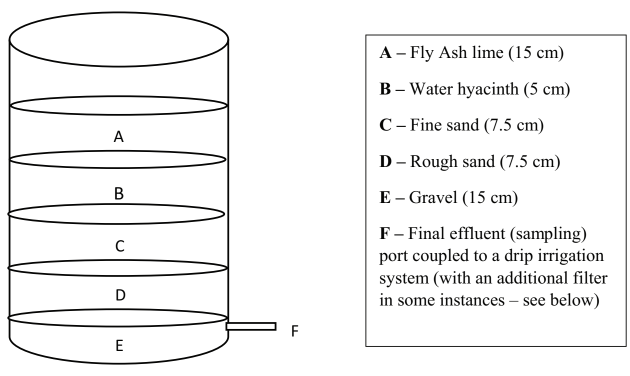

Fig. 1. A representation of the fly ash/lime filter tower greywater treatment reactor (adapted from Ngqwala [24]).

gravel provide for straining and additional treatment of the greywater.

The optimised version of the FLFT which contains water hyacinth for pH adjustment of the treated greywater is designed to be cheap and easy to operate with minimum maintenance [24]. The system removes indicator microorganisms from greywater [23,24] and the effluent has been tested for reuse in irrigation [15]. Attitudes to greywater reuse vary among communities who can be sceptical about it [25], due to the perceived and negative effects on human and environmental health [26]. However, if a community is informed and its members participate in a greywater project, then they can also be in favour of it [27]. In short, these attitudes are complex and have undergone changes in recent years in South Africa [28]. Therefore to facilitate practical implementation of any systems and the long-term sustainability of any greywater reuse programme after treatment, installation and operation of decentralised systems must be done in cooperation with the local community [20]. The scaled-up FLFT was tested in this study in volunteer households in Makana Local Municipality. After treatment, the FLFT effluent was used in irrigation of subsistence vegetable gardens.

2. Materials and methods

2.1. Site selection and system installation

This study was part of civic engagement by the Environmental Health and Biotechnology Research Group to help address some of the pressing needs of the Makana community [29], for example, food security and improvement of sanitation in certain areas of the municipality where reticulation and waste management remain a challenge. The first project activity was the selection of the study sites where the FLFTs would be installed. For this, the existing working relationship of the authors with the community and local non-governmental organisations was used. Five households were recruited in a collaborative fashion with the community and as part of a developing research and knowledge exchange partnership between the Makana community and the authors. An introductory session was run with potential participants, that is, household owners/occupants, before the FLFTs were installed onsite. All the details of the FLFT system, potential benefits/risks and the responsibilities of the household participants' were explained to them. English and isiXhosa were used as mediums of communication to facilitate the communication with the community members in the relevant mother tongues. No personal data was collected for research and data evaluation purposes about any of the households' members at any time during the study.

Once the household owners/occupants agreed to participate, the FLFTs were installed at each of the five study sites through collaboration between the authors and the community members. Minimum maintenance and operational monitoring of the FLFT were required throughout the study. This was achieved through ongoing exchange of information and cooperation between the authors and the household owners/occupants. One of the examples of such tasks included the estimation of the hydraulic retention time of the FLFT. This was estimated based on the observations made by community members. To compensate the community members in participating households for their time and use of the garden space in each household, a remuneration of approximately 35 USD was offered to each volunteering household. During the study, the household occupants maintained the FLFT systems and reported any problems to the authors' team. Any issues that occurred were fixed/addressed in a collaborative fashion between the community members and the authors' team. Another aim of the project was to establish vegetable gardens in the participating households. The hope was that these gardens would remain in use after the completion of the project and potentially provide additional nutrition sources to the household occupants.

The study sites were required to have a fallow garden or a garden with existing vegetation prior to the start of the project and the installation of the FLFT. Out of the five selected study sites, three had a fallow garden, one had a vegetable garden and one had a flower garden. Seedlings of *Beta vulgaris*, *Daucus carota* subsp. *sativus*, *Allium cepa* and *Spinacia oleracea* were purchased from Sunnyside Nursery (Grahamstown/Makana Local Municipality, South Africa). These were then planted at three study sites prior to the FLFT installation, that is, Fingo village (Fingo) Extension 1 and Extension 9. At each site, it was ensured that the plants would be strictly irrigated with the greywater treated with the FLFT system during the study. Diversity of the starting points at the various study sites would provide a detailed examination of the FLFT functioning, the establishment of the vegetables gardens with FLFT effluent irrigation and irrigation of already existing gardens, and effect of irrigation with the FLFT effluent on plant yields/soil properties.

The FLFT systems were set up in 70 L plastic containers that were purchased from BUCO Hardware and Building (Grahamstown, South Africa). These containers were chosen because they are cheap, heavy-duty, easy to obtain, and they should be of low-enough commercial value for them not to be stolen. This is a simple but important sustainability measure for the FLFTs onsite, as crime and theft are both problems in Makana Local Municipality. The FLFTs were assembled in a similar fashion as described previously [15,23,24]. Each household was provided with a sieve with 1 mm filtration openings to remove large food particles from the greywater before this was fed into the FLFTs. The screening of greywater and feeding of the FLFT were similar to the procedure previously described for the mulch tower treatment system [13].

The outflow of three FLFTs was connected to a drip irrigation system with no additional filter (Fig. 2(a)), while effluent from two FLFTs was connected a drip filter and a drip irrigation system (Fig. 2(b)). The additional filter in the two systems had a 150 mesh Y-type plastic screen with disc filters [30]. Placement of the additional filter at the outflow from the FLFTs was aimed at removing any loose debris, solids and other components that might be released from the FLFT into the treated effluent [30]. This should help limit any potential increase(s) in the FLFT effluent turbidity in comparison with the influent. At the same time, the two FLFT versions were part of the project team's effort to examine the long-term physical stability of the FLFT layers and the efficiency of treatment, as well as affordability of the FLFT at the household level.

Fig. 2. Fly ash/lime filter tower connected to drip irrigation system (a) and fly ash/lime filter tower connected to a drip filter with a drip irrigation system (b).

2.2. Sampling

Each FLFT takes up to 30 L of greywater at a time with the hydraulic retention time of approximately 1 h. The hydraulic retention time was estimated based on time measurements taken by the household occupants (using a watch or a cell phone). This time was the period it took for effluent to start trickling from the FLFT outflow, after fresh influent was fed into the system. Greywater samples were collected into sterile 40 mL urine jars (Spellbound Labs, Port Elizabeth, South Africa). Outside of the sufficient number of jars was chemically sterilised using 70% ethanol before sample collection [20]. Then the necessary numbers of jars were filled to the brim with either influent or effluent samples to obtain sufficient sample volumes to perform all the necessary analyses, besides the determination of the Triclosan concentration in the influent and effluent. The sampled volumes were calculated based on preliminary data from the laboratory (data not shown). Unless stated otherwise, all samples of greywater, soil and plants were transported to the laboratory and stored at 4°C until analysis.

Greywater samples for quantification of Triclosan were collected separately from the samples that were taken for the determination of the other greywater parameters. The necessary number of amberlite glass bottles with ground glass stoppers was washed with 10% HCl, detergent and MilliQ water (Millipore/Merck, Port Elizabeth, South Africa). The bottles were subsequently rinsed with ethanol, air dried and dried at 120°C in the UFE 700 oven (Memmert, Schwabach, Germany) overnight. At the respective sampling site, the influent and effluent samples were filled up into the neck of the amberlite bottles to leave minimum headspace. The Triclosan samples were transported into the laboratory and stored before analysis just like the other greywater samples.

