overall project:

Greywater use in peri-urban households in Kitgum, Uganda

Authors: Kulabako, Kinobe, Mujunga, Olwenyi, Sleytr

Abstract

In this study, undertaken within the ROSA project (Resource oriented Sanitation concepts in peri-urban areas in Africa), an understanding of greywater characteristics is created to demonstrate a low cost reuse option involving direct application of untreated greywater to small so called "greywater towers" at household level in peri-urban settlements in Kitgum Town Council. It can be concluded that greywater towers provide a simple method to treat and use greywater for gardening.

Introduction

Urbanization in cities of the developing world like Uganda is virtually synonymous with formation of dense human settlements inhabited by the poor, lack of adequate safe drinking water, lack or inadequate sanitation (excreta, greywater and solid waste) and generally a degraded environment. The high populations living under such conditions are subject to health risks. With the increasing demand for freshwater, it is of paramount importance that water consumption shifts towards one, which promotes consumption of adequate amounts of water of acceptable quality. However, this shift requires that alternative sources of water are identified. Experiences elsewhere in the world including several arid and semi-arid countries indicates that greywater can be a cost effective alternative source of water (Morel and Diener, 2006). Greywater is water coming from cloth washers, bathtubs, showers, kitchen sinks and dishwashers and comprises between 50 to 80% of residential wastewater (Al-Jayyousi, 2003).

Governments allocate substantial amounts of money to develop, treat and transport water resources. On the other hand, more money is spent to collect wastewater, treat it and then transport it to distant places for potential uses. To address the externalities of this paradigm, attention is to be focused on small-scale and on-site treatment of wastewater/greywater. In Uganda, very few households particularly in the peri-urban settlements are connected to the sewerage system. In Kampala, the capital city of Uganda < 7% of the city's households are connected to the sewerage system with the majority using on-site sanitation systems while in Kitgum Town Council (KTC), a semi-arid town in Northern Uganda, on-site sanitation systems predominate (ROSA, 2007).

In the peri-urban areas of Kitgum town like in most cities of developing countries, greywater is disposed of, untreated onto the ground and into open storm water drains. The unsanitary disposal results in creation of malaria mosquito breeding grounds, smelly stagnant waters, children falling ill after playing in the wastewater, etc. (ROSA, 2007). The majority of the communities in the peri-urban settlements of KTC do not reuse the greywater and yet frequently experience water supply shortages following power outages (pumping from the central water supply stalls) and have an inadequate number of boreholes (ROSA, 2007). According to Imhof and Muhlemann (2005), the main barrier for wider and faster dissemination of suitable greywater management systems at household level in the developing countries, is the lack of knowledge and experience. Scientific knowledge is sparse regarding greywater characteristics allowing its reuse. This study, undertaken within the ROSA project (Langergraber et al., 2008), seeks to create an understanding of greywater characteristics and demonstrate a low cost reuse option involving direct application to small gardens at household level in peri-urban settlements in KTC.

Technical detail:

- greywater tower gardens; poles (wooden, iron bars or fence posts) and shading material surrounding the soil and a central stone-packed drain; vegetables (e.g. tomatoes, spinach) are planted into slits of the shading material in the soil;

Background

The project ROSA (Resource-Oriented Sanitation concepts for peri-urban areas in Africa, Langergraber et al., 2008) promotes resource-oriented sanitation concepts as a route to sustainable and ecological sound sanitation in order to meet the UN Millennium Development Goals (MDGs). The project is undertaken in four pilot cities in East Africa namely Arba Minch (Ethiopia), Nakuru (Kenya), Arusha (Tanzania) and Kitgum (Uganda). These cities have a population from several 10,000 up to 500,000 inhabitants and share common problems, e.g. they are situated in rather dry regions resulting in lack of water, have relatively high population growth rates and poor sanitation facilities, if available at all.

Kitgum district is located in Northern Uganda, 452 km from Kampala. The district has experienced civil war characterized with death, abduction, rape, and destruction of social infrastructures and displacement of the people for the last two decades. As a result of this instability, poor sanitation and lack of safe water are the biggest problems encountered in Kitgum. The project study area KTC is the districts headquarter and commercial center of Kitgum district. The town council has an area of 30 km^2 with a population of 62,000 inhabitants spread over 11 parishes and 36 villages. The area includes urban, peri urban and rural typical settlement structures in terms of housing and population density.

