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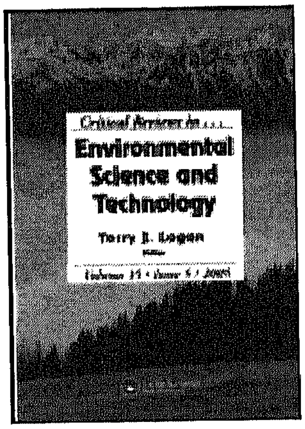

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A Critical Review of Technologies for Pit Latrine Emptying in Developing Countries

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A Critical Review of Technologies for Pit Latrine Emptying in Developing Countries

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Pit latrines are the most common forms of sanitation in urban slums and unplanned settlements in developing countries. Often, little consideration is given to how to deal with the pits once they fill up. The authors summarize pit emptying technologies that have been designed to date to overcome the problem of fecal sludge management in such settings and presents a framework to assist decision makers in identifying potential pit emptying methods based on local technical conditions.

KEY WORDS: sanitation, onsite sanitation, pit latrine, sludge management

I. INTRODUCTION

Most of the world's population does not rely on a piped sewer system. Instead, on-site facilities such as pit latrines are typical methods of providing sanitation in developing countries. In general, there are considerable practical problems as to how to deal with the pits once they fill up, particularly in highly populated areas where space is limited for facilities to be moved or for pit emptying equipment to access the plot. A number of technologies have been tried in developing countries to address this problem, with varying degrees of success.

We begin by explaining the importance of pit emptying in general, followed by a critical review of pit emptying practices and technologies that

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have been developed. The factors affecting pit emptying are discussed and a framework to aid the process of identifying potential technical solutions is described. The article concludes by summarizing the main challenges and limitations of present pit emptying methods.

II. THE NEED TO EMPTY PITS

When a pit latrine is full, there are two options: (a) stop using it and construct a new latrine or (b) empty it (Pickford and Shaw, 1997). Often, the lack of available space or the costs of constructing a new latrine superstructure and pit means that pit emptying may be the only practical alternative (Muller and Rijnsburger, 1994). However, this can also be difficult. One of the earliest documentations of the problems associated with pit emptying in developing countries was by Hawkins (1982), who recognized that the removal of sludge was rarely considered in latrine-building programs. This compounds the problems faced during pit emptying because pits are not designed to facilitate emptying.

Neglecting pit emptying requirements can have serious health and environmental consequences. For example, Parkinson (2008) argued for the need to improve pit and septic tank emptying services in Freetown, Sierra Leone, as part of the Freetown Water and Sanitation Strategy Development, where substandard services have restricted the use of sanitation systems and subsequently contributed to diarrheal disease, cholera outbreaks, and high infant mortality, especially in slums and poor, unplanned areas. Full and overflowing pits pose a risk of contaminating water sources such as wells and have a potential to enter water supply lines. There has yet to be an ideal solution to pit emptying in such areas around the world, where access is the main constraint, although potential small-scale technologies have been piloted. Conventional vacuum tankers are over two tonnes in size (Hawkins, 1982) and cannot enter the narrow streets of unplanned settlements. Even if road access is not a problem, the latrine may be located at the back of the household. The challenge of pit emptying is further complicated by the fact that the contents in a pit and what happens to them are generally not well understood (van Vuuren, 2008). In addition to fecal sludges of different densities, researchers have also reported solid particles, wood, stones, and plastics in pits (Mara, 2009).

III. METHODS OF PIT EMPTYING

Pits can be emptied either manually or by using a machine. Traditional practices usually employ buckets, manual digging, or large vacuum tankers. A number of mechanized pit emptying technologies exist, although none have been proven on a large scale for use in slums. These range from conventional vacuum tankers to small hand-operated pumps that have been used or piloted in urban areas in developing countries.

A. Manual Pit Emptying

Manual emptying is common in many areas worldwide (Water and Environmental Health at London and Loughborough, 1998). In sub-Saharan Africa, manual emptying is widely used in poor urban areas because conventional truck-mounted tankers cannot access the households and the charges are too expensive for users (Water Utility Partnership, 2003). Manual emptying generally involves destroying the squatting slab and digging the sludge out with hand tools such as spades, shovels, and buckets by a team of workers, sometimes borrowed or rented from the customer. Figure 1 shows the equipment used by manual pit emptiers in Faridpur, Bangladesh. If the sludge is liquid, buckets and rope may be used to scoop the sludge out (Eales, 2005). The sludge is then buried in a pit; dumped indiscriminately if it is dry; dumped in drains, streams, or manholes if it is wet; or transferred using a handcart to a small tanker (Bongi and Morel, 2005; Klingel et al., 2002; Muller and Rijnsburger, 1994; Water and Environmental Health at London and Loughborough, 1998). This usually depends on which is the most convenient. Another routine involves flushing the sludge into a deeper pit next to it by breaking the pit lining (Muller and Rijnsburger, 1994; Still, 2002). Emptying of septic tanks is carried out in a similar manner, but does not involve breaking the slab.

Emptying by hand poses serious health risks to the emptiers, especially if no protective clothing is worn. The extent of protection used varies. In

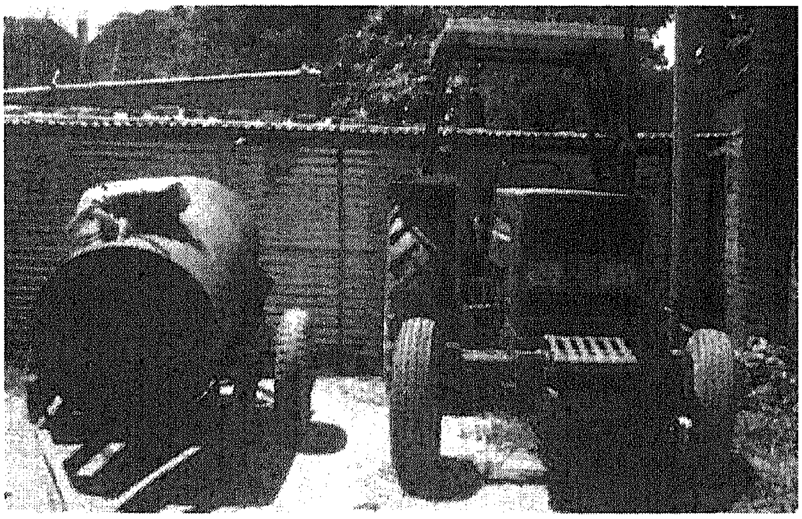


FIGURE 1. Equipment used by manual emptiers in Faridpur, Bangladesh, to store and transport sludge (photo: Practical Action) (Color figure available online).

