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Characterization of greywater from urban and peri-urban areas of Nakuru municipality, Kenya

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Kenya faces serious challenges regarding water and sanitation services. Despite many years of government investment, existing facilities continue to deteriorate and have also failed to meet the demand of increasing population. These challenges are particularly severe in rapidly growing settlements of urban poor. One such settlement is Nakuru municipality which has an average annual population growth of about 8%. The municipality's sewerage connection is inadequate (11% coverage) and only serves middle and high income areas. This study used a semi-structured questionnaire aiming at characterizing and determining the composition of greywater, besides identifying existing water supply and lifestyle characteristics. The total suspended solids range in greywater was 200-3500 mg/l and faecal coliform (FC) count 10^5-10^6 $100mL^{-1}$. High values of FC concentration in greywater can be associated with life style characteristics and the settlement patterns. These results were used to develop site specific greywater treatment systems ideal for peri-urban areas.

Introduction

With a population growth of over 8% in low income urban settlements, many unplanned structures continue to be built in Nakuru municipality, Kenya, where sewerage connection is also inadequate. This has continued to increase the challenge of sustainable access to safe wastewater disposal in the peri-urban areas of the municipality. In such areas, safe wastewater disposal can be achieved by in-situ separation of domestic wastewater into various streams (grey, yellow, beige, brown and black water) at the source of generation. Greywater is domestic wastewater that includes only wash water (laundry, bathing, shower and hand wash or kitchen sink). Yellow water is wastewater stream made up of urine and flush water. Beige water is anal cleansing water while brown water is wastewater stream composed of faeces and flush water. Black water is a combination of both brown and yellow water also referred to as the toilet stream. Source separation allows for adequate treatment of different wastewater flows according to their characteristics. Hence, it is important to characterize wastewater stream generated for purposes of developing a site specific treatment system using the locally available raw materials.

Kenya, like many other countries in the world lacks proper greywater disposal facilities. Greywater contributes to over 70% of domestic wastewater. Its magnitude and effect is quite enormous and could be devastating if not properly disposed off (MWI, 2007). Available greywater treatment techniques are limited or none exists at all. One option feasible in densely populated areas is the onsite treatment. Improving water quality and mitigating water scarcity are closely linked to greywater management. The treatment and control of the effluent is by far insufficient and the options of reuse or recycling effluents need to be explored as a safer way of disposal. Most households are yet to adopt source separation followed by on-site reuse or safe disposal because of limited knowledge in this field.

Safe water and basic sanitation must be regarded as a basic human right and should therefore be accessible and affordable to all (MWI, 2007). To achieve the Millennium Development Goals (MDGs) and the national strategy in the Economic Recovery Strategy for Wealth and Employment Creation (ERS-WEC), it is important to address sanitation challenges in urban and peri-urban areas. Kenya faces serious challenges with regard to water and sanitation services. Despite the efforts of investments provided in the past years by the government and development partners, existing facilities have continued to deteriorate and hence failed to meet the demand of increasing population (MWI, 2007). In many municipalities, greywater stream poses a serious challenge to the ever increasing peri-urban population because of careless nature of its disposal practiced by the inhabitants.

Greywater is characterized as high volume low strength stream that constitutes about 50-80% of domestic wastewater (DHWA, 2002). Its low contribution of N, P, and K (3%, 10% and 34% respectively) to domestic wastewater makes greywater an important portion of the water cycle. In peri-urban areas of Nakuru Municipality, greywater is disposed off in open spaces and sometimes re-used with no pre-treatment. This common practice has led to major environmental and public health concern to the residents (MCN et al., 1999). However, to develop in-situ small scale treatment systems, designers are faced with several limitations. This includes insufficient knowledge on greywater characteristics that is necessary for determining appropriate technological solutions. This is also important in identifying space for constructing a treatment system in these high density urban settlements. Based on this problem, the objective of this study was to characterize greywater stream generated from various households in Nakuru Municipality Kenya and recommend an appropriate treatment technology.

