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Selection of sustainable sanitation technologies for urban slums — A case of Bwaise III in Kampala, Uganda

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ABSTRACT

Provision of sanitation solutions in the world's urban slums is extremely challenging due to lack of money, space, access and sense of ownership. This paper presents a technology selection method that was used for the selection of appropriate sanitation solutions for urban slums. The method used in this paper takes into account sustainability criteria, including social acceptance, technological and physical applicability, economical and institutional aspects, and the need to protect and promote human health and the environment. The study was carried out in Bwaise III; a slum area in Kampala (Uganda). This was through administering of questionnaires and focus group discussions to obtain baseline data, developing a database to compare different sanitation options using technology selection criteria and then performing a multi-criteria analysis of the technology options. It was found that 15% of the population uses a public pit latrine; 75% uses a shared toilet; and 10% has private, non-shared sanitation facilities. Using the selection method, technologies such as Urine Diversion Dry Toilet (UDDT) and biogas latrines were identified to be potentially feasible sanitation solutions for Bwaise III. Sanitation challenges for further research are also presented.

1. Introduction

1.1. Sanitation in slum areas

The major contributors of the pollution load in urban slums into the environment are excreta, grey water and solid wastes (Eriksson et al., 2002, 2009; Howard et al., 2003; Kulabako et al., 2007; Paterson et al., 2007). Slums in developing countries lack basic sanitation services due to poor accessibility, lack of legal status and financial resources (Maksimović and Tejada-Guibert, 2001; Kulabako et al., 2007; Paterson et al., 2007) as well as lack of supportive infrastructure (von Münch and Mayumbelo, 2007). The main sanitation challenges for slums are the ways of enhancing demand for sanitation, the sustainability question and the institutional structures and arrangements for upscaling and replication by other practitioners (Franceys, 2008; Jenkins and Sugden, 2006).

One of the ways to deal with pollution streams in urban slums is through the provision of well functioning sanitation systems. Sanitation here refers to the management of human excreta, grey water, solid waste and storm water. The main polluting constituents are pathogens that endanger public health and nutrients that may cause eutrophication of surface waters and pollution of groundwater. Human excreta management is the key to public health in urban slums since most of the pathogens are of faecal origin. They form a major cause of disease transmission due to the presence of pathogens in excreta and when mixed with wastewater, the pathogens flow downstream and spread in the environment especially during flooding (Feachem et al., 1983; Prüss et al., 2002; Niwagaba et al., 2009).

Human excreta are predominantly disposed in slum areas by use of unlined pit latrines which are usually elevated in areas with a high water table. Other excreta disposal facilities and options include traditional pit latrines, flying toilets (use of polythene bags for excreta disposal that are dumped into the surrounding environment), open defecation and to a small extent ventilated improved pit latrines (VIP) and pour flush toilets by the few high income earners (Kulabako et al., 2007; Muwuluke, 2007). These excreta disposal systems in use are considered unimproved because they are shared by many households (WHO and UNICEF, 2010). Moreover, they pollute the groundwater through direct and indirect discharge of pollution loads into the environment.

The current need to increase sanitation coverage to meet the MDG sanitation target has triggered provision of sanitation systems also in slum areas. However, little thought is given to the treatment of the collected waste. The high population density in slums and the typical

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flood prone locations tend to enhance the problem of overflowing pit latrines and washout of flying toilets. Excreta disposal facilities are a component of the sanitation system, which can be sustainable if it is affordable, developed to ensure pathogen removal and efficient for the recovery and reuse of nutrients contained in the excreta (Otterpohl et al., 1999; Mara, 2003; Kvarnström and af Petersens, 2004; Langergraber and Muellegger, 2005; Bracken et al., 2007). Sustainability of sanitation systems in urban slums may be achieved if technology selection methods that take into account the local situation are adopted.

1.2. Case study area: Bwaise III

This study focused on Bwaise III (32° 34′E, and 0° 21′N), a slum area located in Kampala, Uganda (Fig. 1). Bwaise III has six Local Council (LC) 1 zones (the lowest administrative unit at the Local Government Level) namely: Kawaala, Katoogo, St. Francis, Bugalani, Bokasa, and Kalimali. In total, 15,015 people are estimated to live in an area of 57 ha making the population density 265 persons per hectare (UBOS, 2002; Kulabako et al., 2007). The population growth rate of the study area is currently estimated by the Kawempe Division to be 9%. This is above the national average value of 3.4%. The area was initially a wetland connected to the existing Lubigi wetland to which it drains.

The slum area evolved as a result of illegal encroachment on the wetland. Consequently, there is no legal status of ownership of the area which makes provision of basic water and sanitation services difficult. The high water table and vulnerability of the area to flooding in rainy seasons has also made it difficult to construct pit latrines that are largely used in this area for excreta disposal. This indicates that there is a strong need to take the location into account in providing appropriate sanitation. Recently, an extensive study was carried out to investigate the groundwater situation in Bwaise III (Kulabako et al., 2007, 2008). It was concluded that a large part of the pollution was sanitation-related. This study therefore focuses on the sanitation situation in Bwaise III by analysing the current situation and developing a method to select sustainable sanitation options for excreta management.

2. Materials and methods

This study was carried out in three phases. The first phase involved conducting a household survey to obtain baseline data. The second phase involved developing a database to enable comparison of different technology solutions based on established criteria to relate them to the baseline data. Finally, a multi-criteria analysis was carried out to incorporate the views of experts (technical and non-technical professionals) and stakeholders into the technology selection.

2.1. Sample size and selection

The sample size of 400 households was adopted for the study area of Bwaise III parish in Kawempe division. It was derived from the following expression developed for calculating a sample for proportions (Cochran, 1963; Kish, 1965): $N = Z^2\left(\frac{Pq}{e^2}\right) = Z^2\left(\frac{P(I-P)}{e^2}\right)$, where N is the sample size, e is the desired level of precision ± 5% (Bryan, 1992; Langen, 2007), Z is 1.96 at 95% confidence interval, P is the estimated level of an attribute present in the population which is 0.627 (toilet coverage of

