Quantification Of Physico-Chemical Characteristics And Modeling Faecal Sludge Nutrients From Kampala City Slum Pit Latrines

IJREAT International Journal of Research in Engineering & Advanced Technology, Volume 3, Issue 6, Dec -Jan, 2016
ISSN: 2320 – 8791 (Impact Factor: 2.317)
www.ijreat.org

Quantification Of Physico-Chemical Characteristics And Modeling Faecal Sludge Nutrients From Kampala City Slum Pit Latrines

Daniel Kimuli[1], Ahamada Zziwa*[1], Noble Banadda[1], Isa Kabenge[1], Nicholas Kiggundu[1], Robert Kambugu[1], Joshua Wanyama[1], Peter Tumutegyereize[1], Julia Kigozi[1]

[1]Department of Agricultural and Biosystems Engineering, Makerere University, P.O. Box 7062, Kampala (Uganda)
*Corresponding Author

Abstract

Failure to quantify nutrients in feacal sludge usually leads to its poor disposal resulting into surface water and groundwater pollution. Therefore, this study was conducted to determine and model the distribution of nutrients in pit latrine sludge as a step towards reuse of available nutrients. Sampling was done at 0.0, 0.5, 1.0 and 1.5 m depths from 31 lined and 31 unlined latrines during rainy and dry season. Physico-chemical characteristics such as chemical oxygen demand (COD), dissolved oxygen (DO), moisture content, temperature and nutrients including ammonia, nitrate, total nitrogen, phosphorus and potassium were determined. Results indicated that COD, temperature and DO decreased and moisture content increased with sludge depth. There was no significant variation ($P>0.05$) in nutrients and physico-chemical properties except COD. Strong correlations of $R^2_{Adj} > 0.85$ were obtained between modeled and measured values. The relative root mean square error of the predicted nutrients was less than 10%. Results revealed that the model is good estimator phosphorus concentrations in lined pits followed by total nitrogen in unlined pits and nitrates in lined pits.

Keywords: Nutrients, faecal sludge, latrines, modeling, sanitation

1. Introduction

Increasing urbanization is a phenomenon sweeping across the world especially in developing countries. It is estimated that nearly 50% of the population of Sub-Saharan Africa will be living in urban areas by 2030 (United Nations, 2014). This rapid population increase coupled with limited financial resources and poor planning has constrained urban authorities from providing decent sanitation for the growing urban population. Consequently, persons living in informal settlements, known as slums in Kampala suburbs continually struggle with faecal waste disposal and majority use pit latrines for faecal sludge disposal (Lugali, 2016). The rampant use of pit latrines in Kampala is mainly due to the poor sewer coverage of Kampala with less than 10% of the city being served by the central sewer system and the rest of the population relying on manual and mechanical pit emptying services (Diener *et al*., 2014). It is observed that in these slums there are more users per pit latrine than in other areas of Kampala. More often than not, the pit latrines are shared between families and communities in these slums. In addition, providing adequate and appropriate sanitation facilities in most of Kampala suburbs still remains a major challenge for local governments and urban authorities (Katukiza *et al*., 2012). It is not surprising that inadequate and inappropriate sanitation facilities contribute to a large extent to environmental health problems facing many parts of Kampala with adverse effects on both human and economic developments (Semiyaga *et al*., 2015). Although pit latrines are the dominant faecal waste disposal facilities in Kampala city slum areas, most of them are in a poor state, either filled or almost filled up and therefore there is a need for a sustainable faecal waste management system in these areas (Katukiza *et al*., 2012).

Conventionally in Uganda, faecal sludge is commonly disposed off in three ways; landfilling as sewage sludge, on-site disposal systems such as disposal into water channels and burial into the ground (Diener *et al*., 2014; Katukiza *et al*., 2010; Kulabako *et al*., 2010; Schouten and Mathenge, 2010). However, the growing urbanization of Kampala and her suburbs coupled with increasingly rigorous faecal sludge disposal measures and increasing public pressure, is forcing public and private sludge producers to re-assess their sludge management strategies. Sludge management efforts are being directed more towards the recovery and reuse of nutrients from sludge (Diener *et al*., 2014; Tyagi and Lo, 2013). This interest in nutrients recovery is driven by several factors including scarcity and high costs of artificial fertilizers, public awareness and advancements in nutrients recovery technologies. The nutrients in faecal sludge that are economically feasible to recycle include; nitrogen, phosphorus and potassium (Tyagi and Lo, 2013). In many highly industrialized countries like China faecal sludge has been used in agriculture by direct application to the soil (Walia and Goyal, 2010; Pathak *et al*., 2009; Bertin *et al*., 2007; Cofie *et al*., 2007; Horswell *et al*., 2003). However, in some cases such end-use practices have led to faecal sludge related infections. In Ghana, farmers have complained of itching and swollen feet as they incorporate sludge into the soil during land preparation (Semiyaga *et al*., 2015; Asare *et al*., 2003). In some countries including Ghana and South Africa, experiments have been carried out to produce dried faecal sludge in form of pellets (Strande *et al*., 2014; Nikiema *et al*., 2013). Although researchers like Chaggu (2004) and Lopez Zavala *et al*. (2002) have reported on nutrient availability in faecal sludge, limited studies focused on modeling nutrients distribution in pit latrines have been carried out. The aim of this study was to quantify nutrients in faecal sludge, (determine the physico-chemical characteristics of faecal sludge and model nutrients distribution in faecal sludge.

2. Materials and Methods

2.1 Study Area

The study was conducted in selected parishes of four divisions of Kampala City namely: Kampala central, Kawempe, Nakawa, and Makindye (Figure 1).