Materials and methods

The study was conducted in Nakuru Municipality, Kenya. Nakuru is the fourth largest town in Kenya after Nairobi, Mombasa and Kisumu. Located in the Great Rift Valley, the town lies between latitude 0o 10’ and 0o 20’ South and longitude 36o 10’ East and an average altitude of 1859m above sea level (MCN et al., 1999). The town covers an area of 290 km2 of which Nakuru National park covers 188 km2 leaving 102 km2 to town functions. The current population is estimated at over 450,000 people (MCN et al., 1999). Like many other towns in Kenya, Nakuru, has experienced a rather rapid population growth thus exerting pressure on existing water and wastewater management facilities especially in the peri-urban areas. These areas share some common problems that include little or no sewerage connection to the main sewer line. Furthermore, they are highly populated areas taking over 70% of the inhabitants of the municipality. Based on the population density, the study covered: Middle (>1000<2000) income and low income high density (>2000<4,500 persons/ km2) population areas.

Characterization of greywater

A baseline survey that included identifying and assessing areas having greywater disposal problems was conducted. A cross-sectional survey covering both the urban and peri-urban areas was conducted using a prepared semi-structured questionnaire. During the survey, a sample of 120 households was selected randomly from the identified clusters of low and middle income areas. The questionnaire was randomly administered to these selected households, businesses and schools. Selection of households was proportionate to the population densities. The interviews targeted household heads and/or their spouses. By filling out the questionnaire, direct feedback on the conditions of existing on-site greywater disposal was assessed. Both primary and secondary data was used in estimating the quantity of greywater from the households. Settlement density was measured in household dwelling units (HHDU). This was determined as being a key driver in greywater management since large numbers of people living in densely-populated settlements generate increased volumes of greywater. But, the main disposal method is emptying in the limited spaces available which posses a serious environmental and public health problem to the residents. On-site greywater sampling and analysis from selected households was conducted over a period of eight months. This was mainly through the use of in-situ test and laboratory analysis methods. The overall aim was to get a general understanding of the quality of the greywater emanating from non-sewered areas particularly with respect to its nutrient loading and oxygen demand. The samples were collected randomly from the sites, stored in a cool box with ice blocks and ferried to Egerton University and Nakuru Water and Sanitation Services Company (NAWASSCO) laboratories for analysis. All the samples arrived in the laboratory for analysis within a maximum of four hours of field sampling time which was within field sampling guidelines as recommended by Ayres and Mara (1996).

To determine the composition of various greywater streams, collected samples were divided into two and analyzed for microbiological, chemical and physical composition. The analysis was conducted according to appropriate Kenyan standards and Standard Methods for the Examination of Water and Wastewater, (1998). Samples were analyzed for some of the parameters which included: TSS, TP, TN, pH, oils and grease, electrical conductivity (EC), BOD5, COD and faecal Coliform. The observed compositions were compared with available literature on raw greywater.

Results and discussion

The composition of raw greywater in Nakuru municipality varied from one sampling site to the other. The variation range is presented in Table 1. To isolate the main parameters for consideration in treatment system design, pair-wise ranking method was applied. The major parameter of concern was found to be BOD5 (organic carbon loading) closely followed by faecal coliform. This was in agreement with most of the existing designs based on first order plug-flow model (Equation 1).

$$\frac{C_e}{C_o} = e^{\left(-k_T\ t\right)} \qquad (1)$$

Where
Ce = Effluent BOD5 (Predicted), Co = Influent BOD5 (measured)
t = Hydraulic residence time (d), KT = Temperature dependant rate constant (d-1)
KT = K20 (1.06) (T-20), K20 = Rate constant at 20 0 C (d-1) = 1.104 d-1 (Kadlec and Knight, 1996).
T = Temperature of the liquid in the system (0C)