Material and methods

Research baseline

To ascertain the baseline situation in the study area regarding greywater reuse practices (if any), a review of available publications and or reports was undertaken. Additionally, interviews were held with 38 households within Kitgum Town Council area.

Identification and sensitisation of study households

The characterization of greywater and installation of greywater towers was limited to selected households in Pondwongo village in KTC. Pondwongo was selected because it is a semi-arid area with water scarcity problems necessitating alternative water sources for agriculture. The selection of the study households involved consultations with the town council authorities, community leaders and local residents by the research team. Seven households categorized as i) high class: households with iron roofed houses with cemented floors and plastered walls; ii) medium class: households with iron roofed houses, could lack cement and/or not plastered and, and iii) low class: households with grass thatched were selected. The selected households were sensitized on how greywater could be utilised through agriculture and the associated potential benefits (Figure 1).

Figure 1 Sensitisation of the households by the research team

For greywater treatment the technology of greywater towers (as described in Crosby, 2005) was selected as it is a simple, innovative system, which uses greywater for growing vegetables on a small footprint (<1 m^2) and can be easy self constructed with a few and local materials. Further more it is easy to operate and maintain.

Setting up of the greywater towers

3 greywater towers were set up at each of the selected households. At one household, a control tower garden was set up in exactly the same way as the greywater tower. It was also planted with the same vegetables, but with the only difference that it was being fed with groundwater and not with greywater. Greywater towers are a user friendly and innovative way of using greywater for gardening in low and middle income countries and have been implemented for example in Kenya, South Africa and Ethiopia. The study households were trained by the research team on how to set up the greywater towers as well as on the operation and maintenance aspects of these for effective performance.

When setting up a greywater tower garden, a circle was marked out on the ground with a diameter as that of the shade cloth (Figure 2a). This circle was dug out to form the bottom layer of the tower garden. Side wooden poles (2m high) were planted firmly into the bottom following which a shade cloth was tied around the poles to make a cylinder (Figure 2b). The sides of the shade cloth were then rolled cylinder out before back filling (Figure 2c).

Figure 2 Setting up of a tower garden at one of the households in KTC

The back fill consisted of a mixture of three parts of soil, two parts of animal manure and one part of ash to provide facility. The different parts were measured out by volume using a bucket (Figure 2d). The backfill was then well mixed before applying it (Figure 2e). A bucket with its bottom removed was placed at the bottom in the middle of the tower (Figure 2f). Stones were carefully packed in the bucket in such a way that did not permit fast flow of the water through (Figure 2g). The sides of the bucket were back filled with the soil mixture (Figure 2h). The bucket was then partially pulled out leaving the stones in position. The bucket was placed again and filled with stones and sides back filled (Figure 2i). This was repeated for each soil layer until the top layer of the tower garden (Figure 2j and Figure 2k).

Operation of the greywater towers

Greywater towers were operated in such a way that greywater from the bathroom and laundry was applied on a daily basis. On average each greywater tower could receive about 3 litres of greywater per day. Over the weekend, the greywater towers were splashed with 2 buckets (about 10litres) of clean water to wash away the soap. Selected vegetables such as tomatoes and onions were planted on the greywater towers. The control tower garden received about 3 litres of groundwater per day that was used by the household for domestic purposes.

Greywater sample collection and analysis

Samples were collected from 6 households every two to three weeks from 3 greywater streams (kitchen, laundry and bathroom) for a period of 6 months. Physico-chemical and bacteriological analyses of the greywater were determined for the selected parameters: pH, Dissolved Oxygen (DO), Electrical conductivity (EC), Temperature, Total Dissolved Solids (TDS), Turbidity, Chemical Oxygen Demand (COD), 5-day Biochemical Oxygen Demand (BOD_5), Ammonia-Nitrogen (NH_3-N), Ortho

