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Analysis of physiochemical characteristics influencing disposal of pit latrine sludge in Nakuru Municipality, Kenya

Gudda, F. O.[1]*, Moturi, W. N.[1], Omondi, S. O.[3] and Muchiri, E. W.[2]

[1]Department of Environmental Science, Egerton University, Kenya.
[2]Department of Civil and Environmental Engineering, Egerton University, Kenya
[3]Department of Biological Sciences, Egerton University, Kenya.

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On-site sanitation facilities, mostly pit latrines are the main points of human excreta disposal in peri-urban low-income settlements in Kenya. Collection, treatment and final disposal of pit latrine faecal sludge, pose a significant management problem and present public health risks. The choice of appropriate faecal sludge treatment technology depends on precise region based data on the sludge characteristics that are often unavailable. The study analysed physiochemical characteristics of faecal sludge sampled at different depths of pit latrines. Twenty-four samples were collected from six pit latrines along the depth strata at 1-m intervals from the surface to 3 m depth. Samples were analysed for chemical oxygen demand (COD), biochemical oxygen demand (BOD), ammonia, total nitrogen and total phosphorus. The mean COD: BOD ratio was 1:5 with a concentration of 112800 and 24600 mg/L, respectively. Concentrations for all parameters were variable and higher in comparison with properties reported in literature. Upper layers had higher concentrations than lower depths. The concentrations of the sludge were 10-100 higher than acceptable limits for in-fluent sludge into municipal wastewater treatment plants. These results show that disposal of pit latrine faecal sludge into the wastewater treatment plants without co-treatment overload the system since treatment plants in use currently have not been designed to handle pit latrine sludge. The properties of faecal sludge analysed indicate that the wastewater treatment plants may not be capable of treating faecal sludge unless co treatment mechanisms are applied. Therefore, influent faecal sludge must be maintained within allowable concentrations; otherwise, the effluents may lead to significant environmental pollution impacts.

Key words: On-site sanitation, depth strata, faecal sludge disposal, low-income settlements.

INTRODUCTION

Despite significant steps and achievements towards meeting the Millennium Development Goals (MDGs) on sanitation, approximately 2.5 billion people did not have access to improved sanitation services as at 2015

*Corresponding author. E-mail: freddgudda@gmail.com.

(WHO/UNICEF, 2015).

Sanitation gaps exist regarding services offered to urban poor and rural communities in developing countries. According to the 2015 Joint Monitoring Program (JMP) progress report, in sub-Saharan Africa, only 30% of the current population have access to improved sanitation facilities. In addition, the region has the greatest share of people practicing open defecation and recorded an increase in open defecation cases, whereas all other regions of the world recorded a decrease since 1990 (WHO/UNICEF, 2015).

In Kenya, approximately 60% of the urban dwellers live in peri-urban low-income settlements characterized by inadequate or no sewerage connections (Nilsson and Nyanchaga, 2008). Therefore, on-site sanitation systems (OSS) mostly pit latrines offer points for faecal sludge (FS) and wastewater disposal. OSS may provide attainable and affordable sanitation services to urban dwellers (Kone, 2010). However, utilization of OSS is viewed as a temporary solution awaiting development of sewer-based sanitation systems but these facilities are always in use for longer periods, they serve as permanent and independent sanitation systems (Strande et al., 2014). Therefore, to ensure public safety and environmental protection, there is a need to develop and implement programs for emptying, transportation, treatment and final disposal of the OSS contents (Thye et al., 2011). The current scenario in most cities in sub-Saharan Africa is characterized by absence of supporting infrastructure leading to most of FS ending up in the environment un-treated (Cofie et al., 2006).

Pit latrines offer essential sanitation services as a main point of FS disposal hence play a significant role in ensuring public health safety. The sanitation provision task does not end at the point of pit latrine construction. There is a need to understand that OSS will eventually reach capacity hence require plans for post fill up management and budget support (Still and Foxon, 2012). Most of the municipal treatment plants are designed with knowledge of wastewater characteristics that are widely known. The OSS presents a second problem after fill up as treatment of their sludge requires significant technological readjustment contrary to traditional wastewater treatment. Co-treatment of FS may not be a sound approach in regions where performance of wastewater treatment plants is failing. “High strength” sludge are characterized by high ammonia presenting a great challenge for low cost treatment technologies (Koné et al., 2004).

