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**The impacts of on-site septic tank
wastewater disposal in Kampala city**

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The use of septic tanks as an appropriate decentralized wastewater treatment solution to an inner city area of Kampala has been investigated. Several large septic tanks servicing hostels were monitored in addition to the water quality of four springs used as water source for the local population: two springs sited downstream of the septic tank percolation areas compared to two adjacent springs located within the surrounding unplanned settlements with several pit latrines. Although the septic tanks did not discharge into a constructed percolation area and had not been properly maintained, it has been shown that the unsaturated sandy subsoil acted to attenuate significantly the pollutants and protect the downstream springs. In contrast the springs situated within the unplanned development showed higher levels of contamination which was attributed to poor spring construction in combination with adjacent sources of faecal pollution from pit latrines and surface runoff.

Background

The worldwide trend of increasing urbanization, whereby more than half the world's population now lives in cities, has been particularly rapid in developing countries with the majority of growth occurring in smaller urban areas and peri-urban developments (UN Habitat, 2010). Much of this growth is unplanned and informal with inadequate infrastructure; in particular, the majority of settlements do not have access to adequate water and sanitation facilities (Parkinson and Tayler, 2003). Health risks are compounded as household and drainage water systems are invariably combined, leading to floodwater being contaminated with excreta and standing pools of water providing breeding areas for mosquitoes and other disease vectors. In addition, the poorer communities often inhabit low-lying and marginal land, for instance wetlands and alongside drainage channels, which are polluted with excreta and other wastewater. In such areas a more decentralised approach to the planning of sanitation is required in the cities with wastewater being treated (possibly reused) and disposed closer to where it is produced (Parkinson and Tayler, 2003) with treatment systems such as the septic tank, wastewater stabilization ponds and constructed wetlands examples of appropriate technologies.

In Kampala only 6.4% of the population is served by public sewer (mainly limited to the central division of the city) with 17.5% depending on septic tanks and 69.8% using various forms of pit latrine (NWSC, 2008). Kampala has a hilly topography with many of the poorer sections of society living in unplanned settlements alongside the open drainage channels in the valleys. The areas in Kampala with poor sanitation are also associated with the highest incidences of illness, the most common symptom exhibited being diarrhoea (Nasinyama et al., 2000). Although there is a relatively well developed piped water infrastructure throughout the city, springs remain the main source of water for those living in the low income areas in Kampala who currently depend on 243 protected springs and 75 unprotected springs (in addition to 38 wells) (NWSC, 2004). A recent study in such peri-urban areas of Kampala reported water consumption to be between 3 to 4 jerry cans (80 litres) per family per day averaging out at a daily per capita consumption of 16 litres (Kulabako et al., 2010). Previous studies have shown increased microbiological contamination in shallow groundwater in Kampala during rainfall peaks (BGS, 2001; Howard et al., 2003). This study also made the interesting conclusion that microbiological contamination in 25 protected springs was associated

more with poor sanitary completion of the spring (i.e. eroded backfill, lack of fence etc) rather than the proximity of pit latrines. Hence, it was surmised that the main pathway for the contamination was rapid recharge of the water very close to the spring in response to rainfall from stagnant surface water and solid waste through either preferential flow paths into groundwater or by direct ingress through the spring infrastructure. The surface waste was attributed to the indiscriminate disposal of human faeces in these areas where access to latrines is limited for most people, as well as the faeces from the numerous domestic animals and rodents in the areas. A large proportion (>80%) of the pit latrines in the peri-urban areas of Kampala are of the traditional unimproved type which do not meet the basic criteria of hygiene and accessibility to children, the disabled and elderly, not least because of the poor standard of maintenance and desludging of such infrastructure. Consequently polyethylene bags (“flying toilets”) and open defecation are practiced with the excreta ending up on roofs, drainage channels, and solid waste dumps (Kulabako et al., 2010). In addition, the greywater is normally discharged into poorly constructed and maintained drainage channels, open spaces including roads making these impassable and vacant plots creating ponds of foul-smelling stagnant water.