Phosphorus, Total Phosphorus, Sodium Adsorption Ratio (SAR) and E. Coli. The parameters pH, DO, EC and Temperature were determined in-situ using a calibrated multi-parameter meter (Quanta-Hydrolab). Samples for physico-chemical and bacteriological analyses were collected in acid rinsed and steriled bottles respectively, stored in a cool box at 4^{o}C and transported for analysis to the Public Health and Environmental Engineering Laboratory at Makerere University in Kampala. Prior to the analysis for ortho and total phosphorus, and ammonia nitrogen. The samples were filtered through a 1.2 μm Whatman glass microfibre filter paper (GF/C). COD was determined using the Closed Reflux, Titrimetric method (APHA/AWWA/WEF, 1998). BOD_5 was determined by pressure difference within a closed system (BOD_5 CW7000 direct reading apparatus) according to the instrument manual. Total phosphorus was determined using the ascorbic acid method with persulfate digestion while Ortho phosphorus was measured using the ascorbic acid method (APHA/AWWF/WEF, 1998). NH_3-N was determined using the Direct Nesslerization method (APHA/AWWF/WEF, 1998). Potassium, sodium, calcium and magnesium were determined using atomic absorption spectrometry (Perkin-Elmer 2380). Sodium Adsorption ratio was calculated from the measured concentrations of sodium, calcium and magnesium ions (Alit et al., 2006). E.Coli determination was according to the membrane filtration technique using Chromocult agar (APHA/AWWF/WEF, 1998).

Soil sample collection and analysis

To ascertain the impact of the greywater on the soils, soil samples were collected at each household initially prior to greywater application and analyzed for pH, organic matter content, nitrogen, phosphorus and potassium. After the application of greywater, soil samples from the greywater towers were later picked on a monthly basis for a period of 3 months and analysed for the same parameters at the Soil Science Laboratory at Makerere University, Kampala, according to analytical techniques in Okalebo (2002). pH was measured using the electrode method in a soil-water suspension using a 1:2.5 (w/v) ratio, organic matter determination was according to the Walkley and Black Method, Total nitrogen was analysed using the Kjeldahl method, potassium was determined by flame photometry method while measurement of phosphorus was according to the Bray method (Okalebo, 2002). Given the close proximity of the households in the area, the soils used in the greywater towers were loam soils.

Plant measurements

To assess the impact of greywater application on plant growth, measurements at two households with greywater towers and the control were taken. This involved measurements of stems, leaves, number of seeds, number of leaves, and length of internodes.

Results

Greywater reuse

A review of the baseline study report (ROSA, 2007) indicated that there was no greywater reuse in the study area. The generated greywater is either disposed of in open places (68%) and or open channels traversing the area and where possible, in soak pits by 21% of the households (ROSA, 2007). These findings were corroborated by the interview findings in this study with the majority of the respondent households, 61% and 76% disposing of kitchen and laundry wastewater respectively on the ground. Most of the respondent households (71%) discharge their bathroom wastewater into soak pits. Interestingly, a few respondent households (11%) pour their kitchen greywater into the gardens. Interviews with the locals indicated that they were not aware of any greywater disposal best practices but expressed willingness to reuse greywater if taught how. Responses from the study households indicated that they had no objection to having the demonstration units for greywater reuse (greywater towers) set up at their homes.

Amount of greywater produced

The generation of grey water by households is directly related to the consumption of water. Of the 38 households interviewed, the majority (63%) use 3 to 5 jerrycans of water daily for domestic cores including drinking. Given that each jerrycan holds 20 liters, about 60 to 80 liters of water are used daily for washing kitchen utensils, laundry, bathing and drinking by each household. Since no wastewater enters the sewers in Paradwong parish in KTC, the quantity of greywater generated daily per household may be estimated to be 80% of the water consumption (Punimia, 1998). This means that approximately 48 to 64 liters of grey water are being produced on a daily basis by each household in Ktigum town council. As a result of the water scarcity in the region the quantity of greywater produced is low. The greywater quality generated by these households is therefore highly polluted (section 4.3) as small quantities of water are used for a number of domestic purposes before eventual disposal, as observed in informal settlements worldwide (Armitage et al., 2009).

Physicochemical characteristics of the greywater

The characteristics of the greywater from the different sources (n=35) are presented in Figure 3. The results depict some variation of the measured parameters between source types. The greywater is moderately alkaline with the laundry water having pH values that fall outside the effluent discharge standards (i.e. 6-8, NEMA 1999) but is in line with the range observed elsewhere (i.e. 8-10, Eriksson et al., 2002). The high pH values of the laundry water may be due to the alkalinity of the detergents and or soaps that are used (Christova-Boal et al., 1996). However, given the pH range for other greywater types, the alkalinity of the freshwater used in the area which is primarily groundwater, may also be important (ROSA, 2007). The SAR is higher in laundry water followed by bathroom and kitchen water in that order. The high laundry SAR values may be a result of the type of detergents or soaps used. Long term application of water with a high SAR can be detrimental to the hydraulic conductivity and physical properties of soils and associated plant systems (Wiel-Shafran et al., 2006). Most commercially available bathroom/laundry products are currently manufactured using various types and quantities of sodium salts. Hence given the SAR values of the greywater validates the need to apply freshwater to the greywater towers as a control measure against soil damage (clogging).