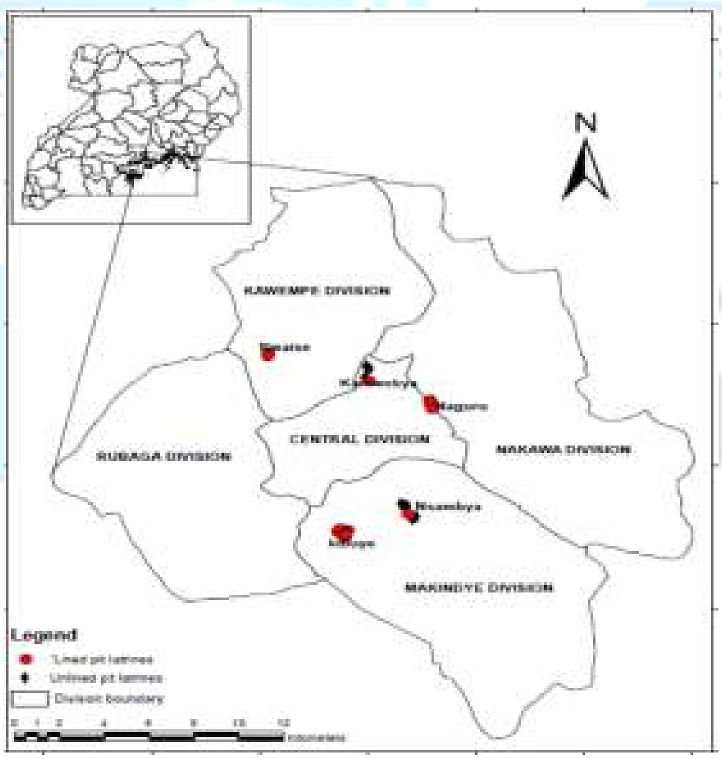

Figure 1: Location of sampled lined and unlined pits in Kampala slums.

2.2 Sampling Design

The sampling units were grouped into lined and unlined pit latrines. A set of 31 pit latrines were randomly selected from each stratum, making a total sample of 62 pit latrines. Stratified sampling design was used based on the assumption that there is large variation between lined and unlined pit latrines. In order to minimize variation within each stratum, pit latrines located in the same locality at elevations ranging from 1165-1170 m and with similar pit depths were selected for sampling. From each pit latrine, sludge samples were drawn at vertical incremental depths of 0.5 m over a depth of 1.5 m starting from the top sludge surface at 0.0 m up to a depth of 1.5 m using a manual sampling device with a graduated delivery pipe. Sludge samples were collected in 250 mL polyethylene containers, stored in ice cooled boxes for 4 hour prior to transportation to the laboratory for analysis.

The study targeted pit latrines that are commonly used by people in rented housing units. This particular category of pit latrines referred to as rentals was chosen because it is the most commonly used category in Kampala slums. In order to make a comparison among the lined and unlined pits, 6 lined and 6 unlined pits were chosen for the rainy season and 25 pits for each type were selected for the dry season. Fifty pits were sampled during the dry season versus 12 pits for the rainy season.

2.3 Sample Collection and Preparation

During the rainy season (between Oct. and Dec. 2014, mean monthly rainfall of 84.4 mm (Accessed at: http://www.accuweather.com) 48 samples from 12 pit latrines were collected in two phases. A total of 200 samples (equivalent of 100 samples for 25 lined pits plus 100 samples from 25 unlined pits, taken at four depths of each pit latrine) from 50 pit latrines were collected during the dry season (between Feb and Mar 2015, mean monthly rainfall of 39.4 mm (Accessed at: http://www.accuweather.com). Sample data used for model validation was collected separately during the second phase of the rainy season in the months of November and December 2014. A total of 296 samples were collected and analyzed. To ensure that samples were taken from the same pit latrine during the rainy season, mapping of the sampling points was done using a hand held GPS. The coordinates of the sampled pits were saved in a GPS and later used to trace the locations during subsequent sampling.

2.4 Sample Analysis

Chemical characteristics including:- ammonia (NH_4^+-N), nitrate (NO_3^--N), total nitrogen (TN), and total phosphorus (TP) were determined by the colorimetric method using a spectrophotometer (Jenway 6405 UV/Vis., Bibby Scientific Ltd, Staffordshire, UK); potassium was determined by the photometric method using a flame photometer (Jenway PFP7, Bibby Scientific Ltd, Staffordshire, UK), COD was determined by the closed reflex colorimetric method using COD photometer (HI 83099, Hanna Instruments Ltd, Bedfordshire, UK), DO was determined using the field DO meter (MW 600, Milwaukee Instruments, Inc., Milwaukee, USA), temperature was determined by a temperature meter (HI 98128, Hanna Instruments Ltd, Bedfordshire, UK) and moisture content was determine by oven dry method. The adopted methods are described in standard methods (APHA, 1998).

2.5 Modeling of Nutrient Distribution

The modeling approach was adopted from Banadda *et al*. (2011) based on the fundamental principle of conservation of mass for dissolved substances (Equation 1).

$$\frac{1}{A}\left\{\frac{\partial}{\partial y}\left[D(y)A(y)\frac{\partial C(y,t)}{\partial y}\right]-\frac{\partial}{\partial y}\left[Q(y,t)C(y,t)\right]\right\}+R(y,t)=\frac{\partial C(y,t)}{\partial t} \qquad (1)$$

Where t is time, y is the coordinate of a point in the sludge body, A(y) is the cross sectional area at point y, D(y) is the vertical distribution coefficient at the point y, C(y,t) is the concentration of nutrient at point y and time t, Q(y,t) is the flow rate at point y and time t, R(y,t) is the net rate of change of nutrients due to sources and sinks at point y and time t.

Using the assumption that nutrients are uniformly distributed at a given sludge depth, the variation in the distribution is found to exist only in the vertical direction relative to the sludge surface (Biswas, 1976). In addition, nutrients transfer within a prescribed time interval is considered constant in the view of the assumption that the parameters for diffusion, D(y), flow Q(y) and area A(y) are constant for all the points (y) within a range of pit depth. Under these conditions, Equation (1) becomes simplified and takes on a steady-state form (Equation 2).

$$D\frac{d^2C(y)}{dy^2} - \frac{Q}{A} \times \frac{dC(y)}{dy} + R(y) = 0 \qquad (2)$$

Hence, the concentration of nutrients at various points along the pit depth is only a function of pit depth. By integration Equation (2) yields the residual concentration of nutrients at any vertical distance or point y due to the steady release of a nutrient at any point i (Equation 3).

$$C_{i,y} = \alpha C_i \qquad (3)$$

Where $C_{i,y}$ is the concentration of nutrient at location y (0.5, 1 and 1.5 m) resulting from the release of nutrient from location i (0, 0.5 and 1 m) and α is the distribution coefficient and C_i is the initial nutrient concentration at location i.

2.6 Statistical Analysis

The mean and standard errors of all samples were determined. Analysis of variance (ANOVA) using GenStat Edition 12 statistical software was used to test for differences between means of samples collected from different pit latrine types and depths for the two seasons. An adjusted R-squared measure of goodness of fit was used to indicate how well the model fits the data (Cameron and Windmeijer, 1997; Magee, 1990). In addition, the relative root mean square (RRMS) error was used to show the model accuracy in estimating nutrient concentration (Legates and McCabe, 1999).