Kibera, Kenya, emptiers often do not wear any protective gear, while laborers in Durban, South Africa, wear heavy gloves and gumboots (Eales, 2005). Fresh excreta and sludge are inevitably spilled during the emptying process (Water and Environmental Health at London and Loughborough, 1998). Examination of face masks used by manual pit emptiers has revealed the presence of helminth species including *Ascaris, Trichuris*, and *Taenia* spp. (roundworm, whipworm, and tape worm, respectively; van Vuuren, 2008). Health risks increase for pits deeper than 1.5 m, as the emptier has to enter the pit (Bhagwan et al., 2008), where gases such as ammonia and methane may be present. In addition, glass and metal pieces in the sludge can cause cuts (Eales, 2005).

In low-income areas of Dar es Salaam, Tanzania, the emptying process can take between 2 and 7 days, and during this period the latrine and disposal hole is left uncovered. This is not only inconvenient but also dangerous to users (Muller and Rijnsburger, 1994). However, it is common practice because conventional methods are too costly, are prone to failure, cannot access the location, or cannot deal with the dense and solid material (Eales, 2005). To facilitate manual emptying, the pit should ideally be closed and left for up to two years to allow for pathogen inactivation; in practice, this is only possible with alternating pits. Raising the pH, temperature, or reducing the water content may shorten this inactivation period (Harvey, 2007).

Most manual emptiers face extensive social stigma. In Kibera, Kenya, manual emptying is mistakenly thought to be illegal. Emptiers usually work at night by torchlight, without protection, and are subject to violence and extortion (Bongi and Morel, 2005; Eales, 2005). In Dhaka, Bangladesh, where manual emptying was made illegal in the 1980s, emptiers have to work at night. Parkinson and Quader (2008) also reported that emptiers often work under the influence of alcohol to escape the smell, which results in inadequate cleaning and spillage.

A notable exception is the eThekwini Municipality in South Africa, where emptying using long-shaft shovels and hay rakes is chosen over vacuum tankers and small diaphragm hand pumps (Eales, 2005). Protective clothing in the form of heavy gloves and gumboots is also used. This was seen as the optimal solution given the constraints of steep terrain, high population density, and narrow paths, which made the alternatives impractical. In addition, it was also estimated that 6,400 jobs would be created over five years and that there would be business opportunities for small enterprises (Macleod, 2005). Though unsafe, pit emptying provides income and employment to large numbers of urban poor and making it safe may have wider economic benefits.

B. Vacuum-Based Methods: Basic Concepts

Most mechanical methods center on utilizing atmospheric pressure or high rates of air flow to suck pit contents through a hose into a container under a partial vacuum. There are four main techniques: the direct vacuum system and pneumatic systems, which comprise the constant air drag system, the air bleed nozzle, and the plug drag system (Bösch and Schertenleib, 1985). The constant air drag and plug drag system can remove denser sludge but requires more skill and effort than the direct vacuum system. This is because it requires the operator to maintain the position of the hose just above the sludge in the former case, or constantly dip the hose in and out of the sludge in the latter case.

C. Conventional Vacuum Tankers

A conventional vacuum tanker is often the favored technology, when able to access the plot and the pit, because there is minimal contact with the pit contents and it is more efficient in evacuating sludge than its alternatives (Eales, 2005). The technology is imported from industrialized countries: a hose connects the pit contents to a truck-mounted tank between 1 and 10 m^3 in capacity and a vacuum pump is connected to the tank (Klingel et al., 2002). According to Pickford and Shaw (1997), a vacuum tanker can lift sludge from a depth of up to 2–3 m. This depth depends on the density and viscosity of the sludge as well as the height of the tank above the ground. However, tankers are not suitable for low-income and slum areas, where many of the population in cities of developing countries live.

There has been very little recent research into the effectiveness of the tanker. Boot (2007) suggested that it is because the constraints faced in urban areas cannot be overcome by tankers. Field tests were carried out in Botswana from October 1983 to February 1984 on two existing tankers—CALABRESE and POOLE—and three prototypes—ROLBA, BREVAC, and ALH—to investigate their ability to empty sludge from pits (Bösch and Schertenleib, 1985). The tankers were tested to find the limit of density and viscosity and the maximum distance between the pit and tanker possible to remove sludge from the pits.

CALABRESE and POOLE were only able to empty liquid as it used the direct vacuum system. ROLBA and BREAVAC were able to handle denser sludge using the plug drag method. ROLBA and BREVAC had hose length limits of 58 and 64 m, respectively, although Mara (1996) reported distances up to 100 m. This length is also dependent on the head difference between the pit and the tanker. However, there were drawbacks to using long hoses, including the settlement of mud, which had to be washed out periodically; the time taken to locate blockages, with contamination during the process; limited opportunity for the hose operator and operator at the suction valve to communicate; and setting up and dismantling times in excess of 15 min (Bösch and Schertenleib, 1985).

While the tanker may have few uses in slums and informal settlements with limited access, some features of the prototypes may be useful in informing future design improvements. For example, the use of a washwater unit saved time and effort in carrying water to clean the hoses and pit. ROLBA also offered high-pressure wash water to liquefy pit contents.

A major disadvantage of vacuum pumps is their inability to deal satisfactorily with certain pit contents, for example, heavy sludge or objects such as stones, sticks, and other rubbish (Harvey, 2007). The high capital and operating costs of conventional vacuum tankers also prohibit small enterprises from entering pit emptying market (Eales, 2005). The equipment costs between US $50,000–80,000 per unit (Klingel et al., 2002). Operationally, there is high reliance on imported fuel and spare parts. Boot (2008) found that fuel and tipping made up about three quarters of the cost of one pit emptying trip. Wear and tear is high, as engines run all day (Hawkins, 1982). Muller and Rijnsburger (1994) also reported that the vacuum tanker fleet in Dar es Salaam experienced long delays in repairs and broken down vehicles were often scavenged to find usable parts.

