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Characteristics of greywater from different sources within households in a community in Durban, South Africa

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

ABSTRACT

The reuse of greywater is steadily gaining importance in South Africa. Greywater contains pollutants that could have adverse effects on the environment and public health if the water is not treated before reuse. Successful implementation of any greywater treatment process depends largely on its characteristics in terms of the pollutant strength. This study investigated the physico-chemical characteristics of greywater from different sources within 75 households in a community in Durban, South Africa. The study was undertaken to create an understanding of greywater quality from different sources within and between households. Greywater samples were collected from the kitchen, laundry and bathing facilities within each of the households. The samples were analysed for: pH, conductivity, turbidity, total solids, chemical oxygen demand (COD) and biological oxygen demand (BOD). There was a significant difference in the parameters analysed between the greywater from the kitchen compared with the greywater from the bathtub/shower and laundry. It was also observed that the characteristics of greywater from the different households varied considerably. The characteristics of the greywater obtained in this study suggest that the greywater generated cannot be easily treatable using biological treatment processes and/or technologies due to the very low mean BOD : COD ratio (<0.5).

Key words | biological treatment, characteristics, greywater, pollutant, reuse, treatment process

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INTRODUCTION

The shortage of potable water is one of the major challenges that many countries are facing today; the situation is becoming very serious and is worsening as many of these countries are experiencing drought (WHO 2006). Today, an inadequate supply of freshwater is one of the principal causes of public health problems facing many developing countries (WHO 2006; Katukiza *et al.* 2015). South Africa is a semi-arid country with spatial and temporal variability in the amount of rainfall received, coupled with high rates of evapotranspiration (Bakare *et al.* 2016). In South Africa, and around the world, there has been an increase in demand for freshwater, placing pressure on the ability of natural systems to provide an adequate quantity and quality because of population growth, urbanization and/or industrialization (Carden *et al.* 2006). This has led to large-scale interest in the application of water reclamation and reuse of domestic, mining and industrial wastewater as alternative water supply sources (Carden *et al.* 2006; Edwin *et al.* 2014). The requirement for freshwater is becoming critical to sustaining development and economic growth in the Southern Africa region. The development of water reuse schemes in South Africa has been generally slow compared to some other developed countries. It is only recently that some water authorities in South Africa have begun to shift their focus to identify various water reuse and recycling schemes. It has been suggested that the large amount of

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greywater generated from South African households could be treated with simple technologies and reused for non-potable needs, such as toilet flushing and outdoor irrigation (Carden *et al.* 2006). Greywater is the water generated from household uses like bathing, laundry and washing of dishes, without input from the toilets (Edwin *et al.* 2014). Greywater makes up to about 60–70% of domestic wastewater volume in most developed countries (Friedler 2004; Edwin *et al.* 2014). The generation of greywater is directly related to the consumption of water in a household and is dependent on a number of factors including the level of service provision, tolerance of residents to pollution and the communities' level of awareness of health and environmental risks (Carden *et al.* 2006). According to Carden *et al.* (2006), it could be assumed that greywater accounts for virtually all water usage in non-sewered areas except for that which is used for drinking purposes, that which is used consumptively in cooking and the water that remains on the surfaces of washed articles.

A variety of research has been conducted to characterize greywater generated from various sources in order to determine greywater quality (Friedler 2004; Jefferson *et al.* 2004; Abu Ghunmi *et al.* 2008; Antonopoulou *et al.* 2013; Bodnar *et al.* 2014; Edwin *et al.* 2014; Katukiza *et al.* 2015). The quality of greywater depends on the source from which it is drawn as well as the use to which this water is put, but there are general characteristics that apply to greywater (Carden *et al.* 2006). Greywater can be divided into two categories based on pollutant loads: high pollutant load and low pollutant load (Friedler 2004). According to Li (2009), greywater generated from household kitchens and those from the laundry are higher in organics and physical pollutants compared to bathroom and mixed greywater. Various factors, such as the number of residents in a household, age distribution, living standard, residents' cultural habits and the quality of the water supplied to the household, may have an influence on the greywater characteristics and result in a wide variation in the quality of greywater generated from different households and from various sources within a household (Morel & Diener 2006).

