Open Access

Greywater Reuse And Recycling Potential: The Case Of Mwanza City

Esnati Osinde Chaggu*

Ardhi University, P. O. Box 35176, Dar- es- Salaam, Tanzania

Abstract: Greywater is wastewater emanating from domestic activities such as laundry, dishwashing, and bathing. This water can have useful on-site uses like irrigating landscape and vegetables in tower gardens. However, its user potential need to include quality studies for determining its safety and achieving public health and environmental protection. Lake Victoria receives greywater from Mwanza City environs and therefore, protecting it from greywater pollution is very important. This research work with study components including socio-economic and the quality of greywater is adding to the need of protecting the lake from pollution. The results, *Faecal Coliforms* values ranging from 12 to too numerous to count (count/100 ml.) and Total coliforms values of 17 to too numerous to count (count/100 ml.) are clearly showing that, the greywater available in Mwanza is not safe. Moreover, it is evident from the heavy metals' results from liquid samples that, the values are insignificantly very low (<0.01 mg/L for Pb and Cu). The pH values are ranging from 5.9 to 7.5 while the recommended World Health Organisation (WHO) range is 6.76 – 8.0. The research is proposing tower gardens as treatment facility for greywater in Mwanza City.

Keywords: Greywater, Reuse, Recycling, Pollution.

1.0. INTRODUCTION

Greywater is wastewater emanating from domestic activities such as laundry, dishwashing, food preparation and bathing [1] excluding excreta. This water can have useful on-site uses like irrigating landscape and vegetables in tower gardens. Though plentiful since long time immemorial, there is no written about greywater in Tanzania. Increase in grey-water production goes hand in hand with population growth. Nationally, the rate of urbanization in Tanzania rose from 6.0% (1957-1967) to 9.6% (1978-1988) according to [2] meaning increased production of greywater, potential for urban agriculture. Urban agriculture is an important component of household income in Sub-Saharan Africa [3] and in China, it supplies up to 90% of urban food market [4]. Urban agriculture was included for the first time as a land use category in The Tanzanian Master Plan of 1979 and was firstly promoted during a severe famine in 1974, and the people started cultivation on all vacant land [5] after President's decree. Currently (2010) with a government motto of "Kilimo Kwanza" in Kiswahili (Agriculture first, in English), greater reuse and recycling of greywater have a ladder to climb on.

Greywater composes 50–80% of residential wastewater generated from all of the house's sanitation equipment (except toilets) [6] and contains hazardous components which could get to a new host or face before disposal into receiving water bodies through similar transmission routes shown in [7] and [8]. This implies that, transmission is possible from greywater through flies or soil to hands, food or fluids, all the way to a new host if sanitation barriers or treatment measures are not instituted. Moreover, greywater contains suspended solids, biodegradable organics, pathogenic organisms and inorganics depending on the used products. Many organics are protein, carbohydrates and fats and they are biodegradable and hence, can lead to pollution load [9] in receiving water bodies.

In Mwanza City, Tanzania, the receiving water body is Lake Victoria which has a total drainage basin area of 193,000 km^2, 44% of which is located in Tanzania. The lake water shed support a range of socio-economic activities which provide means of livelihood to nearly 40 million people [10] and hence, needs protection of pollution from greywater. The possibilities of treating and reusing separate fractions of (human) waste (urine, faeces, black-water or night-soil, greywater and swill) are high due to progressing depletion of crucial resources like water and nutrients [7, 11, 12, 13], and increasing need of food security [14, 15, 16]. Crop fertilization using wastewater has been practiced in many countries [17], Japan since 12th Century and China thousands of years [18], while in Bukoba (Tanzania), traditionally; reuse was regarded as a gesture of respect [19]. This means, greywater should be regarded as a "resource" and has to be treated as close as possible to their source of production [20]. Its reuse in agriculture should however be an interactive process including academic, governmental, private- and public sector [21], with adequate institutional framework for sustainability purposes [22, 23]. Greywater treatment methods depend on location, knowledge, and availability of resources (financial, human and space), with a

*Address correspondence to this author at the Ardhi University, P. O. Box 35176, Dar- es- Salaam, Tanzania; Tel: +255-754 367 662;
Fax: (255-022) – 2775391; E-mail: esnatchaggu@hotmail.com

1874-8295/11

Fig. (1). Location of Mwanza in Tanzania

view of reaching the intended goals, economical, safety, convenience and sustainability [24].

This study therefore was envisaged with a view of firstly, to determine the greywater potential and its quality in some selected wards of Mwanza City in order to protect Lake Victoria from pollution, as fore-mentioned, since it is a source of livelihood to many residents. Secondly, to ascertain acceptance for reuse and recycling by residents for improving food production for their livelihoods before constructing pilot treatment units in the subsequent study. Mwanza has a growth rate of 3.2% [25] and hence, continued production of greywater. Residents dispose their greywater haphazardly which is a public concern not only for the Lake Victoria, but also, poses public health dangers especially by mosquitoes, *Culex quinquefasciatus*, which breed in polluted pond water and may spread bancroftian filariasis [26].

The **general objective** of the study is to determine the physico-chemical properties of greywater from Mwanza City and to determine its reuse and recycling potential. The **specific objectives** of the study are to:

- Select the study wards in the Mwanza City.
- This was very important since it was not possible within the limited resources (financial and time) to study all wards in Mwanza City. Representative wards had to be selected.
- Choose the representative households in the selected wards for questionnaire.
- Study the existing situation of greywater production in the selected wards.
- Determine the existing situation of greywater quality from the chosen households in the selected wards during dry and rainy season.
- Find out the wastewater quality of some selected points of interest with pollution potential to Lake Victoria within the selected wards.
- Find out from socio-cultural and -economic point of view the acceptability to reuse and recycle greywater. This was important for the sustainability of greywater handling.
- Establish the knowledge of the people regarding importance and health implications of greywater.
- Propose a suitable treatment facility for greywater produced at Mwanza City.

2. MATERIALS AND METHODS

2.1. Description of Study Area

2.1.1. Geographical Location

Mwanza City Council has a total area of 1,324 km² out of which, 900 km² (68%) is covered by water and the remaining 424 km² (32%) is dry land. The City is located on the southern shores of Lake Victoria in the north western part of Tanzania at an altitude of 1,140 metres above see level. Mwanza City has two districts of Ilemela and Nyamagana which are among the 8 districts of Mwanza Region. Other districts are Misungwi and Kwimba to the South, Sengerema and Geita to the West, Ukerewe to the North and Magu to the East [27]. The location of Mwanza Region in Tanzania is as shown in Fig. (**1**).