Soil samples were also collected and analysed for selected microbial constituents, bulk density, particle density, loss on ignition, pH and the heavy metal analysis. Unless stated otherwise, all weights were measured using the PA214 analytical balance (OHAUS Europe GmbH, Greifensee, Switzerland). The surface litter was removed from the soil surface by hand using sterilised gloves and then the soil surface horizon A was sampled as described for sampling of surface soils in flood zones [31], and for the mulch layer in the study of Whittington-Jones et al. [20]. Both protocols were developed and optimised before the start of the current study. Plant samples of *Beta vulgaris*, *Daucus carota* subsp. *sativus*, *Allium cepa* and *Spinacia oleracea* were harvested throughout the study. Whole plants were collected as individual samples and rinsed with distilled water before analysis.

2.3. Greywater analysis

The influent and effluent samples from the FLFT were analysed for concentrations of Triclosan, ammonium (NH_4^+), phosphate (PO_4^{3-}), nitrate (NO_3^-), chloride (Cl^-), chemical oxygen demand (COD). The Triclosan concentrations were measured using the respective Abraxis kit (Toxsolutions, Pretoria, South Africa). The Irgasan standard (97% content of Triclosan) was purchased from Sigma-Aldrich, Johannesburg, South Africa, and the concentrations were corrected for the purity of the standard. All steps of the Triclosan determination were performed using the protocol provided by the manufacturer. Samples and calibration solutions were analysed in triplicate and the calibration range was from 0.05 to 2.5 µg/L. All spectrophotometric measurements in the Triclosan quantifications were performed using the Powerwave microplate spectrophotometer (Biotek UK, Swindon, UK).

Measurements of the remaining chemical parameters of influent and effluent were performed using the specialised kits purchased from Merck/Millipore Pty. Ltd. (Johannesburg/Cape Town, South Africa). The COD concentrations were measured using the closed-reflux colorimetric method [32]. Digestions were performed using the TR 300 thermoreactor (Merck/Millipore Pty Ltd., Johannesburg/Cape Town, South Africa). Potassium hydrogen phthalate (Merck/Millipore Pty Ltd., Johannesburg/Cape Town, South Africa) was used as the standard for the preparation of the calibration curves. All COD concentrations were converted into mg KHP (potassium hydrogen phthalate) equivalents per litre (mg KHP eq/L) using the approach of the HACH company [33]. The calibration range was from 0 to 2,000 mg KHP eq/L.

Unless stated otherwise, all COD absorbance measurements were performed using the Shimadzu 1240 UV/VIS spectrophotometer at 610 nm. This wavelength is slightly different from the wavelength used in Merck-supplied spectrophotometer instruments of 600 nm [34]. However, the wavelength is still inside the interval of the secondary visible absorption maximum in the spectrum of the Cr^{3+} ions, which are the chromophore in the COD determination [35,36]. The molar extinction coefficient is therefore unlikely to be significantly different at 600 and 610 nm. The reproducibility of the readings was better at 610 nm and thus this wavelength was used in all COD absorbance measurements.

Concentrations of NO_3^- were determined using the Merck kit and the method analogical to the US EPA Method 353.2 [37]. From this point forward and/or unless stated otherwise, all absorbance measurements in all analytical techniques based on absorption spectrophotometry were performed in triplicate using the same instrument as with the COD determination. The number of replicates applies to both calibration solutions and samples. The only difference between the individual techniques' absorbance measurements was the different wavelengths used in quantitative analyses. The NO_3^- concentrations were quantified at 540 nm. Potassium nitrate (Merck/Millipore Pty Ltd., Johannesburg/Cape Town, South Africa) was used as the standard in the construction of the calibration curve in the range of 2–20 mg/L.

The PO_4^{3-} concentrations were measured using the Merck kit with analogical to the US EPA Method 365.2/3 [38] and the Standard method 4500-P [32]. Potassium orthophosphate was used as the calibration standard and the calibration curves were constructed in interval ranging from 1 to 10 mg/L. All measurements were performed at 660 nm, which is similar to the wavelength of the maximum in the molybdate-reducing agent methods [39]. Thus the wavelength of 660 nm was used in all absorbance measurements in the phosphate assays.

Concentration of NH_4^+ in the influent and effluent samples was measured using the Merck kit and the procedure was analogical to the US EPA method 350.1 [40]. Ammonium chloride was used as the calibration standard and the linearity range of the method was 1–10 mg/L, with absorbance read at 660 nm. The wavelength used for the ammonium indophenol blue determination is slightly different from the wavelength used by other authors, for example, 630 nm reported by Hall [41]. However, the chromophore identity, that is, indophenol blue, was the same and this chromophore has sufficient absorbance between 600 and 700 nm to provide the necessary sensitivity of the absorbance readings needed in this study [42]. Therefore, the use of 660 nm wavelength is justified in the authors' opinion and the obtained results are considered reliable.

The Cl^- concentrations were quantified using the Merck kit protocol which was analogical to the US EPA method 325.1 [43]. The calibration standard in all the determinations and sample measurements was calcium chloride and all absorbance readings were taken at 450 nm. The calibration range was 1–10 mg/L. The pH of the water samples was measured using the Hanna Comb pH and CE meter (Hannah Instruments, Port Elizabeth, South Africa). Turbidity of the influent and effluent samples was measured using the Lutron TU-2016 portable turbidity meter (Test and Measurement Instrument CC/The Instruments Group, Johannesburg, South Africa).

The following consumables were purchased from Spellbound Labs (Port Elizabeth, South Africa) for the enumeration of FCs and the total mesophilic bacteria: sterile 90 mm plastic petri dishes, Oxoid anaerobic gas packs and the Pall-Gelman GN-6 Metricel sterile membrane filters (pore size 0.45 μm, diameter 47 mm). The m-FC agar and nutrient agar were purchased from Merck/Millipore Pty. Ltd. (Johannesburg/Cape Town, South Africa). Unless stated otherwise, all incubations were done in the Labcon incubator Model FSIM B and/or the Labcon low temperature incubator LTIE 10 (both bought from Labmark, Johannesburg, South Africa). All sterilisations in the study were performed using the Model RAU-53Bd REX MED autoclave (Hirayama Manufacturing, Tokyo, Japan). Unless otherwise stated, all inoculations were performed using a laminar flow hood.

FC was enumerated using the membrane filtration technique as blue colonies on the m-FC agar after incubations at 44.5°C ± 0.2°C for 24 h [23,24]. Concentrations of the total aerobic bacteria (TAB) in greywater samples were enumerated using the spread-plating technique on nutrient agar as outlined by Whittington-Jones et al. [20]. Incubations were performed at 37°C for 24 h. The total anaerobic bacteria (TNB) were enumerated in the same fashion as TAB, but the incubations were performed anaerobically as outlined for bifidobacteria by Tandlich et al. [44], but nutrient agar was used and not agars specific for bifidobacteria. All bacterial concentrations were expressed as colony-forming unit per 100 mL (CFUs/100 mL).

2.4. Soil and plant analysis

The extraction of leachable bacteria from the soil was achieved using sterile physiological saline and the general procedure of extraction of bacteria from mulch was followed [20]. These bacteria are expected to be loosely attached to the soil particles and can be detached when the soil receives the FLFT effluent. Measurement of this parameter can indicate the fraction of bacteria that can contaminate groundwater by percolation of the FLFT effluent down the soil profile. These bacteria can also be mobilised and potentially contaminate the surface soil horizons due to infiltration and lateral movement of the FLFT effluent in the irrigated soil. Briefly, 1 g of soil was mixed with 100 mL of physiological saline and the suspensions were vortexed using the MT19 Deluxe Vortex Mixer (Chiltern Scientific, Australia) for 2 min. Then decimal dilutions of the extract were performed with sterile physiological saline (0.9% aqueous solution NaCl; Sigma-Aldrich, Johannesburg, South Africa). The spread-plating, incubation and counting were done in the same fashion as with the TAB and TNB. Bacterial concentrations in soils irrigated with the treated greywater were expressed as colony-forming units per 1 g of dry weight of soil (CFUs/g dw).