3. Results and Discussion

The levels of nutrients (mean ± standard error) obtained in this study are greater than the nutrient value of the conventional cow dung and poultry manure reported by Ssonko *et al.* (2015), Ewulo *et al.* (2007) and Adediran *et al.* (1999) implying that faecal sludge can be a better source of nutrients.

3.1 Physico-chemical characteristics of faecal sludge

Figures 2 to 5 show variation in physico-chemical characteristics of sludge in lined and unlined pits during the rainy and dry seasons. During the rainy season, dissolved oxygen (DO) in lined pit latrines ranged between 0.96 mg/L and 1.72 mg/L while in unlined pit latrines, DO ranged between 0.97 mg/L and 1.32 mg/L. For the dry season, DO in lined pit latrines averaged 0.66±0.27 mg/L and 0.58±0.21 mg/L in unlined pits. DO concentration decreased with sludge depth in both types of pits and seasons (Figure 2). Buckley *et al*. (2008) and Still and Foxon (2012) reported that this trend occurs because of the obstruction of oxygen by fresh excreta that comes into the pit when the pit latrine is in use. Therefore, anaerobic conditions prevail in sludge below the top surface and processes such as nitrification that require oxygen are inhibited. There was no significant variation ($p>0.05$) in DO with sludge depth and between lined and unlined pits in the rainy and dry seasons.

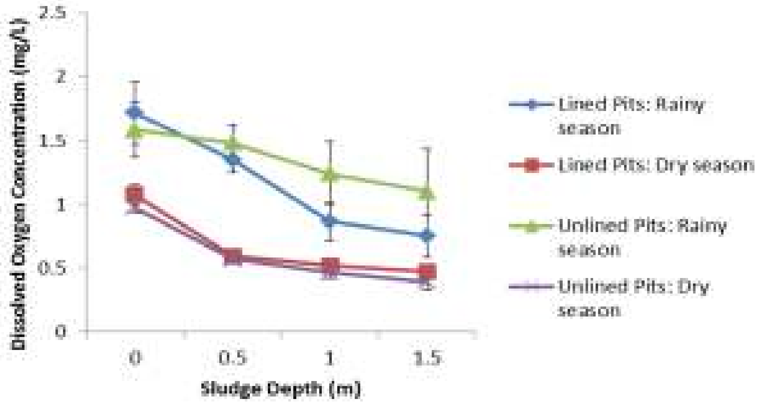

Figure 2: Variation of dissolved oxygen with pit latrine type and season

For the rainy season, the temperature averaged 24.2±0.7ºC in lined pits and 24.1±0.7ºC for unlined pits. During the dry season, temperature averaged 26.2±0.7ºC and 25.4±0.7ºC in lined and unlined pits respectively. Temperature decreased with sludge depth in both lined and unlined pits and during both seasons (Figure 3). The higher temperatures that existed in the pits in the dry season may have been contributed by the high ambient temperatures that occur during that season. There was no significant variation ($p>0.05$) in temperature with sludge depth and between lined and unlined pits during the rainy and dry seasons. The average temperature of sludge in both lined and unlined pits during both seasons falls in the range (0 to 30°C) reported by Nwaneri (2009). The pit latrines of the study area were characterized by high moisture levels of 70 to 92%. These moisture levels are responsible for the trend of falling temperature with depth by creating a cooling effect despite the exothermic metabolic activities taking place in the pits that would raise pit temperatures beyond mesophilic temperature levels. Buckley et al. (2008) and Strande et al. (2014) showed that mesophilic conditions are likely to prevail in pits with temperatures that fall in the range of 20 to 45°C.

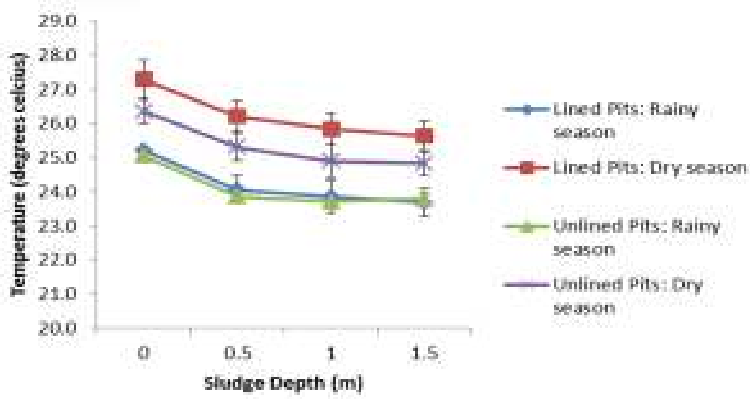

Figure 3: Variation of temperature with pit type and season

During the rainy season, the moisture content averaged 85.8±2.6% in lined pits and 89.0±4.6% for unlined pits and in the dry season, the moisture content averaged 77.1±4.2% and 80.9±2.9% in lined and unlined pits, respectively. There was no significant difference ($p>0.05$) in moisture content with sludge depth and between lined and unlined pits during both seasons. The average moisture content in unlined pits in the rainy and dry seasons falls within the range of 80% to 92% as reported by Chaggu (2004). In this study (Figure 4) the moisture content showed a general increase with sludge depth because pits were located below the groundwater table. Kulabako (2005) reported that the groundwater table in the low-lying Kampala areas is less than 1 m below the ground. This implied that there was a net movement of water into the pits located in the study area an observation also reported by Buckley *et al.* (2008).

However, Bakare *et al.* (2012) as well as Still and Foxon (2012) indicated that moisture content decreases with sludge depth because the unlined pits used in their studies were located above the groundwater table implying that there was a net movement of water out of the pits. The exchange of sludge and water that occurs between the pits and the surrounding soils presents risks of groundwater pollution and the health of the residents that consume water in such contaminated aquifers is compromised (Semiyaga *et al*., 2015; Nyenje *et al,*. 2014; Nyenje *et al*., 2013; Katukiza *et al*., 2010; Dzwairo *et al*., 2006).