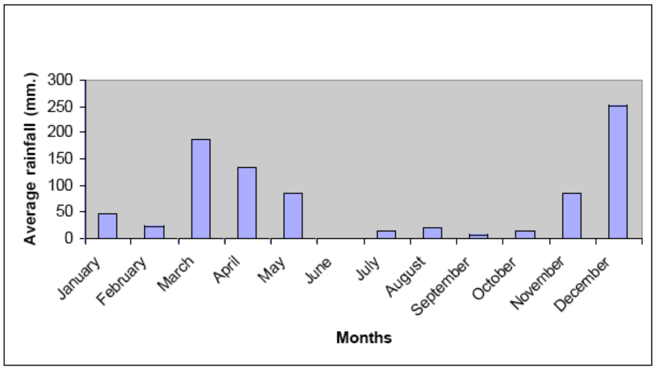

Fig. (2). Mwanza City Council Monthly Rainfall in mm. (with standard deviation ±80.37) Source of raw data: [28].

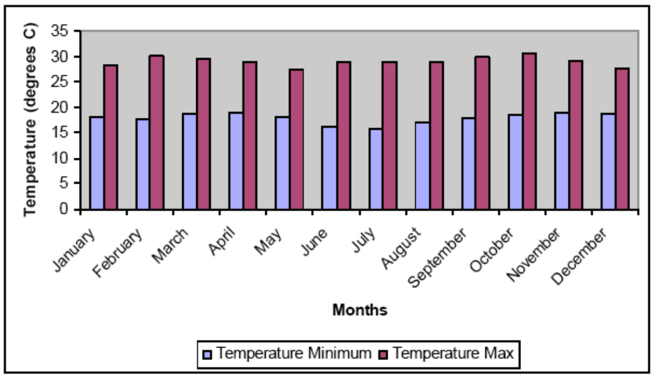

Fig. (3). Average Monthly Temperature for Mwanza City Council Source of raw data: [28].

2.1.2. Climate

Mwanza City usually receives between 700 mm. and 1000 mm. of rainfall per annum, with two rainy seasons. The short rains occur from August – October and long rain season from December to May in each year (Fig. **2**). Due to these elevations of 1140 meters, above sea level, and the favourable lake winds, Mwanza has a pleasant tropical climate which could be used for biological treatment of greywater.

The temperature of Mwanza City ranges between 20^0C and 30.7^0C in the hot season and 15^0C and 20^0C in the cooler months. The varying situation is depicted in Fig. (**3**).

2.1.3. Vegetation

About 10 % of Mwanza City is built-up area. The remaining area consists of forested land, valleys and cultivated plains, grassy, undulating granites and granodiorite geologic formations. Isolated hill masses and rock outcrops are outstanding characteristics specific to the city. Typical soils are well-drained red sandy loams generated from crustaceous rocks [27]. The rocky formations are characterizing the habit of lives of the people in the sense of sanitary facilities used at Mwanza which will be presented in the results section.

2.1.4. Water Situation

The urban hydrology is composed of streams and the Lake Victoria, situated in the western end of the city. River Mirongo is the main watercourse traversing the city in east-west manner, flowing as far as from Magu district *via* Igoma and Nyakato sub-urban areas. This river has become an open sewer, receiving every sort of pollutants (both domestic wastewater and raw/semi-treated industrial effluents). The river has a flow ranging from 0.001 – 0.302 m^3/s at the Barnaba Bridge in Nyakato to 0.031 – 0.698 m^3/s at the bridge near the lake discharge point [27].

The city is to a great extent supplied with clean water (piped water) mainly from Lake Victoria, the availability of which varies from ward to ward. Some wards are getting smooth flow of water all the time such as Nyamagana, Mirongo, Isamilo, Mbugani, Pamba, Igogo and Mkuyuni while other areas (Butimba, Mkolani, Mahina, Buhongwa, Mkolani, Igoma) are not yet connected to the main city network. Moreover, the storm water is collected by an open channel system which is limited to the planned built-up urban areas in the city centre and the adjacent wards.

2.1.5. Mwanza Population and faecal sludge production

Total population and its growth in Mwanza City were respectively about 547,107 people and 3.2% [25]. Internal migrations of people from rural to urban areas were about 8% and the birth rate is 4.6. The population density is 134 people per sq. km, being the second in the country after Dar es Salaam City.

The population that depends on on-site sanitation was 604,074 in 2007. The total faecal sludge production was estimated in the same year to be 24,163 m^3/a, while the Biological oxygen demand (BOD_5)-load was 110 kg/d; dry solids 1,324 kg/d and *helminth eggs* 3,500 N/1,000ml. Such figures indicate a necessity to study all the wastewater fractions in general, that is, greywater, other fractions of liquid waste and solid waste.

2.2. Field Visits

This research work started by establishment of study sites through field visits where the ward executive leaders assisted the researcher in choosing potential sampling sites. Furthermore, the potential key respondents to up-front prepared questionnaires were identified through the assistance of City Council of Mwanza and those who have worked or researched in Mwanza City. Moreover, 40 houses were randomly selected for greywater quantity and quality determination. Four points were cited for sampling along River Mirongo since it disposes its effluents into Lake Victoria, namely: an area where a mix of river and Lake water occurs and upstream where there is a bridge near to wastewater treatment plant, at Mabatini and near the bridge where car wash is done. The results are indicated in the results section. Finally, the selection of areas where the decentralized greywater treatment facilities would be located (later not in this study) was done during the field visits.

2.3. Sampling for Greywater Quality Determination

2.3.1. Sampling Procedures

The sampling of greywater in Mwanza City Council was conducted between December, 2008 and June 2010. The selected wards for sampling were Igoma and Mbugani.