However, Muller and Rijnsburger (1994) also recognized that tankers are more efficient overall. Two reasons can be identified:

- Pits can be emptied within one or two trips (Pickford and Shaw, 1997). In Viet Tri, Vietnam, 1,000 septic tanks are reportedly emptied by two vacuum tankers annually; a more reliable statistic may be that 150 septic tanks are emptied by one vacuum tanker annually (Klingel, 2001).
- Vacuum tankers can carry pit contents directly to treatment without an intermediate transfer location (Boot, 2008).

The ALH emptying system tested during trials in Botswana was unique in that it was a remote system with the pump unit separate to the drum. The drum was taken to a nearby tanker, where its contents were sucked out. It was designed particularly to access areas not accessible by the other four systems by increasing the operating range to over 150 m. Problems were experienced transporting the full drum and setting up, although further tests were recommended (Bösch and Schertenleib, 1985). Such a system requires a failsafe method of stopping the process once the drum has been filled (Franceys et al., 1992). There are very few reports of remote systems being used in practice.

D. Minivacuum Tankers

Smaller versions of conventional vacuum tankers have been developed to improve accessibility to high-density settlements. Among the most publicized are the UN-HABITAT Vacutug and MAPET.

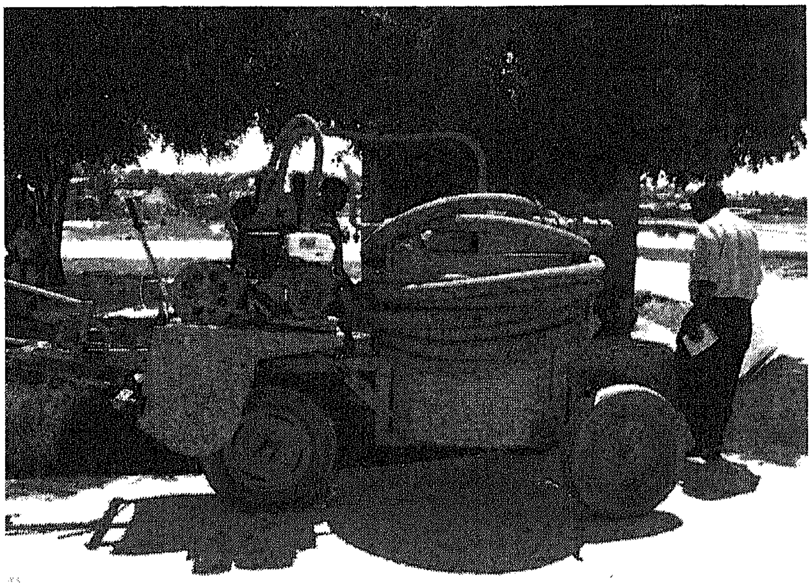


FIGURE 2. The UN-HABITAT Vacutug (photo: Steven Sugden) (Color figure available online).

UN-HABITAT VACUTUG

The Vacutug (Figure 2) was initially designed and built in 1995. In the first phase, the prototype MK I was trialed in Kibera, Kenya. Trials for an improved model, MK II, started in 2003 in Kenya, Bangladesh, Senegal, Tanzania, India, Mozambique, South Africa, and Ghana. The Vacutug was conceived to

- Provide accessibility in dense areas,
- Have cheap capital costs,
- Be able to cover running costs with its revenue,
- Be able to take the pit contents to an adequate disposal site, and
- Be able to empty dense sludge (United Nations Human Settlements Programme, n.d.).

The design is based on the following assumptions:

- An individual produces 40–50 L of sludge annually.
- The pits serviced are dry pits in good ground conditions, without groundwater ingress.
- The minivacuum tanker serves a family of 10 people (United Nations Human Settlements Programme, n.d.).

The Vacutug (MK II) has three main components:

- A 6 kW petrol engine that gives it a maximum road speed of 5 km/h,
- A vacuum pump with a free air capacity of 2,200 L of airflow per minute, and
- A hose made of PVC and 75 mm in diameter (United Nations Human Settlements Programme, n.d.).

The Vacutug is usually used with a 500 L tank made from mild steel and mounted on a steel frame. Operating the Vacutug requires two people. In Dhaka, the entire Vacutug staff comprises five people: one supervisor, one head operator, two assistant operators, and a driver (Parkinson and Quader, 2008).

The Vacutug was relatively successful in Nairobi, Kenya, and Dar es Salaam, Tanzania, but still faced difficulties in Dhaka, Bangladesh, and Durban, South Africa, due to narrow lanes, dense population, and steep topography. There was insufficient power for the long hoses to reach inaccessible locations (Macleod, 2005; Parkinson and Quader, 2008). This was due to the very different layout of the settlements between Dhaka and Kibera. Other disadvantages listed include the limited storage capacity and slow speeds (Parkinson and Quader, 2008).

As a result of the experience in Dhaka, a modified model was locally developed and manufactured by the Mirpur Agricultural Workshop and Training School (MAWTS). A much larger 1,900 L tank, which takes 10–20 min to fill, is used, in conjunction with a 200 L satellite tank. The tank is mounted on a trailer instead of being self-propelled and transfers its waste into the much larger 1,900 L transfer tank. The aim was to improve mobility while allowing collection and transportation to occur simultaneously.

The outcomes of the trials appear to have been mixed. In Maputo, Mozambique, operation ceased because the operators were not able to break even financially (Building Partnerships for Development, 2008b). Issaias (2006) recommended that operators should aim to take at least eight loads daily in order to cover costs, although calculations by Médecins Sans Frontières estimated that if at least five loads were taken daily in Maputo, the Vacutug could earn up to US $12,000 in a year (Alabaster, 2008). According to Parkinson and Quader (2008), in Dhaka, significant efforts are required to cover running costs, and the operation is unlikely to recover capital costs. This indicates that profitability is highly dependent on local conditions, possibly due to the revenue earned per tank load and haulage distances. Macleod (2005) stated that the operation becomes impractical and uneconomical if the pit contents must be disposed more than 1 km away. The use of transfer stations may be useful in such cases.