In terms of basic water quality parameters, greywater is considered to be comparable to low- or medium-grade wastewater (Friedler 2004); however, there are several key differences in the quality of greywater that need to be considered in order to narrow in on the specific challenges involved in its treatment and reuse. Soaps and detergents are often alkaline, so the pH of greywater tends to be in the range 7–8 (Jefferson *et al.* 2004) and, unlike wastewater that can contain high concentrations of N, P and K, only minor quantities of nutrients have been detected in greywater samples, rarely exceeding 5 mg/l (Jefferson *et al.* 2004). Many researchers have documented that greywater constituents are partly recalcitrant, i.e. slowly or even non-biodegradable (Friedler 2004; Jefferson *et al.* 2004). According to Dixon *et al.* (1999), biodegradation of greywater starts under anaerobic conditions within 2 days of storage. The maximum biodegradability of greywater under anaerobic conditions measured as chemical oxygen demand (COD) has been found to range from 60 to 80% while under aerobic conditions it has been found to be above 85% (Elmitwalli & Otterpohl 2007; Zeeman *et al.* 2008). The BOD : COD ratio of greywater has been reported to be substantially low varying from 0.25 to 0.64 (Friedler 2004; Jefferson *et al.* 2004), thus indicating that greywater generated from households are slowly, or even non-, biodegradable.

Microbiological contaminants of household greywater have received much attention in recent research (Dixon *et al.* 1999; Ottosson & Stenström 2003; Birks & Hills 2007) due to their ability to cause human illness. Microbial pathogens are often considered the most significant health concern associated with greywater reuse. Reviews of various characterization studies that include microbial parameters show that kitchen sink and dishwasher effluent are often the most highly contaminated due to the presence of food and grease particles and warn of high *Salmonella* counts in these streams (Birks & Hills 2007). Other sources, such as water from the bath, hand basin and clothes washing machine, are the principal contributors of organisms of faecal origin, attributable to the washing of soiled clothing or diapers, hand washing after toilet use and bathing. Ottosson & Stenström (2003) outline the full spectrum of hazardous microbial agents potentially present in household greywater and provide an outline for assessing the health risks they present. Pathogenic organisms identified include faecal bacteria, *Campylobacter*, *Salmonella*, *Legionella*, enteric viruses (especially *Rotavirus*), and protozoa, including *Giardia* and *Cryptosporidium* (Ottosson & Stenström 2003). This study was undertaken to gather information on

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greywater quality from different sources within and between households in order to identify the type of treatment processes that would be required for the type of reuse application. Thus, this paper reports on an investigation of the variation in the characteristics of greywater from different sources within a randomly selected number of households in a community in Durban, South Africa.

METHODOLOGY

Study area

The study area used for this investigation, as in Bakare *et al.* (2016), is the Umhlabeni informal settlement in the eThekwini Municipality, Durban, South Africa. The area is predominantly a low income peri-urban settlement which is densely populated (Bakare *et al.* 2016). Households in this area are non-sewered and without onsite waterborne sanitation. The population in the area is homogeneous in terms of their income level and diet. Seventy-five independent households were selected at random within the community for this study. The total number of inhabitants in the selected 75 households was 240: 115 adult women, 83 adult men and 42 are under the age of 18. The inhabitants had a wide distribution of age, with an average age of 32 years.

Greywater sampling

This study independently sampled and assessed the physical and chemical properties of greywater generated from the kitchen, laundry and bathing sources. Three sets of samples for each greywater source were collected from the 75 households over a period of 4 weeks mainly during the weekdays. Grab samples were collected once a day from each source within 2 hours from production usually by/before noon in sterilized 1 L sampling bottles, and sealed and labelled before placing in a cooler box containing ice. Samples were collected directly from the shower or bathtub, and the laundry water was collected from the manual washing areas while the kitchen water was collected from the kitchen sink. Samples were immediately analysed where possible or stored at not more than 4 °C for a maximum of 24 hours.