Disposal of OSS sludge remains a significant challenge in numerous developing countries (Water Utility Partnership, WUP, 2003; Bongi and Morel, 2005). FS content may end up in open grounds, ditches, roadsides, watercourses and lakes (Strauss et al., 1997). In Kenya, pit latrine emptying is done by registered entities disposing the contents in municipal waste treatment plants. However, Waste Stabilization Ponds (WSPs) are designed for wastewater leading to significant organic loading by faecal sludge. Straus et al. (1997) reported that to achieve effective FS treatment in municipal wastewater plants, two parallel batches-operated settling or thickening tanks should be included in the design. The tanks must have a minimum of 3 h of settling followed by four stabilization ponds in series retaining the content for a minimum of 30 days. The ponds are anaerobic, as facultative conditions do not develop because of the high ammonia concentrations. In the contrary, most municipal treatment plants in use currently have not been designed to handle the treatment OSS sludge. The circumstances are a clear recipe for failure of the WSPs. Source separation would lead to efficient handling of the sludge. In addition, treatment should depend on the end use to enable resource recovery (Rose et al., 2015).

Characteristics of FS vary with location, households and regions (Fernandez et al., 2004). Literature based characterization gives only qualitative information that cannot be used in designing FS treatment facilities. Accurate region based data on characterization of FS is necessary for designing treatment plants and choice of appropriate treatment technologies (Bassan et al., 2013). However, there is limited, variable or unavailable data on pit latrine FS parameters. In addition, understanding the variations of the parameters along the depth strata would provide supplementary information for designing emptying technologies. The objective of this study was to characterize variation of FS across pit latrines and with depth.

MATERIALS AND METHODS

Study area

The study was carried out in Hilton Settlement within Nakuru Municipality, Kenya. The selected pit latrines were in a low-income peri-urban settlement. Nakuru town is one of the fastest growing municipalities in Kenya. It is the fourth largest urban centre with a population of about 307,990 inhabitants (GoK, 2010). The major economic activities of the settlement’s inhabitants are in the informal sector with irregular sources of livelihood. Availability of safe water and proper sanitation present a major problem to the local authorities because most settlements have no water and sewerage connection. Anecdotal information indicates that the study area falls within a fault line of the Eastern Rift Valley. The geology of the area is characterized by volcanic rocks and sediments making digging of deep pit latrine vaults problematic (McCall, 1967). Therefore, a significant number of pit latrines are relatively shallow necessitating frequent emptying cycles.

Faecal sludge sampling

Sample collection was carried out in January 2015 during the dry season as most pit latrine emptying occur in that period of the year as the ground has low moisture content. Six pit latrines that had never been emptied and shared by more than one family and without connection to water sources were selected purposively.

Samples were obtained directly along the pit latrine depth strata at 4 depths (0.0, 1.0, 2.0 and 3.0 m) using a modified faecal sludge

Table 1. Comparison of variation in faecal sludge characteristics in literature.

Parameter	Source of data			
	Strauss et al. (1997)	**Koné and Strauss (2004)**	**Bassan et al. (2013)**	**Appiah-Effah and Nyark (2014)**
TP	_	-		2088
TN	_	-		4083
NH_3	2000-5000	3300	_	2568
BOD	_	7600	2126	11835
COD	20000-50000	49000	12437	85998
BOD: COD	5.1-9:1	6.4:1	5.8:1	7.3:1

Concentration (mg/L).

sampler. The sampling points were informed by specifications of sampling at intervals of 0.5 depth differences for pit latrines with a depth maximum of about 1.5 m (Buckley et al., 2008). However, in the study area, pit latrines had depths of more than 5 m, necessitating sampling points of at least 1-m difference to enable an analysis of representative sample of the pit content. Faecal sludge sampling protocol was followed strictly to avoid mixing of samples from various layers of the pit latrine content. Twenty-four samples were obtained along the pit latrine strata. Field observation was used to select the type of the OSS (shared, dry pit latrine and never desludged before) and key informant interviews were used to obtain information from the waste treatment plant operator at the municipal sewerage plant. Formal written and oral consent was obtained from the study respondents prior to sample collection and the interview. Sample analysis was done at the municipal water and sewerage laboratory. Ethical consent was obtained from Egerton University ethics committee.