The septic tank is recognised under Ugandan legislation (the Public Health Act, 1964) and therefore on-site options, including the septic tanks, are likely to remain the most appropriate decentralized sanitation solution for most Kampala residents for the foreseeable future. A septic tank acts primarily as a settlement chamber providing quiescent, anaerobic conditions that facilitate the reduction of the organic and suspended solids content of wastewater. A well constructed and maintained septic tank can remove 15–30% of the BOD (and often more in warmer climates) and retain between 50–70% solids (Canter and Knox, 1985). However, the removal of viruses, bacteria and other micro-organisms within the tank is negligible with the level of faecal coliforms, the standard indicator bacteria, in septic tank effluent reported at $10^6 - 10^8$ MPN per 100 ml (Canter and Knox, 1985; Van Cuyk et al., 2004). Equally, the environment within the septic tank is largely ineffective in reducing the nutrient loading of the wastewater, acting only to convert the influent organic nitrogen to ammonium achieving little total nitrogen removal across the process (Canter and Knox, 1985; Beal et al., 2005). A crucial component of the gravity flow septic tank treatment system is the soil treatment system. The effluent should be discharged into a series of percolation trenches which spread the loading over a wide surface area. In the vadose zone above the water table the effluent percolates with very low velocities due to unsaturated flow and this time of travel is one of the key factors in the removal and elimination of bacteria and viruses (Cave and Kolsky, 1999). Much research has concentrated on the flow of effluent and the mechanisms of pollutant attenuation within the subsoil (Beal, et al., 2005; Gill et al., 2007). The biogeochemical mechanisms for purification and hydraulic performance are complex and have been shown to be highly influenced by the biomat zone which forms at the soil-gravel interface along the base and wetted sides of the percolation trenches (Beal et al., 2005). Anaerobic activity has been attributed as the main clogging process in biomats (Siegrist and Boyle, 1987) which have generally been shown to have low hydraulic conductivities, in the region of 0.006 m/d for clay subsoils up to 0.05 m/d for sand (Bouma, 1975). This reduced percolation rate can cause the effluent to pond above the biomat but leaves unsaturated conditions below, for aerobic degradation processes to operate on percolating effluent. Pathogens in particular can be dramatically reduced through 0.6 to 0.9 m of unsaturated subsoil yielding near complete removal of faecal coliform bacteria and greater than 4 log reduction in viruses (Van Cuyk et al., 2004; Gill et al., 2007). However, in many cases the effluent from a septic tank is discharged into a soak pit which concentrates both the hydraulic and organic loading leading to saturated conditions below and this partial pollutant attenuation and /or ponding and surface water runoff.

Finally, it should be recognised that protection of groundwater from on-site sanitation alone does not necessarily provide the required improvements in health (Cave and Kolsky, 1999). Studies would suggest that better well construction and protection are often the more critical factors as well as the transport, storage and use of water which have been identified as major sources of drinking water contamination, regardless of the quality of the water source.

Methodology

Site characteristics

An area within Kampala was investigated which contained a number of septic tanks serving hostels next to and above an unplanned settlement on one side of the hill facing the Nakulabye / Kasubi suburbs. In recent years several private hostels have been constructed in the west of this area to provide accommodation for

students of Makerere University (see Figure 1 and Photograph 1). This area has been relatively well-planned and each hostel was serviced by piped water and a septic tank for wastewater treatment prior to discharge into the subsoil. Several of the hostels also had their own additional source of groundwater collected from shallow wells in the basements of the buildings. This groundwater was pumped up to the header tank on the roof to avoid paying high prices for the metered piped water supply. To the east and further down into the valley bottom of this study area was an un-planned peri-urban area, shown schematically on Figure 1, which predominantly relies on the local springs and pit latrines for their water and sanitation needs. Some of the springs used were in close proximity to the effluent discharge points from the hostels as detailed in Table 1.