Laboratory analysis

Physico-chemical analyses of the greywater collected were determined for the selected parameters: pH, conductivity, turbidity, total solids, COD and biological oxygen demand (BOD). All analyses were carried out using *Standard Methods for the Examination of Water and Wastewater* (APHA 2012). The COD was determined using the open reflux method for particulate samples while the BOD was determined using the 5-day procedure incubation at 20 °C with OxiTop manometric equipment. The pH, conductivity and turbidity were determined *in situ* using a calibrated Orion Star A215 pH/conductivity meter and a TB300 IR Orbeco Hellige turbidity meter, respectively.

A comparison of the characteristics of greywater collected from the households for each parameter was performed using univariate analysis of variance (ANOVA) with a *post-hoc* Scheffe test (Brownlee 1966). The univariate ANOVA is used to compare several means while the *post-hoc* Scheffe tests are designed for situations in which one has already obtained a significant omnibus F-test with a factor that consists of three or more means and additional exploration of the differences among means is needed to provide specific information on which means are significantly different from each other. The *post-hoc* Scheffe tests are a critical step in the univariate ANOVA process because they allow for the determination of which means are significantly different from the others. Thus for the analysis of data generated from this study, this statistical analysis was found appropriate to determine if there exist significant differences in the quality of greywater generated between households as well as greywater generated from the identified sources within a household. The statistical tests were done using SPSS 22.0 software package.

RESULTS AND DISCUSSION

The results obtained from the physico-chemical characterization of greywater collected from various sources within the

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different households are presented as box and whisker plots in Figures 1–6. The pH results are presented in Figure 1.

The average measured pH value for the different sources (kitchen, laundry and bath) were found to be 6.25, 9.58 and 9.24 respectively. It was observed that the greywater from the kitchen had the lowest pH value. This could be attributed to the fact that greywater generated from the kitchen was mostly contaminated with fractions of food particles and oils, and degradation of the greywater will occur more rapidly in an anoxic condition compared to the greywater generated from other sources. The relatively higher pH values for greywater collected from the laundry and from bathing may be due to the alkalinity of the type of detergent and/or soap used for these activities. Statistical analyses conducted using univariate ANOVA with a *post-hoc* Scheffe test indicated that the difference in the measured pH values for the different greywater sources was significant ($p < 0.05$). The overall average pH value from the three

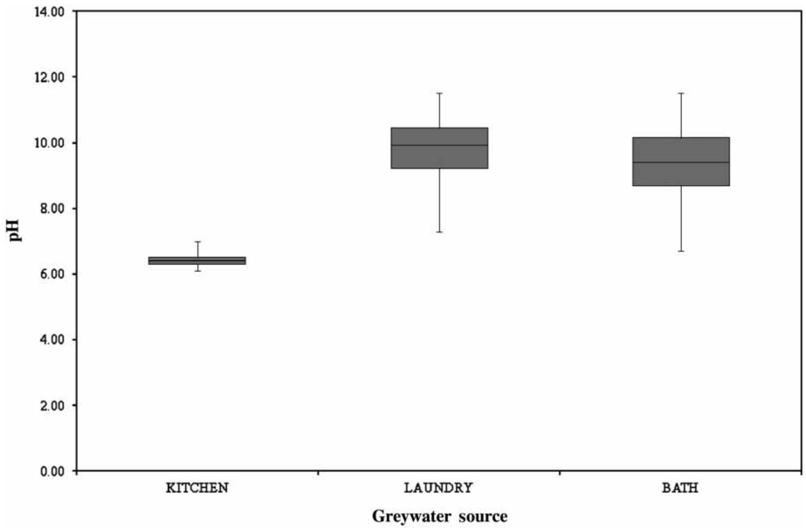

Figure 1 | Box and whisker plot for the pH results. The extremes of the whisker represent the maximum and minimum values respectively. The outline of the box represents the third and first quartile and the line in the box represents the median.