Unless stated otherwise, all soil properties were measured using the general procedures/protocols of Rowell [45] and Moyo et al. [46]. In loss on ignition, the drying was performed at 105°C for 24 h, while the ignition was done at 400°C in muffle furnace for 24 h. Concentrations of selected metals were determined after the extraction of soil samples irrigated with FLFT effluent using the modified protocol of Tuin and Tels [47]. 5 g of soil samples was weighed using Pioneer™ PA2102 balance (OHAUS Europe GmbH, Greifensee, Switzerland) and transferred into 250 mL Erlenmeyer flasks (Sigma-Aldrich, Johannesburg, South Africa). Using a 50 mL graduated measuring cylinder, 50 mL of 1 M HCl was added and the flasks were sealed with aluminium foil and Parafilm™ (Parafilm, Oshkosh, WI, USA). The resulting soil suspensions were placed in orbital shaker and shaken at 150 rpm at 20°C for 24 h.

The extended extraction time was estimated to be sufficient to recover all the metal ions from the soil samples. After shaking, 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 (Bemlab Pty Ltd., Cape Town, South Africa). The concentrations were expressed as mg per kilogram dry weight (mg/kg dw). The following parameters were measured for the collected plant samples: the length of the plants, the fresh and dry weights of the plants. The plant dry weights were determined at 65°C for 72 h as outlined by Ngqwala et al. [15].

2.5. Statistical analysis

Paleontological Statistics software for education version 2.17c (Natural History Museum, University of Oslo, Oslo, Norway) was used to conduct the statistical analysis of the measured data. The particular tests were the one-tail and two-tail Mann-Whitney test and the Kruskal–Wallis analysis of variance by ranks. All statistical tests were performed at 5% level of significance. The Mann-Whitney test was used to assess, if there were statically significant differences and decrease between the influent and the effluent values of individual parameters during a given sampling. This was done to see whether the pilot scale FLFTs provided stable and statistically significant removal of the individual components of greywater. The aim was to establish whether the FLFTs in this study provided consistent treatment, so that the probabilistic approach to the evaluation of treatment efficiency [13,17,23] could be replaced with a simple calculation of the removal efficiencies (Eq. (1)). The Kruskal–Wallis analysis of variance by ranks was applied to the evaluation of the plant growth data.

3. Results and discussion

After installation, greywater of mixed origin was fed into all FLFTs, but the treatment performance was only evaluated after the removal efficiencies had stabilised which took place 4 weeks into the study. Then sampling for data collection to evaluate the FLFT efficiency in greywater treatment started and continued from the beginning of July until the end of November 2015. A total of 15 samples were collected at each of the five study sites, that is, a total of 75 influent and 75 effluent samples were collected and analysed. The first parameter to be analysed was the concentration of Triclosan and the concentrations were below 0.05 μg/L in all samples. This is lower than the Triclosan concentrations reported by Amlqvist and Hanæus [48] for Triclosan in greywater samples from Sweden, which ranged from 0.075 to 16.6 μg/L. As a result, irrigation of soil with the FLFT effluent is unlikely to have influence on the microbial constituents of the irrigated soil in Makana Local Municipality [49].

With all other parameters, all samples were analysed for microbial and chemical components to investigate the treatment efficiency and to establish whether the effluent parameters are within the water quality guidelines for the reuse of greywater for small-scale irrigation/agriculture in South Africa [50]. The treatment efficiency of the FLFTs was evaluated through the calculation of the removal efficiency defined in Eq. (1):

$$\text{Removal efficiency } (\%) = \frac{[\text{influent}] - [\text{effluent}]}{[\text{influent}]} \times 100 \qquad (1)$$

In Eq. (1), [influent] stands for the influent concentration of the particular chemical or microbial component (mg/L or CFUs/100 mL or CFUs/mL), while [effluent] stands for the effluent concentration of the particular chemical or microbial indicator (mg/L or CFUs/100 mL or CFUs/mL).

Removal of FC was analysed and summary of the measured data is shown in Fig. 3. Based on all the 75 measurements, the overall average influent FC concentration was equal to 58 ± 24 CFUs/100 mL, while the overall average effluent concentration of FC was equal to 22 ± 7 CFUs/100 mL. For all sampling occasions, the influent FC concentrations were statistically significantly different from the FC concentrations in the FLFT effluent (the two-tail Mann-Whitney test with p-value = 0.01219). At the same time, all the 75 influent concentrations were higher than the effluent values and this difference was statistically significant (one-tail Mann-Whitney test with p-value = 0.01831). Based on these numbers, Eq. (1) yielded the average removal efficiency of 62%.

Ngqwala et al. [51] reported that the FC concentrations ranged from 0 to 490 CFUs/100 mL in the Kleinemonde area of the Eastern Cape Province of South Africa. During the treatment of the greywater using an FLFT without the water hyacinth layer, the influent concentration of FC ranged from 720 to 1,000 CFUs/100 mL, while the effluent FC concentrations were inside the interval from 0 to 5 CFUs/100 mL [51]. This gives the removal efficiencies between 99% and 100%. Another laboratory version of the FLFT with a mulch layer provided the probabilistic removal efficiency of between 58% and 71% of the influent FC concentrations, which ranged from 10 to 176,000 CFUs/100 mL [22]. In the last study, the probabilistic removal efficiency calculations had to be applied to the entire duration of the study. This is not the case in the current study, as the removal efficiencies stabilised after 4 weeks. Thus one of the aims, that is, simple evaluation of the removal efficiency by calculations based on Eq. (1) was achieved.

Based on the FC data and the literature references, the FC concentrations in this study span a narrower interval than the concentrations from previous studies on greywater composition in the Eastern Cape Province of South Africa. The average and overall removal efficiency for FC is comparable with the data of Tandlich et al. [22], but lower than the removal efficiencies reported by Ngqwala et al. [51].

The FC concentrations in the effluent were compared with the guidelines for the reuse of greywater in small-scale

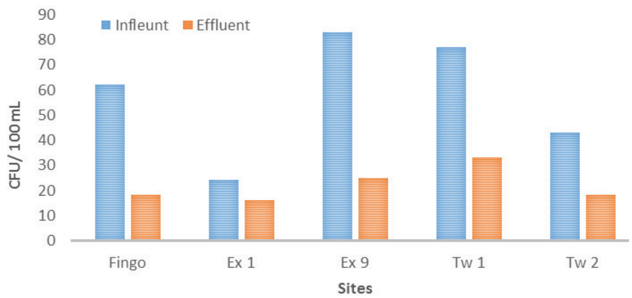

Fig. 3. The average FC concentrations in the influent and the FLFT-treated greywater at the five study sites in Makana Local Municipality which are as follows: Fingo - Fingo Village; Ex 1 - Extension 1; Ex 9 - Extension 9; Tw 1 - Town 1; Tw 2 - Town 2.

agriculture in South Africa [50]. The risk that can evaluated for irrigation of vegetable gardens in the participating households, if it is assumed the FC concentrations are equivalent to concentrations of *Escherichia coli*. The effluent FC concentrations indicate that irrigation with the FLFT treated greywater can pose increasing risk to human health, plants and soil irrigated with the treated greywater (Table 7.4 in reference [50]). Therefore, mitigation measures should be implemented. For example, the grown vegetables should be washed with dishwashing detergent before human consumption, if they are to be consumed raw [50]. In addition, a chlorinator should be installed at the outflow of the FLFT to provide additional disinfection of the FLFT effluent before its reuse in irrigation.

Results of the analysis of the physico-chemical parameters of the FLFT treatment of greywater are shown in Fig. 4 and Table 1. At the same time, the soil analysis results are shown in Table 2. The average influent pH ranged from 8.3 ± 0.7 to 9.1 ± 0.8, while the effluent pH values on average ranged from 7.0 ± 0.6 to 7.4 ± 0.6. In isolated cases, highly alkaline pH values were observed, but these were exceptions (Fig. 4(a)).