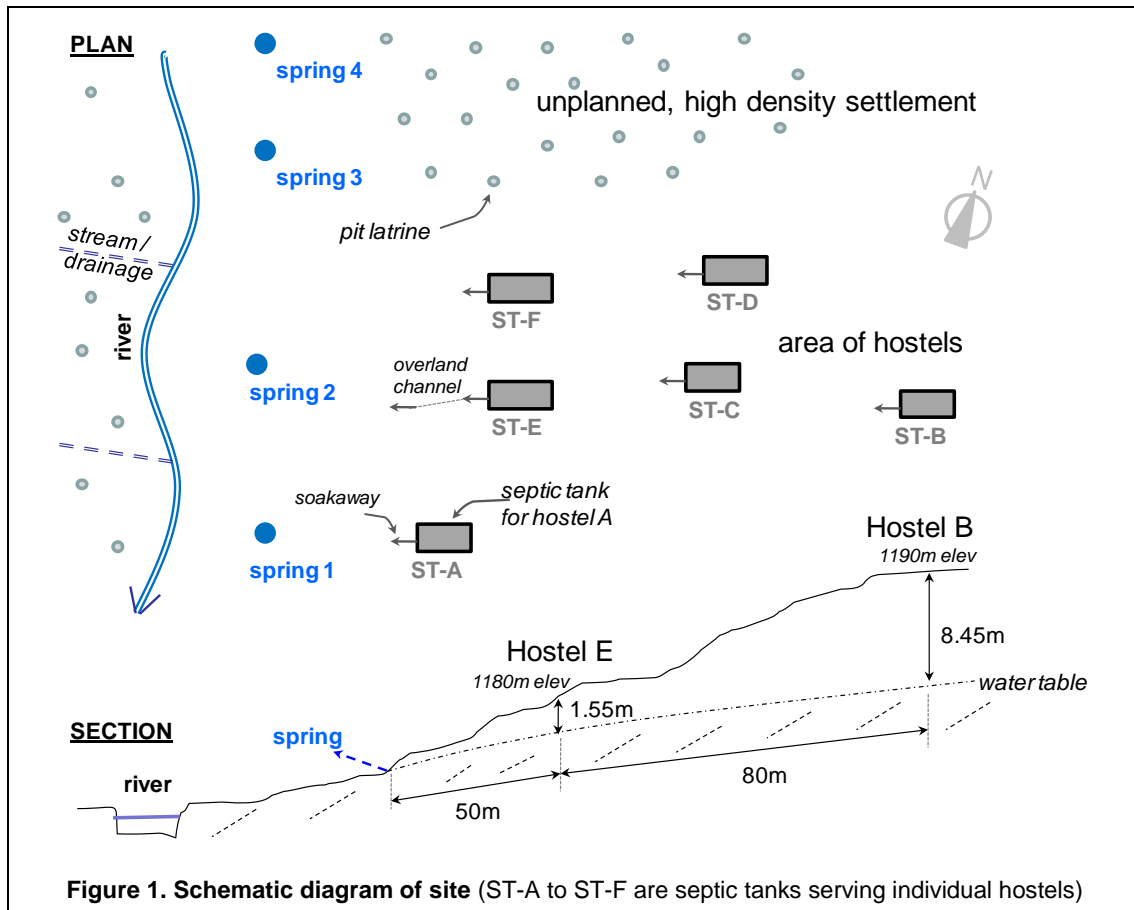


Figure 1. Schematic diagram of site (ST-A to ST-F are septic tanks serving individual hostels)

Field studies

Water usage in hostels and peri-urban area

The monthly metered consumption for each hostel was obtained from the caretaker of each building for each semester as well as the number of students resident in the property during those periods. At Spring 1 and Spring 3 observations were made to quantify the number of people collecting water and the quantity collected on four separate days per spring - 2 weekdays and 2 holidays. A questionnaire was also given to 10 different households in the unplanned settlement in order to determine the source and amount of water used.