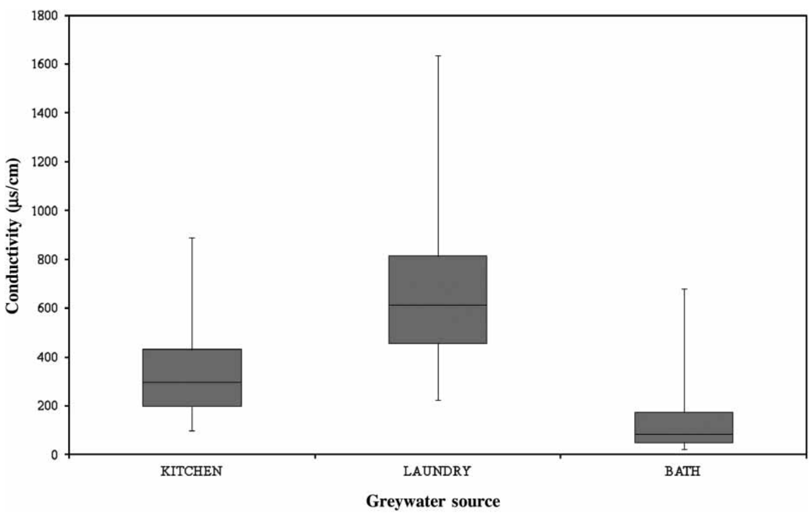

Figure 2 | Box and whisker plot for the conductivity results. The extremes of the whisker represent the maximum and minimum values respectively. The outline of the box represents the third and first quartile and the line in the box represents the median.

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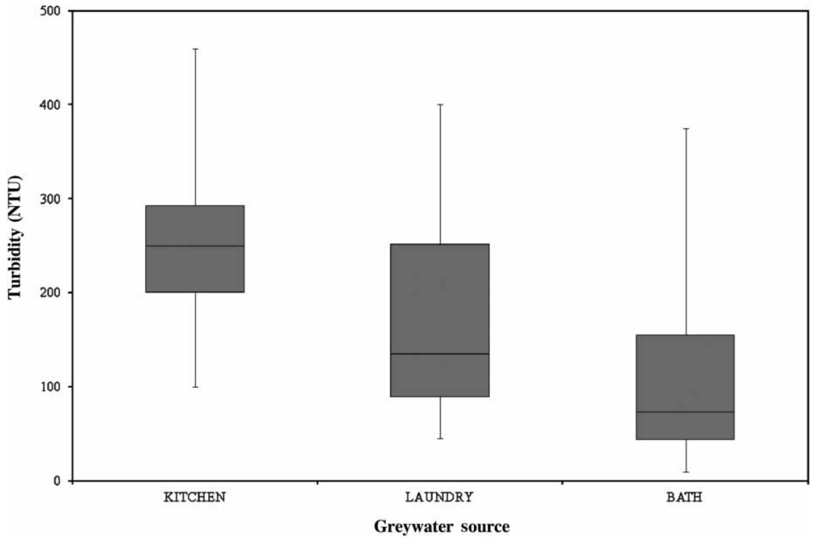

Figure 3 | Box and whisker plot for the turbidity results. The extremes of the whisker represent the maximum and minimum values respectively. The outline of the box represents the third and first quartile and the line in the box represents the median.