Sample analysis

Sample analysis was done in accordance with the standard methods of analysing water and wastewater (APHA, 2005). Parameters that were analysed included biochemical oxygen demand (BOD), chemical oxygen demand (COD), total nitrogen (TN), total phosphorus (TP) and ammonia (NH_3^+). Samples were stored in cool boxes and transported to the laboratory. The samples were stored at 4°C until analysis. Analysis of BOD and NH_3^+ were done within 12 h after sampling, whereas the analyses of other parameters were done within 24 h of sampling. Samples were homogenized to make representative sample, then a stock solution of 0.05 g/ml prepared and used for analysis. Standard laboratory reagents and apparatus were used to characterize the selected physicochemical parameters of the FS samples.

Data analysis

Descriptive statistics was used to show the average concentration of the various parameters across pit latrines and at different depths. One-way ANOVA was used to establish the differences in concentrations with sampling depths and among the studied pit latrines. Tukey's method of post-hoc analysis showed the points where there are significant differences in concentration between the sampling depths. The analyses were done at 95% confidence intervals using Minitab Version 16 and Excel software.

RESULTS

Characteristics of the faecal sludge

The one-way Anova analysis at 95% CI showed significant variation in FS characteristics within and across pit latrines. The large ranges in average concentrations of COD and BOD show large differences in level of organic content degradation of the sludge among pit latrines (Table 1).

Table 2 shows the mean and standard deviation for the analysed parameters. Average FS concentrations are high because of limited dilution by water, household wastes disposal and low degradation rates associated with anaerobic conditions.

Faecal sludge properties variation with depth

The analysis showed a decrease in concentration of measured parameters with depth of sampling. The average concentrations of the sludge sampled from different depths are compared statistically in Table 3.

Organic loading of the sludge

Chemical oxygen demand represents the total organic loading indicating the extent of degradation of the sludge at different depths. The average COD concentration reduces from the surface layer to 3 m depth (Table 3). There was a 22% change of COD concentration of FS from the surface layer to 3 m depth (Table 3). The reductions of COD with depth indicate increasing stability of FS with depth but the reduction is not statistically significant ($p>0.05$) between the surface layer and 3 m depth. Lower layers of the sludge are relatively stable because of the longer storage duration. However, the concentration at lower depths are lower than the fresh sludge sampled at the surface depths confirming the need for further treatment of sludge obtained at all depths of the pit latrine before reuse or disposal into the environment.

The average BOD concentration and changes from the surface layer to 3 m depth are as reported in Tables 2 and 3. The concentration of BOD was not significantly different across the pit latrines ($p=0.93$) but significantly different with depth ($p<0.05$). Comparison of concentration with depth is significantly different between

Table 2. Average concentration of biochemical properties of pit latrine FS (n=132).

Parameter	Mean	SD	Minimum	Median	Maximum
TN	3232	872	1717	3106	5496
TP	2906	1257	613	2936	4927
NH_3	2895	1037	1300	2663	5100
BOD	24600	9069	11000	22750	39500
COD	112800	29809	72000	108000	176000
BOD: COD	1:4.6	1:3.3	1:6.5	1:4.74	1:4.5

Concentration in mg/L, SD: Standard deviations, n=number of samples analysed.

Table 3. Variations of FS characteristics with depth.