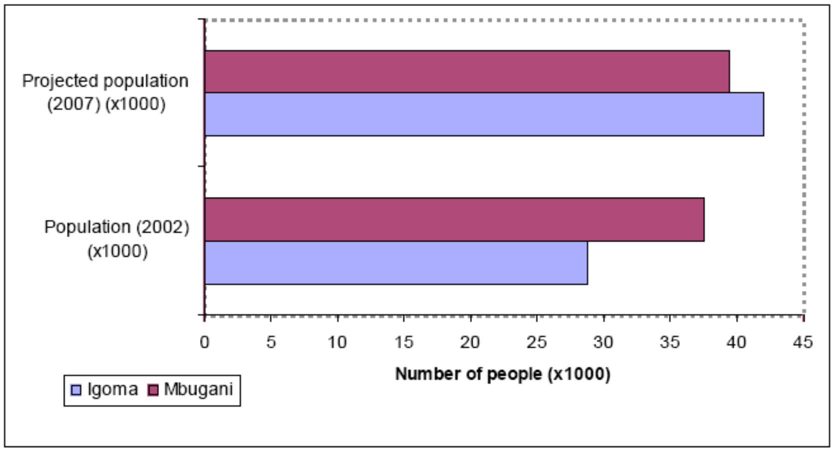

Fig. (4). Population of Selected wards in Mwanza city Council

These wards discharge greywater partly within their surroundings and into River Mirongo, which eventually ends up in Lake Victoria. A total of 40 samples were collected, preserved with sulphuric acid and then stored in the cool box and were transported to Dar-es-Salaam for laboratory analysis. However, some parameters whose quality deteriorates over time were measured on-site. They included total dissolved solids (TDS), temperature, Electrical Conductivity (EC), pH and Salinity. The laboratory work was done at Ardhi University, Environmental Laboratory Science and Technology Department. In each case, one litre samples were collected for laboratory analysis. The samples were collected during the dry and rainy season.

The houses, in which the samples were collected, were randomly selected, and the samples were collected from 8.00 pm. to 12.00 pm. and early morning hours since that was the time when people were taking bath after their daily work and sleep.

2.3.2. Analytical Methods

All parameters were determined using standard methods [29] on-site and at Ardhi University laboratory. The total chemical oxygen demand (CODt) of the sample was determined by the principle that, organic material is oxidized by potassium bichromate in acid conditions with a help of a catalyst (Ag^+). The used procedure was modified for high COD concentrations by diluting the samples.

Other determined parameters using [29] included the total suspended solids (TSS), total solids (TS) and volatile suspended solids (VSS) and volatile solids (VS), total and *faecal coliforms*, ammonia nitrogen and nitrate nitrogen (NH_3-N and NO_3-N). It is worthy to note that, surfactants though very important have not been studied in this work. They will be covered in the second part of the study which will basically deal with construction of greywater treatment facilities and determination of treatability of greywater.

3. RESULTS AND DISCUSSION

3.1. Sampled Wards Population

Two wards (Igoma and Mbugani) were chosen for sampling purposes. They were selected since they have people with different income brackets, located in unplanned settlement and have a big potential of polluting Lake Victoria. Residents are located in rocky area where they could not get adequate depth for pits to dispose all the generated liquid waste. The total population in the sampled wards is shown in Fig. (**4**).

3.2. Head of Households, Education Income Level and Expenditure Results

It was evident from the study area that heads of households were men in 90% and women in 10% of the cases. This situation could be so due death of husbands or divorces and hence, the problem of single parents and women heading the households. The education level of heads of households varied from never been to any school (8.7%), primary school 69.6%, secondary school 17.4% to Vocational School 8%. Many respondents were in the primary and secondary school level.

The income level of households ranged from Tshs. 30,000/= to Tshs. 200,000/= (USD 20 – USD 132, exchange rate of September 2010) per month. The occupation of residents by gender indicated that 85.7% of men were mostly occupied by commercial activities relative to women 14.3%. The low percentage of women dealing with commercial activities shows a clear sign that they are proceeding with their known normal cores of domestic work. The expenditure pattern showed that, residents generate inadequate money for the necessities of life. This situation indicates the poverty problems the people are battling with. Residents require a minimum of Tshs. 30,000/= and a maximum of Tshs 150,000/= (USD 20 and 100) per month for food implying a clear possibility of residents getting some extra money from other sources. Such income levels complicate the production of greywater especially when water is to be paid for.

3.3. Wastewater Disposal, Soil Conditions and Shower/Bathing Place

Mwanza area is experiencing rocky conditions and hence, difficult to dig deep pits for containing wastewater. About 70% and 8% of the residents in Igoma and Mbugani Wards respectively, are experiencing wastewater disposal problems. The cited problems were water logging, bad smell, floods from the neighbourhood and toilets, poor disposal of

Table 1. Used Water Source, Distance from Source and Available Water for Igoma and Mbugani Wards

Source	Percentage (%) of Respondents in Wards		Distance to Water Source (km.)	Percentage (%) of Respondents		Available Water to Residents Per Day		
	Igoma	Mbugani		Igoma	Mbugani	litres	Igoma	Mbugani
In-house tap	30.4	64.0	0-0.5	95.7	100	20-40	0	0
Public Tap	4.4	4	0.5-1	0	0	41-60	8.7	8
Neighbours tap	60.9	32	1-1.5	0	0	61-80	39.1	36
Spring well/borehole	0	0	0	0	0	>80	26.1	56

greywater causing disease to children, area is not clean, flies and mosquitoes immediately after the rainy season. Those who indicated that, they are not experiencing problems said that their houses are sparse and so have enough area for disposal. Often greywater is led directly and haphazardly to the house surroundings and later, part of it finds its way to Lake Victoria. This practice is not good since it jeopardizes the aesthetic value of the environment and poses potential hazards to children who like to play in pools of stagnant water. However, this practice is mainly found in the unplanned settlement part of the city. In some occasions it was observed that the residents separated the bath and kitchen water from the toilet waste in order to increase the life-time of the pit. Residents who take a bath or shower at the same place with the latrine were found to be 8% in Mbugani Ward and those who use separate rooms but same pit was 69.6% and 76% correspondingly for Igoma and Mbugani Wards while, those who use separate rooms and separate pits were respectively 17.4% and 8%. The already separation of greywater from blackwater observed in Mwanza offers a good chance of treating the greywater separately for subsequent use. The other details of the sampled wards are briefly explained hereunder:

Mbugani ward is mainly characterized by unplanned settlements especially in the slopes of rocky hillsides and sensitive land, which are stripped of their vegetative cover and aggravated by the mining of stones and sand for use in construction. Sanitation is generally poor, and the residents mostly depend on shallow pit latrines. Greywater is disposed of haphazardly in open areas. According to our survey, grey water production per capita ranges between 7 litres to 10 litres per shower. Showering is done twice a day. Therefore, grey water production per day is estimated to be 14 litres/ca/day and 20 litres/ca./day. The average family/household found in this study was 8 people implying, the greywater production estimate of 112 to 160 litres per household per day.