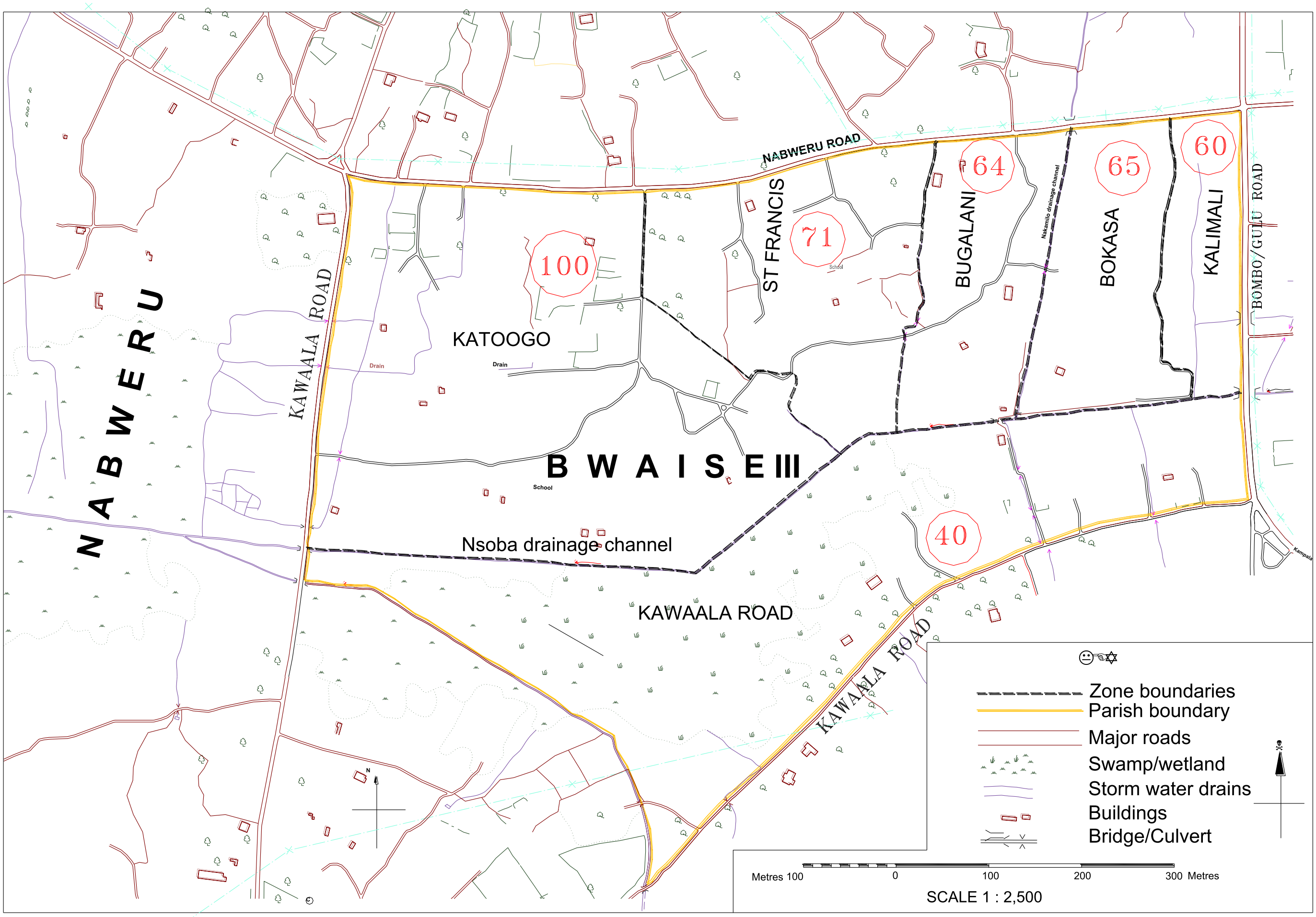

Fig. 1. Map of Bwaise III parish showing the Local Council zones and the corresponding sample size indicated in circles.

62.7% from the Kawempe Division three year development plan 2006–2009) and q is $1-P$. The expression gives a value of 361 but 400 households were used in this study to cater for none responses to the interviews and the 5% precision and sampling error. The number of households sampled in the parish zones of Kawaala, Katoogo, St. Francis, Bugalani, Bokasa, and Kalimali were 40, 100, 71, 64, 65 and 60, respectively. It was based on the number of households in a parish zone. The randomisation was based on the type of sanitation facility, the household income level (low, and medium), the family head (male, and female) and the need to cover different locations in an LC1 zone. The final decision on the actual number of households selected and their location in each zone took into consideration the actual situation on the ground through consultations with the Kawempe Division Administrators, Local Council Leaders and field observations. The study area boundaries were the six zones of Bwaise III parish (Fig. 1).

2.2. Questionnaires

Structured, semi-structured and unstructured questionnaires were used to collect information from household heads and other key informants in Bwaise III. Unstructured questionnaires were based on the interaction with the informant to elicit information and used as part of observation field work (Punch, 2005; Patton, 1990). They were formulated to include sustainability issues and their indicators as applied to sanitation options in slum areas. The questionnaire was checked for validity by pre-testing it on 10% of the households that were used in the study after which improvements were made for final administering in the study area. Data collection was carried out either early in the morning or late in the evening being the time when most residents and household heads are at home (Muwuluke, 2007). Household heads were targeted rather than women as household income earners are the ones who make the final decisions. Of the families investigated, 30% are headed by women. In addition, there were polygamous families with only women available at home to respond to the questionnaires because their husbands were rarely present. Household interviews were also conducted by employing a random selection method and targeting household heads (Bryan, 1992) in order to obtain information on water consumption, excreta management systems including their ownership and solid waste management practices.

2.3. Field investigations

Data on the current sanitation practices and sanitation situation in Bwaise III were collected by interviewing key informants and through transect walks in the study area. Key informants are people and organisations that have been involved in the implementation of sanitation activities in the study area. They included officials from government institutions (Ministries and Universities), non-governmental organizations and private sector. Transect walks were also made in the six LC1 zones together with their respective LC1 leaders to assess the current sanitation practices and functionality of the existing sanitation facilities. These were systematic walks with key informants through the study area aimed at observing the current sanitation practices and carrying out informal and informative interviews using a checklist for completeness.

2.4. Technology selection process scheme

A flow chart (Fig. 2) shows the method used to select the technically feasible and sustainable sanitation options. It includes two levels: technology selection and multi-criteria analysis.