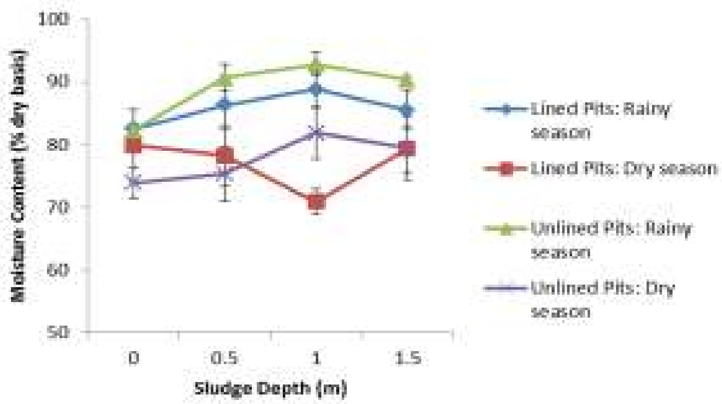

Figure 4: Variation of moisture content with pit type and season

In the rainy season, COD averaged 32,384±457 mg/L in lined pit latrines and 21,520±569 mg/L for unlined latrines and in the dry season, the COD averaged 31,842±1,900 mg/L and 27,373±943 mg/L in lined and unlined pits respectively. A presentation of COD values in g/g dry weight is presented in Appendix 1 and 2. There was significant variation ($p<0.05$) in COD values with sludge depth in lined and unlined pits during the dry season and statistical significant differences existed only between 0 m and 1 m, and between 0 m and 1.5 m of sludge depths in lined pits while in unlined pits statistical significant differences existed between sludge depth of 0 m and 0.5 m, 0 m and 1 m, 0 m and 1.5 m. There was no significant variation ($p<0.05$) in COD values with sludge depth in lined and unlined pits during the rainy season. There was significant variation ($p<0.05$) in COD values between lined and unlined pits during the rainy and dry seasons. From Figure 5, COD in both lined and unlined pits during both seasons decreased with sludge depth, a trend which was also observed by Buckley et al. (2008), Nwaneri (2009) and Bakare *et al*. (2012). The COD results from this study fall in the range of 20,000 to 50,000 mg/L which was also reported by Heinss et al. (1998), Chaggu (2004), Koné and Strauss (2004) and Nwaneri (2009). COD was lower in unlined pits than lined pits during both seasons due to the dilution effect of moisture content (Nwaneri, 2009). The COD concentration values obtained in this study are far greater than the value provided by the Uganda National Environment Regulations (1999) which state that effluent is environmentally safe for discharge into water or land with a COD concentration of 100 mg/L. In the view of the above discussion, it is clear that faecal sludge in the study area was not stabilized enough and hence stabilization is required before this sludge can be used for agriculture.

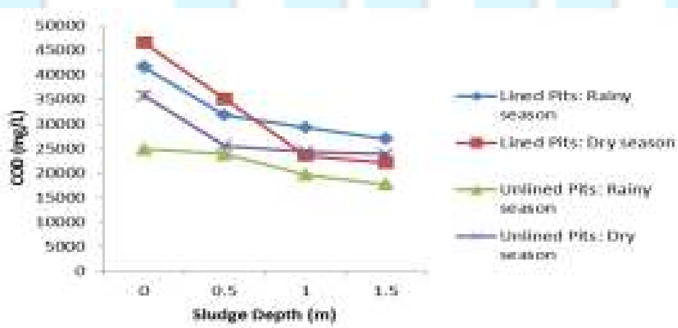

Figure 5: Variation of COD with pit type and season

3.2 Nutrient concentration in pit latrines

Ammonia-nitrogen

Ammonia-nitrogen averaged 2,020±57 mg/kg in lined pits and 2,646±22 mg/kg for unlined latrines during the rainy season and for the dry season, the ammonium-nitrogen averaged 191±43 mg/kg and 227±71 mg/kg in lined and unlined pits respectively. There was significant variation ($p<0.05$) in ammonium nitrogen with sludge depth in unlined pits during the rainy season and statistical significant differences existed between sludge depth of 0 m and 0.5 m, 0 m and 1 m, 0 m and 1.5 m. However, there was no significant variation ($p>0.05$) in ammonium nitrogen with sludge depth in lined pits during the rainy and dry seasons and in unlined pits during the dry season. There was no significant variation ($p>0.05$) in ammonium-N in lined and unlined pits during rainy season and during the dry season. The concentration of ammonium-N increased with sludge depth in both lined and unlined pits during both seasons, except for sludge depths of 0.5 m and 1 m in lined and unlined pits respectively where ammonium nitrogen concentration reduces with sludge depth during the rainy season. The increase in ammonium nitrogen concentration with sludge depth is due to nitrogen mineralization where organic nitrogen is converted ammonium nitrogen by a diverse population of heterotrophic bacteria in an alkaline environment (Havlin et al., 2005). A study by Nabulime (2015) showed that pH of faecal sludge in unlined pits increases with sludge depth from 7.9 to 8.4 between 0 and 1.5 m of sludge depth. The increase in sludge pH to alkaline conditions favors the process of mineralization (Havlin et al., 2005). The unexpected decrease in ammonium nitrogen concentration in both lined and unlined pits during the rainy season was due to the dilution effect associated with the increase in moisture content in pits (Nwaneri, 2009; Chaggu et al., 2007). Kulabako (2005) and Kulabako et al. (2007) conducted geo-hydrological studies in Bwaise slums and found out that the groundwater table rises to less than 1.5 m below the ground during the rainy season and this favors the ingress of water from the bottom layers of the surrounding soil into the pits. Furthermore, the increase in moisture content in both lined and unlined pits during the rainy season was also due to flooding caused by storm water.

Nitrate-nitrogen

During the rainy season, nitrate-nitrogen averaged 506±27 mg/kg in lined pits and 705±59 mg/kg in unlined latrines and in the dry season, nitrate-N averaged 254±27 mg/kg and 194±59 mg/kg in lined and unlined pits respectively. There was significant variation ($p<0.05$) in nitrate nitrogen concentrations with sludge depth in lined pits during the rainy season and statistical significant differences existed between sludge depth of 0 m and 0.5 m, 0 m and 1 m, 0 m and 1.5 m. There no was significant variation ($p>0.05$) in nitrate nitrogen concentrations with sludge depth in unlined pits during the rainy season. In addition, there was significant variation ($p<0.05$) in nitrate nitrogen concentrations with sludge depth in lined and unlined pits during the dry season and for lined pits statistical significant differences existed between sludge depth of 0 m and 1.5 m, 1 m and 1.5 m while in unlined pits statistical significant differences existed between sludge depth of 0 m and 1 m, 0 m and 1.5 m. There was no significant variation ($p>0.05$) in nitrate-N concentration between lined and unlined pits during both the rainy season and dry season. The results also showed a decreasing trend for nitrate nitrogen (NO3--N) with sludge depth in both types of pits and seasons. This observation is attributed to the reduction in the nitrification or microbial oxidation of NH4+ to NO3- with decreasing dissolved oxygen concentration which was observed to decrease with sludge depth in both pit types and seasons (Havlin et al., 2005). The nitrification process is a two-step microbial oxidation process which involves the conversion of NH4+ to NO2- and then to NO3- in the presence of oxygen by a set of autotrophic bacteria including nitrosomonas and nitrobacter respectively (Havlin et al., 2005). In the light of the above discussion, it can be noted that sludge at the bottom layers of the pit may contain less nitrate nitrogen compared to that found at the top layers and therefore the former is less suitable for supplying nitrate nitrogen for agriculture than the latter.