Parameter	0 m Mean±SD	1 m Mean±SD	2 m Mean±SD	3 m Mean±SD	p-value
TN	3615.7±814.8	3575±1102	3226 ± 904	2767± 632	0.415
TP	3723±1121	1649±966	2889±564	4279±485	0.003
NH_3	3154±620	2750±1817	2763± 517	2950± 212	0.913
BOD	36833±2961	22750±3254	21500±3362	16083±3597	<0.0001
COD	133333±24089	116000±40398	92000±8390	104000±11314	0.099
BOD : COD	3.6:1	5:1	4.3:1	6.5:1	

Concentration (mg/L), surface layer (n) = 6, 1 m (n) = 6, 2 m (n) = 6, 3 m (n) = 4, SD; Standard deviation, p<0.05 is significant, p>0.05 is not significant; p-value-comparison of surface layer and 3 m.

the surface layer and the lower depths at 95% CI (Tukey's Method). The significant differences in BOD concentration within a pit latrine indicate variations in the biological degradation of the organic matter from the upper layers to the lower depths. Reductions of the BOD with depth indicate increasing stability of the sludge hence reduction in microbial degradation. This can be justified by increasing COD: BOD ratio with depth (Table 3). When the ratio is greater than 3, then it shows lower biodegradability of the sludge because the biologically degradable component has been broken down. Therefore, based on the ratio reported at 3 m depth (Table 3), the sludge is most stable and could be associated with storage for a long period in an OSS system (Heins et al., 1998).

Nutrients in faecal sludge

The mean nutrient concentrations are higher than data in literature. Concentration of NH_3 was highest at the surface, whereas concentrations of TP and TN were highest at the 3 m depth (Table 3). There was a significant difference in concentration of TP at the surface and at 3 m depth (p=0. 003). However, there was no significant difference in concentration with depth for NH_3 and TN. One-way ANOVA indicated significant differences in concentration of NH_3 (F=13. 95, p=0. 00) and TN (F=12. 29, p=0. 00) across the pit latrines.

DISCUSSION

The characterization showed that the FS has "high strength" properties (Strauss et al., 1997). This property is because samples were from pit latrines without connection to water sources leading to low moisture content of the sludge. Biodegradability of the FS is relatively low as indicated by a BOD : COD ratio greater than 3. Only the surface sludge was highly biodegradable with a BOD : COD ratio of 3.6 and it could be because of freshly deposited faeces that has not undergone degradation (Heinss et al., 1998). Similar findings of low biodegradability of the FS associated with storage for long periods in OSS systems have been reported in previous studies (Heins et al., 1998; Bassan et al., 2013). In addition, low biodegradability could be because of household disposal of solid wastes into the pit latrine vaults increasing its organic load.

The BOD concentrations were in the range reported in Appeadu and Ougodogou as 2126 mg/L by Bassan et al. (2013). However, they were lower s compared to those reported by and Strauss (2004) and Appiah-Effah and Nyarko (2014) who reported values of 7600 and 11835 mg/L, respectively. The differences could be because of the depths of sampling and age of sampled FS. Fresh FS at higher depths had higher concentrations of BOD in comparison with older ones in deeper layers that have undergone significant degradation.

The concentrations of COD were two times higher than those reported by SANDEC as 49000 mg/L (Koné and Strauss, 2004). However, they were in the range of values reported as 85,998 mg/L in peri-urban areas of Ashanti region in Ghana (Appiah-Effah and Nyarko, 2014). The higher COD concentration is an indication of presence of resistant organic matter in the sampled FS. This will necessitate higher consumption of oxygen by microorganisms to degrade the faecal sludge (Sawyer and McCarty, 1978). High COD concentrations show the presence of resistant organic materials in the FS leading to slow degradation. The materials may result from disposal of household wastes like food remains and papers. In addition, the organic loading of materials used in anal cleansing like tissue paper, corncobs, rags and leaves may contribute to higher COD concentration (Tilley et al., 2008). High concentrations of COD would require longer treatment time and higher oxygen consumption for breakdown of the high organic matter.

High TP concentration at the surface could be because of disposal of wastewater having detergents or presence of detergents. Lower concentrations that are significant are because phosphorous is consumed by microorganisms in faecal sludge for growth. However, the absence of significant differences in concentration of NH_3 and TN with depth can be associated with dilution of faecal sludge within a pit latrine. In addition, significant differences across pit latrines are because of the differences in household characteristics. Decreasing concentrations of TN with depth could be because of the higher mineralization of organic nitrogen over time. Surface concentrations were higher because of addition of fresh faecal materials. The differences in ammonia concentration with depth and among the pit latrines are an indication of differences of organic nitrogen breakdown. Higher concentrations of ammonia at the surface indicate higher microbial activity associated with sludge degradation, and because of the mineralization of organic nitrogen in FS (Epstein, 2002).