2.4.1. Technology selection

Technology selection was carried out using an Excel-based tool that was developed under this study. It comprises of the input data that are area specific, an assessment sheet where technology characteristics are subjected to the technical criteria and environment compliance as well as the output sheet with technically feasible options. The aim was to eliminate non-feasible options for the next level of assessment. Area specific input data for the following verifiable and policy variables were:

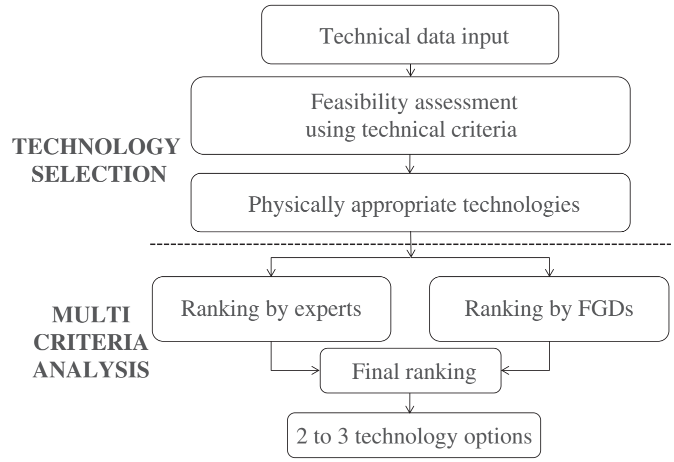

Fig. 2. Flow chart for selection of sustainable sanitation options applied in this study (FDGs: focus group discussions, and MCA: multi-criteria analysis).

a) Data on the following known and verifiable parameters: present population density, accessibility, data on existing water supply situation, ground water table and excavation constraints.
b) Variables for parameters that can change according to strategic decisions or technologies e.g. persons served, service levels and coverage. These are targets set by the service providers like the National Water and Sewerage Corporation (NWSC). Moreover, they also have to be in line with the Government policies such as the policy on water supply to the urban poor at lower tariff and the Poverty Eradication Action Plan (PEAP, 2004).

A number of technologies were considered in the technology selection, based on whether they are currently used in slums or have potential for use in slum settings. Conventional sewerage is costly to implement and operate and is not suitable for urban slum settings. It has been found to be an anti-poor technology by virtue of its higher cost and water requirements compared to simplified sewerage, which has been used in urban poor areas in South Asia, South America and South Africa (Paterson et al., 2007; Mara, 2003). Waterborne systems are feasible where the communities can afford the related tariffs, there is space for the simplified sewerage network including the wastewater treatment unit and the resource recovery in the form of nutrients and biogas is not a priority. There are also prefabricated systems from polyethylene such as mobilets but their functionality is the same as that of pit latrines which is one of the technology options. Therefore, the technology options that were subjected to technical feasibility and further screening by multi-criteria analysis for applicability in slum areas included: urine diversion dry toilet (UDDT), biogas toilet/latrine, compost pit latrine, traditional pit latrine, lined ventilated improved pit latrine, pit latrine with urine diversion, *Fossa Alterna*, pour flush toilet connected to twin pits and simplified sewerage possibly connected to the main sewer of the nearby urban conventional system.

The identified technology options were subjected to technical criteria to determine their appropriateness in the study area. They included: water availability and consumption for water borne systems, excavation depth, accessibility to vacuum trucks and pickups and treatment requirements such as recovery of nutrients and energy in the form of biogas and environment protection against pollution based on National and World Health Organization effluent discharge standards. It was assumed that the maximum flood level is 0.5 m above ground level, that the space between housing blocks is adequate for implementation of these systems and that there is market for the sanitised end products.

2.4.2. Multi-criteria analysis

The selected technologies were screened further by use of multi-criteria analysis (MCA) to take into account the perception of the stakeholders. The selected sanitation options for excreta disposal were presented to the stakeholders for ranking. This was done using focus group discussions (FGDs) taking into account gender, age and representation from the six zones of the study area. There were a total of six FGDs; three for both females and males each composed of representatives from two neighbouring LC1 zones in Bwaise III. In addition, various experts ($n=20$) participated in the ranking of the technically feasible sanitation options.

2.4.2.1. Ranking of technologies by FGDs. The pair-wise method was used for ranking of the sanitation technologies by the FGDs on a pair by pair basis. Using this structured method, two sanitation technologies were compared each at a time for the nine technology options (Table 1A). FGDs were held to establish perceptions and preferences from the communities about the technology options suitable for the study area (Table 1B). The technologies were presented to the beneficiary community (represented by FGDs) using IEC (Information, Education and Communication) materials (Fig. 3) in the participatory discussion of the merits and demerits of these technologies with respect to sustainability indicators before the ranking activity.

In each comparison, the technologies were given scores on a scale of 1 to 5 (1 being the lowest and 5 the highest) based on their attributes and this varied for different FGDs (Table 3B). The FGD ranking for a particular technology was based on the FGD count referred to as the number of times it was chosen as the preferred option in the pair-wise matrix (Table 1A) using the sustainability criteria (Table 2). The FGD counts for a particular technology from the six FGDs were added to obtain its total FGD count used for the overall ranking (Table 1B). For technologies that have the same total FGD count, a comparison between the two in the pair-wise matrix was used to break the tie. In this study, a compost pit latrine and a biogas latrine ranked the same because they were each preferred by 3 FGDs in the matrix.

This method was more useful in prioritizing the needs of the beneficiary community than in a one-stage ranking. It offers an opportunity for special interest groups such as women, children, elderly and people with disabilities to influence the choice and design of the sanitation technologies. This is in agreement with Jenkins and Sugden (2006) that the beneficiaries should be involved at early stages of the design process and systems must be designed so that they meet their needs. Pair-wise ranking enabled the potential beneficiaries to make decisions in a consensus oriented manner.

2.4.2.2. Ranking of technologies by experts. Experts composed of technical and non-technical professionals ranked the technically feasible sanitation options. They included social scientists, engineers, public health specialists and institutional experts. Pre-determined sustainability criteria (Table 2) together with a matrix for ranking of technologies were presented to experts who determined the scores for the sustainability indicators (Table 3A). To estimate scores for the selected criteria for the alternative options, a scale of 1–5 was adopted (Al-Kloub et al., 1997; Mendoza et al., 1999; von Münch and Mels, 2008). Technical information about available excreta management technologies was established as reported in the literature (Mara and Guimarães, 1999; Paterson et al., 2007; Tilley et al., 2008; van der Steen, 2008). Sanitation was viewed as a system comprising of collection, storage, treatment and reuse/disposal. The selection of the potential sanitation option was based on technical feasibility and sustainability considerations used in previous studies (Kvarnström et al., 2004; Starkl and Brunner, 2004; Myšiak, 2006; von Münch and Mayumbelo, 2007) with involvement of the beneficiaries. Selected sustainability aspects that were considered and whose criteria were established included: socio-cultural, technical, health and environmental, and economical and institutional (Table 2). These sustainability aspects were given scores based on their respective specific indicators depending on their degree of importance.