Total Nitrogen

The total nitrogen concentration averaged 45,237±198 mg/kg in lined pits and 42,594±270 mg/kg in unlined latrines during the rainy season and for the dry season, total nitrogen averaged 40,035±91 mg/kg and 39,215±39 mg/kg in lined and unlined pits respectively. There was significant variation ($p<0.05$) in total nitrogen concentration with sludge depth in unlined pits during the rainy season and statistical significant differences existed between sludge depth of 0 m and 0.5 m, 0 m and 1 m, 0 m and 1.5 m. However, there was no significant variation ($p>0.05$) in total nitrogen concentration with sludge depth in lined pits during the rainy season and in both lined and unlined pits during the dry season. There was no significant variation ($p>0.05$) in total nitrogen between lined and unlined pits during the rainy season and dry season. Total nitrogen in faecal sludge occurs in various forms including inorganic (NH4+-N, -N) and organic forms. These forms are interrelated through microbial and chemical transformations. In this study, the results of total nitrogen obtained are greater and less than results reported by Chaggu (2004) and Lopez Zavala et al. (2002) respectively. Chaggu (2004) and Lopez Zavala et al. (200) reported 17,820 mg/kg and 60,100 mg/kg as total nitrogen concentrations in their studies respectively.

Phosphates

During the rainy season, total phosphates averaged 7,590±428 mg/kg in lined pits and 8,449±738 mg/kg for unlined latrines and in the dry season, phosphates concentration averaged 12,393±1390 mg/kg and 8,815±544 mg/kg in lined and unlined pits respectively. There was significant variation ($p<0.05$) in phosphates with sludge depth in unlined pits during the rainy season and statistical significant differences existed only between sludge depth of 0 m and 1.5 m. However, there was no significant variation ($p>0.05$) in phosphates with sludge depth in lined pits during the rainy season and in both lined and unlined pits during the dry season. There was no significant variation ($p>0.05$) in phosphates concentration between lined and unlined pits during the rainy season and significant variation ($p<0.05$) between lined and unlined pits in the dry season. The results of phosphates obtained in this study fall in the range of 6,900 to 25,000 mg/kg and are similar to those s reported by Chaggu (2004).

Potassium

Potassium concentration averaged 21,796±869 mg/kg in lined pits and 31,707±5066 mg/kg in unlined latrines during the rainy season and for the dry season, potassium concentration averaged 20,500±1087 mg/kg and 30,750±815 mg/kg in lined and unlined pits respectively. There was no significant variation ($p>0.05$) in potassium concentration with sludge depth and no significant variation ($p>0.05$) in potassium concentration between lined and unlined pits during both rainy and dry seasons. The results of potassium obtained in this study fall in the range of 8,000 to 37,000 mg/kg and are comparable to those reported by Chaggu (2004).

Model Prediction of Nutrients in Pit Latrines

The model is a good estimator of the measured data since the regression analysis between the predicted and measured data revealed adjusted R square values greater than 0.85 ($R^2Adj>0.85$) indicating that the measured data explained more than 85% of the variation of the predicted data and only less than 15% can be attributed to unknown variables or inherent variability. This is also supported by the strong degree of association ($r >0.9$) between the predicted and the measured data. Furthermore, the relative root mean square error (RRMSE) of the predicted nutrients was less than 10% implying that the suggested model was more than 90% accurate in predicting measured nutrient concentrations. Therefore, the model performance was judged to be satisfactory based on the criteria of $R2>0.5$ and $RRMSE<50\%$ (Moriasi *et al.*, 2007; Fumagalli et al., 2013; Chung *et al.*, 1999). The comparison between measured and modeled concentrations of nutrients is depicted in Figures 6 to 10.

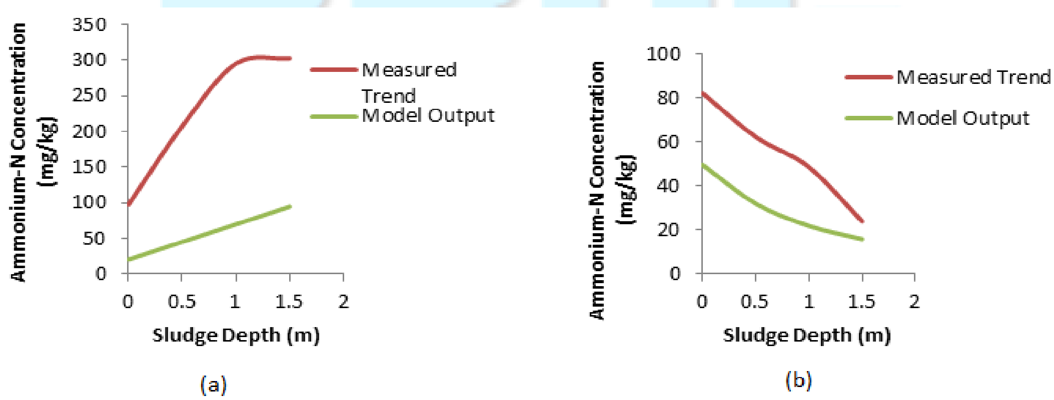

Figure 6: Measured and modeled concentration profiles for ammonium-N in (a) lined pits and (b) unlined pits

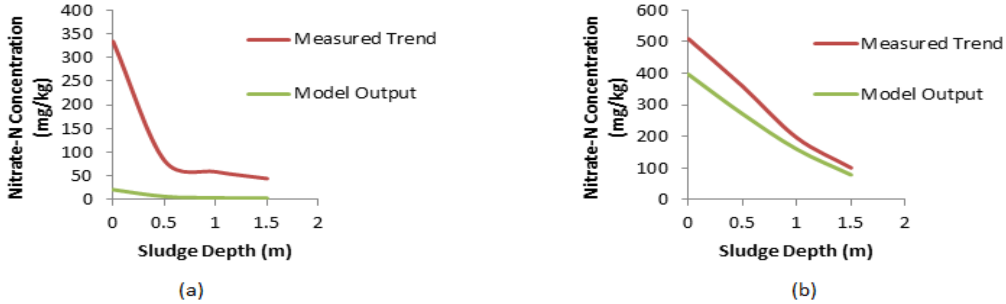

Figure 7: Measured and modeled concentration profiles for nitrate-N in (a) lined pits and (b) unlined pits