The temperature is relatively highest for bathroom waters with the kitchen and laundry waters having almost similar average values. The probable explanation for this discrepancy is that waters for bathing purposes particularly in the mornings are warmed up. All the greywater source types exhibit high turbidity, with mean values greater than the stipulated national effluent discharge standard (i.e. >100 NTU, NEMA 1999). The laundry waters have the highest turbidity most likely due to more soap use compared to that in the kitchen and bathroom. During sample analysis the laundry greywater was blue in colour with a cloudy appearance which was thought to result from more soap use. Turbidity in these wastewaters may also be related to the presence of high content of suspended solid material in the wastewaters (Eriksson et al., 2002). Here, possible high suspended solid material content is found in laundry water followed by bathroom water. The likely explanation may be the dirty laundry and bathing by the children who were the majority in the households visited.

The average TDS content of kitchen and bathroom greywater sources are generally within the national effluent discharge standards (i.e. <1000 mg/l, NEMA 1999) which is not the case with the values occurring in laundry water. The total dissolved solids content of the greywater types follows a similar trend to that of electrical conductivity with laundry exhibiting higher values (Figure 3).

All the greywater sources have mean phosphorus levels with in the national effluent discharge standards (i.e. < 5 and 10 mg/l for Ortho and Total-P, respectively) as indicated in Figure 3. The total phosphorus levels indicate that phosphorus containing detergents are used (i.e. > 3mg/l, WHO, 2006). Despite this, phosphorus when disposed to the greywater tower is not a problem since it is a plant nutrient. However, problems may accrue if the soils become phosphate saturated resulting in leaching to the groundwater and or to run-off to a surface water source. The ammonia nitrogen levels for the greywater obtained here, are higher than values cited in other studies in the developed countries with the greywater in these cases considered light (Birks and Hills, 2007; Eriksson et al., 2002).

The greywater types exhibit high mean BOD_5 and COD values well above the national effluent discharge standards (i.e. >30 mg BOD_5/l and 100 mg COD/l). The high COD in Kitchen greywater is in line with the high COD values recorded for the developed countries (Travis et al., 2008). Laundry greywater exhibits the highest BOD_5 values followed by kitchen greywater.

Bacteriological characteristics of greywater

E.coli were used to characterize the bacteriological quality of the greywater from the 3 sources. There was not much variation in the E.coli results for the different greywater source types with the bathroom greywater having less E.coli counts compared to the other 2 sources (Table 1). The bacteriological counts of the greywater sources is similar to that of raw sewage as observed for greywater discharging from informal settlements (Carden et al., 2007). The high E.coli counts exhibited in the kitchen greywater may be due to the sources of water used which are mainly open streams and waters from River Pager, given the limited availability of boreholes. According to a water quality survey by Oxfam, Environmental Researchers and KTC Health Department and Water Sector in January 2007, sampled streams and rivers had E. Coli counts of ≥ 100 cfu/100ml. It was noted that the counts are most likely higher in the wet season given the poor environmental sanitation in the area. Additionally, the children who frequently wash kitchen utensils have dirty and contaminated fingers.