There was a statically significant difference between the influent and effluent pH values for all the 75 sampling occasions (two-tail Mann-Whitney test *p*-value = 0.01243). The effluent pH was 15.7%–18.7% lower than the influent values

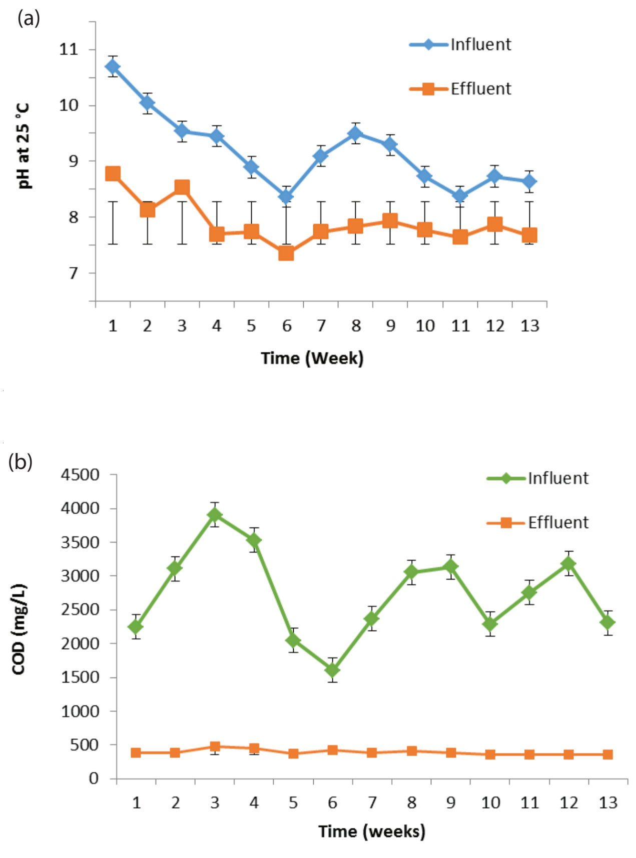

Fig. 4. The temporal profile of the average pH values of the influent and effluent (a) and the average COD values of the influent and effluent (b) from the five FLFTs installed in the volunteer households.

and this decrease was statistically significantly different for all 75 samples (one-tail Mann-Whitney *p*-value = 0.00005). The average influent pH values are comparable with the ones reported by Ngqwala et al. [51], who reported values ranging from 7.9 to 9.2. At the same time, the FLFT effluent pH values are lower than the values reported by Ngqwala et al. [51], that is, 12.0–12.8. The buffering is due to the presence of the water hyacinth layer. The FLFT effluent pH values are well inside the interval from 6.5 to 8.4 for the unrestricted irrigation with minimum risks to human and environmental health (Table 7.4 in reference [50]).

The average turbidity values in the FLFT influent ranged from 343 ± 243 to 761 ± 398 NTU, while the effluent values ranged from 24 ± 5 to 609 ± 330 NTU (Table 1). The influent values were statistically significantly different from the effluent turbidity values for all individual results from the 75 sampling occasions (two-tail Mann-Whitney test *p*-value = 0.01219). The one-tail Mann-Whitney test results showed that the average turbidity of the FLFT influent was statistically significantly higher than the effluent values (*p*-value < 0.00001). Based on these results, the FLFT provided a stable removal of turbidity from the treated greywater after the initial 4-week period of stabilisation. The FLFT removal efficiency for turbidity ranged from 20% to 97%.

Three sites contained FLFT with no drip filter and these were Fingo – Fingo Village; Ex 1 – Extension 1; Ex 9 – Extension 9. On the other hand, two sites had a drip filter installed at the outflow of these FLFT and these included Tw 1 – Town 1; Tw 2 – Town 2. The turbidity data were separated into two additional groups, that is, all data from the sites with no drip filter were put into one group and all data from the sites with drip filters were put in the other group. The one-tail and two-tail Mann-Whitney test were re-run again at 5% level of significance. This was done to see, if the drip filter addition led to the decrease in the turbidity of the FLFT effluent.

Outcome of this statistical testing showed that the effluent turbidity at Fingo, Ex 1 and Ex 9 was always different from the effluent turbidity at Tw 1 and Tw 2; and that difference was statistically significant (two-tail Mann-Whitney *p*-value = 0.00002). At the same time, the effluent turbidity at Fingo, Ex 1 and Ex 9 was always higher from the effluent turbidity at Tw 1 and Tw 2; and this difference was statistically significant (one-tail Mann-Whitney *p*-value < 0.00001). Therefore the drip filter contributed to the decrease in the FLFT effluent turbidity and should thus be part of the FLFT installed at the household level in Makana Local Municipality.

In a previous version of the FLFT, Ngqwala et al. [51] reported that influent turbidity in a laboratory-scale FLFT ranged from 85 to 98 NTU. In the same study, the FLFT-treated greywater, that is, effluent, had turbidity values ranging from 1.7 to 2.0 NTU [51]. This indicates removal efficiency of 98%. Zuma and Tandlich [52] reported that influent turbidity in the Eastern Cape ranged from 48 ± 2 to 505 ± 2 NTU. In the same study, the FLFT effluent values of turbidity ranged from 0.7 ± 2 to 341 ± 2 NTU, with the probabilistic removal efficiency ranging from 46% to 95% [52]. As a result, the turbidity values measured in this study are comparable with or higher than the values previously measured in the Eastern Cape Province of South Africa.

No reference values for turbidity were found in the guidelines for reuse of greywater is small-scale agriculture

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

Sampling site	Fingo		Extension 1		Extension 9		Town 1		Town 2	
Chemical components	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent
pH	9.1 ± 0.6	7.4 ± 0.6	8.5 ± 1.0	7.3 ± 0.6	8.3 ± 0.7	7.0 ± 0.6	8.3 ± 1.1	7.3 ± 0.5	9.1 ± 0.8	7.4 ± 0.5
Turbidity	601 ± 327	404 ± 329	463 ± 227	263 ± 137	761 ± 398	609 ± 330	687 ± 440	24 ± 5	343 ± 243	24 ± 8
COD (mg KHP eq/L)	2,290 ± 52	400 ± 10	3,000 ± 137	397 ± 6	2,110 ± 47	341 ± 7	2,760 ± 97	408 ± 2	2,650 ± 52	409 ± 3
NO_3^- (mg/L)	59.1 ± 0.1	28.9 ± 0.6	60 ± 24	24 ± 63	62 ± 2	30 ± 1	47.3 ± 0.2	21.7 ± 0.4	52.5 ± 0.1	24.7 ± 0.4
PO_4^- (mg/L)	2.5 ± 0.5	1.2 ± 0.5	4.0 ± 0.1	1.9 ± 0.2	3.2 ± 0.2	1.5 ± 0.1	2.5 ± 0.2	1.2 ± 2.1	2.5 ± 0.3	1.3 ± 0.1
NH_4^+ (mg/L)	3.0 ± 0.0	1.5 ± 0.0	6.4 ± 0.1	3.1± 0.0	2.9 ± 0.0	1.1 ± 0.1	2.7 ± 0.0	1.3 ± 0.0	4.5 ± 0.1	2.1 ± 0.0
Cl^- (mg/L)	10.4 ± 0.1	6.2 ± 0.2	14.6 ± 0.1	8.6 ± 0.1	8.5 ± 0.2	5.0 ± 0.0	8.0 ± 0.0	4.9 ± 0.1	8.8 ± 0.1	5.3 ± 0.1
TAB (CFUs/mL)	$(2.0 \pm 0.8) \times 10^7$	$(2.5 \pm 0.8) \times 10^6$	$(2.0 \pm 0.6) \times 10^7$	$(3.8 \pm 1.7) \times 10^6$	$(5.2 \pm 0.2) \times 10^7$	$(4.1 \pm 1.5) \times 10^7$	$(3.0 \pm 1.4) \times 10^7$	$(3.8 \pm 8.1) \times 10^6$	$(2.9 \pm 1.7) \times 10^7$	$(2.0 \pm 0.9) \times 10^7$
TNB (CFUs/mL)	$(1.9 \pm 0.8) \times 10^7$	$(2.3 \pm 0.6) \times 10^7$	$(0.3 \pm 0.1) \times 10^7$	$(1.1 \pm 0.9) \times 10^7$	$(0.3 \pm 8.8) \times 10^7$	$(1.2 \pm 0.5) \times 10^7$	$(1.6 \pm 3.0) \times 10^7$	$(1.9 \pm 0.5) \times 10^7$	$(1.9 \pm 0.5) \times 10^7$	$(2.1 \pm 0.6) \times 10^7$