Nevertheless, Alabaster (2008) argued that the Vacutug is sustainable in dense slums. The technology offers smaller enterprises opportunities to enter the market (Macleod, 2005) and has the potential to generate income and recover costs (Alabaster and Issaias, 2003).

The pilot project in Dhaka shows that the Vacutug offers advantages over traditional manual emptying services. It is certainly more hygienic. The service is faster and more efficient. There is less smell. This method does not break the slab or rings, unlike emptying by hand (Parkinson and Quader, 2008).

There is consensus that there is scope for the design to be improved, however. No vacuum tanker system using direct suction, including the Vacutug, can empty pits more than 2 m deep, more than 30 m from the street or in very narrow paths. Maneuverability of the MAWTS system could also be improved: the Dhaka operators found the 200 L satellite tank difficult to push over long distances, as it was mounted on a rickshaw wheel (Parkinson and Quader, 2008), but there is a conflict between the need for maneuverability and larger tank capacity. The present cost of a Vacutug in Bangladesh is reported at US $4,000 (Uttam, 2009).

MICRAVAC TANKER

The Micravac has a 2 m^3 tank and a high-capacity vacuum pump at 9,000L per minute (MCA Vehicles, n.d.). The Micravac was the precursor to the Vacutug, designed in the early 1980s to work on unsurfaced roads of 1.8 m width in Kibera, Kenya. The UNEP/UNDP/Dutch Joint Project on Environmental Law and Institutions in Africa (United Nations Environment Programme, 2001) reported two Micravac tankers having been used in the City of Blantyre, Malawi, together with two Leyland vacuum tankers. The Micravacs experienced excess demand, compared to the Leyland tankers, due to its maneuverability in unplanned settlements. The Micravac was also trialed in Zimbabwe, which found it to be effective and simple to use (Jere et al., 1995).

E. Manual Pumps

Small-scale equipment have been developed based on vacuum pump technology, but operated manually rather than mechanically. Compared to manual pit emptying, this class of technologies uses more sophisticated tools that may improve the efficiency and safety of the emptying process. The earliest reference found was the testing of the BUMI hand pump during Botswana field tests (Bösch and Schertenleib, 1984), where the results were less than ideal. Difficulties encountered were hose blockage, manpower requirements, and the inability to empty dense sludge or sludge containing sandy material and rubbish.

MANUAL PIT EMPTYING TECHNOLOGY

The Manual Pit Emptying Technology (MAPET) system was developed in Dar es Salaam, Tanzania, in the 1980s by WASTE Consultants together with the Dar es Salaam Sewerage and Sanitation Department (DSSD; Muller and Rijnsburger, 1994). The two core elements of the MAPET are the piston pump with the flywheel and the 200 L vacuum tank (Figure 3). Each is mounted on a pushcart.

The pump has a 6 inch PVC cylinder made from sewage piping encasing a leather piston. The sewage piping was available at the DSSD, but the piston leather had to be imported from the Netherlands. It was chosen over the diaphragm pump because it was more durable given the local conditions. The use of a manual pump reduces the dependence on imported fossil fuel. As with the technologies previously mentioned, the sludge is pumped indirectly. This prevents blockages and wear and tear. It takes about 5–20 minutes to fill up a 200 L tank, depending on the viscosity of the sludge and the pumping head.

The 25 kg flywheel has an approximate diameter of 800 mm, a rotation speed of 40–60 rotations per minute, and pumps 20 L per stroke. It was designed to make the best use of manpower for a pumping head of 3 m.

The vacuum tank is welded from 3 mm sheet metal. Initial attempts used an oil drum but this was discovered to be susceptible to corrosion and implosion at −0.4 bar (40,000 Pa). It has a gourd shape to optimize transport, steering, and tipping. This produces a lower center of gravity and is easier to manage on the pushcart.

FIGURE 3. Pit latrine emptier especially designed for this project, Dar es Salaam, Tanzania 1992 (photo: WASTE; Muller and Rijnsburger, 1994) (Color figure available online).

A 3/4 inch (19 mm) air hose connects the pump to the tank and a minimum 4 m long, 4 inch (100 mm) Bauer hose pipe connects the tank to the pit. The hose pipe was chosen to match DSSD's tanker hose pipes. The use of hose pipes also means that the squatting slab and superstructure is not damaged during the emptying process, as opposed to manual emptying.

Separate pushcarts were used after various methods of haulage was tested. The decision to use imported Chinese tricycle wheels proved to be a challenge. The tires were irregularly sized and weak and the ball bearings could not take a loaded tank cart, especially on poor roads. However, the alternative was to use expensive, heavy, and wide car wheels, which would have made the width of the MAPET over 800 mm. This was the maximum diameter specified to allow the MAPET to traverse narrow paths and gates. Again, manual pushcarts were chosen to avoid the need for fuel.

The technology is simple and does not require high-end equipment or skill to build and maintain. Minor maintenance usually involves spot-welding loose components and dealing with tire punctures. Major, expensive maintenance is typically carried out on the bearings, guides, piston leather, or valves of the hand pump and the bearings or tires of the wheels.

As with the Vacutug, Still (2002) maintained that the low-cost technology encourages small enterprises to enter the market; there is no evidence, however, that the MAPET has survived past the pilot phase.

Depending on the density and viscosity of the sludge, the MAPET can provide up to 3 m of head (Tilley et al., 2008). On the other hand, a technical drawback of the system is its premise of on-site disposal. This works well in Dar es Salaam, where such practice is socially acceptable and physical conditions—sufficient space and a low groundwater table—generally allow it to be done (Building Partnerships for Development, 2008a). This may not be the case in other contexts. As the MAPET is manually pushed, it would be impractical to have to transport the sludge over 1 km (Muller and Rijnsburger, 1994). Another disadvantage is the imported component of the MAPET. Building Partnerships for Development (2008b) cited this as part of the reason why MAPET is no longer used in Dar es Salaam. When the foreign part broke, it could not be replaced or substituted by local parts. The other reason cited was the lack of institutional backing due to the dissolution of the DSSD.

LONDON SCHOOL OF HYGIENE AND TROPICAL MEDICINE (LSHTM) GULPER/MANUAL DESLUDGING HAND PUMP

The LSHTM sludge gulper (Gulper), or Manual Desludging Hand Pump (MDHP), as referred to by Oxfam, was developed to empty septic tanks (Oxfam, 2008). The Gulper operates by a direct up-and-down action similar to a water pump, with one or two operators raising and lowering the handle.