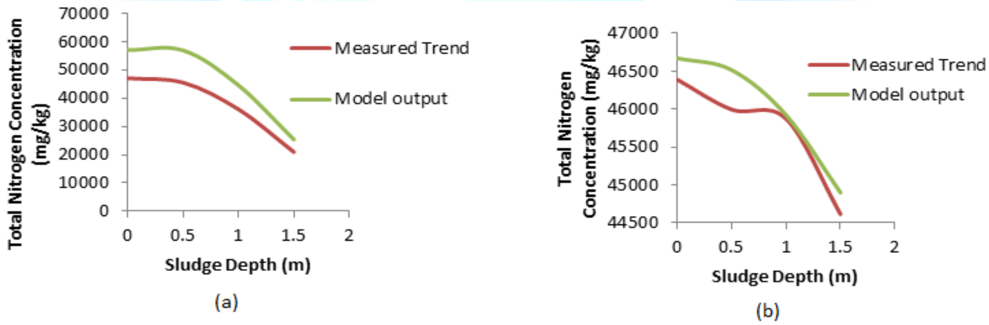

Figure 8: Measured and modeled concentration profiles for total nitrogen in (a) lined pits and (b) unlined pits

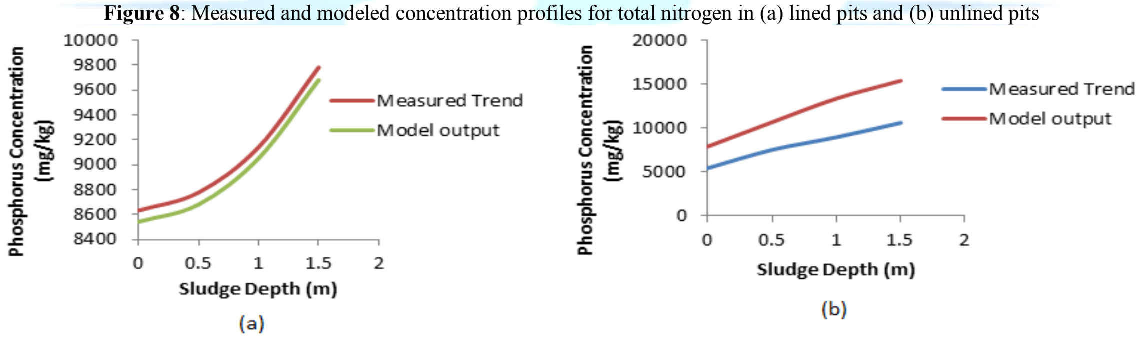

Figure 9: Measured and modeled concentration profiles for phosphorus in (a) lined pits and (b) unlined pits

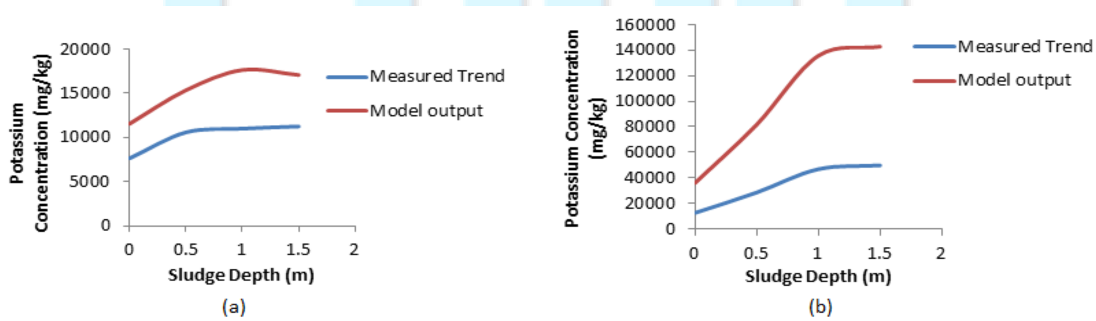

Figure 10: Measured and modeled concentration profiles for potassium in (a) lined pits and (b) unlined pits

IJREAT International Journal of Research in Engineering & Advanced Technology, Volume 3, Issue 6, Dec -Jan, 2016
ISSN: 2320 – 8791 (Impact Factor: 2.317)
www.ijreat.org

4. Conclusions

Faecal sludge contain nutrients in the following concentrations: ammonia is varying from 151 mg/kg to 4,865 mg/kg while nitrate from 73 mg/kg to 624 mg/kg, total nitrogen from 38,290 mg/kg to 47,001 mg, phosphates from 7,017 mg/kg to 16,077 mg/kg and potassium from 15,375 mg/kg to 44,868 mg/kg. The nutrients are found in concentrations that are greater than the concentrations for the same nutrients in cow dung which is popularly used as farm manure implying that faecal sludge has more potential of supplying nutrients for soil enhancement. The results of this study are the first of the kind and can go a long a way in changing perceptions of feacal sludge managers and policy makers about feacal sludge. However, it is imperative to note that faecal sludge is not only a good source of nutrients but also an enormous source of pathogenic microbes. It is therefore important that the microbiological risks involved in using such sludge are put into perspective and hence the need to investigate nutrient recovery strategies to foster the utilization of faecal sludge while mitigating the occurrence of pathogens and odours in addition to circumventing peoples' perceptions and acceptability of a unique resource.

The study confirms that COD decreases with sludge depth and in this study varied from 17,677 mg/L to 46,571 mg/L. In pit latrines stabilization of faecal sludge is therefore increasing with sludge depth and sludge found at the bottom layers of the pit is less pathogenic, odorous and safer to use than that found at top layer of the pit material. The study reveals that sludge temperatures are varying from 23°C to 27°C and mesophilic conditions are prevailing in pits of the study area, dissolved oxygen concentrations are indicating prevalence of anaerobic conditions in pits and varying from 0.39 mg/L to 1.72 mg/L while moisture content is varying from 70% to 92% on dry weight basis and sludge is characterized as being watery. Thus, these findings imply that faecal sludge management in Kampala slums may be geared towards utilization of available nutrients. In this study, only COD was measured as a sludge stabilization indicator. There is a need to measure other stabilization indicators such as dehydrogenase activity which is a good indicator that permits one to evaluate the activity of microorganisms in sludge.

The model predicts phosphorus in lined pits with the highest accuracy followed by total nitrogen in unlined pits and nitrates in lined pits with accuracy of 99.9%, 99.5% and 99.4%, respectively. The model is therefore better at predicting the aforementioned nutrients in the corresponding pits than ammonia and potassium.