Subsoil investigations

An assessment was made of the unsaturated subsoil into which the septic tank effluent was discharged in order to understand pollutant attenuation mechanisms above the water table. In most cases the effluent discharged into a soakaway adjacent to the septic tank which was clearly overloaded, leading to an area of standing water and surface flow. In some cases the effluent had been channelled to a soakaway area further away from the hostel as shown in Photograph 2, presumably to remove the stagnant effluent away from the hostel perimeter. The site assessment procedure used for on-site wastewater treatment in Ireland (EPA, 2009) was followed in order to determine the characteristics of the unsaturated subsoil. This involved

digging a trial hole down to the water table just downstream of Hostels E and F, as well as carrying out a series of falling head percolation tests to establish the field saturated hydraulic conductivity, k_{fs} (Mulqueen and Rodgers, 2001). Subsoil samples were also taken back to the laboratory for particle-size distribution analysis according to BS1377: Part 2 (1990). Soil permeability was also established by taking an undisturbed sample of soil in a circular steel mold and carrying out a Falling Head Permeameter test in accordance with BS1377: Part5 (1990).

Septic tank effluent, groundwater and spring water quality

Water samples were taken from the septic tank outlets at each of the hostels, from the four springs, from groundwater that had collected in the trial holes in the percolation areas of Hostels E and F and also from the local ground water pumped from beneath Hostels C and D. Analysis was carried out on-site for pH and Electrical Conductivity (EC) using field probes. Samples were collected in sterile glass bottles and transported in a cool box to the National Water and Sewerage Corporation laboratory for chemical and microbiological water quality testing within 4 hours. Tests for all chemical and microbiological parameters (BOD₅, COD, TSS, NH₃-N, NO₂-N, NO₃-N, Total P, Total coliforms and *E. coli*) were carried out as per Standard Methods (APHA, 1998).



Photograph 1. Hostel



Photograph 2. Septic tank effluent channelled down to soakaway near spring

Results and discussion

Water usage and septic tank condition

The amount of metered water used per hostel is shown in Table 1 which shows large differences in water consumption between the hostels. Hostels B and D used between 86 and 122 litres per capita per day (Lcd), compared to half that water usage in Hostel C and extremely low water usage (3 Lcd) in Hostel A. This apparent difference between the hostels was due to the fact that Hostels A and C augmented their water supply from their own on-site wells in the basement, as discussed above and so their real water usage was likely to be similar to the consumptions measured in Hostels B and D.

The dimensions of the septic tanks were also measured from which mean hydraulic retention times (HRTs) were calculated on the assumption that 80% of the water consumed was discharged as wastewater to the septic tank in each hostel. The sizes of the septic tanks ranged from 20 to 85 m³ but did not seem to correlate with the number of people in each hostel thus resulting in a range of different HRTs from 2 to 5 days. It should be noted that the optimum HRT design for a septic tank is between 2 -4 days (Canter and Knox, 1985; EPA, 2009) and so these septic tanks were not excessively loaded hydraulically. However, all the septic tanks were a single chamber rather than the recommended two chamber design which would affect their solids removal performance. The septic tank for Hostel A had been emptied twice since 1999 and the tank for Hostel C emptied once since 2007, whereas as both tanks for Hostels B and D had never been emptied since their installations in 2003 and 2005 respectively. The recommended frequency for desludging septic tanks is once every one to three years (Mara, 1996).