Total phosphorous concentrations documented were relatively high and it could be attributed to detergents used in unit washing and disposal of grey water into the pit latrines and diets of pit latrine users. Similar findings were reported in the study on public pit latrines in Kumasi (Awuah et al., 2014). High TP concentration in the sludge sourced from detergents may affect decomposition because they have a negative impact on microbial activities with some of these detergents being biocides; hence inhibiting microbial activities in the FS which may be beneficial to the degradation processes (Block et al., 2001; Kawasaki et al., 2002). Phosphorous immobilizes other chemicals like zinc and copper that are essential for microbial life, making the reported concentrations a cause of concern to the beneficial microorganisms for faecal sludge degradation (Chang et al., 1983). The documented TP concentrations justify the need for further treatment of the FS as the current concentration would lead to algal growth, odour and oxygen depletion if the sludge is disposed into water bodies.

The documented high nutrient concentration in FS is a cause of concern regarding treatment method, reuse and final disposal. The relatively high nutrient concentrations in faecal sludge are an important justification for use as farm manure (Awuah et al, 2014). However, within the study area, there is limited or no use of pit latrine sludge in farms, hence the material is discarded as wastes. Similar findings on non-reuse of pit latrine sludge were reported in previous studies (Chaggu et al., 2002; Strande et al., 2014). However, there have been reported beneficial uses of the FS in agriculture that can be adopted in the current context to minimize environmental impacts of disposal into the environment (Koottatep et al., 2001; Keraita et al., 2003; Scott et al., 2004; Cofie et al., 2005).

The FS collected from pit latrines in the area are disposed into the municipal WWTPs without any co treatments. The disposal is majorly into manholes connecting to main sewerage lines or direct into the ponds. The municipal authority has programs for controlling the number of emptying lorries draining their content but no programs for pre-treating the FS. There are organizations collaborating with private companies and the municipal council in beneficiation programs. The programs focus on solid FS from pit latrines that are dried for reuse in small scale. However, the process has not been rolled out comprehensively and is in the initial stages of implementation. Municipal WWTPs are not designed for treatment of sludge from OSS facilities because of the high organic load and solids in the FS. However, with co-treatment, the facilities can treat the FS under close monitoring (Straus et al., 2000; Chaggu, 2004). Problems and technical difficulties may arise in treating FS in WWTPs but there are guidelines on using the system to treat FS. Disposal of FS in its state without quantitative monitoring has a causal effect on the poor functioning of the WWTP (Lopez-Vazquez et al., 2004).

All the documented characteristics of the sludge are above the minimal standard concentrations recommended for in-fluent sludge by the National Environmental Management Authority (EMCA, 1999). Ammonia concentration is 29 times higher than the recommended standard of 100 mg/L. The WWTP system is facultative therefore high ammonia concentration would affect aerobic conditions necessary for sludge degradation (Zimmo et al., 2003). Ammonia concentrations above the range of 40 to 50 mg/L have toxicity to algal growth, which is essential for the WWTP functioning (Koné and Strauss, 2004). For COD and BOD concentration in the sludge, pre-treatment to a concentration of 650 and 150mg/L respectively, would make the concentration to be in the same range with parameters of urban wastewater that can be treated in WSP (Inganiella et al., 2000**).** However, the BOD and COD documented in this study were 164 and 173 times the recommendations for characteristics capable of treatment in WWTPs. Total phosphorous and total nitrogen characteristics are equally high, hence would encourage eutrophication of the WWTPs reducing efficiency of the treatment plants. Disposal of the FS into water bodies would also lead to massive algal growth and oxygen depletion. Therefore, based on FS characteristics documented above, there is a need for better treatment prior to disposal into the environment to reduce potential for pollution. Appropriate treatment of FS would significantly contribute to the achieving Sustainable Development Goals target on sanitation provision for all developed by the United Nations General Assembly in 2015.