Appendices

Appendix 1: Variation of COD in pit latrines during the rainy season in Kampala slums, Uganda

Parameter	Unit	Rainy Season							
		Lined pits, n=48, Mean±s.e.				Unlined pits, n=48			
		Sludge Depth (m)				Sludge Depth (m)			
		0	0.5	1	1.5	0	0.5	1	1.5
COD	mg/L	41,611±297	31,783±387	29,222±446	26,924±348	24,904±141	23,840±453	19,659±394	17,677±174
	g/g dry weight	182±30	188±37	178±18	140±22	103±10	226±89	254±92	172±76

Appendix 2: Variation of COD in pit latrines during the dry season in Kampala slums, Uganda

Parameter	Unit	Dry Season							
		Lined pits, n=100				Unlined pits, n=100			
		Sludge Depth (m)				Sludge Depth (m)			
		0	0.5	1	1.5	0	0.5	1	1.5
COD	mg/L	46,571±851	35,089±836	23,609±593	22,090±523	35,797±622	25,535±344	24,360±465	23,803±380
	g/g dry weight	105±10	117±6	64±5	143±4	130±12	277±73	280±50	326±59

Acknowledgements

This study was financed through the Sanitation Research Fund for Africa Project that was co-funded by the Water Research Commission (South Africa) and the Bill and Melinda Gates Foundation. Special thanks go to Mr. Ben Byomugabe and Mr. Alfred Ahumuza for the assistance in the laboratory and the field work. Kampala City Council Authority (KCCA) and Uganda National Council for Science and Technology (UNCST) are acknowledged for the permission granted to carry out this research.

References

[1] **Adediran, J. A., Akande, M. O., Taiwo, L. B., and Solubo, R. A. (1999)**. Comparative Effectiveness of Organic Based Fertilizer with mineral fertilizer on crop yield. *In proceedings of 25th annual conference of soil science society of Nigeria. Benin* (Vol. 99, p. 91)

[2] **APHA (1998).** Standard methods for the examination of water and wastewater. 20th Edition. Washington, DC: American Public Health Association.

[3] **Asare, I., Kranjac-Berisavljevic, G., and Cofie, O. (2003).** Faecal sludge application for agriculture in Tamale, Ghana. *Urban Agriculture Magazine*, *10*, 31-33.

[4] **Bakare, B. F., Foxon, K. M., Brouckaert, C. J., & Buckley, C. A. (2012).** Variation in VIP latrine sludge contents. *Water SA*, *38*(4), 479-486.

[5] **Banadda, N., Nhapi, I., and Wali, U. G. (2011).** Determining and modeling the dispersion of non point source pollutants in Lake Victoria: A case study of Gaba Landing site in Uganda. *African Journal of Environmental Science and Technology*, *5*(3), 178-185.

[6] **Bertin, L., Capodicasa, S., Occulti, F., Girotti, S., Marchetti, L. and Fava, F. (2007).** Microbial processes associated to the decontamination and detoxification of a polluted activated sludge during its anaerobic stabilization, Water Research, 41: 2407-2416.

[7] **Biswas, A.K. (1976).** Systems Approach to Water Management, McGraw-Hill, Inc. Pp 429.

[8] **Buckley C. A., Foxon K. M., Brouckaert C. J., Rodda N., Nwaneri C., Balboni E., Couderc A. and Magagna D. (2008).** Scientific Support for the Design and Operation of Ventilated Improved Pit Latrines (VIPs) and the Efficacy of Pit Latrine Additives. Water Research Commission. Report No. TT357/08.

[9] **Cameron, A. C., and Windmeijer, F. A. (1997)**. An R-squared measure of goodness of fit for some common nonlinear regression models. *Journal of Econometrics*, *77*(2), 329-342.

[10] **Chaggu, E. J. (2004).** Sustainable environmental protection using modified pit-latrines. *PhD, Wageningen University, The Netherlands*.

[11] **Chaggu, E. J., Sanders, W., and Lettinga, G. (2007).** Demonstration of anaerobic stabilization of black water in accumulation systems under tropical conditions. *Bioresource technology*, *98*(16), 3090-3097.

[12] **Chung, S.W., Gasman, P.W., Kramer, L.A., Williams, J.R., and Gu, R. (1999).** Validation of EPIC for two watersheds in southwest Iowa. *Journal of Environmental Quality* 28: 971–9.

[13] **Cofie, O., Kranjac-Berisavljevic, G., and Drechsel, P. (2007).** The use of human waste for peri-urban agriculture in Northern Ghana. *Renew. Agric. Food Syst.* 20, 73–80.

[14] **Diener, S., Semiyaga, S., Niwagaba, C.B., Muspratt, A.M., Gning, J.B., Mbeguere, M., Ennin, J.E., Zurbrugg, C. and Strande, L. (2014).** A value proposition: Resource recovery from faecal sludge-Can it be the driver for improved sanitation? Resources, Conservation and Recycling, 88: 32-38.

[15] **Dzwairo, B., Hoko, Z., Love, D., & Guzha, E. (2006).** Assessment of the impacts of pit latrines on groundwater quality in rural areas: A case study from Marondera district, Zimbabwe. *Physics and Chemistry of the Earth, Parts A/B/C*, *31*(15), 779-788.

[16] **Ewulo, B. S., Hassan, K. O., and Ojeniyi, S. O. (2007)**. Comparative effect of cow dung manure on soil and leaf nutrient and yield of pepper. *International Journal of Agricultural Research*, *2*(12), 1043-1048.

[17] **Fumagalli, M., Perego, A., and Acutis, M. (2013).** Modelling nitrogen leaching from sewage sludge application to arable land in the Lombardy region (northern Italy). *Science of the Total Environment* 461–462: 509–518.

[18] **Havlin, J.L., Beaton, J.D., Tisdale, S.L., Nelson, W.L. (2005).** Soil fertility and fertilizers: An introduction to nutrient management, seventh edition, Pearson Prentice Hall, New Jersey.

[19] **Heinss, U., Larmie, S. A., and Strauss, M. (1998).** Solids Separation and Pond Systems for the Treatment of Faecal Sludges in the Tropics. Lessons learnt and recommendations for preliminary design. SANDEC Report No. 5/98. Second Edition. Swiss Federal Institute for Environmental Science and Technology (EAWAG) and Water Research Institute (WRI), Accra/Ghana.