Table 1. Greywater composition range and Kenyans standards for wastewater disposal

Parameter	Units	Range	Kenyan standards (KEBS-KS 05)
pH		5.7-8.6	6-9
EC	mS/cm	0.38-2.35	NS
Ammonia	mg/l	0-15.54	0.5
Total nitrogen(TN)	mg/l	2.21-340	NS
Total phosphorous(TP)	mg/l	1.2-13.1	NS
Total suspended solids (TSS)	mg/l	200-3,580	2000
BOD5	mgO2/l	115-1,610	500
COD	mg/l	290-8,320	1000
Oils & Grease	mg/l	8-241	NS
Faecal coliform	CFU 100mL-1	480,000-1,800,000	NIL

NS-No Standards

To develop a site specific treatment system, Equation 1 forms the basis of the mathematical expression needed for design and sizing purposes. This first order plug-flow kinematics describes BOD5 removal in a subsurface flow constructed wetland. Removal of the soluble BOD5 is due to microbial growth attached to plant roots, stems, and leaf litter that has fallen. The major source of oxygen for these reactions is plant translocation of oxygen from the leaves to the root zone and reaeration at the water surface for free water surface wetlands.

Compared to allowed discharge standards from Kenya Bureau of Standards (KEBS), certain sites met the requirement for one or more parameters. However, all the sites failed to meet the faecal coliform zero discharge standard for safe greywater disposal. On a worldwide scale, pollutant concentrations in greywater were generally high (Wiel-Shafran et al., 2006; Shmueli, 2003). Probably, this could be associated with water scarcity that forced most inhabitants in the low income; high density population areas to reuse greywater generated thus producing thick concentrated streams.

The anionic surfactants concentrations (oils and grease) in raw greywater ranged between 8-241 mg/l which was much higher than 0-10mg/l reported by Wiel-Shafran et al. (2006) and similar findings by Ramon et al. (2004). Ideally, laundry effluent should have high surfactants followed by kitchen and bath effluents. Though reuse of raw greywater was sited in some areas, most environmental studies focusing on effect of surfactants in waters have reported toxicity to aquatic organisms and plants when concentrations are higher (Garland et al., 2004). This is mostly associated with elevated salinity levels and also, plant type under irrigation. An effective treatment system forms barriers in soil nutrient enrichment and pathogen transmission pathways where they can be destroyed or reduced to an acceptable level before further treatment or reuse.

The concentration range of total suspended solids in greywater was 200-3,500 mg/l and faecal coliform (FC) was 10^5-10^6 CFU $100mL^{-1}$. High values of FC concentration in greywater can be associated with life style characteristics and the settlement patterns. Occurrence of faecal coliform bacteria in water indicates a risk of human illness or infection through contact with water. Though source separation is practiced in these areas, laundry water from washing nappies is the major contributor of high FC levels. In the high and middle income areas, FC levels were lower because of the use of disposable baby diapers which are considered expensive by the low income urban dwellers. Greywater is still considered a health hazard by many authorities. This is probably due to the high presence of indicator bacteria whose survival is favoured by the high content of easily degradable organic compounds. Also greywater easily turns anaerobic and the arising foul smell may lead to the conclusion that it is septic. Greywater is considered of low strength and low BOD_5, when compared to nutrient rich black water which is discharged from households and directed to centralized sewerage systems. Greywater is reused with no pre-treatment mostly in the peri-urban areas. It is mainly used in urban agriculture for watering vegetables in the kitchen gardens, mopping houses, washing pit latrines and also sprinkled on earth surfaces during the dry periods to reduce dust. Hence, untreated greywater is recognized as a potential valuable resource, although in most cases, its potential drawbacks are not taken into account.