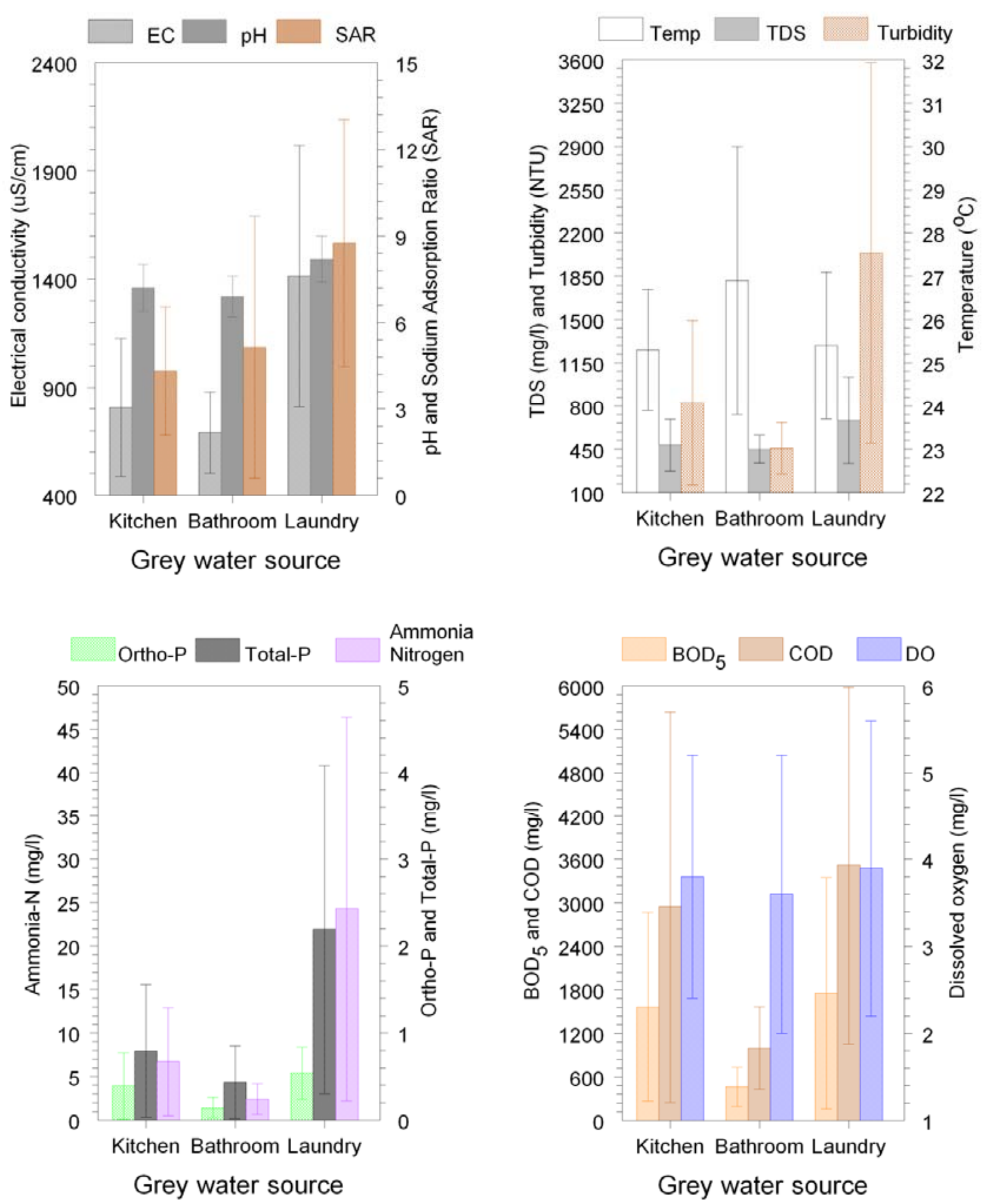

Figure 3 Characteristics of greywater from different sources in Kitgum Town Council (bars represent mean values ± standard deviation; n ≥ 35)

Table 1 Bacteriological quality (E.Coli) of the greywater source types (n = 8; Log 10 E.coli/100 ml)

Greywater source	Average value	Range
Kitchen	8.42	<0- 9.32
Bathroom	7.50	<0- 8.24
Laundry	8.53	<0- 9.40

Soil Characteristics

The initial characteristics of the soils at the study households prior to application of greywater are presented in Table 2. The results indicate largely alkaline soils with high phosphorus contents (> 15 mg/kg, Landon, 1991) and low nitrogen, potassium and organic matter. The phosphate decrease in the soils following greywater application may be attributed to plant uptake as indicated by the healthy appearance of these (Figure 4). Despite the high ammonia-nitrogen levels in the greywater (Figure 3), the nitrogen content in the soils following greywater application are hardly affected. This may be attributed to uptake by plants and also to a less degree the relatively high pH values (pH>7) leading to ammonia volatilization and loss to the atmosphere as nitrogen (Zimmo et al., 2003).