Table 1A
Matrix for ranking of technologies using the Pair-wise method. This table represents the outcome of a focus group discussion (FGD) of females in Katoogo and Kawaala road Local Council zones.

	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)	FGD count	FGD ranking
(a)		b	c	d	e	f	a	h	i	1	8
(b)	b		c	d	e	b	b	h	i	3	5
(c)	c	b		d	e	f	c	c	i	3	6
(d)	d	d	d		e	d	d	d	i	6	4
(e)	e	e	e	e		e	e	e	i	7	2
(f)	f	f	f	d	f		f	f	i	6	3
(g)	g	b	c	d	e	f		g	i	2	7
(h)	a	b	c	d	e	f	g		i	0	9
(i)	i	i	i	i	i	i	i	i		8	1

Key: (a) septic tank system, (b) biogas toilet/latrine, (c) pour flush toilet with twin septic pits, (d) urine diversion dry toilet, (e) compost pit latrine, (f) pit latrine with urine diversion, (g) simplified sewerage system (h) traditional pit latrine, and (i) VIP latrine.

Table 1B
Ranking of technology options by focus group discussions (FGDs).

Technology	FGD counts for technology options						Total count	Overall ranking
(a)	1	2	1	0	1	1	6	8
(b)	5	4	6	6	4	3	28	4
(c)	4	3	5	4	3	3	22	5
(d)	7	7	6	7	6	6	39	1
(e)	2	5	4	5	5	7	28	4
(f)	4	5	6	5	7	6	33	3
(g)	3	2	0	2	0	2	9	6
(h)	0	0	2	2	4	0	8	7
(i)	7	5	4	5	5	8	34	2

Key: (a) septic tank system, (b) biogas toilet/latrine, (c) pour flush toilet with twin pits, (d) urine diversion dry toilet, (e) compost pit latrine, (f) pit latrine with urine diversion, (g) simplified sewerage system (h) traditional pit latrine, and (i) VIP latrine.

2.4.3. Final ranking of the sanitation technologies

The final ranking was achieved using the average FGD scores for the parameters defining sustainability indicators and the weighted scores of the sustainability indicators by the experts. The normalized score of a sustainability indicator was obtained as follows: $F = \left[\sum_{i=1}^{n} \left(\frac{a_i}{c}\right)\right] \times G$ where F is the normalized score of a sustainability indicator, n is the number of parameters defining the criteria for a sustainability indicator, a is the average FGD score of a parameter for sustainability criteria, c is the total of the average FGD scores for criteria defining a sustainability indicator and G is the expert's weighted score for a sustainability indicator. The sum of the normalized scores (F) for all sustainability indicators was the total final score for a technology option and determined its final rank.

3. Results

3.1. Existing sanitation situation

3.1.1. Human excreta management

The excreta disposal facilities in Bwaise III range from simple/traditional pit latrines to flush systems with septic tanks. The majority of the residents (>50%) use elevated pit latrines for excreta disposal. Other excreta disposal technologies used include Ventilated Improved Pit (VIP) latrines and pour flush toilets (Fig. 4A).

Most of the sanitary facilities are shared and 75% of the slum dwellers use shared facilities. Community or public toilets are accessed by 15% of the people and 10% of the existing sanitary facilities are privately owned and not shared (Fig. 4B). Shared facilities are used by at least two

A B C D

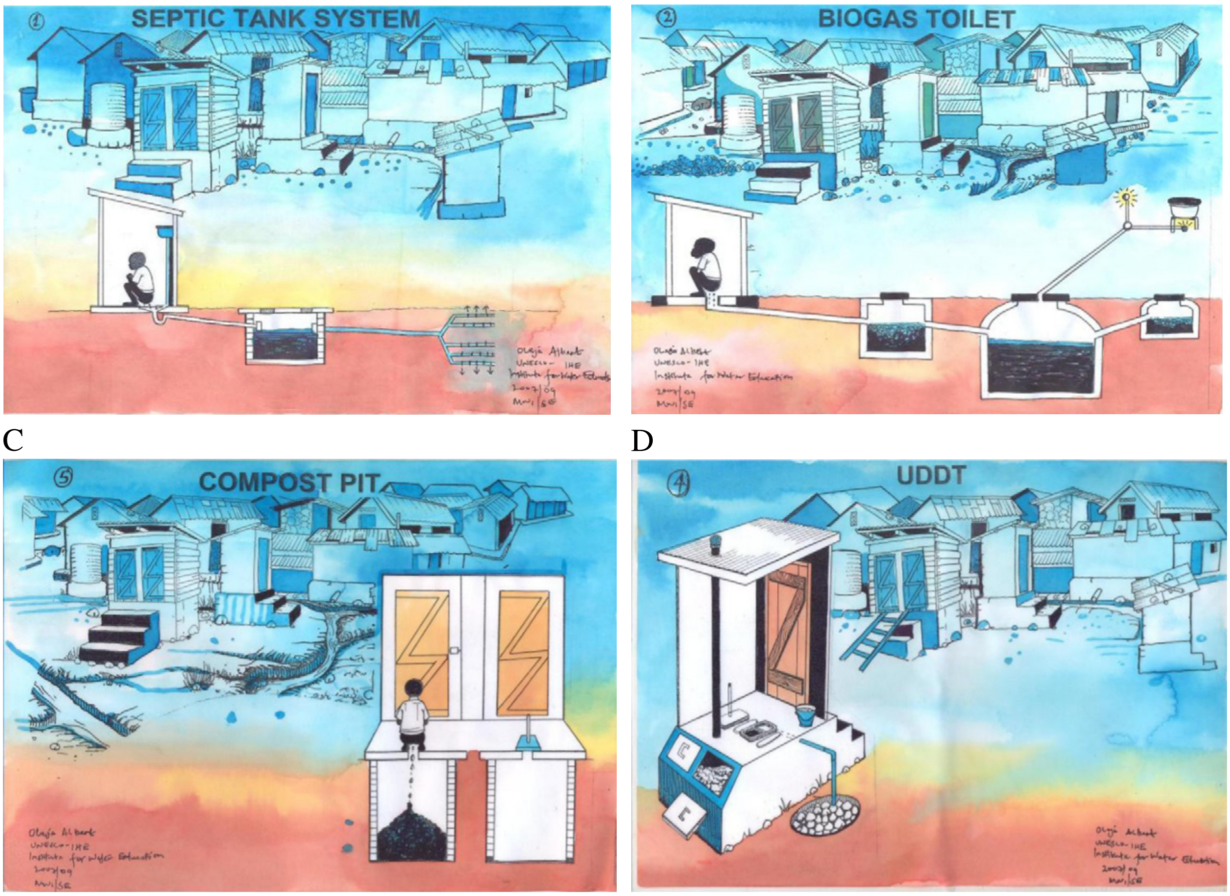

Fig. 3. Information, Education and Communication (IEC) materials used in the focus group discussions: (A) septic tank system, (B) biogas toilet, (C) compost pit latrine and (D) Urine Diversion Dry Toilet (UDDT).

households responsible for their maintenance while public or community toilets are used by the general public located at market places and public institutions. The findings showed that almost all respondents claimed to have access to a sanitation facility irrespective of the type of system.