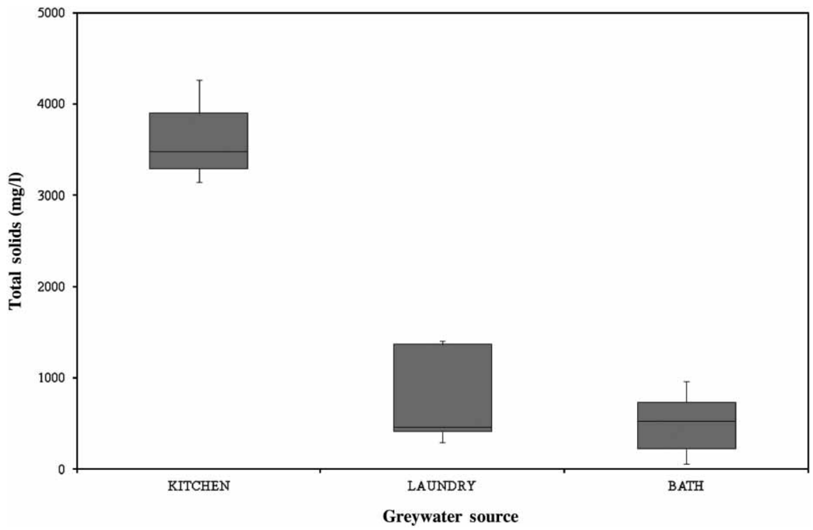

Figure 4 | Box and whisker plot for the measured total solid concentration. The extremes of the whisker represent the maximum and minimum values respectively. The outline of the box represents the third and first quartile and the line in the box represents the median.

sources was found to be 8.35. This value falls within the range 6.5–8.4 (USEPA 2004) which is said to be an appropriate value that will enhance easy treatment or will not have adverse impacts on soil or plants when used for irrigation.

Figure 2 presents the conductivity results. The conductivity of the greywater is a measure of the salinity of all dissolved ions present. The average measured conductivities for the different sources (kitchen, laundry and bath) were 320, 680 and 156 μS/cm respectively. Greywater from the kitchen and laundry showed higher conductivity values than greywater from the bath. Comparison of the values using univariate ANOVA with a *post-hoc* Scheffe test indicated that the difference was significant ($p < 0.05$).

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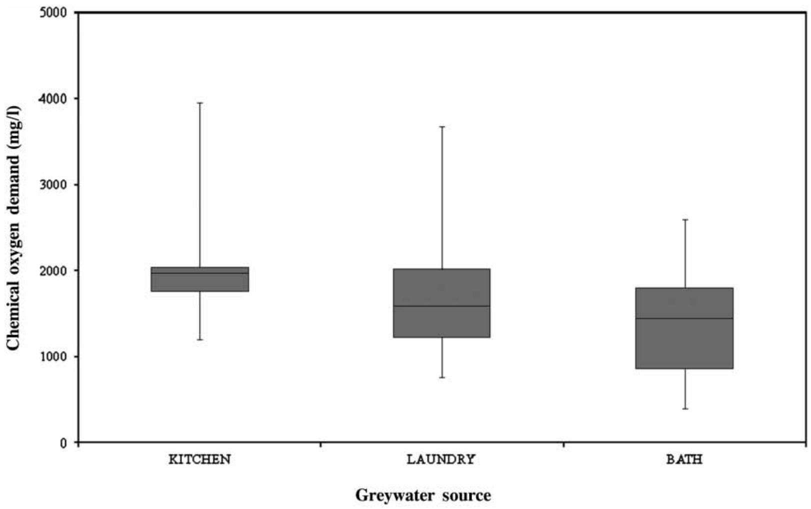

Figure 5 | Box and whisker plot for the measured COD. The extremes of the whisker represent the maximum and minimum values respectively. The outline of the box represents the third and first quartile and the line in the box represents the median.

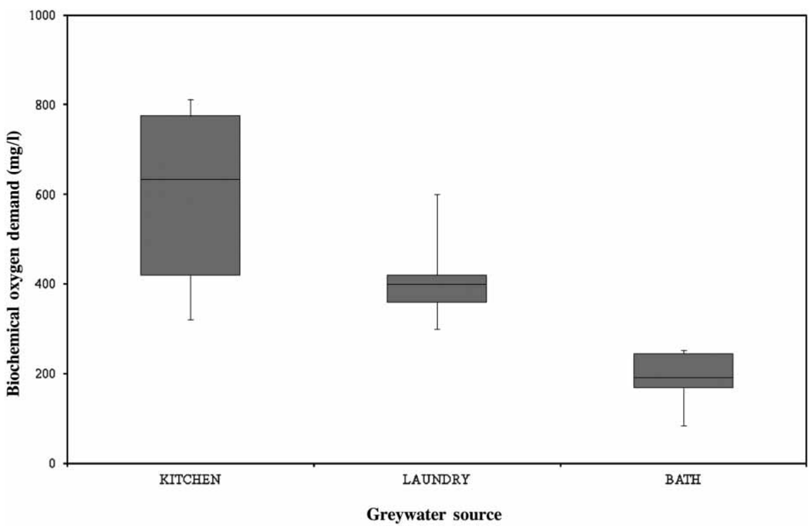

Figure 6 | Box and whisker plot for the measured BOD. The extremes of the whisker represent the maximum and minimum values respectively. The outline of the box represents the third and first quartile and the line in the box represents the median.