Table 2 Soil chemical characteristics at the study households prior to and after application of greywater (Average values±SD; initial: n = 7; after application: n=14)

Parameter	Initial	After application
pH	9.06±0.85	8.79±0.66
Nitrogen (%)	0.086±0.021	0.085±0.015
Phosphorus (mg/kg)	21.89±7.80	19.79±20.82
Potassium (meq/100g dry soil)	2.52±0.90	2.22±0.83
Organic matter (%)	1.61±0.53	1.55±0.42

Figure 4 (a) Growth of tomatoes (on top) and onions (in the sides (b) flowering of tomatoe plants

Plant growth Observations and Measurements

The observations of the planted vegetables are shown in Figure 4. The observations revealed healthy growth of the planted vegetables.

Plant measurement results carried out at 2 households (A & B) and control greywater towers are presented in Table 3. The results show that the tomato and onion plants receiving greywater at household B generally performed well compared to those that received the groundwater (control). The relatively lower performance by the plants in the greywater towers at household A may have been a result of the poor operation. Also it suffices to point out that during growth, the vegetables in most of the greywater towers were attacked by pests, leading to stunted growth and or death.

Community perceptions and challenges to greywater reuse using greywater towers

Informal interviews held with the locals in Paradwong village in Kitgum Town Council reveal that they currently have knowledge of the greywater tower and would want to have one at their homes. A walk through the area, revealed fifteen additional households that set up greywater towers after seeing the benefits associated with the study units. Additionally, more households have set up small gardens of vegetables on their land and are applying greywater directly to the plants. Where vegetables have been harvested from the greywater towers, the households have converted the area into small gardens irrigated with greywater (Figure 5).

The use of the greywater towers had some challenges as observed and reported by the residents. Little greywater is produced particularly from laundry since 1) many of the households do not wash their clothes on a daily basis and 2) the general water scarcity in Kitgum. The shade cloth used was attacked by roaming animals in the area and tore within two months. Here, some protection fences had to be installed around the greywater towers. The planted vegetables were attacked by pests and diseases implying the need for pest control.

Table 3 Plant measurements

	Control	A	B
Tomatoes			
Length of 1st Stem (cm)	3	3	3.4
Length of 1st leaf (cm)	43.3	27.2	37.5
Length of leaflet (cm)	10.4	8	11.7
No of flowers	16	7	18
No of seeds	1	5	5
Length of inter-node (cm)	14.5	17.2	18
No of branches	4	4	7
Onions			
No of leaves	9	10	8
Length of leaf (cm)	8.7	15	19

Figure. 5 Area around greywater towers used as a small garden and planted with pumpkins.

Conclusions

- Greywater is poorly managed in Kitgum Town Council with the largest population of the community (68%) pouring the greywater onto the ground while 21% dispose their greywater into drain channels and soak pits. Very few (11%) pour this wastewater into the garden.

- The main sources of greywater in the area are laundry, bath areas and kitchen.
- Laundry water except for temperature generally had the highest mean values of the parameters assessed followed by kitchen and bathroom greywater.
- The effect of greywater application on the soil characteristics was not significant with respect to potassium, organic matter and nitrogen content. However there was a slight decrease in phosphorus content.
- Tomato and onion plants grown in the greywater towers thrived with the greywater. However, they were attacked by pests.

Recommendations

- Given the greywater characteristics presented in this study, greywater should be properly managed to prevent contamination of the environment and disease prevalence.
- Given the positive response to the application of greywater in gardens in Kitgum Town Council, there is need to increase sensitization of the community people on greywater reuse and associated benefits to scale up this reuse option.
- There is need for research to ascertain the bacteriological quality of the leafy crops to assure safety.
- The hydraulic load of a greywater tower should be ascertained so as to guide the number of gardens needed for a particular quantity of the generated greywater for optimum performance.

Acknowledgements

The work is carried out within the project ROSA (*Resource-Oriented Sanitation concepts for peri-urban areas in Africa*; Contract No. 037025-GOCE; duration: 1.10.2006 – 31.3.2010), a Specific Target REsearch Project (STREP) funded within the EU 6th Framework Programme, Sub-priority "Global Change and Ecosystems". The authors are grateful for the support.

References

Alit, W., Zeev, R., Noam, W., Eilon, A., Amit, G. (2006). Potential changes in soil properties following irrigation with surfactant-rich greywater. *Ecological Engineering* 26, 348-354.

Al-Jayyousi, O.R. (2003). Greywater reuse: towards sustainable management. *Desalination* 156, 181-192.

Armitage, N.P., Winter, K., Spiegel, A., Kruger, E. (2009). Community-focused greywater management in two informal settlements in South Africa. *Water Science and Technology* 59(12): 2341-2350.