During the field visits, the user-load of the pit latrines was found higher than expected. Transect walks through the area clearly revealed that the user-load per latrine was high, with almost all latrine facilities shared by more than two households. The user to stance ratio was found to range from 1:30 to 1:70 which is higher than the recommended value of 1:20 by the Uganda Ministry of Health. This is in agreement with a previous study by PLAN (2001) that found it common for 10 households to share a stance. The high usage frequency requires also a high pit latrine emptying frequency. In a situation where landlords are not held

Table 2
Sustainability indicators and criteria.

Sustainability indicator	Criteria
Socio-culture	Acceptance: *Proportion of users unhappy with the proposed technology option.*
	Perception/complexity: *Ability of beneficiaries to participate in operation and maintenance.*
	Use-ability: *How easy it is to use the proposed facility as viewed by the intended beneficiary community.*
Technical	Local labour: *Capacity of local contractors to undertake the associated technical works.*
	Robustness: *Sensitivity to improper use, durability and sensitivity to harsh environment.*
	Materials: *Availability of local materials for facility construction.*
	Fit existing system: *Upgradeability to suit the local infrastructural and physical conditions.*
Health and environment	Environmental pollution: *Risk of emission of pollutants to the environment such as nutrients and organic matter.*
	Exposure to pathogens: *Risk of negative health impact associated with pathogens and contact with excreta during system management.*
Economics	Capital cost: *Investment's requirement for the system.*
	Land: *Space required for the system to be constructed.*
	Operation and maintenance: *Resources (time, money, and energy) for the system to serve its design life.*
	Resource recovery: *Possibility of nutrient recovery from proposed technology for agricultural use.*
	Energy: *biogas recovery.*
Institutional	Adoptability: *The ability of the beneficiary to use the technology.*
	Management: *System for overseeing that the facility serves its intended purpose.*
	Policy (WATSAN): *Strategic decisions by the government to increase sanitation coverage and service level to the urban poor.*

Table 3A
Scoring of sustainability indicators by experts ($n = 20$).

Sustainability indicator	Experts				Average scores	Weighted average scores (%)
	Social scientists/economists	Technical/engineers	Institutional specialists	Public health specialists		
Socio-culture	4.6	4.6	4.6	4.2	4.5	24.9
Technical	3.4	3.4	3.2	3.6	3.4	18.8
Health and environment	3.8	3.6	4.4	4.8	4.2	23
Economics	4.2	4.2	2.6	3	3.5	19.4
Institutional	2.6	2.6	2.4	2.4	2.5	13.9
Total						100

liable, this remains challenging. Similar experiences are reported in urban slums of other developing countries (Chaggu, 2004; Mugo, 2006). Several contributing factors to ground water pollution were identified: unlined pits of excreta disposal facilities, leachate from decomposing solid waste dumps, uncollected grey water and storm water. It was also observed that most of the elevated pit latrines have a provision at the rear end for emptying the faecal sludge in either the adjacent storm water drain during rains or in excavated pits. This is a cheap practice by slum dwellers to make a hole through the feacal sludge chamber for pit latrine emptying. It is one of the potential exposure pathways through which the inhabitants get infected with pathogens present in the unsanitised feacal sludge discharged into the environment.

3.1.2. Water supply situation

In Bwaise III, most residents have access to piped water from public standpipes. However, the cost per unit (e.g., a 20 L jerry can, or m^3) at the public standpipe is often more than 5 times higher than the tariff charged per m^3 by the National Water and Sewerage Corporation (NWSC) due to the extra charge by the service point caretakers in order to make profit. There are also a number of water vendors who sell a 20 L jerry can of water at a price higher than that charged at standpipes (Oleja, 2009). They obtain water from the existing water sources to sell to consumers who lack a water connection and those who do not use unprotected springs as water sources due to public health concerns when there are dry zones with low pressure in the piped water supply network. Therefore, a number of slum dwellers who cannot afford this cost have resorted to obtaining water for potable use from nearby protected and unprotected springs and open shallow wells. The level of water supply service in slums is still low (Fig. 5A) with very few house connections and an average per capita water consumption of 18 L/cap day for the six local council zones (Fig. 5B). This is lower than the minimum per capita water consumption of 20 L/cap day set by the Uganda Ministry of Water and Environment (DWD, 2000) and the minimum global standards set by WHO.

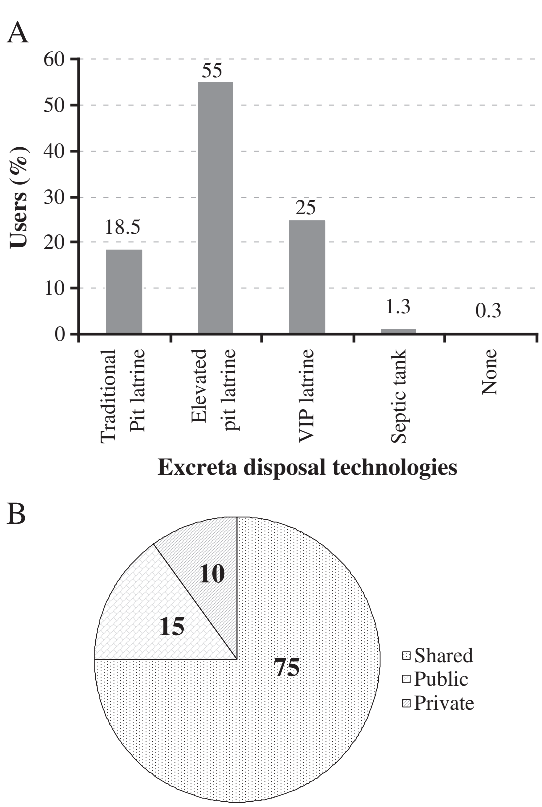

Fig. 4. A: Excreta disposal technologies in Bwaise III and the percentage of users making use of excreta disposal technologies. B: Ownership of excreta disposal facilities in Bwaise III.