Table 1. Metered water use in hostels 2008/09 and septic tank characteristics								
	Hostel A		Hostel B		Hostel C		Hostel D	
	Sem. 1	Sem. 2	Sem. 1	Sem. 2	Sem. 1	Sem. 2	Sem. 1	Sem. 2
Water consumed (m ³ /month)	20	29	479	421	491	279	259	464
No. students	230	230	142	115	300	300	91	180
Per capita demand (L/p.d)	3	4	112	122	55	41	95	86
Septic tank volume (m ³)	64.3		19.8		56.1		84.7	
Mean hyd. retention (days)	3.0		1.8		2.0		5.0	
Distance to spring (m)	45		140		15		30	

The results of the questionnaire given to 10 families living in the neighbouring low-income areas revealed that all families used the unprotected springs due to its low cost and proximity and that the average consumption per week was between 12 to 20 Lcd (average 15.9 Lcd), considerably less than the water consumption in the hostels. All the respondents also stated that they used their own pit latrines for sanitation, an example of which is shown discharging directly into the stream running through the settlement in Photograph 3. The surveys at the springs revealed that the average water drawn daily from the Spring 1 was 14 115 litres compared to 12 006 at Spring 3. Based on the average consumption, this would indicate that Spring 1 was likely to be serving approximately 900 people and Spring 3 supplying 750 people which is considerably higher than recommended Sphere standard (2004) of 400 people per spring. Photograph 4 shows the condition of the springs with clearly eroded backfill, cracks in the concrete lining and no protective fence.



Photograph 3. Stream through area with latrine discharging into it



Photograph 4. Water being collected from Spring 3

Subsoil investigations

The trial holes dug just downstream of Hostels E and F, in addition to a deep construction site excavation near to Hostel B, enabled the depth the water table profile down the hill to be plotted, as shown on the section in Figure 1. This revealed a reducing depth of unsaturated subsoil with distance down the slope to the point where the springs emerge. Hence, the springs were more at risk of contamination from the septic tank effluent from the hostels which are furthest down the slope due to proximity (as expected) but also the

shallower layer of unsaturated subsoil. Subsoil sample particle-size distribution analysis classified the soils in the unsaturated zone next to Hostels B, E and F to be *sandy silt* comprised of approximately 10 % gravel, 40% sand and 50% silt / clay. The series of falling head percolation tests in the unsaturated subsoil yielded mean values of field saturated hydraulic conductivity, k_{fs} of 1.1 m/d (equivalent to a normalised permeability coefficient, k_N of 3.0 m/d) and soil permeability (k) from the Falling Head Permeameter test in the laboratory yielding a value of 2.5 m/d which correlates well with other studies on such subsoil (BGS, 2001). Hence, this subsoil exhibited good drainage characteristics which would be acceptable according to on-site treatment standards for the discharge of septic tank effluent into a properly constructed percolation area as long as there was more than 1 m of unsaturated subsoil to provide acceptable attenuation and treatment of pollutants. However, as discussed the effluent for these systems was not discharged into a series of parallel percolation pipes, rather concentrated into soakaways which would compromise the treatment to some extent. It should also be noted that the ARGOSS guidelines (BGS, 2001) would characterise such a site with <5 m unsaturated sandy silt subsoil as being at a significant risk of polluting the water table.

Septic tank effluent, groundwater and spring water quality

The results from the septic tank effluent analysis are presented in Table 1. Surprisingly perhaps, considering the under-sizing of the tanks, the organics, solids, nutrients and indicator bacteria concentrations all compare reasonably to studies carried out on more correctly designed septic tanks. The pH of the effluent ranged from 7.6 to 8.1. The septic tanks with the lowest retention times (ST-B and ST-C) had the lowest ammonia concentrations, indicative that much of the organic-N fraction in the influent had not had time to be mineralised into ammonia. This was not the case with phosphorous however, which indicates that much of the phosphorous in the effluent was due to anaerobic processes solubilising the particulate P in the sludge which would have a much longer solids retention time in the tank.