CONCLUSION AND RECOMMENDATIONS

The results show variation of faecal sludge properties within and across pit latrines. Documented characteristics of COD, BOD, TN, NH_3 and TP indicate higher concentrations as compared to those reported in literature necessitating region based analysis to inform development of appropriate FS treatment technologies. The COD concentration that infer on the extent of degradation showed a reduction in concentration by 22% from surface to 3 m depth but with no significant differences between surface concentration and lower depths. This indicates that there is need for further decomposing of the FS though there were reductions in organic loading with depth.

The BOD concentrations at 3 m were significantly lower than those at the surface, indicating the presence of biological degradation of FS but the average concentration at the lower depth were higher than those safe for treatment in WWTPs. In addition, the mean BOD : COD ratio was five indicating that the sampled FS had low degradability. The sludge characteristics show that the current disposal method of OSS sludge present organic loading on the WWTPs which may lead to treatment failure. Nutrients concentrations are important in WWTPs functioning as the system is dependent on algae and aerations balance for optimal performance. However, the documented characteristics are up to 100 times higher than the recommended maximum concentrations of FS permissible for treatment in municipal treatment plants.

The resulting effect of disposing these FS in WWTPs would lead to significant pollution, as the wastewater would be released into the ecosystem before complete degradation because the system cannot sufficiently treat the influent waste. The study recommends that it is necessary to implement a mechanism for co-treatment of FS with focus on maintaining allowable volumes to be processed. Moreover, the design of the treatment technology should be based on FS characteristics of the local context. There is a need for further studies to understand FS characteristics in peri-urban settlements to inform appropriate treatment options. Moreover, there is need to find out how FS can be made safe and acceptable for use as manure.

CONFLICT OF INTERESTS

The authors have not declared any conflicts of interests.

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REFERENCES

APHA (2005). Standard Methods for the Examination of Water and Wastewater, APHA, AWWA and WEF, 21st Edition, 2005.

Appiah-Effah E, Nyark KB (2014). Characterization Of Public To Rural Areas of Ashanti Region of Ghana. J. Appl. Sci. Environ. Sanit. 9(3):175-184.

Awuah E, Amankwaah-Kuffour R, Gyasi SF, Lubberding HJ, Gijzen HJ (2014).Characterization and management of domestic wastewater in two suburbs of Kumasi,Ghana. Res. J. Environ. Sci. 8(6):318.

Bassan M, Tchonda T, Yiougo L, Zoellig H, Mahamane I, Mbéguéré M, Strande L (2013). Characterization of faecal sludge during dry and rainy seasons in Ouagadougou, Burkina Faso. In *Proceedings of the 36th WEDC International Conference, Nakuru, Kenya* pp. 1-5.

Block C, Ten Bosch C, Hartog B, Lemaire P, Stelter N (2001). Determination of the microbicidal effect of laundry detergents: New test method to determine the microbicidal effect of laundry detergents within a washing process. Tenside Surfactants Detergents 38(3):140-146.

Bongi S, Morel A (2005). Understanding small scale providers of sanitation services: A case study of Kibera. *Report.* Water and Sanitation Program, Africa, Nairobi.

Buckley C, Foxon K, Brouckaert C, Rodda N, Nwaneri C, Balboni E (2008). Scientific Support for Design and Operation of Ventilated Pit latrines and the Efficacy of Pit Latrine Additives. Rep. Water Res. Comm. pp. 3-12.

Chaggu EJ (2004). Sustainable environmental protection using modified pit-latrines. PhD, Wageningen University, The Netherlands.

Chang AC, Page AL, Sutherland FH, Grgurevic E (1983). Fractionation of phosphorus in sludge-affected soils. J. Environ. Qual. 12(2):286-290.

Cofie O, Kranjac-Berisavljevic G, Drechsel P (2005). The use of human waste for peri urban agriculture in Northern Ghana. Renew. Agric. Food Syst. 20(2):73-80.

EMCA (1999). The Environmental Management and Coordination Act No.8 of 1999 Kenya Gazette Supplement. Nairobi, Kenya.

Epstein E (2002). Land application of sewage sludge and biosolids. CRC Press.