Igoma ward is characterised by both urban and rural characteristics. Most of the houses have bath-rooms without floors, walls and unroofed. Generally, bath-rooms are in poor conditions and greywater is discharged into open areas. The top soil in Igoma ward is sandy; therefore, greywater soaks easily into the soil after being discharged.

3.4. Engagement and Purpose of Farming and Land Tenure

In Igoma ward, 60.9% of the residents are engaged in farming while 34.8% are not. The case in Mbugani ward is different, only 16% of the households are engaged in farming while 84% are not. In both the cases, the garden sizes vary from ¼ acre to one hectare; but more than 50% have less than 0.5 of an hectare. The type of crop mainly grown in all wards is maize grown by 34% of the residents (26% in Igoma and 8% in Mbugani). The main purpose of farming is to supplement availability or bought food as cited by 56.5% of the respondents. Only 8.7% indicated that it is the major source of household food. Those who farm for both food and cash crop were only 4.4% in Igoma and 16% in Mbugani wards.

The nature of land tenure was observed to be public land in 95.7% of the cases in Igoma ward, while, customary land 56% and leasehold 48% are used at Mbugani ward. Such land tenure systems have an impact on farming and reuse potential of greywater. Conditions to use the land may deter the residents from reusing or recycling greywater if not owners of the land.

3.5. Generation of Greywater and its use in Igoma and Mbugani Wards

Generation of greywater depends to a greater extent on the amount of water used by the households and number of people in the household or size of the household. Where water is available in-house (tap water), the generation of greywater will be higher relative to those who need to walk longer distances. In the study wards in Mwanza City, the situation was as presented in Table **1**. In the homes water is mostly stored in plastic containers. Results showed that, 91.3% in Igoma and 100% in Mbugani wards store their water in plastic containers varying from 10 litres to 60 litres.

The amount of water used in the kitchen per day, its disposal place and that used for washing clothes and bathing were as summarized in Table **2**. Assuming that 80% of the water supplied for domestic use ends up as wastewater [30] and due to the fact that greywater composes 50-80% of residential wastewater generated, coupled with the facts presented in section 3.3, it clear that about 4480 m^3 – 8000 m^3 of greywater is produced in the study sites per day. This is a

Table 2. Amount of Water used in the Kitchen Per Day, Laundry and Bathing Water in Igoma and Mbugani Wards

Wards	% of Water Used in the Kitchen Per Day			% of Residents producing Laundry Wastewater		
	11-30 litres	31-40 litres	>40 litres	11-30	31-40	>40
Igoma	4.4	39.1	52.2	0	0	100
Mbugani	20	56	28	8	24	68

Table 3. Knowledge of Wastewater Treatment in some Selected Wards in Mwanza City

Knowledge of Wastewater Treatment	Percentage (%) of Respondents in Wards	
	Igoma	Mbugani
Yes	17.4	36
No	78.3	64
Is it ok. To treat greywater for reuse		
Yes	65.2	40
No	26.1	42
Reuse Possibilities		
Wash clothes	8.7	6
Irrigation	60.9	28
Toilet Cleaning	4.4	0
Brick Making	0	2
Accepting paying fee for treatment of used water		
Yes	82.6	56
No	8.7	44
Amount that residents are willing to pay for treatment		
Amount (Tshs.)	300-5000 (USD 0.2 – 3.3)	500-15000 (USD 0.33-9.9)

substantial amount for irrigation and other use purposes if adequately treated.

About 21.7% and 8% of the respondents respectively for Igoma and Mbugani wards said that they keep greywater for reuse purposes while the rest do not. The purpose of using the greywater is mainly for cleaning the house as indicated by 17.4% the residents in Igoma ward. Gardening purposes accounted for 4.4% of the residents in Igoma ward and 4% of those in Mbugani ward. Those who could not reuse the greywater doubted its quality in 26.1% and 44% of the respondents respectively for Igoma and Mbugani wards. However, 47.8% of residents in Igoma ward and 52% in Mbugani ward prefer to use clean water rather than greywater for gardening and dust protection. These results indicate a need for advocacy and educating the people possibilities of reuse of greywater.

The disposal of used kitchen and laundry water according to field results were 86.9% for kitchen and 92.3% for laundry in Igoma ward, and respectively in Mbugani ward, 88% and 72% are disposing their used water by pouring it on the ground or in trenches. Only 8.7% and 12% respectively for Igoma and Mbugani wards uses the sewerage system. The situation might change in future since Mwanza City is expected to get a big sewerage project.

3.6. Knowledge of Used Household Water

When asked whether the used households' water has any effects on the environment, the residents were of the opinion that yes in 60.9% and 42% 52% in Igoma and Mbugani wards. However, 34.8% of people in Igoma and 48% in Mbugani wards said no. Such results indicate the need to educate people for reuse of greywater. A number of them are not aware of the hazard potential of greywater. For those who said yes, they mentioned the effects as water logging 4.4% in Igoma, causing diseases 56.5% and 48% respectively in Igoma and Mbugani; drying the grass/crops 4.4% and 4% correspondingly in Igoma and Mbugani, while, for space availability was yes in 78.3% and 84% in Igoma and Mbugani and correspondingly no for 13% and 16%. Those who said no, indicated that if well handled and disposed, greywater is easily absorbed by land, that is, seeps into the ground.

Those who said yes were of the opinion that causes of problems were mainly poor management of disposed greywater mentioned by 52.2% of respondents in Igoma and 60%

Table 4. Results of Wastewater Samples from Selected Points in Mwanza City in Dry Season

Points	Temp. (^{0}C)	pH	Salinity (ppt)	TDS (mg /L)	EC (µscm$^{-1)}$	NH_3-N (mg /L)	NO_3-N (mg /L)	COD (mg /L)	SO_4 (mg /L)	TSS (mg /L)	VSS (mg /L)	COD:VSS
R. Mi-rongo	20.6	7.22	0.3	342	684	11.5	5.6	18	28	550	250	0.45
Mbugani Ward												
Min.	22.36	6.76	0.79	790.00	1574.07	52.83	0.68	589.20	6.47	1805.00	926.67	0.64
Max	24.10	7.70	4.70	4260.00	8520.00	210.00	1.10	2175.00	14.00	11750.00	5750.00	0.38
STD	0.94	0.48	1.33	1286.39	2576.40	45.43	0.29	655.04	3.85	3167.08	1624.16	0.40
Average	22.36	6.76	0.79	790.00	1574.07	52.83	0.68	589.20	6.47	1805.00	926.67	0.64
Igoma Ward												
Min.	20.56	6.98	1.27	1198.70	2397.10	40.60	0.60	670.40	7.75	2967.50	860.00	0.78
Max	21.20	8.00	3.90	4240.00	8480.00	173.00	2.10	1150.00	15.00	15900.00	2100.00	0.55
STD	0.36	0.50	1.27	1254.28	2508.34	54.83	0.80	303.13	7.27	4658.79	626.85	0.48
Average	20.56	6.98	1.27	1198.70	2397.10	40.60	0.60	670.40	7.75	2967.50	860.00	0.78