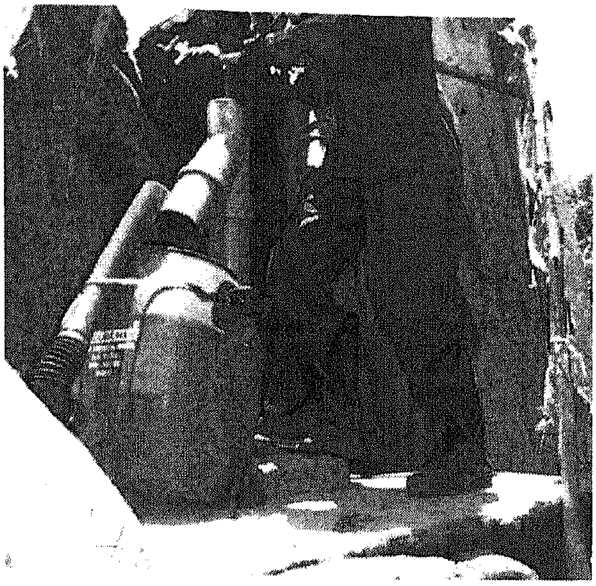


FIGURE 4. Pit emptiers testing the Gulper (Color figure available online).

This lifts the sludge up the body and discharges it through the Y-connection (Figure 4; Ideas at Work, 2009).

The key components of the Gulper are the pipe, handle, hose, footstep, and screen. There are two types available. The short type is 180 cm and the long type is 230 cm. Apart from the Gulper, other equipment required to carry out the pit emptying operation include a bucket (minimum 50 L), fiber bags if possible, a hoe and shovel, and protective equipment (Ideas at Work, 2009).

At GBP £20 (US $40) in Aceh, Indonesia (Boot [2007]), it is significantly cheaper than the other technologies described previously. This appears to be more promising than the Vacutug and MAPET in allowing small, independent enterprises or even individuals to enter the market. As opposed to manual emptying, the Gulper is faster and does not destroy the squatting slab. On the other hand, the Gulper can only pump down to 1 m, resulting in more frequent emptying requirements. As with the MAPET, it is only feasible independently for on-site disposal because the 50 L bucket must be regularly emptied as it fills up.

Feedback from Cambodia (Ideas at Work, 2009) has been positive with suggestions to include short sections that can be removed or added depending on the pit depth and that the clamp and footrests be strengthened and lengthened.

Table 1 summarizes the advantages and limitations of manual emptying and the conventional vacuum tankers, UN-Habitat Vacutug, MAPET, and LSHTM Gulper.

TABLE 1. Advantages and limitations of pit emptying technologies

Manual emptying	Conventional vacuum tanker	Vacutug	MAPET	Gulper
Dig out the sludge using hand tools Advantages: • Can access most locations • Affordable and easy-to-use equipment • Equipment easily available	A vacuum pump mounted on a motorized tanker Advantages: • Safe: less contact with sludge • Fast emptying times	A self-propelled mechanized vacuum pump Advantages: • Safe: less contact with sludge • More mobile than a conventional vacuum tanker • Faster emptying than manual methods	A manual pump and small tank mounted on pushcarts Advantages: • Cheaper than motorized equipment	Manual hand pump Advantages: • Can access most locations • Cheap • Can be made locally
Limitations: • No means of disposing the sludge off site • Destroys squatting slab • Health risks if emptier is not properly protected • Slow emptying times • Possible social stigma	Limitations: • Cannot access narrow roads • Equipment and operation is expensive • High maintenance requirements • Difficult to empty dense sludge and solid material	Limitations: • Cannot access very dense areas • Expensive, but cheaper than a conventional vacuum tanker • Slow speed • Limited storage capacity	Limitations: • Difficult to transport sludge over long distances • Specialized repair required (welding)	Limitations: • No means of disposing the sludge off site • Cannot empty entire pit (if pit is deep) • Slow emptying times

F. Sludge-Degrading Additives

The concept of using additives to degrade the amount of sludge or reduce the rate of sludge accumulation has been discussed, but very little published information was found. Jere et al. (1998) found that the use of spore forming nonpathogenic bacteria could effectively reduce sludge volumes. This would lead to less frequent emptying and may change the requirements of pit emptying technologies. However, trials have had variable success and further studies are required to determine its viability (Harvey, 2007).

IV. HAULAGE AND DISPOSAL

Once the sludge is collected, it has to be disposed somewhere. Therefore, haulage, transfer, storage, and disposal of the fecal sludge must be considered together with the emptying phase. The lack of provision of adequate facilities may result in indiscriminate or illegal disposal of sludge to rivers, open drains, the sea or any open space (Water Utility Partnership, 2003), particularly if the emptying technology used does not possess appropriate haulage capacity for long distances, local capacity is weak, and effective legislation is not in place. For example, manual emptiers in Kibera, Kenya, typically dump the sludge in nearby streams, which contaminates the river (Bongi and Morel, 2005).

A. On-Site Disposal

Disposal of sludge close to the latrine is considered the most economic method (Still, 2002). In Dar es Salaam, this involves digging a latrine, filling it up with sludge, letting the liquid leach out of the sludge for one or two days, and then covering it with at least 30 cm of dry, excavated soil (Muller and Rijnsburger, 1994). On-site disposal is common in low- to medium-density areas (Water Utility Partnership, 2003), but is increasingly limited by the space available and the depth of the groundwater table (Muller and Rijnsburger, 1994). Care must be taken to ensure that the sludge is not dug up before it has decomposed. If the sludge has decomposed, that is, when the pathogens have died off, the sludge becomes safer to handle.

B. Direct Haulage to Treatment Facility or Sewerage Network

If not disposed on site, sludge can be discharged at sewage treatment plants, composted, or buried in landfill sites (Still, 2002). Instead of being treated or disposed, sludge can also be used for agriculture, aquaculture, or biogas production due to its high nutrient value. There are health risks associated with applying sludge on crops and in fish ponds or tanks, which must be considered.