Septic tank for hostels	BOD ₅ (mg/l)	COD (mg/l)	TSS (mg/l)	NH ₃ -N (mg/l)	Total P (mg/l)	Total coliforms /100 ml
ST-A	320	1612	226	31.5	36.2	3.8x10 ⁷
ST-B	319	876	188	9.4	18.1	4.0x10 ⁷
ST-C	178	486	221	11.9	52.7	5.0x10 ⁶
ST-D	328	1684	220	20.8	35.8	9.8x10 ⁷

Groundwater pumped from the basement of Hostels C and D was analysed which showed relatively clean water with a low pH (see Table 2), although the existence of *E. coli* (even at low concentrations) in the Hostel C water would be cause for concern. However, the sampled water from the trial pits dug down to the water table near the percolation area of the septic tanks in Hostels E and F showed distinctly different chemical signatures with clear evidence of septic tank pollution. It should be recognised that this rather crude test does show that the depth of subsoil had acted to remove significant amounts of the organics, phosphorus and a 3 log reduction in the indicator bacteria, although significant concentrations still remained.

Groundwater for hostels	pH	EC (μS/cm)	BOD ₅ (mg/l)	COD (mg/l)	TSS (mg/l)	NH ₃ -N (mg/l)	Total P (mg/l)	<i>E.coli</i> /100 ml
Hostel-A (pumped)	5.5	172	2.4	5.4	22	<0.05	0.1	0
Hostel-C (pumped)	5.7	204	2.8	4.0	27	<0.05	0.1	88
Hostel-E (trial pit)	7.3	804	45.6	181	190	12.2	1.0	4.0x10 ³
Hostel-F (trial pit)	7.3	782	21.2	127	205	11.0	0.9	1.2x10 ³

The water quality from the four springs in the area used for water supply is shown in Table 3. Whilst the physical indicators (pH and EC) show that both springs were clearly receiving groundwater from the bedrock aquifer similar to the water quality pumped from the basement of the hostels, there is a noticeable difference between the quality (especially microbiological) of Springs 1 and 2 compared to Springs 3 and 4. Spring 3 and 4 show stronger evidence of contamination with higher organics, traces of ammonia and most importantly *E. coli* indicator organism. There are a few *E. coli* in Springs 1 and 2 giving some indication of faecal pollution (probably the septic tank discharges) but this shows that the subsoil between the soakaway and the springs had been fairly effective in attenuating the pollutants in this location. The concentration in Springs 3 and 4 must have originated close to the wells in the form of latrines or other human activity which matches the conclusion made by the Howard et al. (2003) study discussed previously. In contrast the water quality of the surface water running through the settlement shows high levels of contamination.

Table 3. Spring water and stream characteristics

Spring	pH	EC ($\mu\text{S/cm}$)	BOD ₅ (mg/l)	COD (mg/l)	TSS (mg/l)	NH ₃ -N (mg/l)	Total P (mg/l)	<i>E.coli</i> /100 ml
Spring 1	5.8	161	6.9	17.6	0	<0.05	0.1	2
Spring 2	5.8	207	4.8	11.2	0	<0.05	0.2	6
Spring 3	5.3	203	12.0	25.0	0	0.3	0.2	62
Spring 4	5.2	230	10.3	21.3	0	0.5	0.2	78
Stream	6.9	607	18.4	30	40	18	0.8	6.0x10 ⁵

Conclusion

The use of septic tanks as an appropriate decentralized wastewater treatment solution to an inner city area of Kampala has been investigated. Whilst the septic tanks do not discharge into a correctly constructed percolation area and have not been properly maintained, it has been shown that the unsaturated sandy subsoil had acted to attenuate significant concentrations of pollutants and protect the downstream springs used as water sources for the surrounding population. In contrast, the springs situated within the unplanned development indicated higher levels of contamination which has probably originated close to the wells in the form of latrines or other human activity. Finally, water usage for the low income people who collect water in jerry cans from the springs has been shown to be between 12 to 20 Lcd compared to those in the hostels with a piped water supply who were using in excess of 100 Lcd.

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