in Mbugani wards. Very few cited the problems of soap in the greywater (4.4% in Igoma and 12% in Mbugani wards) whereas, 4% of respondents in Mbugani ward mentioned as well the problem of volume of water. Nonetheless, a number of people do not have adequate space for disposal of greywater. Some people have knowledge of treatment of wastewater and think it is alright to treat wastewater for reuse purposes as shown in Table **3**. Those who did not accept to pay for treatment of used water said they have no money but as well, there is no need of it due to the presence of trenches especially in Mbugani ward.

3.7. Laboratory Results

The laboratory results were as indicated in Table **4** with discussions in subsequent sections.

3.7.1. pH and Temperature

It is clear from Tables **4** and **5** that, households had greywater with pH within the recommended range by WHO standard (6.5 – 8.5). Temperatures were 20.6 – 28.1 ^{0}C which is within the expected level of tropical conditions. The characteristics of greywater produced by community vary depending on the used ingredients [26]. The nature of greywater is markedly influenced by factors such as diet, methods of washing clothes and utensils, habits of personal hygiene, and the existence of bathrooms and other facilities.

The pH and temperature are important parameters in greywater treatment since most micro-organisms which are necessary for biodegradation have their temperature ranges for them to survive. Depending on the used greywater treatment technology, for example in anaerobic degradation or digestion which is a biological process where organic carbon is converted by subsequent oxidations and reductions to its most oxidized state (CO_2), and its most reduced state (CH_4), the methanogens have their specific pH (6.8-7.8) and temperature range (20-35^{0}C) [31] production of biodegradation by-products. Biodegradation means the biological transformation of an organic chemical to another form [32]. Methane production can only represent the hydrolysis rate of particulate organic matter when there is no accumulation of intermediary products [33]. The intermediary products are often due to a certain range of pH (<6.8) which is not favoured by methanogens. The observed pH and temperature at Mwanza clearly shows that methanogenic activity will take place in the treatment facilities to be constructed later. They will be covered structures and therefore, anaerobic conditions will prevail. The anaerobic biodegradability of the materials can be calculated from the maximum methane yield and the COD of the substrate, according to [9]:

$$BD = \frac{CH_{4,\max}}{W_{sam}} \frac{COD_{sam}}{2.85} 100 \qquad (1)$$

where BD represents the biodegradability (in % of VS), $CH_{4,max}$ the maximum methane yield (in STP ml.), W_{sam} the sample weight (in g-VS), COD_{sam} is the COD of the sample (in $gO_2\ g^{-1}VS$) and the factor 2.85 corresponds to the COD (gO_2) of 1 STP litre of methane. However, biodegradability was not determined in the current greywater samples due to limited possibilities of determining the CH_4 by then.

In addition to that, temperature is one of the major (key) factors or variables influencing the overall digestion process of waste in anaerobic reactors ([9, 31, 34, 35, 36]). Micro-organisms are classified into "temperature classes" on the basis of optimum temperature and the temperature span where the species are able to grow and metabolize and affect the particles removal through influencing the wastewater viscosity and conversion of organic matter ([31, 36]). When enzyme concentration is not rate-limiting, the rate of hydrolysis as a function of temperature can be described by the

Table 5. Results of Wastewater Samples from Selected Points in Mwanza City Soonafter Short Rain Season

Parameter	Unit	Average Influent to the Lake	Mixed River and Lake	Bridge Near WWT Plant	Near Bridge Car Wash	River Mirongo at Mabatini	Average HH Greywater
pH	-	7.2	7.1	6.9	7.5	6.8	6.93
EC	μscm^{-1}	491.5	759.3	509	1162	494	947.75
TDS	mg /L	245.5	79.7	254	581	247	474.25
Salinity	PPt	0.2	0.1	0.2	0.6	0.2	0.57
Temp.	0C	25.2	24.9	25.7	27.2	28.1	26.83
NH_3-N	mg /L	0.155	0.15	0.64	28.25	0.66	12.98
NO_3-N	mg /L	1.6	0.8	3.6	0.7	2.5	2.15
SO_4	mg /L	28.5	1	30	0	30	88.00
PO_4	mg /L	1.755	0.34	0.81	0.51	13.75	9.29
Colour	mg /L	3.5	13	9	247	19	218.50
Turbidity	mg /L	5	4	4	101	5	185.75
Alkalinity	mg /L	290.5	83.5	77	248	95	190.13
Chloride	mg /L	99	27.5	52	213	51	168.75
COD	mg /L	68.5	43	304	960	107	529.75
BOD_5	mg /L	26.5	20	168	449	52	264.50
TS	mg /L	412.5	150	350	850	375	568.75
VS	mg /L	187.5	50	250	650	275	468.75
FC x 10^5	Count/100ml	21	39	61	44	TN	29.00
TC x 10^5	Count/100ml	45.5	76	TN	89	TN	24.50
Pb	mg /L	0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Cu	mg /L	0.007	<0.01	<0.01	<0.01	<0.01	<0.01

WWT = Wastewater Treatment HH = Household

Arrhenius equation (Equation 2) for enzyme catalysis ([9, 37]):

$$k = A.e^{-\Delta G^*/RT} \quad (2)$$

where k represents the kinetic rate constant or hydrolysis rate constant (in d^{-1}); A is the Arrhenius constant, G* the standard free energy of activation ($Jmol^{-1}$) with typical values of 15-70 $kJmol^{-1}$ [38]; T the temperature (K) and R the gas constant with 64 (± 14) kJ mol^{-1} as a typical value for enzyme kinetics [39]. The hydrolysis of pollutants will be determined after construction of greywater treatment facility.