C. Transfer Stations

Transfer stations reduce the distance pit emptiers have to go to dispose of the sludge, allowing them with more time to generate income emptying pits. There are two types of transfer stations: fixed and mobile transfer stations. A mobile transfer station could take the form of a tractor pulling a tank and has the following advantages over a fixed station: a smaller tank volume required (2 m^3), increased mobility, and it is not subject to planning restrictions (Muller and Rijnsburger, 1994).

V. FACTORS AFFECTING THE SELECTION OF AN APPROPRIATE PIT EMPTYING METHOD

The technologies and methods described previously represent the range of practices presently used to empty pits. These vary in terms of cost, efficiency, and operation and maintenance requirements and are appropriate to different situations. For example, manual emptying is extremely slow but much cheaper than vacuum tankers, which also require significant maintenance. The difficulty arises, then, in selecting the method that is most suitable to the local conditions and can be sustained by available resources.

There are many factors to consider in the decision-making process. The critical technical factors are described here; however, it must not undermine the importance of other social and economic factors. These technical factors can be classified into five broad categories: pit latrine characteristics, sludge characteristics, characteristics of pit emptying method, characteristics of disposal site, and geography.

A. Pit Latrine Characteristics

The particular design of the pit latrine has an impact on the selection of the optimal emptying process. Some latrines, such as Ecosan toilets, may eliminate the need to empty pits. However, Ecosan toilets are not always suitable to the local situation if there is no demand for fertilizers (e.g., in urban settings). As noted by Hawkins (1982), the removal of sludge was rarely considered in latrine-building programs. Therefore, to facilitate pit emptying, it may be just as beneficial to modify the latrine design as the emptying method. Once constructed and in use, it is difficult to make modifications to the latrine.

The pit latrine design influences factors such as the pit contents and the rate at which the pit fills. Take for example alternating pits. If used

TABLE 2. Estimate of the rate of solids accumulation (liters per person per year) recommended by Franceys et al. (1992)

	Method of anal cleaning	
Pit	Water	Solid material
Wet	40	60
Dry	60	90

appropriately, the sludge is left to decompose for about 2–3 years before it is removed. After two years, the sludge is odorless and pathogen-free (Pickford, 1995). This is the only case where Hawkins (1982) considers manual emptying to be a suitable option. Indeed, it may be the only option because the sludge solidifies and cannot be removed by vacuum pumps (Tilley et al., 2008).

Hawkins (1982) defined two main categories of latrines. The first are pits where liquids are allowed to seep out; the second are vaults where liquids and solids are retained. The sludge is likely to be thicker and more compact in the first case. As presently available technologies have limited success with thick sludge, the pit emptying method must be chosen carefully. A smaller pit will fill up more quickly. This, and the rate at which solids accumulate, will determine the life of the pit (Pickford, 1995) and the frequency at which pits have to be emptied. The rate of solids accumulation varies widely within an area and between areas (Still, 2002). The factors affecting this rate, as described by Pickford (2005) are the number of users, the amount of excreta produced by each person (Table 2), characteristics of the surrounding soil, depth of the groundwater table, existence of pit lining, and, material used for anal cleaning. Still (2002) identified the important factors as the number of users, the degree of drainage of the pit contents, and the amount of other household waste, such as rags, cloths, plastic, and glass, being disposed in the pit. There is evidence that the rate of sludge accumulation decreases over time because of the increase in the rate of decomposition (Still, 2002). Pickford (2005) also identified consolidation as a factor. The combination of these factors result in the number of years it takes a pit to fill, which varies between 3 and 20 years (Still, 2002).

B. Sludge Characteristics

The amount of urine and feces an individual excretes varies widely, even locally, depending on water consumption, climate, diet, and occupation. According to Franceys et al. (1992), the amount of urine produced depends significantly on temperature and humidity. This means that pit emptying technologies may have to deal with a wide variation of sludge composition.

Within the depth of the pit, differences in the nature of pit contents have also been reported (van Vuuren, 2008). According to Hawkins (1982), the pit may have up to three layers depending on the circumstances: floating scum, liquid, and sludge and sediment. A well-drained pit does not have a scum or liquid layer. The formation of a scum layer appears to be due to a large number of users per cross-sectional area of the pit. Observations suggest that a significant sludge layer starts to form after six months (Hawkins, 1982).

The material found in the pit other than urine and excreta can vary widely depending on the local practices for anal cleaning and rubbish disposal. The material used for anal cleaning can either be water or solid material such as paper, leaves, and corncobs (Pickford, 2005). Moisture content will also increase if sullage is discharged into the pit. The organic content of sullage can be quite high (Hawkins, 1982). These factors may have implications on the fluidity of the sludge and risk of blockages.

The higher the density of sludge, the greater the static head required of a vacuum-based pit-emptying technology. Sludge density may range between 0.97 and 1.75 kg/dm^3. Studies have also indicated that the properties of sludge are independent of the presence of free water in the pit (Hawkins, 1982).

Apart from density, sludge flow properties are another consideration for vacuum-based technologies. This is because the vacuum system depends on the material pumped behaving as a fluid (Hawkins, 1982). Where the sludge is partly compacted and dry, water may be added and the sludge agitated to improve its viscosity (Hawkins, 1982; Still, 2002). According to Hawkins (1982), the hardest part of emptying is getting the sludge to move, after which it remains fluid, generally due to yield stress, shear thinning, and thixotropy. A decrease in organic content also leads to a reduction of sludge fluidity. This implies that the fluidity of sludge decreases with time. Therefore the age of the pit contents may give an indication of the sludge properties.

C. Characteristics of Pit Emptying Method

The emptying technology must be able to access the roads leading to the pit location as well as the inside of the pit. In particular, the width of the pit emptying equipment determine its ability to access the latrine. Vacuum tankers have the option of using longer hoses, but the maximum horizontal distance it can park from the pit latrine is approximately 50 m, unless the pit is located above the tanker and the process is helped by gravity (Still, 2002).

For vacuum-based emptying, the amount of pumping head that the technology provides determines the depth of sludge that can be removed. According to Coffey (2008), the low height of the Vacutug's tank (1.5 m above ground level) compared to a conventional vacuum tanker (up to 3 m) means that the Vacutug can theoretically pump sludge with a specific gravity of 2.0 from a depth of 3.5 m below ground level, whereas a vacuum tanker has a theoretical capacity of 2.0 m depth. However, these theoretical figures do not take into account viscosity and friction, and therefore the actual figures are much less.