Table 2
Results of soil analysis at all sampling sites

	Fingo		Extension 1		Extension 9		Town 1		Town 2	
	Initial	After	Initial	After	Initial	After	Initial	After	Initial	After
pH	6.50 ± 0.00	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 ± 0.01	0.75 ± 0.02	0.12 ± 0.04	0.89 ± 0.03
Particle density (g/cm^3)	2.1 ± 0.1	2.11 ± 0.03	2.2 ± 0.2	2.00 ± 0.02	2.4 ± 0.2	2.05 ± 0.01	2.48 ± 0.02	2.23 ± 0.06	2.31 ± 0.1	2.27 ± 0.06
LOI (%)	10.81 ± 0.02	14.0 ± 1.3	11.33 ± 0.03	13.3 ± 1.6	11.03 ± 0.01	15.8 ± 1.2	13.05 ± 0.04	15 ± 3	13.89 ± 0.02	15 ± 1
TAB (10^6 CFUs/g dw)	0.8 ± 1.1	0.8 ± 1.2	0.9 ± 1.0	0.6 ± 0.8	1.9 ± 2.3	0.6 ± 0.7	1.4 ± 1.8	1.0 ± 1.4	2.6 ± 3.3	1.3 ± 1.7
TNB (10^5 CFUs/g dw)	6.5 ± 6.7	5.7 ± 7.2	13 ± 1	5.5 ± 6.6	12 ± 15	11 ± 15	14 ± 18	13 ± 18	26 ± 34	11 ± 14

in South Africa [50]. The World Health Organisation guidelines for the safe reuse of greywater in agriculture also do not contain target values for turbidity [53]. The FLFT effluent is treated and so it can be classified as reclaimed water and so the guideline for the uses of reclaimed water can be applied to evaluate the turbidity reading from this study [54]. This evaluation indicates that the FLFT effluent does not meet the criteria for class A reclaimed water (Table 1 in reference [54]). Therefore, additional disinfection of the FLFT must be implemented into the further version of this treatment system. As discussed with the FC results, a chlorinator should be installed at the outflow from the FLFT to achieve additional disinfection of the effluent before its use in garden irrigation.

The average COD concentrations in the influent varied between 2,110 ± 47 and 3,000 ± 137 mg KHP eq/L (Table 1), with the range of value spanning from 1,500 to 4,000 mg KHP eq/L (Fig. 4(b)). The average FLFT effluent concentrations of COD ranged from 341 ± 7 to 408 ± 2 mg KHP eq/L. The influent greywater COD was on average always different from the effluent COD and that difference was statistically significant at 5% level of significance (two-tail Mann-Whitney p-value < 0.00001). The effluent COD was on average always lower the influent value and this decrease was statistically significantly different (one-tail Mann-Whitney p-value < 0.00001). The average removal efficiency for COD ranged from 83% to 87%.

In Ngqushwa Municipality, Ngqwala et al. [51] reported influent/raw greywater values ranging from 0.80 to 1,260 mg KHP eq/L. In the same study, the FLFT effluent without water hyacinth layer contained between 0.98 and 7.4 mg KHP eq/L [51]. Thus the FLFT without the water hyacinth layer provides no removal of COD (based on the minimum literature values) or the removal can range up to 99% [51]. At the same time, Zuma and Tandlich [52] reported a probabilistic/cumulative removal of COD ranging from 36.5% to 62.3% for a laboratory-version of the FLFT without water hyacinth addition. Thus the data from the current study are higher than or comparable with the literature data on FLFT removal of COD from greywater in the Eastern Cape Province of South Africa.

The average COD concentrations in the FLFT effluent are borderline for no to increasing risk to human and environmental health (Table 7.4. in reference [50]). Fly ash has been reported to act as an adsorbent of organic matter, that is, COD components of the greywater [55,56]. Thus increasing the amount of fly ash in the FLFT might provide and improve removal of COD from the treated greywater. As the ratio of fly ash and lime in the top layer of the FLFT is fixed, increasing the volume/size of the FLFT reactor might provide the answer. Therefore, future studies should focus on further scale-up of the FLFT described in this study. Investigating the relative significant of the various mechanisms of COD removal, for example, straining and adsorption might also facilitate the optimisation of the FLFT performance with respect to COD removal. As such, the investigations into the COD fractionation inside the FLFT will be required using the general procedures as outlined by Orhon and Cokgor [57].

On average, the NO_3^- concentrations in the FLFT influents ranged from 47.3 ± 0.2 to 62 ± 2 mg/L. At the same time, the effluent values varied between the minimum of 21.7 ± 0.4 mg/L and the maximum of 30 ± 1 mg/L. At a given sampling site, the influent nitrate concentrations were statistically significantly different from the effluent values as indicated by the results of the two-tail Mann-Whitney test at 5% level of significance (p-value = 0.005452). Testing using the one-tail Mann-Whitney test at 5% level of significance led to the conclusion that there was a statistically significant removal of nitrates in the FLFT systems, based on the average NO_3^- concentrations (p-value < 0.00001). The removal efficiency for the nitrates ranged from 51% to 60% of the influent concentrations and this was consistent throughout the study.

In the Eastern Cape Province of South Africa, Ngqwala et al. [51] reported the NO_3^- concentrations from 25 to 55 mg/L in the FLFT influent and from 1.8 to 9.0 mg/L in the effluent. This results in the nitrate removal efficiencies that range from 84% to 93%. Zuma and Tandlich [52] reported that the untreated greywater concentrations ranged from 0 to 10 ± 2 mg/L in greywater from the Eastern Cape Province of South Africa influent. Using the probabilistic approach to removal efficiency, the laboratory-scale FLFTs were able to remove between 31% and 36% of the influent nitrate concentrations. Therefore the NO_3^- concentrations measured in the current study were comparable with or higher than the literature values measured in previous studies with the FLFT without the water hyacinth layer.

The removal efficiency for nitrates in the study is inside the interval reported in the previous studies with the FLFT system. And the possible mechanisms include sorption competition [13,17].and the presence of denitrification bacteria. Nitrate concentrations in the FLFT effluent were evaluated in terms of the total nitrogen content listed in the South African guidelines (Table 7.4 in reference [50]). Even before ammonium is considered, irrigation of the soils with FLFT effluent was found to carry risk significant risk to human and plant health at all study sites (Table 7.4 in reference [50]). This could provide a partial explanation for the observations on plant yields measured. The FLFT should be inoculated with denitrification bacteria and its operation must be further investigated for the optimisation of the nitrate removal.

Taking mean values into consideration, the PO_4^{3-} concentrations in the FLFT influents ranged from 2.5 ± 0.2 to 4.0 ± 0.1 mg/L. At the same time, the effluent values varied between the minimum of 1.2 ± 0.5 mg/L and the maximum of 1.9 ± 0.2 mg/L. At a given sampling site, the influent phosphate concentrations were statistically significantly different from the effluent values as indicated by the results of the two-tail Mann-Whitney test at 5% level of significance (p-value = 0.000097). Testing using the one-tail Mann-Whitney test at 5% level of significance led to the conclusion that there was a statistically significant removal of nitrates in the FLFT systems, based on the average PO_4^{3-} concentrations (p-value = 0.00024). The removal efficiency for the phosphates ranged from 48% to 53% of the influent concentrations and this was consistent throughout the study.