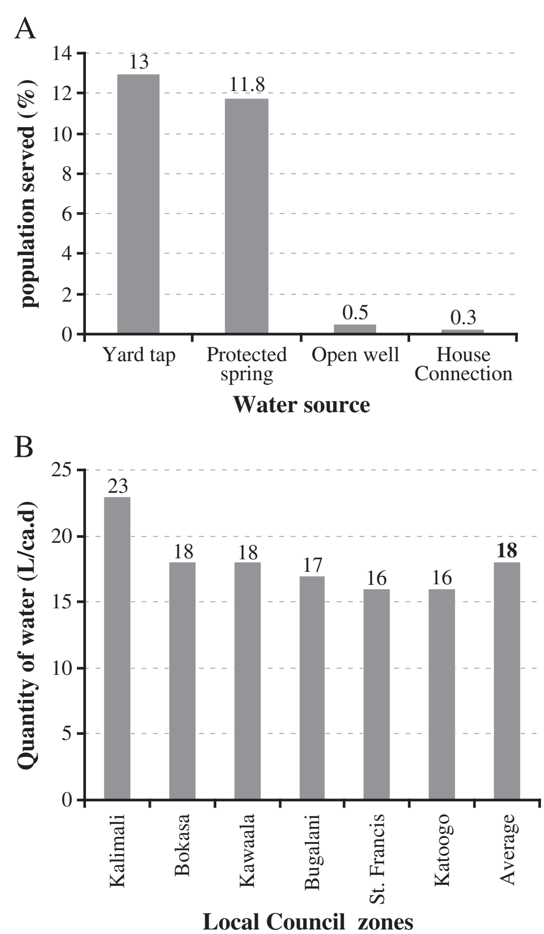

Fig. 5. A: Percentage of households using a water connection or water source. B: Water consumption (L/capita.day) in the local council zones of Bwaise III.

Fig. 6. Photographs illustrating sanitation status in Bwaise III in Kampala (Uganda). (A) Blocked storm water drain and (B) solid waste dump and an elevated pit latrine in the vicinity of a household in a slum area.

3.1.3. Solid waste management

There is poor solid waste management in Bwaise III which has resulted in illegal disposal of solid waste into storm water drains (Fig. 6A) and next to the houses (Fig. 6B), thus making the sanitation situation worse. The solid waste is largely organic, comprising food (bananas, potatoes, and pineapples) peelings, vegetable leaves and stems from households, small restaurants and food markets. Other fractions include plastics, glass and metal scrap. The potential recycling options include compost manure, recycling of plastics, glass and metal scrap, and energy in the form of biogas (KCC, 2006). There are a number of stakeholders involved in the solid waste management that include the Kampala City Council (KCC) and private companies (Fig. 7). There are also village health teams formed by the communities especially before the rainy season begins in response to common flooding problems. Households usually burn the solid waste during the dry season as a quickest way of disposing it. This is in spite of the negative effect to health by smoke and problematic noncombustible components of mixed waste such as fresh waste, glass and metallic parts though they account for a smaller fraction than the dry organic solid waste.

3.2. Technology selection

Selection of appropriate technology for collection, storage, and treatment of waste streams is vital for sustainability of any sanitation system. In this study, a selection of the excreta disposal facilities was made with involvement of stakeholders to take into account their views (Fig. 2). They included the residents of Bwaise III and professionals involved in the water and sanitation sector in Kampala. This was done after establishing the current sanitation situation in the study area in order to select sustainable sanitation systems. Physically appropriate technologies that passed the technical criteria were biogas latrine, Urine Diversion Dry Toilet (UDDT), compost pit latrine, pit latrine with urine diversion and lined ventilated improved (VIP) pit latrine. These were considered as physically appropriate for installation in the Bwaise III. The technologies that did not pass the technical criteria were the water borne systems including simplified sewerage pour flush toilet and septic tank system due to low per capita water consumption and the unimproved technologies such as traditional pit latrine and *Fossa Alterna* that cause discharge of pollution load into the environment.

3.2.1. Focus group discussions

Focus group discussions (FGDs) were conducted to obtain the sanitation preferences of the residents and key informants. The residents were provided with information on the different sanitation options using Information, Education and Communication (IEC) materials as part of community participation in decision making.

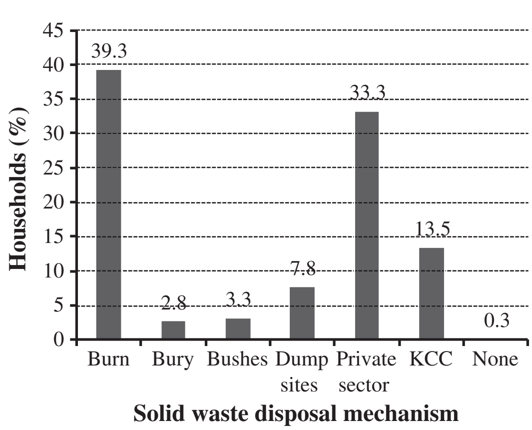

Fig. 7. Typical solid waste disposal mechanisms in Bwaise III and the percentage of households applying a solid waste disposal mechanism.

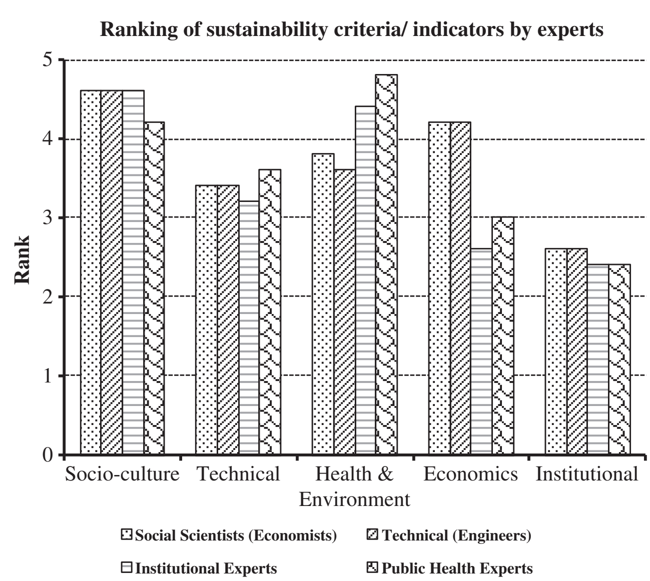

Fig. 8. Ranking of sustainability indicators by experts ($n = 20$) during multi-criteria analysis.

Table 3B
Scoring of sustainability indicators by focus group discussions (FGDs).