3.7.2. Total Solids (TS) and Volatile Solids (VS)

When one talks about treatment of wastewater or greywater, it is often important to realize that, there are individual components which need to be treated. One of these important components is the complex presence of solids in greywater. Determination of the level of available solids assists in choosing the treatment technology and suggesting possible reuse modalities. The solids can be determined in a number of categories depending on the intended use. In the Mwanza case, total, volatile and dissolved solids (TDS) were determined results of which are presented in Table **5**. Volatile solids represent the fraction that could be degraded and hence, possible to get biogas from the wastewater. Total solids can have inert components as well and hence, possible accumulation of sludges which will obviously need to be handled in its own merit. The high level of VS values relative to TS values indicated that there were a lot of biodegradable components in the greywater. However, some of the components might be slow degradable ones.

3.7.3. Ammonia Nitrogen and Nitrate Nitrogen (NH_3-N and NO_3-N)

Results in Table **4** and **5** indicate that, the NH_3-N level varied between 6.25 to 29.4 mg/L and NO_3-N, 0.5 to 2.7 mg/L for household samples. Ammonia compound levels are important to be determined since they have an impact on people's health, like high level of nitrates causes blue-baby-syndrome. In addition to that, high levels of ammonia compounds inhibit the hydrolysis and hence, low methanogenic activity of the greywater. This implies that, the greywater will not be able to be stabilized if there are high levels of ammonia [40]. [41] reported that ammonia inhibition occurs at total ammonia concentrations between 1500 – 3000 mg-N/L at pH level exceeding 7.4, but adaptation to high ammonia concentrations is very well possible. In the case of Mwanza results (Table **4** and Table **5**), the values were insignificantly low and hence, there is no cause of alarm. [42] proposed that, the ammonia nitrogen threshold levels in the influent of anaerobic ponds in the tropics should not exceed 400 - 500 mg-N/ L to avoid toxicity of ammonia. In Mwanza, the treatment facility of greywater that is under construction is improved tower gardens, study results of which will be presented in future.

3.7.4. Sulphate (SO_4)

Sulphate values ranged on average from 6.47 – 88 mg/L for the studied households as indicated in Table **5**. These values are lower than the WHO standard of 600 mg/L and therefore, currently there is no problem. High levels of sulphates at household level could be from the type of soaps used. However, the used soap types s in Mwanza city together have not been studied during the current research work. Sulphates are components that are introduced into the environment through natural processes or using products. High levels of sulphate can be lowered by calcium containing compound to form calcium sulphate as this has low level of solubility but complete removal from solution is not viable [43].

3.7.5. Copper (Cu) and Lead (Pb)

The analysis of heavy metals permits detection of pollutants that may be either absent or present in certain concentrations either in surface or underground water or in either the wastewater or sediments. The effects of heavy metal contaminants especially in fish causes health hazard to people [10] and in some occasions deaths of human beings. Many of these metals serve no known biological function in the marine environment, but can act with other chemical species to increase toxicity [44]. Moreover, in the case of all the collected liquid samples in Mwanza, the presence of Cu and Pb was insignificant as seen in Table **5**.

3.7.6. Chemical Oxygen Demand (COD)

COD serves as a general parameter that covers all organic constituents of wastewater or greywater. There are various fractions of COD possible to be determined in wastewater depending on interest according to standard methods [29] with user modifications as need be, some of which are as follows:

$$COD_{ss} = COD_t – COD_p \quad (3)$$

$$COD_{col} = COD_p – COD_{dis} \quad (4)$$

where:

OD_{ss} = COD of suspended solids

COD_t = Total COD

COD_p = Paper filtered COD

COD_{dis} = COD from membrane filtered samples

COD_{col} = Colloidal COD

The COD:VSS results for the case of Mwanza City sampled areas as indicated in Table **4** revealed that, the minimum ratio was 0.09 gCOD/gVS and maximum 0.78 gCOD/gVS. The results indicate that the samples were homogeneous.

3.7.7. Faecal Coliforms (FC)

Faecal Coliforms are pathogenic organisms whereby, their presence in the environment is a health risk and a treatment concern. [8] cited that “people as an “asset” for development often produce in secret human “waste” which is of public concern”. Where present, it is an indication that excreta has come into contact with water or excreta has been haphazardly disposed of. Results in Table **5** showed that *faecal coliforms* were present in greywater produced at Mwanza study areas. Obtained values at household level varied from 21 to too numerous to count (count/100 ml.). This implies that, the greywater if haphazardly disposed has a potential of polluting the environment and the receiving water bodies. Anaerobic digesters have a capability of killing pathogens to a certain degree in greywater. The *faecal coliform’s* average survival time in wet sludge at 20-30^{0}C have been found to be <50 days [45]. Such temperatures are present in Mwanza and therefore, if space could be available anaerobic digestion is another treatment option. Anaerobic digesters reduced the number of bacteria, parasite eggs, viruses and other pathogenic organisms in the effluent of UASB reactor by ± 90% [46]. This is not sufficient to meet the WHO [47] Guidelines for reuse (like for *E-Coli* 1000 no./100 ml.) and hence, post treatment is necessary. Sufficient challenge describes the beneficial effect of low exposure to toxins, which improves health [48] by building up natural resistance to attack pathogens. Presence of pathogenic organisms is a health risk in sludges and is a treatment concern, although the collection, haulage and treatment of faecal sludges (FS) in urban areas in developing countries remains as yet unresolved [49, 50].

Possibilities of getting FC in greywater might come from washing of babies’ clothes and nappies (diapers) which is likely to increase the count substantially. Some data suggest that bacteria grow well in greywater [26]. Moreover, a substantial danger from pathogens is posed by careless tipping of greywater on the ground; and if one particular area is always used, its continual moistness will favour the survival of helminthes, such as hookworm, and the breeding of flies and mosquitoes [26].

3.7.8. Greywater Reuse and Recycling Potential

Reuse and recycling of greywater is not common in East Africa. However, evidence from some literature [16];[19] indicate that reuse of wastewater is common in Kenya, Tanzania and Uganda. As fore-mentioned in section 3.6, some residents have the knowledge of greywater reuse and 60.9% and 28% cited the reuse possibilities in agriculture for irrigating various food crops. The potential of reuse and recycling of greywater from the socio-economic and cultural point of view is available in Mwanza although education and advocacy should be part and parcel of the practice.