[20] **Horswell, J., Speir, T. W., and Van Schaik, A. P. (2003).** Bio-indicators to assess impacts of heavy metals in land-applied sewage sludge. *Soil Biology and Biochemistry*, *35*(11), 1501-1505.

[21] **Katukiza, A. Y., Ronteltap, M., Niwagaba, C. B., Foppen, J. W. A., Kansiime, F. P. N. L., & Lens, P. N. L. (2012).** Sustainable sanitation technology options for urban slums. *Biotechnology advances*, *30*(5), 964-978.

[22] **Katukiza, A. Y., Ronteltap, M., Oleja, A., Niwagaba, C. B., Kansiime, F., and Lens, P. N. L. (2010).** Selection of sustainable sanitation technologies for urban slums—A case of Bwaise III in Kampala, Uganda. *Science of the total environment*, *409*(1), 52-62.

[23] **Kone, D., and Strauss, M. (2004).** Low-cost Options for Treating Faecal Sludges (FS) in Developing Countries – Challenges and Performance. Paper presented to the 9th International IWA Specialist group conference on wetlands systems for water pollution control; and to the 6th International IWA Specialist Group Conference on Waste Stabilisation Ponds, Avignon, France, 27th Sept. - 1st Oct. 2004.

[24] **Kulabako, N. R., Nalubega, M., & Thunvik, R. (2007).** Study of the impact of land use and hydrogeological settings on the shallow groundwater quality in a peri-urban area of Kampala, Uganda. *Science of the Total Environment*, *381*(1), 180-199.

[25] **Kulabako, R. (2005).** Analysis of the impact of anthropogenic pollution on shallow groundwater in peri-urban Kampala. PhD Thesis, Royal Institute of Technology, Sweden

[26] **Kulabako, R. N., Nalubega, M., Wozei, E., & Thunvik, R. (2010).** Environmental health practices, constraints and possible interventions in peri-urban settlements in developing countries–a review of Kampala, Uganda. *International journal of environmental health research*, *20*(4), 231-257.

[27] **Legates, D. R., & McCabe Jr, G. J. (1999).** Evaluating the use of “goodness-of-fit” measures in hydrologic and hydroclimatic model validation. *Water resources research*, *35*(1), 233-241.

[28] **Lopez Zavala M. A., Funamizu N. and Takakuwa T. (2002)**. Characterization of faeces for describing the aerobic biodegradation of faeces. Journal of Environmental Systems and Engineering, JSCE, 720/VII-25 99-105.

[29] **Lugali, Y. (2016).** Modeling sludge accumulation rates in pit latrines: case of Kampala city slums. Unpublished MSc. Thesis, Makerere University, Kampala, Uganda.

[30] **Magee, L., (1990).** R^2 Measures Based on Wald and Likelihood Ratio Joint Significance Tests. *The American Statistician* 44 (3) 250-253.

[31] **Moriasi, D. N., Arnold, J. G., Van Liew, M. W., Bingner, R. L., Harmel, R. D., & Veith, T. L. (2007).** Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. *Trans. Asabe*, *50*(3), 885-900.

[32] **Nabulime, M.N. (2015).** Characterization of faecal sludge for improved pit emptying and sludge disposal. Unpublished MSc. Thesis, Makerere University, Kampala, Uganda.

[33] **National Environment (Standards for Discharge of Effluent into Water or on Land) Regulations, 1999.** Accessed at: www.nemaug.org/regulations/effluent_discharge_regulations.pdf on 10/10/2014

[34] **Nikiema, J., Cofie, O., Impraim, R., and Adamtey, N. (2013)**. Processing of fecal sludge to fertilizer pellets using a low-cost technology in Ghana. *Environment and Pollution*, *2*(4), 70-87.

[35] **Nwaneri, C. F. (2009).** *Physico-chemical Characteristics and Biodegradability of Contents of Ventilated Improved Pit Latrines (VIPs) in EThekwini Municipality* (Doctoral dissertation, University of KwaZulu-Natal).

[36] **Nyenje, P. M., Foppen, J. W., Kulabako, R., Muwanga, A., & Uhlenbrook, S. (2013).** Nutrient pollution in shallow aquifers underlying pit latrines and domestic solid waste dumps in urban slums. *Journal of environmental management*, *122*, 15-24.

[37] **Nyenje, P. M., Havik, J. C. N., Foppen, J. W., Muwanga, A., & Kulabako, R. (2014).** Understanding the fate of sanitation-related nutrients in a shallow sandy aquifer below an urban slum area. *Journal of contaminant hydrology*, *164*, 259-274.

[38] **Pathak, A., Dastidar, M. G., and Sreekrishnan, T. R. (2009).** Bioleaching of heavy metals from sewage sludge: a review. *Journal of environmental management*, *90*(8), 2343-2353.

[39] **Schouten, M. A. C., & Mathenge, R. W. (2010).** Communal sanitation alternatives for slums: A case study of Kibera, Kenya. *Physics and Chemistry of the Earth, Parts A/B/C*, *35*(13), 815-822.

[40] **Semiyaga, S., Okure, M. A., Niwagaba, C. B., Katukiza, A. Y., & Kansiime, F. (2015).** Decentralized options for faecal sludge management in urban slum areas of Sub-Saharan Africa: A review of technologies, practices and end-uses. *Resources, Conservation and Recycling*, http://dx.doi.org/10.1016/j.resconrec.2015.09.001

[41] **Ssonko, R. E., Kiggundu, N., and Banadda, N. (2015).** Waste engine oil contamination of soil and its bioremediation. *Environmental Engineering & Management Journal (EEMJ)*, *14*(8) 1969 - 1975.

[42] **Still, D., and Foxon, K. (2012).** Tackling the Challenges of Full Pit Latrines, Volume 1: Understanding sludge accumulation in VIPs and strategies for emptying full pits. *Report to the Water Research Commission*.

[43] **Strande, L., Ronteltap, M., and Brdjanovic, D. (Eds.). (2014)**. *Faecal sludge management: Systems approach for implementation and operation*. IWA Publishing Pp114.

[44] **Tyagi, V.K. and Lo, S. (2013).** Sludge: A waste or renewable source for energy and resources recovery? Renewable and Sustainable Energy Reviews, 25: 708-728.

[45] **United Nations (2014).** World Urbanisation Prospects. UN, New York, USA Accessed on 15/10/2015 at: esa.un.org/unpd/wup/highlights/wup2014-highlights.pdf

[46] **Walia, M., and Goyal, S. (2010).** Effect of heavy metal contaminated sewage sludge on soil microbiological properties and growth of Indian mustard. *Archives of Agronomy and Soil Science*, *56*(5), 563-574.