Sustainability function		Average FGD scores for sustainability indicators based on scale of 1 (low) to 5 (high)					Total score
Indicator	Criteria	Biogas lat	UDDT	Compost pit	Lat./U Div	Lined VIP lat	
Socio-culture	Acceptance	3	4	3	4	4	18
	Perception/complex	2	4	3	4	4	17
	Use-ability	3	4	3	4	5	19
							54
Technical	Local labour	3	5	4	4	5	21
	Robustness	2	4	2	2	2	12
	Materials	3	3	3	3	4	16
	Fit existing system	4	4	3	4	5	20
							69
Health and environment	Environmental pollution	4	5	4	3	2	18
	Exposure to pathogens	4	4	3	2	2	15
	Land requirement	4	5	2	2	2	15
							48
Economics	Capital cost	3	4	4	4	3	18
	Operation and maintenance	4	4	3	3	3	17
	Nutrient reuse	2	5	3	2	1	13
	Energy recovery	5	1	1	1	1	9
							57
Institutional	Adoptability (local level)	3	4	3	4	4	18
	Policy (WATSAN)	3	3	2	3	4	15
							33

Table 1A shows a total count for each of the sanitation options by an FGD in each of the six zones of Bwaise III parish and this was done by the six FGDs. The total counts are results from pair-wise ranking of the technologies by FGDs (Table 1A) based on a score scale of 1 to 5 with five being the highest. The most favoured option for use by the communities in the current situation was a UDDT followed by a lined VIP latrine (Table 1B).

3.2.2. Ranking of sustainability indicators by experts

Ranking of the selected options during multi-criteria analysis was carried out by professionals from academic institutions, government and private sector involved in the water and sanitation sector in Uganda ($n = 20$). This was based on various parameters considered as indicators for sustainability of the sanitation interventions in slum areas (Table 2). The results from the relevant professionals working in the water and sanitation sector (Fig. 8) show that social scientists/economists and engineers ranked all aspects of sustainability to be almost equally important with the exception of health and environment. The average scores of the sustainability criteria by FGDs and the weighted scores of the sustainability indicators by experts were used to determine the final technology score and rank (Table 3B). A urine diversion dry toilet ranked the highest and a compost pit latrine ranked the lowest.

4. Discussion

4.1. Human excreta management

Pit latrines are the dominant type of excreta disposal in Bwaise III due to their low cost as a result of the use of available raw materials for construction and the low level of water services and lack of affordability for water borne systems. The pit latrines are elevated due to the high water table. Very few people use VIPs and flush toilets connected to the septic tanks due to the high investment costs of these systems and lack of willingness by landlords to invest in sanitation facilities. Use of polyethylene bags ("flying toilets") and open defecation with the former dumped in drainage channels or solid waste dumps has also aggravated the problem of pollution. Previous studies have reported that most of the spring water sources in the peri-urban areas of Kampala are contaminated with pathogens of faecal origin (Howard et al., 2003; Nsubuga et al., 2004; Kulabako et al., 2007), which can be attributed to the current poor sanitation practice.

There has been a lot of sanitation interventions (for excreta disposal) in Bwaise III by NGOs (PLAN, 2001) but most of them have failed due to lack of stakeholder participation at all stages of the project cycle. The lined VIPs that have been implemented were either based on systems implemented in areas with favourable soil formations such as non-collapsing soils with low water table or in other peri-urban areas that have space and legal status or ownership. Sanitation facilities in Bwaise

Table 3C
Final ranking for technology options.

Sustainability function		Experts' weighted scores (%)	Normalized scores used in ranking of technology options by FGDs				
Indicator	Criteria		Biogas latrine	UDDT	Compost pit latrine	Latrine with urine diversion	Lined VIP lat.
Socio-culture	Acceptance	24.9	1.4[a]	1.8	1.4	1.8	1.8
	Perception/complexity		0.9	1.8	1.4	1.8	1.8
	Use-ability		1.4	1.8	1.4	1.8	2.3
Technical	Local labour	18.8	0.8	1.4	1.1	1.1	1.4
	Robustness		0.5	1.1	0.5	0.5	0.5
	Materials		0.8	0.8	0.8	0.8	1.1
	Fit existing system		1.1	1.1	0.8	1.1	1.4
Health and environment	Environmental pollution	23	1.9	2.4	1.9	1.4	1
	Exposure to pathogens		1.9	1.9	1.4	1	1
	Land requirement		1.9	2.4	1	1	1
Economics	Capital cost	19.4	1	1.4	1.4	1	1
	Operation and maintenance		1.4	1.4	1	1.0	1
	Nutrient reuse		0.7	1.7	1	0.7	0.3
	Energy recovery		1.7	0.3	0.3	0.3	0.3
Institutional	Adoptability (local level)	13.9	1.3	1.7	1.3	1.7	1.7
	Policy (WATSAN)		1.3	1.3	0.8	1.3	1.7
Total score		100	20	24.3	17.6	18.8	19.3
Final ranking			2	1	5	4	3

[a] Normalised score for biogas latrines with respect to *acceptance*: 3/(54)*24.9 = 1.4.

III were constructed without considering sanitation as a system that comprises of collection, storage, treatment and safe disposal/reuse. The concept of a sanitation system was therefore lost and this caused failure to operate and maintain the systems, resulting in environmental pollution due to lack of treatment of increased volumes of waste generated. As a result, there are challenges to be overcome that include: design and implementation of flood proof sanitation systems suitable for local conditions in slums and developing an emptying system for many existing pit latrines (to be improved) in slums to cope with a high filling rate. In addition, further research is needed on comparative performance of improved mixed and separate excreta disposal systems to ascertain the attributes of the combinations with respect to pollution reduction in slums and recovery of resources in the form of nutrients and biogas.

The pit latrines in Bwaise III are shared by more than two households. The VIPs that were constructed by NGOs are shared by up to 7 households indicating a high user-load and consequently a high filling rate. Operation and maintenance of the shared toilets in Bwaise III is done by landlords, who reside in the affluent areas in Kampala and often outside the country and mainly aim at maximizing profit from rent while the few privately owned are maintained by the owners. This implies that current and future interventions in selecting technologies and subsequent provision sanitation services should involve landlords, preferably through the Local Council Admnistration. There is a problem of lack of willingness by the tenants to contribute to the maintenance of the shared facility. It is attributed to lack of ownership and the population dynamics: the population settlement versus occasional flooding and movement to look for better employment opportunities. The slum inhabitants whose income improves either become landlords in Bwaise III or in another place, or shift and rent in a better place (Kulabako et al., 2010). Consequently, the demographic dynamics in urban slums are a challenge for sanitation improvement.