A high conductivity value is usually not a problem unless the greywater is intended to be reused for irrigation purposes. The reason is that a high conductivity value could have an adverse effect on the plants and may lead to a long-term impact of salt loading in the soil when used for irrigation. The conductivity value obtained from the three sources investigated in this study is well below the value that could lead to any such adverse effects when used for irrigation, according to Grattan (2002).

All three sources from which greywater were collected exhibited a very high turbidity value as presented in Figure 3, with greywater from the kitchen exhibiting the highest turbidity of the three. This could be a result of the amount of soap used in the kitchen and the fact that the greywater from the kitchen source was highly contaminated with food particles which contributes to high suspended solid materials. The average measured turbidities for the different sources (kitchen, laundry and bath) were found to be 252

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NTU, 170 NTU and 120 NTU respectively. Comparison using univariate ANOVA with a *post-hoc* Scheffe test indicated that the differences were significant ($p < 0.05$).

The results obtained from the measured total solid concentrations in the greywater are presented in Figure 4. Greywater collected from the kitchen exhibited the highest total solid concentration, which was attributed to the fact that the greywater from this source was the most contaminated fraction with food particles. The average measured total solid concentration in the kitchen greywater was found to be 3,589 mg/l. The total solid concentration in the laundry greywater was lower with an average measured value of 736 mg/l while that from bathing was found to be the lowest with an average value of 504 mg/l. Comparison using univariate ANOVA with a *post-hoc* Scheffe test indicated that the differences was significant ($p < 0.05$).

COD measures the amount of oxygen required to oxidize the organic material present in a water sample. The measured value of COD is usually higher than that of measured BOD in many waste streams because many organic substances can be oxidized chemically rather than biologically. Measured COD is an indication of the polluting strength of the greywater generated from the three sources within the household investigated. Figure 5 presents the results of the measured COD in the greywater samples investigated.

According to the measured COD, the kitchen greywater has the most polluting strength with an average COD value of 2,074.50 mg/l, indicating a high level of organic compounds. The COD for the laundry greywater was lower with an average value of 1,628.49 mg/l and that from the bathing lowest with an average value of 1,426.37 mg/l. Application of univariate ANOVA with a *post-hoc* Scheffe test indicated a significant difference ($p < 0.05$) from the three different sources investigated.

BOD measures the amount of organic compounds in the greywater which can be oxidized biologically rather than chemically. Similar findings to that for COD were observed for the BOD of the greywater (Figure 6).

The measured BOD for greywater from the kitchen source exhibited the highest fraction of organic compounds with an average value of 604.50 mg/l. The measured BOD for the greywater from the laundry was lower with an average value of 413.75 mg/l, while that from the bath water was the lowest with an average value of 185.25 mg/l. The univariate ANOVA with a *post-hoc* Scheffe test indicated that there was significant variation ($p < 0.05$) in the measured BOD from the different sources within the household investigated. The measured BOD of the greywater from the different sources is in agreement with the measured COD investigated in this study, and as such it could be inferred from this study that greywater from the kitchen source contains the highest organic compounds compared to the other sources investigated. Thus, greywater from the kitchen source in the households investigated had the greatest polluting strength.

CONCLUSIONS

The purpose of this paper was to provide an understanding of the physico-chemical characteristics of greywater from different sources within randomly selected households in a peri-urban community in Durban, South Africa. The common sources of greywater identified in this community were from the kitchen, laundry and bath. The characterization results obtained in this study has provided information on the inherent variability of greywater quality from different households and from different sources within a household. A high amount of variability was observed in the physico-chemical properties of the greywater generated between the households investigated as well as from the different sources within household, as shown in Figures 1–6 and confirmed by the statistical analysis conducted.