APHA/AWWA/WEF (1998): *Standard methods for the examination of water and wastewater. 20th edition, American Public Health Association, American Water Works Association,* Water Environment Federation Publication, Washington, D.C., USA.

Birks, R., Hills, S. (2007). Characterisation of indicator organisms and pathogens in Domestic greywater for recycling. *Environmental Monitoring Assessment* 129, 61-69.

Carden, K., Armitage, N., Winter, K., Sichone, O., Rivett, U., Kahonde, J. (2007). The use and disposal of greywater in the non-sewered areas of South Africa: paper 1-Quantifying the greywater generated and assessing its quality. *Water SA 33(4),* 425-432.

Christova-Boal, D., Eden, R.E., McFarlane, S. (1996). An investigation into greywater reuse for urban residential properties. *Desalination* 106, 391-397.

Crosby, C. (2005): Food from Used Water: Making the Previously Impossible Happen. URL: http://www.dwaf.gov.za/Events/WaterWeek/2005/Documents/WaterWheelJan05d.pdf [Accessed on 31.03.2007].

Eriksson, E., Auffarth, K., Henze, M., Ledin, A. (2002). Characteristics of grey wastewater. *Urban Water 4*, 85-104.

Imhof, B. and Muhlemann J. (2005). *Greywater treatment on household level in developing countries-A state of the art review.* Department of Environmental Sciences at the Swiss Federal Institute of Technology (ETH), Zürich, Switzerland.

Landon, J.R. (ed.) (1991). A Handbook for soil survey and agricultural land evaluation in the tropics and subtropics. *Longman Scientific and Technical Group Ltd,* Hong Kong, PR China.

Langergraber, G., Meinzinger, F., Lechner, M., de Brujne, G., Sugden, S., Niwagaba, C.B., Mashauri, D., Mutua, B.M., Teklemariam, A., Achiro, I., Kiarie, S.C., Laizer, J.T., Ayele, W. (2008): The ROSA project – A new approach to sustainable sanitation in Eastern African cities. *Proceedings of the 6th IWA World Water Congress*, 8-12 September 2008, Vienna, Austria. (CD-ROM, paper 664279)

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

NEMA, (1999). *Environmental standards and preliminary environment impact assessment for water quality and discharge of effluent into water/land in Uganda.* National Environment Management Authority, Kampala, Uganda.

Okalebo, R. (2002). *Laboratory methods of soil and plant analysis. A working manual,* 2nd Edition, Nairobi, Kenya.

Punimia, A. (1998). *Wastewater Engineering (Including Air Pollution). Environmental Engineering-2.* Laxmi Publications (P) Ltd., New Delhi, India.

ROSA (2007).*Baseline study of Kitgum Town Council.* Makerere University ROSA Staff, Kampala, Uganda.

Travis, M.J., Weisbrod, N., Gross, A. (2008). Accumulation of oil and grease in soils irrigated with greywater and their potential role in soil water repellency. *Science of the Total Environment* 394, 68-74.

Wiel-Shafran, A., Ronen, Z., Weisbrod, N., Adar, E., Gross, A. (2006). Potential changes in soil properties following irrigation with surfactant-rich greywater. *Ecological Engineering* 26, 348-354.

WHO (2006). *WHO guidelines for the safe use of wastewater, excreta and greywater, Volume IV Exctreta and greywater use in agriculture.* World Health Organisation, Geneva, Switzerland.

Zimmo, O.R., van der Steen, N.P., Gijzen, H.J. (2003) Comparison of ammonia volatilisation rates in algae and duckweed-based waste stabilisation ponds treating domestic wastewater. *Water Research 37*(19), 4587–4594.

.

Name: R. Kulabako,
J. Kinobe,
J. Mujunga
S. Olwenyi
Organisation: Department of Civil Engineering, Makerere University
Town, Country: Kampala, Uganda
e-mail: rkulaba@tech.mak.ac.ug,
jkinobe@tech.mak.ac.ug,
olwenysamuel@yahoo.com,
jmujunga@tech.mak.ac.ug

Name: K. Sleytr
Organisation: University of Natural Resources and Applied Life Sciences, Vienna; Institute for Sanitary Engineering and Water Pollution Control
Town, Country: Vienna, Austria
e-mail: Kirsten.sleytr@boku.ac.at