4.2. Water supply

Water supply reliability is as important as providing a sanitation facility to ensure a safe water chain in Bwaise III. Water is used for domestic consumption including drinking, bathing, washing hands and for transport in case of water borne systems such as flush toilets connected to septic tanks. Generally in Kampala city in which Bwaise is located, there is infrastructure for water supply but the residents in peri-urban settlements have limited access to piped water. The supply is unreliable due to problems of dry zones in the network that is compounded by high costs (5 times the tariff of the National Water and Sewerage Corporation) charged by the caretakers of the standpipes and vendors. Other sources of water include springs and open well in the neighbourhood (Fig. 5A). Rain water harvesting is also practiced during the rainy season despite lack of reliable data. The other issues include long walking distances to the water sources and lack of a corridor for water pipes and other basic services in unplanned informal settlements. These findings are similar to those obtained in previous studies for other surrounding peri-urban areas in Kawempe Division in Kampala (Kiyimba, 2006; UN-Habitat, 2006) and are comparable to other similar settings in developing countries (Coates et al., 2004). Unfortunately, the shallow ground water sources have been found to be contaminated with nutrients (N, P), thermotolerant coliforms (TTCs) and faecal streptococci (FS) originating from multiple sources of contamination (Howard et al., 2003; Nsubuga et al.;, 2004; Kulabako et al., 2007). The low per capita water consumption also implies that use of water borne sanitation systems such as simplified sewerage may not be feasible sanitation options for urban slums even though a piped water infrastructure may be available.

4.3. Solid waste management

Lack of proper solid waste management is another major problem to the environment and to the public health in slums. In developing countries, less than 50% of the solid waste generated (80% of which is organic) in urban areas is collected centrally by the municipalities or private sector, with limited recycling or recovery of recyclable materials (Kaseva and Gupta, 1996; Chanakya et al., 2009). This low collection efficiency is also reflected in the case of Bwaise III. Despite the focus on sanitation improvement by some NGOs and CBOs, the low collection efficiency of waste in urban areas including slums implies that a substantial amount of solid waste remains uncollected. This most likely results in environmental pollution and negative public health effects. Poor management of organic solid waste can lead to methane emissions from solid waste dumps as well as leaching of nutrients and organic matter into the natural environment (Chanakya et al., 2009; Holm-Nielsen et al., 2009). Therefore, the main issues to address are collection of the increasing volume of solid waste generated, the heterogeneity of the solid waste characteristics and the treatment and disposal/reuse methods. For future research, a similar technology selection method can be applied to solid waste management using a participatory approach for technology options such as composting, anaerobic digestion and for recycling of plastics and metal scrap.

4.4. Ranking of the technologies using sustainability criteria

Ranking of the technologies by both the beneficiary community and the professional experts determined the preferred sustainable sanitation options. Nine technologies (Table 1B) were ranked by the FGDs instead of the five technologies that passed the technical criteria (Table 3C). This was done to find out if the technically omitted technologies would be ranked low by the FGDs after they were presented with the merits and demerits of each technology using IEC materials (Fig. 3). Water borne systems (simplified sewerage, and septic tank system) and unimproved facilities (pit latrine) were ranked low in comparison to preferences such as a UDDT (Table 1B). The FGDs ranked the UDDT first followed by a lined VIP latrine. The latter was also favoured probably because it is one of the common improved sanitation systems in place compared to flush toilets connected to septic tanks used by only a small percentage of the population (Fig. 4B). In addition, a traditional pit latrine which is one of the common types of excreta disposal facilities in Bwaise III ranked second to the last. This implies that the communities are aware of the environmental pollution caused by existing unimproved excreta disposal facilities but have no option due to lack of funds and complexity of the slum settings. Consequently, involvement of stakeholders enabled a better selection of the sanitation options suitable for the local situation. It is also important to note that under the four categories of social scientists, engineers, public health specialists and institutional experts, social aspects ranked highest with an average score of 4.5 compared to institutional aspects with an average score of 2.5 (Table 3A). This outlines the importance of non-technical considerations in choosing a sanitation system. A weighing was applied in order to integrate the results of the FGDs and the experts to reflect the opinions of the stakeholders in the final ranking of the technologies after multi-criteria analysis.

The UDDT system ranked highest because of its attributes that include: construction and repair with locally available materials and small land requirements, no constant water requirement for use, prolonged service life since it can be emptied for reuse, suitablility for flood prone areas due to non mixing of waste streams and odour control that is achieved through proper usage. However, there are challenges in using this type of facility in slums such as acceptability by the users, market for the end products, source of ash for odour and smell reduction as well as pH elevation for pathogen inactivation, the high filling rate leading to high emptying frequencies for urine and faeces in slums. The compost pit latrine ranked low due to the requirement of secondary treatment of the leachate, design considerations including operation and maintenance as well as start up requirements. The results show that different specialists have different perceptions on what weighs most for a sanitation system to be sustainable. The different perceptions of experts influenced the results on the one hand (especially the economical and health and environment criteria), but increased the external validity of the sustainability concept on the other hand. A biogas latrine ranked second because it also requires less land and has benefits of biogas while a VIP latrine was ranked third because it is also one of the systems that can be constructed with locally available materials and does not use water.

The technology selection method that has been used in this study is useful in obtaining sustainable sanitation options for a particular urban slum based on the local conditions. It also takes into account social aspects that are usually left out during service provision in slums. All the steps in this method are needed in order to choose sustainable sanitation solutions for urban slums in any geographical location. The method does not predict the relative effects of the changes in sustainability aspects for long term planning, but allows making a choice by combining technological and social sustainability.

5. Conclusions

The existing sanitation systems in Bwaise III are unsustainable and are largely unimproved, which lead to ground water pollution and unhygienic conditions. In addition, most residents do not benefit from solid waste services provided by the local government or private sector due to limited access in the slum and low levels of affordability. Currently there are very few house water connections and an average water consumption of 18 L/cap day which makes water-based systems such as simplified sewerage unattractive. Results from a multi-criteria analysis show that stakeholders' influence on sanitation options is the key for sustainability, though ranking of appropriate sanitation options was also influenced by the users' and experts' perceptions of the technologies. The method of selecting technically appropriate sanitation options and thereafter letting the beneficiaries choose from the options through focus group discussions ensures a participatory approach. The identified sustainable sanitation options for Bwaise III are Urine Diversion Dry Toilet (UDDT) and biogas latrines.

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