Any technology must be able to operate consistently throughout its design life. Some critical factors include a technology that is understandable and physically useable, affordability in operation and maintenance (OandM), and a desirable and socially acceptable type and level of service (Water and Environmental Health at London and Loughborough, 1998).

Strauss and Montangero (2002) pointed out that while external agencies often partially or fully fund the initial capital costs, they do not fund the OandM cost. OandM is a crucial factor in ensuring the sustainability of a technology. The engine of a vacuum tanker, for example, is required to run throughout the day, leading to quick deterioration and vulnerability to breakdown from inadequate preventive maintenance (Hawkins, 1982). Breakdowns of vacuum tankers led to only one out of the original six vacuum tankers remaining in use in Accra in 2007 (Boot, 2008).

For the technology to be sustainable, spare parts must be obtained without difficulty, and, if possible, locally (Water and Environmental Health at London and Loughborough, 1998). The use of local equipment and material increases the probability that spare parts and appropriate maintenance skills are available (Pickford, 2005). It is common for the lack of spare parts to put an emptying service out of operation, as was the case with the MAPET in Dar es Salaam (Muller and Rijnsburger, 1994) and desludging vehicles in Freetown, Sierra Leone (Parkinson, 2008).

To an individual living in a slum or informal settlement, even the cost of buying a shovel, drum, and cart (US $130) can be prohibitive (Eales, 2005). Besides capital cost, there are recurring operating costs (Eales, 2005; Water and Environmental Health at London and Loughborough, 1998), such as fuel, permits for emptying, haulage cost, fee for disposal, use of cleaning facilities, replacement of spare parts, maintenance, and salaries.

D. Characteristics of Disposal Site

The distance to the disposal site and traffic conditions is a key factor, especially for pit emptying technologies with low sludge storage capacities, slow road speeds, and inconvenient modes of transport. Providing adequate access to disposal sites should be a priority (Water Utility Partnership, 2003). Eales (2005) described how in Kibera, Kenya, the amount of sludge emptied each night is determined by the time it takes to carry the 100 L drum on a handcart through the steep bumpy roads to the most convenient disposal point. This results in the pit emptiers preferring to work near a road or river.

Time spent transporting sludge to a disposal site is time that could have been spent by an expensive vacuum pump emptying more pit latrines. This implies an inefficient use of vacuum pumps. A previous study indicated that in Dar es Salaam where there was no transfer system, vacuum tankers spent 60% of the time travelling (Hawkins, 1982). This may result in a large increase in costs (Franceys et al., 1992). Still (2002) stated that the MAPET and Vacutug are impractical if the disposal site is more than 1 km away. Klingel et al. (2002) promoted the use of several decentralized disposal sites instead of one central disposal site to overcome the problem.

Case studies have shown that inaccessibility to the disposal site will encourage illegal or indiscriminate dumping of sludge (WUP, 2003; Klingel et al., 2002). The difficulty lies in finding suitable sites, because they can often only be found on the outskirts of the city (Strauss and Montangero, 2002).

E. Geography

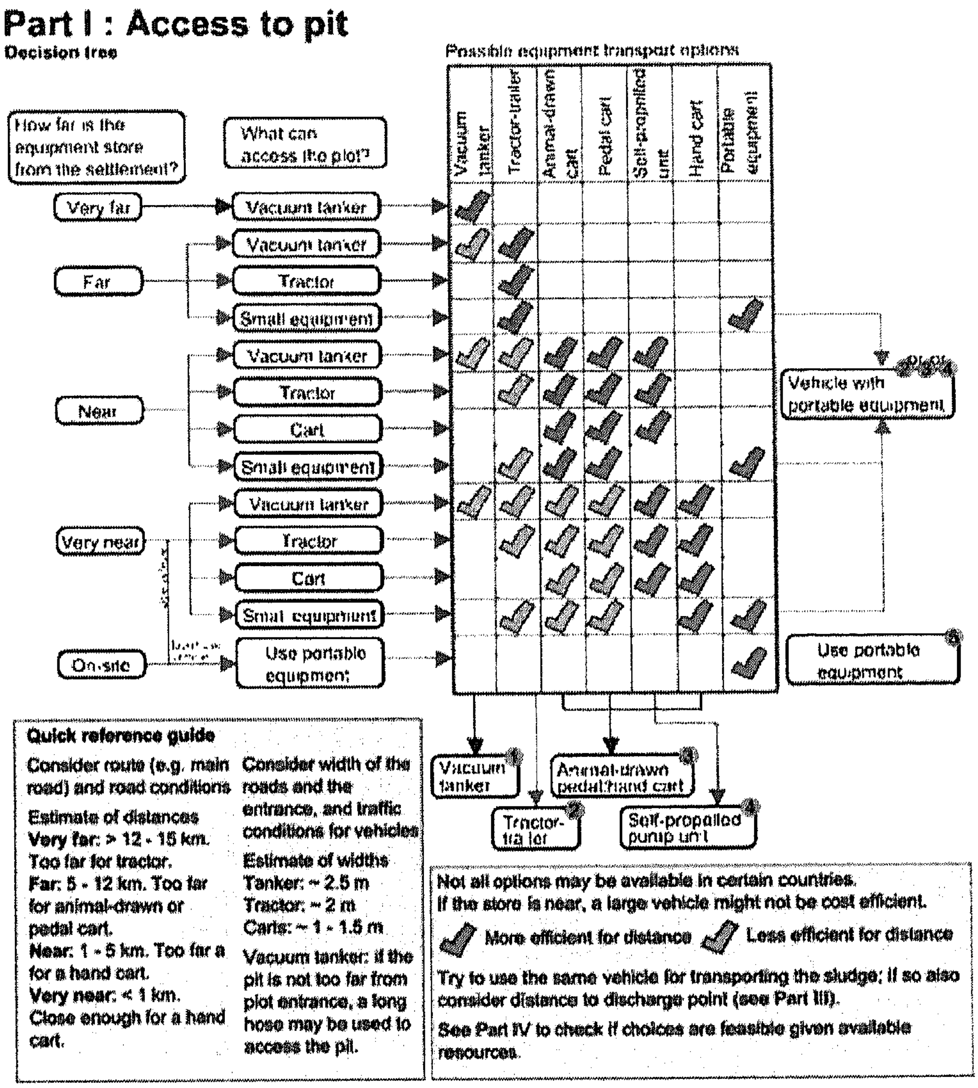
Geography can have significant effect on the viability on technological and organizational solutions (Klingel et al., 2002). The ability of the pit emptying equipment to access the site and the pit remains a key constraint in slums and informal settlements. Factors affecting accessibility include topography, width of roads, and location of the pit relative to the road.