4.0. CONCLUSIONS

The following concluding remarks can be made out of this study:

i. Igoma and Mbugani wards in Mwanza were selected for study purposes since they have people with different income brackets, located in unplanned settlement and have a big potential of polluting Lake Victoria.

ii. Greywater quality generated in Mwanza City's selected households (40) is contaminated by faecal matter. Observed values for *faecal coliforms* in the household samples ranged from 21 Count/100ml. to too numerous to count.

iii. Presence of observed contamination by faecal matter confirms the need for treatment of greywater for reuse purposes to avoid health hazards. Improved tower gardens could be a good treatment facility.

iv. A number of residents in Mwanza City have no knowledge of greywater treatment as indicated by 78.3% and 64% of respondents correspondingly in Igoma and Mbugani wards. However, 65.2% and 40% respectively for Igoma and Mbugani said it is alright to treat greywater.

v. Greywater reuse needs educating the community and continued advocacy. In Igoma ward 34.8% while in Mbugani ward 48% felt that greywater has no adverse effects to the environment.

vi. Reuse and recycling potential that has been determined from the qualitative point of view showed that, residents are ready to reuse the greywater especially for irrigation as cited by 60.9% and 28% of the people correspondingly for Igoma and Mbugani wards.

vii. Residents are ready to pay per month Tshs. 300 – 5000 (USD 0.2 – 3.3) in Igoma ward and Tshs. 500 – 15,000 (USD 0.33 – 9.9) in Mbugani wards for greywater treatment.

viii. The quality of greywater in terms of Cu and Pb is insignificant for both greywater from the households and other selected points for sampling purposes as shown in Table **5**. Result values in all cases ranged from 0.007 to 0.01 mg/L.

ix. The greywater pH values observed ranged from 5.9 to 7.5 while the recommended World Health Organisation (WHO) range is 6.76 – 8.0.

x. People of Mwanza City, especially those residing in the study wards, are already separating the greywater (17.4% and 8% respectively in Igoma and Mbugani wards) due to inadequate pit volume for excreta disposal and therefore, a greater chance for treating the greywater for reuse purposes.

xi. Generated greywater in Igoma and Mbugani wards per day ranges between 4480 m^3 to 8000 m^3.

xii. The greywater in Mwanza City is homogeneous as evidenced by the COD:VSS ratio of the samples which varied between 0.09 - 0.78 gCOD/gVS.

6.0. ACKNOWLEDGEMENTS

I would like to acknowledge the Victoria Research Initiative (VicRes) for the financial support and continued guidance during the research. Without their crucial input the research could not come this far. Further thanks go to Mwanza City Council for their permission to work safely in their locality. Moreover, Ardhi University is highly thanked for granting permission and laboratory facilities for the research. Finally but not least, special appreciation goes to Mr. T. Bigambo who gave assistance during data collection.

REFERENCES

[1] Winblad, U. (ed), *Ecological Sanitation*, Swedish International Development agency, Stockholm, 1998.

[2] Ministry of Lands and Human Settlements, *National Human Development Policy*, Government Printer Dar Es Salaam - Tanzania, 2000.

[3] F. Streiffeler, "Urban Agriculture, Biotechnology in Organic Waste Management, From Solid Waste Disposal to Resource recovery in The Netherlands", in Euro Summer School Programme, 2003, pp.1-29.

[4] J. Smit and J. Nasr, "Urban Agriculture for Sustainable Cities: Using Wastes and Idle Land and Water Bodies as Resources", J. Environ. and Urbanization, vol. 22, pp. 483-499, Oct. 2010, [Online] Available: http://eau.sagepub.com/content/4/2/141 [Accessed Jan. 10, 2011].

[5] B. B. K. Majani, "Instruments of Intervention for Urban Agriculture, Dar-es-Salaam", Unpublished report, University College of Lands and Architectural Studies, Dar-es-Salaam, Tanzania, 1997.

[6] P. Lens, G. Zeeman and G. Lettinga, *Decentralised Sanitation and Reuse: Concepts, systems and implementation*, IWA Publishing, TJ International (Ltd), Padstow Cornwall, UK., 2001.

[7] S. A. Esrey, A. Ingvar, A. Hillers and R. Sawyer, *Closing the loop: Ecological Sanitation for Food Security*, UNDP and SIDA, Publications on water Resources no. 18 Mexico, 2001.

[8] E. J. Chaggu, "Sustainable Environmental Protection Using Modified Pit-Latrines", Ph.D. Thesis, Wageningen University and Research Centre, ON, The Netherlands, 2004.

[9] W. T. M. Sanders, "Anaerobic Hydrolysis During Digestion of Complex Substrates", Ph.D. Thesis Wageningen University, ON, The Netherlands, 2001.

[10] B. Nobble, I. Paul, S. Onywere, P. Nampala, and J. S. Tenywa, Ed., *Integrated Risk Assessment and Management of Pollutants in Lake Victoria Basin*, VicRes, Uganda, 2009.

[11] G. Zeeman, W. Sanders and G. Lettinga, "Feasibility of the On-site Treatment of Sewage and Swill in Large Buildings", Wat. Sci. and Tech., vol. 41, pp.9-16, 2000. [Online] Available: http://www.iwaponline.com/wst/04101/wst041010009.htm [Accessed Jan. 20, 2011].

[12] G. Lettinga, P. Lens, and G. Zeeman, *Environmental Protection Technologies for Sustainable Development, Decentralised Sanitation and Reuse*, IWA Publishing, UK, 2001.

[13] K. Kujawa-Roeleveld, T. Elmitwalli, A. Gaillard, M. van Leeuwen, and G. Zeeman, "Co-digestion of Concentrated Black Water and Kitchen Refuse in an Accumulation System (AC) within a DESAR concept", Water Sci. and Tech., vol. 48, pp. 121-128, 2003. [Online] Available: http://www.iwaponline.com/wst/04804/wst048040121.htm [Accessed Dec. 4, 2010].

[14] E. Smaling, "An Agro-ecological Framework for Nutrient Management with Special Reference to Kenya", Ph.D Thesis, Wageningen Agricultural University, ON, The Netherlands. 1993.

[15] I. Scoones, and C. Toulmin, *Soil Nutrient Budgets and Balances: What Use for Policy?* Russell Press Nottingham, U. K., 1999.

[16] E. J. Chaggu and E. John, "Ecological Sanitation Toilets in Tanzania", in Third International Conference on Integrated Environmental Management in Southern Africa, Johannesburg, Aug. 28, 2002. Available: http://www2.gtz.de/Dokumente/oe44/ecosan/en-ecosan-tansania-2002.pdf [Accessed Jan. 15, 2011].

[17] C. Schönning, *Evaluation of Microbial Health Risks Associated with the Reuse of Human Urine*, Swedish Institute for Infectious Diseases Control, Stockholm, 2001.

[18] U. Winblad and W. Kilama, *Sanitation Without Water*, Sida, Stockholm, 1978.