The pH values of greywater sources for the kitchen, laundry and bathing ranged from 6.10 to 7.0, 7.28 to 12.58 and 6.71 to 11.50 respectively. These values are within ranges obtained from previous studies of greywater qualities (Bodnar *et al.* 2014; Edwin *et al.* 2014; Katukiza *et al.* 2015) except for the values obtained for the kitchen sources. The pH values for the kitchen source in this study was lower than in previous studies; these low values are attributed to the high contamination of greywater with fractions of food particles and oils which influences spontaneous anoxic conditions and acidification of organics. The pH values from the different sources investigated in this study are appropriate for irrigation and will

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not adversely affect soils or plants (USEPA 2004; Abu Ghunmi *et al.* 2008). The measured conductivity, turbidity and total solids of the greywater samples in this study are within the ranges obtained from previous studies (Abu Ghunmi *et al.* 2008; Antonopoulou *et al.* 2013; Bodnar *et al.* 2014; Edwin *et al.* 2014). The conductivity values obtained from the various sources was significantly lower than the value (<1,300 μS/cm) that can have adverse effects on the plant and soil when used for irrigation (Grattan 2002). The results from this study showed that greywater from the bath source presents lower conductivity, turbidity and total solids compared to the other sources.

The priority pollutants in greywater generated from various sources within households are usually the organic components present in the greywater. COD and BOD are appropriate parameters that are used to measure the organic pollutants in water. COD and BOD varied between households investigated as well as from different sources within a household.

The COD and the BOD ranged respectively from 1,200 to 3,955 mg/l and 320 to 812 mg/l for greywater from the kitchen source, the highest among the sources investigated, 760 to 3,672 mg/l and 300 to 600 mg/l for greywater from the laundry source, and 400 to 2,600 mg/l and 85 to 253 mg/l for greywater from the bath source. The greywater generated from different sources within the 75 households investigated in this study exhibited relatively high COD compared to the BOD. The ratio of the BOD to the COD serves as a good indicator of the biodegradability of greywater generated from the different sources within the households investigated. It was observed in this study that the greywater generated from all the three sources investigated had very low mean BOD : COD ratios (ratios significantly lower than 0.5). The mean BOD : COD ratios were 0.29, 0.25 and 0.13, respectively, for kitchen, laundry and bath in this study. These ratios are within the range (0.25–0.64) reported in the literature (Friedler 2004; Jefferson *et al.* 2004).

Greywater generated from bathing activities was the least contaminated source among all the sources considered in this study and greywater from the kitchen was the most contaminated. This study therefore proposes that the least contaminated greywater source from households should be prioritised for reuse. The findings from this study are very similar to various studies reported in literature (Friedler 2004; Jefferson *et al.* 2004; Abu Ghunmi *et al.* 2008; Antonopoulou *et al.* 2013; Bodnar *et al.* 2014; Edwin *et al.* 2014; Katukiza *et al.* 2015).

The characteristics of the greywater obtained in this investigation conducted indicate the necessity of treatment prior to disposal into the environment or for reuse purposes (including non-potable reuse). However the greywater quality generated from the community in which the study was conducted cannot be easily biodegraded as revealed by the very low BOD : COD ratio. This study therefore recommends that appropriate treatment methods should be developed to treat the greywater generated from this community. Natural treatment systems such as horizontal roughing filtration systems or constructed wetlands could be considered because of low cost and maintenance requirements.

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REFERENCES

Abu Ghunmi, L., Zeeman, G., van Lier, J. & Fayyad, M. 2008 Quantitative and qualitative characteristics of grey water for reuse requirements and treatment alternatives: the case of Jordan. *Water Sci. Technol.* **58**, 1385–1396.

Antonopoulou, G., Kirkou, A. & Stasinakis, A. S. 2013 Quantitative and qualitative greywater characterization in Greek households and investigation of their treatment using physicochemical methods. *Sci. Total Environ.* **454–455**, 426–432.