It contains salts, solid particles, fat, oil and nutrients. These substances may have negative effects on human health, soil and ground water quality. For instance, pathogen ingestion through consumption of raw vegetables, irrigated with untreated greywater is an important disease transmission route. In addition, greywater has laundry soap which contains surfactants and sodium as filling. Soils turn sodic when sodium gradually replaces calcium and magnesium on the surface of these soil particles. With too much sodium, the soil disperses when less saline water such as rain falls. This clogs soil pores forming a compacted layer at the surface and leading to soil erosion. In effect, greywater causes environmental in addition to public health problems if carelessly disposed off, without any form of treatment.

Unfortunately, careless disposal of greywater is becoming increasingly common, a practice mistakenly considered safe by many inhabitants of informal urban settlements. Results from field survey of two most densely populated areas (Kaptembwa and Kwarhonda) showed that greywater from the households is disposed off in any available space (Figures 1 and 2). In Kaptembwa, 65.9 percent of the residents used any available empty space for disposal of greywater. While for Kwarhonda estate, it was 44.8 percent. This is a clear indication that greywater management in Nakuru Municipality is a big challenge.

A first step in greywater management from the densely populated low income areas of Nakuru Municipality involves characterisation (Figure 1). Knowing the composition and quantity of greywater is important in development of a decentralised greywater treatment system. The mechanisms that are available to improve greywater quality are numerous and often interrelated. However, it is also important to know the current disposal methods and mitigation measures in place. The residents are used to disposing off greywater in any available empty space including the earth roads. It is much easier to manage greywater in areas with low rainfall or during the dry spells since it easily infiltrates into the soil after emptying. However, during rainy seasons, rainfall causes rising of groundwater table leading to waterlogged soils and emptied greywater is conveyed to low-lying areas. This leads to primary pollution of sensitive environments like rivers, wetlands and unprotected boreholes, or within flood plains.

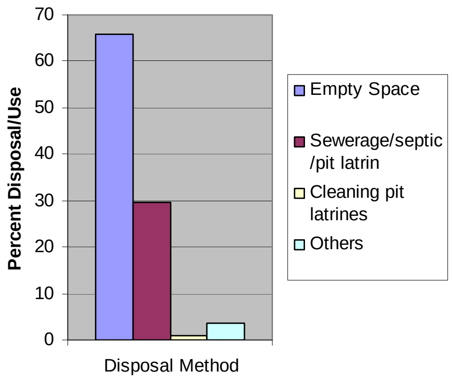

Figure 1: Greywater disposal-Kaptembwa

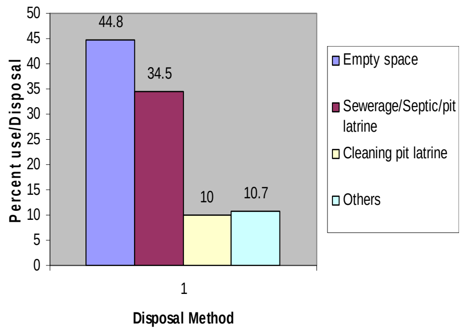

Figure 2: Greywater Disposal-Kwarhonda

Conclusion and recommendations

These results show a significance difference in pollutant concentration ranges among the different greywater sources. Variation in greywater characteristics in terms of quality from the same source level (houses, institutions, hotels, office building etc.) makes given general recommendations regarding planning and design of greywater treatment system difficult. Characterization of greywater acts as a guide in the process of designing, installing and maintaining site specific greywater treatment systems in a sustainable manner. Hence, considering the characteristics of greywater, its treatment is important since it forms part of a sanitation system that includes the users, collection, transport, treatment, solid waste, storm water and industrial wastewater. Such systems apart from improving the general living conditions by offering a clean environment, also, offer aesthetic, educational and ecological benefits to the people. Thus, it forms an important tool for planning, sound public health and environmental management. For further research, there is need to evaluate available greywater treatment systems and the basis of their designs. Also, develop and pilot test different greywater treatment systems in the municipalities so as to develop a strong data base.

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Keywords

Sanitation; Characterize; Greywater; Peri-urban.

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