Fernandez RG, Ingallinella AM, Sanguinetti GS, Ballan GE, Bortolotti V, Montangero A, Strauss M (2004). Septage Treatment using WSP1.

Government of Kenya, KNBS (2010). Population and housing census. Nairobi.

Heinss U, Larmie SA, Strauss M (1998). Solid separation and pond systems for the systems for the treatment of faecal sludges in the tropics. EAWAG. Dübendorf, Switzerland, EAWAG.

Ingallinella AM, Fernandez RG, Sanguinetti G (2000). Co-Treating Septage and Wastewater in Ponds–Results of Field Research Conducted at Alcorta, Argentina. Sanitary Engineering Centre, University of Rosario, Argentina and SANDEC. EAWAG/SANDEC, PO Box, 611.

Kawasaki K, Kubo M, Fujitani T (2002). U.S. Patent No. 6,468,950. Washington, DC: U.S. Patent and Trademark Office.

Keraita B, Drechsel P, Amoah P (2003). Influence of urban wastewater on stream water quality and agriculture in and around Kumasi, Ghana.Environ. Urban. 15(2):171-178.

Koné D, Brissaud F, Vasel JL (2004). State of the art of facultative ponds in West Africa: removal performances and design criteria. In: Proceedings, 6th IWA specialist conference.

Koné D (2010). Making urban excreta and wastewater management contribute to cities' economic development: a paradigm shift. Water Policy 12(4):602-610.

Koné D, Strauss M (2004). Low-cost options for treating faecal sludges (FS) in developing countries–Challenges and performance. In*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 (Vol. 27).

Koottatep T, Polprasert C, Oanh NTK, Montangero A, Strauss M (2001). Sludges from on site sanitation systems-low-cost treatment alternatives. In IWA Conference On Water And Wastewater Management for Developing Countries pp. 29-31.

Lopez-Vazquez CM, Dangol B, Hooijmans CM, Brdjanovic D (2014). Co-treatment of faecal sludge in municipal wastewater treatment plants. Faecal Sludge Management—Systems Approach Implementation and Operation. IWA Publishing. pp. 177-198.

McCall GJH (1967). Geology of the Nakuru-Thomson's Falls-Lake Hannington Area: Degree Sheet No. 35 SW Quarter and 43 NW Quarter (with Coloured Maps) (No. 78). Geological Survey of Kenya.

Rose C, Parker A, Jefferson B, Cartmell E (2015). The characterization of feces and urine: a review of the literature to inform advanced treatment technology. Crit. Rev. Environ. Sci. Technol. 45(17):1827-1879.

Scott CA, Faruqui NI, Raschid-Sally L (2004). Wastewater Use in Irrigated Agriculture: Management Challenges in Developing Countries.

Still D, 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.

Strande L, Ronteltap M, Brdjanovic D (2014). Faecal sludge management: Systems approach for implementation and operation. IWA Publishing.

Strauss M, Larmie SA, Heinss U (1997). Treatment of sludges from on-site sanitation-Low-cost options. Water Sci. Technol. 35(6):129-136.

Thye YP, Templeton MR, Ali M (2011). A critical review of technologies for pit latrine emptying in developing countries. Crit. Rev. Environ. Sci. Technol. 41(20):1793-1819.

Tilley E, Lüthi C, Morel A, Zurbrügg C, Schertenleib R (2008). Compendium of sanitation systems and technologies. Dübendorf: Swiss Federal Institute of Aquatic Science and Technology (Eawag).

United Nations General Assembly (2015). Transforming our world: the 2030 Agenda for sustainable development (Resolution adopted by the general assembly on 25th September, 2015).

WHO/UNICEF Joint Water Supply, Sanitation Monitoring Programme, & World Health Organization. (2015). Progress on drinking water and sanitation: 2014 Update. World Health Organization.

WUP (2003). Better Water and Sanitation for the Urban Poor. Kenya, European Communities and Water Utility Partnership.

Zimmo OR, Van Der Steen NP, Gijzen HJ (2003). Comparison of ammonia volatilisation rates in algae and duckweed-based waste stabilization ponds treating domestic wastewater. Water Res. 37(19):4587-4594.