The PO_4^{3-} concentrations were reported to range from 2.0 to 2.1 mg/L in the FLFT influent and from 0.17 to 0.45 mg/L in the effluent in the Eastern Cape Province of South Africa [51]. This results in the phosphate removal efficiencies that range from 78% to 92%. Zuma and Tandlich [52] reported that the untreated greywater contained phosphate concentrations ranging from 0 to 47 ± 2 mg/L in greywater from the Eastern Cape Province of South Africa influent. In the same study, the FLFT effluent concentrations of PO_4^{3-} ranged from 0 to 14 ± 1 mg/L [52]. Using the probabilistic approach to removal efficiency, the laboratory-scale FLFTs were able to remove between 33% and 62% of the influent phosphate concentrations. Therefore the PO_4^{3-} concentrations measured in the current study comparable with or lower than the literature values measured in previous studies with the FLFT without the water hyacinth layer. The removal efficiency for phosphate in the study is inside the interval reported in the previous studies with the FLFT system or lower.

Organic phosphorus can also theoretically be present in greywater, for example, in the form of DNA of microorganisms such as FCs. However, the organic phosphorus concentrations from these sources are likely to be negligible in comparison with the inorganic phosphate concentration in the greywater. As a result, phosphate concentrations in the FLFT effluent were evaluated in terms of the total phosphorus content listed in the South African guidelines and it was assumed that total phosphorus was equal to the phosphate concentrations measured in this study (Table 7.4 in reference [50]). The results indicate that the FLFT effluent can be used for unrestricted irrigation. No adverse effects on human or plant health are expected.

The NH_4^+ concentrations in the FLFT influents ranged from 2.7 ± 0.0 to 6.4 ± 0.1 mg/L. At the same time, the effluent values varied between the minimum of 1.1 ± 0.1 mg/L and the maximum of 3.1 ± 0.0 mg/L. At a given sampling site, the influent ammonium concentrations were statistically significantly different from the effluent values as indicated by the results of the two-tail Mann-Whitney test at 5% level of significance (p-value = 0.0000067). Testing using the one-tail Mann-Whitney test at 5% level of significance led to the conclusion that there was a statistically significant removal of ammonium in the FLFT systems, based on the average NH_4^+ concentrations (p-value = 0.000104). The removal efficiency for the ammonium ranged from 50% to 62% of the influent concentrations and this was consistent throughout the study.

Ngqwala et al. [51] reported the NH_4^+ concentrations from 47 to 54 mg/L in the FLFT influent and from 27 to 34 mg/L in the effluent. This results in the ammonium removal efficiencies that range from 37% to 42%. Zuma and Tandlich [52] reported that the untreated greywater contained ammonium concentrations ranging from 0.2 ± 0 to 17 ± 0.8 mg/L in greywater from the Eastern Cape Province of South Africa influent. In the same study, the FLFT effluent concentrations of Cl^- ranged from 39 ± 0.6 to 265 ± 57 mg/L [52]. Using the probabilistic approach to removal efficiency, the laboratory-scale FLFTs had ammonium removal efficiency between 20% and 25% of the influent concentrations. Therefore the NH_4^+ concentrations measured in the current study comparable with or lower than the literature values measured in previous studies with the FLFT without the water hyacinth layer. The removal efficiency for ammonium in the study is higher than reported in the previous studies with the FLFT system.

The ammonium concentrations in the FLFT effluent were evaluated in terms of the total nitrogen content listed in the South African guidelines (Table 7.4 in reference [50]). This was combined with the evaluation of the nitrate concentrations. Even before ammonium is considered, irrigation of the soils with FLFT effluent was found to carry risk significant risk to human and plant health at all study sites (Table 7.4 in reference [50]). This could provide an explanation for the observations on plant yields measured.

On average, the Cl^- concentrations in the FLFT influents ranged from 8.0 ± 0.0 to 14.6 ± 0.1 mg/L. At the same time, the effluent values varied between the minimum of 4.9 ± 0.1 mg/L and the maximum of 8.6 ± 0.1 mg/L. At a given sampling site, the influent chloride concentrations were statistically significantly different from the effluent values as indicated by the results of the two-tail Mann-Whitney test at 5% level of significance (p-value = 0.005). Testing using the one-tail Mann-Whitney test at 5% level of significance led to the conclusion that there was a statistically significant removal of chlorides in the FLFT systems, based on the average Cl^- concentrations (p-value = 0.0044). The removal efficiency for the chlorides ranged from 39% to 41% of the influent concentrations and this was consistent throughout the study.

For greywater from Ngqushwa Local Municipality, Ngqwala et al. [51] reported the Cl^- concentrations from 25 to 31 mg/L in the FLFT influent and from 3.3 to 32 mg/L in the effluent. This results in the chloride removal efficiencies that range from 3% release to 87% removal. Zuma and Tandlich [52] reported that the untreated greywater concentrations ranged from 38 ± 0 to 313 ± 60 mg/L in greywater from the Eastern Cape Province of South Africa influent. In the same study, the FLFT effluent concentrations of Cl^- ranged from 39 ± 0.6 to 265 ± 57 mg/L [52]. Using the probabilistic approach to removal efficiency, the laboratory-scale FLFTs were able to remove 20% of the influent chloride concentrations. Therefore the Cl^- concentrations measured in the current study lower than the literature values measured in previous studies with the FLFT without the water hyacinth layer. The removal efficiency for chlorides in the study is inside the interval reported in the previous studies with the FLFT system. No reference values of chloride concentrations were found in the in the South African guidelines for reuse of greywater in irrigation (Table 7.4 in reference [50]).

The average TAB levels in the influent ranged from $(2.0 \pm 0.8) \times 10^7$ to $(5.2 \pm 0.2) \times 10^7$ CFUs/mL, while the effluent values were on average inside the interval from $(2.5 \pm 0.8) \times 10^6$ to $(4.1 \pm 1.5) \times 10^7$ CFUs/mL. The mean value of the TAB removal efficiency varied between the minimum of 21% and the maximum of 88%. The average TNB concentrations in the FLFT influent ranged from $(0.3 \pm 0.1) \times 10^7$ to $(1.9 \pm 0.8) \times 10^7$ CFUs/mL, while the effluent values varied between $(1.1 \pm 0.9) \times 10^7$ and $(2.3 \pm 0.6) \times 10^7$ CFUs/mL. Release of TNB from the FLFTs was recorded at all sampling sites. The particular average values ranged from the minimum of 11% and the maximum of 266%.

Results of the two-tail Mann-Whitney test at 5% level of significance indicate that there were statistically significant differences between the average influent and the average effluent concentrations of aerobic and anaerobic bacteria (p-value = 0.01218 for TAB and p-value = 0.0129 for TNB). There was a significant removal of aerobic bacteria and a statistically significant release of anaerobic bacteria (p-value ≤ 0.00604 for both parameters in the one-tail Mann-Whitney test at 5% level of significance). As a result, the FLFT was a source of anaerobic bacteria for the irrigated soils at all sampling sites in this study.

Reference values could only be established for the greywater concentrations of TAB. In that study, Whittington-Jones et al. [20] reported that TAB in the influent of the mulch-tower system ranged from 0.76×10^4 to 30×10^4 CFUs/mL. In the same study, the effluent TAB values varied between the minimum concentration of 6.3×10^4 CFUs/mL and the maximum value of 220×10^4 CFUs/mL [20]. Therefore the FLFT used in the current study did not release any aerobic bacteria into the environment after greywater treatment. At the same time, the TAB values in this study are higher than the respective reference values from literature. Based on the authors understanding, this is the first study in the Eastern Cape Province of South Africa were the TNB are reported.