APHA (American Public Health Association) 2012 *Standard Methods for the Examination of Water and Wastewater*, 20th edn. American Water Works Association and Water Environmental Federation, Washington, DC.

Bakare, B. F., Mtsweni, S. & Rathilal, S. 2016 A pilot study into public attitudes and perceptions towards greywater reuse in low cost housing development in Durban, South Africa. *J. Water Reuse Desalination* **6**, 345–354.

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Birks, R. & Hills, S. 2007 Characterization of indicator organisms and pathogens in domestic greywater for recycling. *Environ. Monit. Assess.* **129**, 61–69.

Bodnar, I., Szabolcsik, A., Baranyai, E., Uveges, A. & Boros, N. 2014 Qualitative characterization of household greywater in the Northern great plain region of Hungary. *Environ. Eng. Manage. J.* **13**, 2717–2724.

Brownlee, K. A. 1966 *Statistical Theory and Methodology in Science and Engineering*. Wiley, New York.

Carden, K., Armitage, N., Winter, K., Sichone, O. & Rivett, U. 2006 *Understanding the Use and Disposal of Greywater in the Non-sewered Areas in South Africa, WRC Report No 1524/1/07*, Water Research Commission, Pretoria, South Africa.

Dixon, A., Butler, D., Feweks, A. & Robinson, M. 1999 Measurement and modelling of quality changes in stored untreated grey water. *Urban Water* **1**, 293–306.

Edwin, G. A., Gopalsamy, P. & Muthu, N. 2014 Characterization of domestic gray water from point source to determine the potential for urban residential reuse: a short review. *Appl. Water Sci.* **4**, 39–49.

Elmitwalli, T. & Otterpohl, R. 2007 Anaerobic biodegradability and treatment of grey water in upflow anaerobic sludge blanket (UASB) reactor. *Water Res.* **41**, 1379–1387.

Friedler, E. 2004 Quality of individual domestic greywater streams and its implication for on-site treatment and reuse possibilities. *Environ. Technol.* **25**, 997–1008.

Grattan, S. R. 2002 *Irrigation Water Salinity and Crop Production*. Publication 8066, University of California, Oakland.

Jefferson, B., Palmer, A., Jeffrey, P., Stuetz, R. & Judd, S. 2004 Greywater characterisation and its impact on the selection and operation of technologies for urban reuse. *Water Sci. Technol.* **50**, 157–164.

Katukiza, A. Y., Ronteltap, M., Niwagaba, C. B., Kansimme, F. & Lens, P. N. L. 2015 Greywater characterization and pollutant loads in an urban slum. *Int. J. Environ. Sci. Technol.* **10**, 1–4.

Li, F. 2009 *Treatment of Household Greywater for Non-Potable Reuses*. PhD Thesis, Hamburg University of Technology.

Morel, A. & Diener, S. 2006 *Greywater Management in Low and Middle-Income Countries: Review of Different Treatment Systems for Households or Neighbourhoods. Sandec Report no 16/06*, Swiss Federal Institute of Aquatic Science and Technology Eawag Dübendorf, Switzerland.

Ottosson, J. & Stenström, T. A. 2003 Growth and reduction of microorganisms in sediments collected from a greywater treatment system. *Letters Appl. Microbiol.* **36**, 168–172.

USEPA (United States Environmental Protection Agency) 2004 *Guidelines for Water Reuse. EPA/625/R-04/108*.

WHO 2006 *WHO Guidelines For The Safe Use of Wastewater, Excreta and Greywater, Volume 4, Excreta and Greywater use in Agriculture*. Available from: http://www.who.int/water_sanitation_health/publications/gsuweg4/en/ (accessed 24 October 2016).

Zeeman, G., Kujawa, K., de Mes, T., Hernandez, L., de Graff, M., Abu Ghunmi, L., Mels, A., Meulman, B., Temmink, H., Buisman, C., van Lier, J. & Lettinga, G. 2008 Anaerobic treatment as a core technology for energy, nutrients and water recovery from source-separated domestic waste. *Water Sci. Technol.* **57**, 1207–1212.

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