[19] F. P. Baijukya and B. S. Piters, "Nutrient Balances and Their Consequences in the Banana-based Land Use Systems of Bukoba dis-

trict, Northwest Tanzania", Agriculture, Ecosystems and Environment, vol. 71, pp. 147-158, December 1998.

[20] WSSCC VISION 21: "A Shared Vision for Hygiene, Sanitation and Water Supply and Framework for Action, Water Supply and Sanitation Collaborative Council, 2000", Available: http://www.unwater.org/downloads/vision21.pdf [Accessed Oct. 10, 2010].

[21] E. J. Martijn, F. Huibers and J. B. van Lier, "Appropriate Agricultural Use of Treated Effluent Under (semi-) Arid Climate Conditions", MSc. Lecture Notes Wageningen University, ON, The Netherlands, 2003.

[22] M. M. Duqqah, "Treated Sewage Water Use in Irrigated Agriculture – Theoretical Design of farming Systems in Siel Al Zarqa and the Middle Jordan Valley in Jordan", Ph.D Thesis Wageningen University, ON, The Netherlands. 2002.

[23] J. M. Kikwete, "Announcement of The President of United Republic of Tanzania on Kilimo Kwanza (Agriculture First)", Dar-es-Salaam, Tanzania. 2009.

[24] Free encyclopedia, Available: http://en.wikipedia.org/wiki/Greywater [Accessed 24th March, 2011].

[25] National Bureau of Statistics, *National Census Results*, Government Printer, Dar-es-Salaam, Tanzania, 2002.

[26] R. Francey, J. Pickford, and R. Reed, *A Guide to the Development of On-site Sanitation*, WHO Geneva, 1992.

[27] Mwanza City Council, *Mwanza City Profile*, Tanzania, 2007.

[28] Meterological Department, *Weather Report*, Dar-es-Salaam, Tanzania. 2004.

[29] Standard Methods, *Examination of Water and Wastewater*, APHA, AWWA, WPCF, 18th Edition, Am. Publ. Health Association, Washington DC., 1992.

[30] Metcalf and Eddy, *Wastewater Engineering: Treatment and Reuse*, McGraw Hill New York, 2003.

[31] S. Rebac, "Psychrophilic Anaerobic Treatment of Low Strength Wastewaters", Ph.D Thesis Wageningen Agricultural University, ON, The Netherlands, 1998.

[32] C. P. L. Grady, "Biodegradation: Its Measurement and Microbiological Basis" Biotechnology and Bioengineering, vol. 27, pp. 660-674, May 1985.

[33] A. Veeken and B. Hamelers, "Effect of Temperature on Hydrolysis Rates of Selected Biowaste Components", Bioresource Technology vol. 69 pp. 249-254, September 1999.

[34] A. Barnett, L. Pyle, S. K. Subramanian (1978*), Biogas Technology in the Third World: A Multidisciplinary Review*, IDRC Ottawa Canada, 1978.

[35] K. Wang, "Integrated Anaerobic and Aerobic Treatment of Sewage", Ph.D Thesis, Wageningen University, ON, The Netherlands, 1994.

[36] N. Mahmoud, G. Zeeman, H. Gijzen and G. Lettinga, "Solids Removal in Upflow Anaerobic Reactors, A Review", Bioresource Technology, vol. 90, pp. 1-9, October 2003.

[37] P. W. Artkins, *Physical Chemistry, third ed*., Oxford University, Oxford, 1986.

[38] M. F. Chaplin and C. Bucke, *Enzyme Technology*, Cambridge University Press, 1990.

[39] J. A. Roels, *Energetics and Kinetics in Biotechnology*, Elsevier, Amsterdam, 1983.

[40] H. M. Elmashad, G. Zeeman, W. K. P. van Loon, G. P. A. Bot and G. Lettinga, "Anaerobic Digestion of Solid Animal Waste in an Accumulation System at Mesophilic and Thermophilic Conditions, Start up", Water Science and Technology, vol. 48, pp. 217-220, 2003, [Online] Available: http://www.iwaponline.com/wst/04804/wst048040217.htm, [Accessed March 24, 2011].

[41] N. A. Mignone, Biological Inhibition/Toxicity Control in Municipal Anaerobic Digestion Facilities, [Online] Available: http://www.awpca.net/Biological%20Inhibition.pdf [Accessed on March 25, 2011].

[42] M. Strauss, S. A., Larmie, U. Heinss and A. Montangero, "Treating Faecal Sludges in Ponds", in Conference on Waste Stabilization Pond, Marratech, 1999, pp. 20-23, Available: http://www.eawag.ch/forschung/sandec/publikationen/ewm/dl/treating_FS_in_Ponds_Strauss_IWA.pdf [Accessed March 25, 2011].

[43] A. S. Chacha, "Assessment and Treatment Options of Tannery Wastewater: Case Study: Afro Leather Industry Mbagala", BSc. Dissertation, University College of Lands and Architectural Studies, Dar-es-Salaam, ON, Tanzania, 2005.

[44] Environmental Protection Agency, *The Incidence and Severity of Sediment Contamination in Surface Waters of the United States Volume 1: National Sediment Quality Survey*, Office of Science and Technology, Washington D.C., EPA 823-R-97-006, 1997.

[45] M. Strauss and U. J. Blumenthal, *Use of Human Wastes in Agriculture and Aquaculture, Utilization Practices and Health Perspectives*, EAWAG, Switzerland, 1997.

[46] E. Kijne, *Biogas in Asia - Inventory Field Study on the State-of-Development of Biogas Digesters for Household Use in Tropical Rural Communities*, CDP Utretcht, The Netherlands, pp.1-10, 1984.

[47] WHO, *Guidelines for the safe use of wastewater, excreta and greywater*, 2007 Available http://www.who.int/water_sanitation_health/wastewater/gsuww/en/index.html [Accessed, March 25, 2011].

[48] M. A. Ottoboni, *The Dose Makes the Poison*, Vincente Books, Berkeley CA. 1984.

[49] G. Lettinga, L. Hulshoff-Pol, and G. Zeeman, Anaerobic Wastewater Treatment, in Biological Wastewater Treatment, Wageningen University, The Netherlands, 1998.

[50] M. Strauss, "Treatment of Sludges from Non-Sewered Sanitation Systems", in Aqua '98 Seminario-Taller Saneamiento Basico y Sostenibilidad Cali, Colombia, 1998.

Received: December 06, 2010 Revised: April 04, 2011 Accepted: April 06, 2011