The soils at individual sampling sites had a pH ranging from 5.76 ± 0.02 to 7.16 ± 0.02 (Table 2). After the completion of the study, the surface horizon of the soils had pH values between 7.16 ± 0.04 and 7.53 ± 0.16 (Table 2). On average, the soil pH after irrigation was marginally higher as indicated by the results of the one-tail and two-tail Mann-Whitney test results at 5% level of significance (p-values ≤ 0.0014).

Before the start of the soil irrigation with FLFT effluent, the bulk density of soils ranged from 0.11 ± 0.02 to 0.84 ± 0.01 g/cm^3 (Table 2). After the completion of the study, the surface horizon of the soils had bulk densities ranging from 0.64 ± 0.02 to 1.02 ± 0.08 g/cm^3 (Table 2). When comparing the initial and the treated soil samples, there was a statistically significant difference and increase in the bulk density at all sampling sites with the exception of Fingo (p-values ≤ 0.0391).

The particle density of soils ranged from 2.1 ± 0.1 to 2.48 ± 0.02 g/cm^3 (Table 2) before irrigation with the FLFT effluent began. After the completion of the study, the particle density varied between 2.00 ± 0.02 and 2.27 ± 0.06 g/cm^3 (Table 2). There was no statistically significant difference in the particle density of the soil before and after irrigation with FLFT effluent at Fingo (p-value = 0.5390 in the two-tail Mann-Whitney test at 5% level of significance) and at Town 2 (p-value = 0.9768 in the two-tail Mann-Whitney test at 5% level of significance). Statistical significant decrease in the particle density was observed at all the remaining sites (p-values ≤ 0.00003 in the one-tail and two-tail Mann-Whitney test at 5% level of significance).

The loss on ignition (LOI) of soils before irrigation with the FLFT effluent ranged from 10.81% ± 0.02% to 13.89% ± 0.02% (Table 2). After the completion of the study, the surface horizon LOI in the sampled soils was inside the following interval: 13.3% ± 1.6%–15% ± 3% (Table 2). On average, the soil LOI after irrigation was marginally higher as indicated by the results of the one-tail and two-tail Mann-Whitney test results at 5% level of significance (p-values < 0.047). However, this finding must be treated with caution, given the size of the standard deviation of the individual LOI values in Table 2.

If wastewater is to be reused for irrigation, it is important to consider the microbiology of the soil as this plays an important role in the health of the soil [58]. Soil characteristics are often affected by its microbial community and they include soil pH, mineralization of organic matter, moisture content and retention; and the survival of pathogens in the soil [59]. Soil microorganisms also play an important role in soil fertility, plant growth, soil structure, carbon and nitrogen storage [59,60]. Some soil microbes can also facilitate the degradation and breakdown of toxins and pollutants [60]. The TAB concentrations in the soils at the study sites were measured first before the irrigation with the FLFT effluent began. The measured mean values ranged from $(0.8 \pm 1.1) \times 10^6$ to $(2.6 \pm 3.3) \times 10^6$ CFUs/g dw. The TAB concentrations were measured again after the completion of the study and the respective average values ranged from (0.6 ± 0.8) × 10^6 to (1.3 ± 1.7) × 10^6 CFUs/g dw.

The TNB concentrations in the soils at the study sites were measured first before the irrigation with the FLFT effluent began and were found to range from (6.5 ± 6.7) × 10^5 to (26 ± 34) × 10^6 CFUs/g dw. The TNB concentrations were measured again after the completion of the study and the respective average values ranged from (5.7 ± 7.2) × 10^5 to (13 ± 18) × 10^5 CFUs/g dw. At each sampling site, the two-tail Mann-Whitney test was run to see, if the TAB and TNB were influenced by the irrigation with the FLFT effluent. At four out of the five sampling sites, there were no statistically significant differences in the TAB and TNB values measured before and after the irrigation with the FLFT effluent; and these sites were (p-value > 0.15): Fingo, Extension 1, Extension 9 and Town 1. At the Town 2 sampling sites, the TAB and TNB were influenced by the irrigation with the FLFT effluent (p-value < 0.04).

The FC concentrations in soils at the study sites before irrigation with the FLFT was initiated were equal to the following values (CFUs/g dw): 92 ± 1 at Fingo, 113 ± 5 at Extension 1, 99 ± 5 at Extension 9, 83 ± 2 at Tw 1 and 74 ± 2 at Tw 2. After the completion of the study, the soil FC concentrations were re-measured at each study site and the following concentrations were recorded (CFUs/g dw): 90 ± 12 at Fingo, 120 ± 28 at Extension 1, 102 ± 2 at Extension 9, 85 ± 9 at Tw 1 and 76 ± 6 Tw 2. The two-tail Mann-Whitney rest was run at 5% level of significance to test for statistically significant differences between the FC concentrations before and after the irrigation of the respective site soil with the FLFT effluent. Results of this testing indicate that irrigation with FLFT effluent did not have a statistically significant influence on the soil FC concentration at any of the study sites (p-values = 0.3768–0.6625).

To the best of the authors' knowledge, this is the first study reporting the effect of irrigation with treated greywater on TAB and TNB in South Africa. This makes the findings a baseline for the assessment and a potential reference point for future studies. A potential toxic effect of the selected metal concentrations on the yields and growth of the cultivated plant species was detected. Therefore the lack of changes in the TAB and TNB as a result of irrigation with the FLFT effluent was unlikely to have a detrimental effect on the plant growth observed in this study, that is, on soil fertility towards the cultivated species. The FC concentrations in this study are comparable with the *Escherichia coli* concentrations reported by Palese et al. [61].

Concentrations of selected metal species in the soils at the individual sampling sites were measured after the irrigation with the FLFT effluent. The aim was to establish whether the FLFT layers could serve as a source of metals that could have toxic side effects on the plant growth. Extraction of metals from environmental matrices using a 1 M HCl solution was used to extract the metals from sewage sludge as Tuin and Tels [47] reports that the extraction efficiencies ranging from 80% to 100% for the HCl-based extraction of Cu, Pb, Cd and Mn from solids. These extraction efficiencies are likely to be comparable or higher in this study as the extraction time was increased to 24 h. The measured metal concentrations are shown in Table 3, with each value being an average of two replicate measurements/extractions.

The overall average Mn concentration was equal to 45 ± 18 mg/kg dw. There is no guideline for the concentration of Mn in the respective South African guidelines for greywater reuse [50]. Deshumkh et al. [62] reported that concentration of Mn in soils irrigated with sewage for 5–20 years ranged from 1.15 to 15.7 mg/kg dw. This value together with the average values measured in this study is below the safe limit/threshold of 2,000 mg/kg dw [63]. As a result, irrigation with greywater treated with FLFT does not pose threats to human health with respect to the Mn concentration (Table 3).

The overall average Cu concentration was equal to 1.52 ± 0.64 mg/kg dw. In the vadose zone, the soil Cu concentrations have been reported to range from 0.68 ± 0.42 mg/kg dw, when the soil was irrigated with recycled wastewater [62]. Mzini and Winter [64] analysed the heavy metal content in greywater and soils irrigated with respective greywater around the Umtata dam in the Eastern Cape Province of South Africa. For copper, the authors reported that the surface layer of soil, similar to the horizon sampled in this study, contained between 21.84 and 22.25 mg/kg of Cu [64]. According to Gupta and Sinha [65], the soil concentration of Cu, which exceeds 21 mg/kg increases the likelihood of toxicity of plants. Based on this, the copper concentrations from this study are higher than selected literature data, but lower than previous data reported in South Africa. No significant toxicity towards plants grown in the soil irrigated with the FLFT effluent is expected.

The measured concentrations of Pb in the greywater irrigated garden soils were on average equal to 3.8 ± 3.3 mg/kg dw. The Pb concentrations from 5.28 to 5.67 mg/kg in the surface soil horizons in greywater irrigated soils in the Eastern Cape Province of South Africa [64]. Khalid et al. [66] reported that concentration of Pb in soils irrigated with wastewater ranged from 10 to 31 mg/kg dw and that the European Union allows a maximum permissible limit of 300 mg/kg. Therefore the data from the current study indicate that the concentrations of lead levels in the sampled soils from Makana Local Municipality are lower than data from selected international studies and similar studies in South Africa. The safe levels of Pb in the FLFT effluent-irrigated soils have not been exceeded, according to the international standards. The Cd concentrations were below the detection of the ICP method used, that is, 0.5 mg/kg dw. This detection limit is about one order of magnitude higher than the Cd levels reported in previous studies from South Africa [64[. Therefore additional studies on the fate of cadmium in the FLFT effluent-irrigated soil must be performed in the near future.

Table 3
Metal analysis of soil irrigated with greywater treated with the FLFT

Sampling sites	Metal concentration (mg/kg dw)							
	Mn	Cu	Pb	Cd	Mg	K	Al	Fe
Fingo	21	1.5	7.9	<0.5	184	111	349	327
Ext 1	50	1.8	5.0	<0.5	75	60	335	439
Ext 9	71	2.5	5.0	<0.5	91	156	328	489
Tw 1	42	0.9	0.9	<0.5	77	70	376	463
Tw 2	42	0.9	<0.5	<0.5	187	52	302	392

Concentrations of K and Mg must be assessed in irrigated soils as they have strong influence on properties such as soil hydraulic conductivity [67]. The soil concentrations of Mg were on average equal to 122 ± 57 mg/kg dw, while the average potassium concentrations were equal to 89 ± 43 mg/kg dw. Concentrations of Mg and K in the FLFT effluent-irrigated soil are lower than the concentrations of both metals reported in the greywater-irrigated soil by Mzini and Winter [64]. Those authors reported levels of 236.7–255.7 mg/kg for K and 1,283–1,434 mg/kg in the surface horizons of the greywater-irrigated soils [64]. Therefore, the average concentrations of Mg and K from this study are lower than the results from similar studies in the Eastern Cape Province of South Africa.

The mean aluminium concentrations in the soils in Makana Local Municipality irrigated with the FLFT effluent were equal to 338 ± 27 mg/kg dw. This far exceeds the Al concentrations reported for the surface horizons of the greywater-irrigated soils in the Umtata dam area of Eastern Cape Province of South Africa, which ranged from 0.183 to 0.217 mg/kg [64]. As a result, the Al concentrations in the soils irrigated with the FLFT effluent were higher than similar study results from South Africa. Soil concentrations of aluminium in the Makana soil irrigated with the FLFT effluent can be toxic to plants [68]. Further studies will have to be conducted to ascertain the significance of this observation at a larger scale of FLFT use. The average Fe concentrations in soils irrigated with the FLFT effluent ranged were equal to 422 ± 64 mg/kg dw. No reference data for South Africa could be found by authors in the literature. Given the neutral soil pH, no iron toxicity is foreseen towards the grown plants.

Examples of plants grown on the soil irrigated with FLFT effluent are shown in Fig. 5.

Three plants were harvested per sampling site. They were washed thoroughly with distilled water, and then weighed. The fresh weights in the following text are always listed in the order of Fingo, Extension 1 and Extension 9. The average fresh weights of the *Spinacia oleracea* plants were determined to be 10.4 ± 0.1, 15.5 ± 0.53 and 19.4 ± 0.17 g. The fresh weights for *Allium cepa* were equal to 14.47 ± 0.58, 15.71 ± 0.39 and 10.76 ± 0.26 g. At the same time, the fresh weights for the *Daucus carota* subsp. *sativus* plants were determined to be 46.67 ± 0.47, 35.65 ± 0.98 and 24.10 ± 0.28 g. Finally, the fresh weights for *Beta vulgaris* were measured and equal to 61.84 ± 0.52, 51.50 ± 0.56 and 18.42 ± 0.16 g. The Kruskal–Wallis analysis of variance by ranks at 5% level of significance was conducted to check for statistical significant differences in the fresh weights of the plants harvested from the three sampling sites. All types of plants harvested at three different sampling sites had different fresh weights and those differences were statistically significant at 5% of significance (*p*-values = 0.02651–0.02732).

The plant height was measured using a tape measure. The average height of the *Spinacia oleracea* was equal to 35.1 ± 1.6, 30.2 ± 0.6 and 14.8 ± 0.5 cm. For *Allium cepa*, the average height of plants was 26.6 ± 3.2, 10.6 ± 0.6 and 14.5 ± 0.5 cm. At the same time, plants of *Daucus carota* subsp. *sativus* had the average heights of 31.2 ± 1.0, 16.3 ± 0.1 and 14.2 ± 0.1 cm. Finally, plants belonging to *Beta vulgaris* had the following lengths: 36.3 ± 0.8, 15.5 ± 0.5 and 30.5 ± 0.6 cm. Results of the Kruskal–Wallis analysis of variance by ranks indicated that the plant heights were statistically and significantly different between Fingo, Extension 1 and Extension 9 (*p*-values = 0.02317–0.03742).

a)

b)

Fig. 5. The garden at Fingo site during the course of the study (a) and examples of each of the plant species grown and harvested in the study (b).

The yield of individual plant species at Fingo, Extension 1 and Extension 9 was measured as the plants dry weight. On average, the yield of *Spinacia oleracea* was equal to 1.60 ± 0.25, 1.00 ± 0.03 and 0.70 ± 0.02 g. There was no statistically significant difference between the spinach yield at the three sites with vegetable gardens established as part of this study (the Kruskal–Wallis analysis of variance by ranks at 5% level of significance *p*-value = 0.3012). For the yields for three remaining plant species studied, there was a statistically significant difference among the values measured at the three study sites (*p*-values = 0.02571–0.03794 in the Kruskal–Wallis analysis of variance by ranks at 5% level of significance). The actual average yields were as follows (g of dry weight): 0.49 ± 0.03, 0.44 ± 0.04 and 0.36 ± 0.02 (*Allium cepa*); 1.27 ± 0.10, 0.99 ± 0.01 and 0.96 ± 0.02 (*Daucus carota* subsp. *sativus*) and 4.24 ± 0.16, 2.53 ± 0.17 ± 0.17 and 1.38 ± 0.06 (*Beta vulgaris*).

The plant height recorded in this study is comparable with those measured by Salukazana et al. [69] for *Spinacia oleracea* and *Beta vulgaris*. Data for *Allium cepa* recorded in this study are lower than or comparable with the data of Salukazana et al. [69]. Fresh weights were lower in the current study than in the study of Salukazana et al. [69]. The Al concentrations in the analysed soils and the resulting toxicity to the grown plants could provide an explanation for the observed plant analyses results. Further studies will have to be focused on this aspect of the FLFT effluent reuse in Makana Local Municipality.

4. Conclusions

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 terms of the water infrastructure, all the three study sites which were located in the Grahamstown East area of Makana Local Municipality lacked basic greywater disposal systems such as sinks in the kitchen and tubs in the bathrooms. Therefore, the FLFT reactor made it easier and safer from the public health point of view for the household occupants to dispose their greywater. They were able to re-use their greywater to irrigate their garden. The sites that were in town were equipped with greywater disposal systems. Therefore, for the commercialisation of the filter tower, the system would have to be connected to the sinks and bathtubs. The aluminium concentrations in the analysed soils provide an explanation for the observed plant growth data. The FLFT should be inoculated with denitrification bacteria and its operation must be further investigated for the optimisation of the nitrate removal. Further studies will have to be focused on this aspect of the FLFT effluent irrigated vegetables in Makana Local Municipality.

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