VI. A DECISION-MAKING FRAMEWORK FOR SELECTING PIT EMPTYING METHODS

Based on the previous critical review of existing pit emptying technologies and the relevant factors affecting each one, a decision-making tool was developed to assist practitioners in comparing the possible options for pit emptying in a community based on local technical factors. It is noted that important economic and social factors must also be considered when determining the appropriate method for implementation.

Palaniappan et al. (2008) described the design of an ideal decision-making tool. For pit emptying, the following criteria were considered: (a) an ideal decision-making tool would allow the user to evaluate different pit emptying methods based on a range of criteria; (b) the tool should also consider the pros and cons of each method, the resources required to implement and operate the technology, especially with respect to maintenance needs, institutional factors affecting its operation, and the associated costs and financial viability; (c) there should be a suitable user interface that is able to extract relevant information from the user and then suggest appropriate methods that meet the user's requirements; and (d) it should allow the user to make an informed decision without having to refer to many other sources.

The framework takes the form of a decision tree. For simplicity, the decision tree assumes that the locations where the equipment is stored and sludge is discharged, either to disposal or treatment, have already been determined. The decision tree is expanded into three parts that reflect the



Quick reference guide

Consider route (e.g. main road) and road conditions

Estimate of distances
Very far: > 12 - 15 km. Too far for tractor.
Far: 5 - 12 km. Too far for animal-drawn or pedal cart.
Near: 1 - 5 km. Too far a for a hand cart.
Very near: < 1 km. Close enough for a hand cart.

Consider width of the roads and the entrance, and traffic conditions for vehicles

Estimate of widths
Tanker: ~ 2.5 m
Tractor: ~ 2 m
Carts: ~ 1 - 1.5 m

Vacuum tanker: if the pit is not too far from plot entrance, a long hose may be used to access the pit.

Not all options may be available in certain countries.
If the store is near, a large vehicle might not be cost efficient.

✓ More efficient for distance ✓ Less efficient for distance

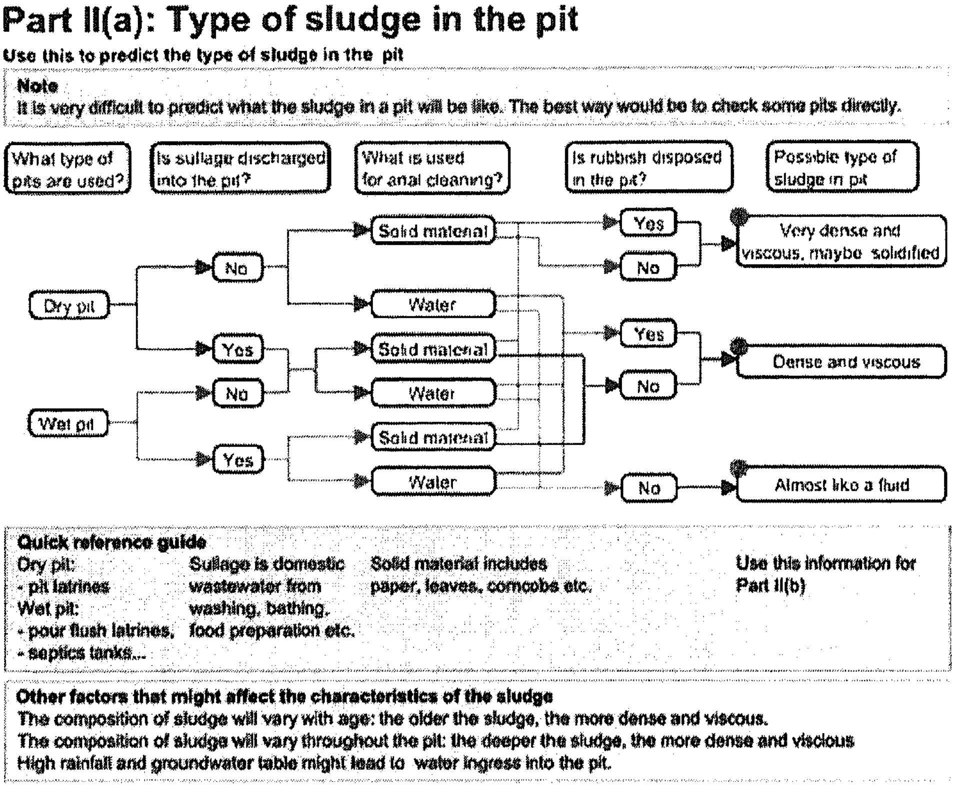
Try to use the same vehicle for transporting the sludge; if so also consider distance to discharge point (see Part III).

See Part IV to check if choices are feasible given available resources.

FIGURE 5. Pit emptying decision tree part I (Color figure available online).

sequence of operating a pit emptying service from leaving the equipment storage facility (or another pit) to transporting the collected sludge to a discharge point:

- Part I: Access to the pit (Figure 5)
- Part II: Emptying the pit (broken down into two sections)
  - Part II(a): Type of sludge in the pit (Figure 6)
  - Part II(b): Devices to empty the pit (Figure 7)
  - Part III: Methods to transport the sludge to the discharge site (Figure 8).



Part II(a): Type of sludge in the pit

Use this to predict the type of sludge in the pit

Note
It is very difficult to predict what the sludge in a pit will be like. The best way would be to check some pits directly.

Quick reference guide
Dry pit:
- pit latrines
Wet pit:
- pour flush latrines,
- septics tanks...

Sullage is domestic wastewater from washing, bathing, food preparation etc.

Solid material includes paper, leaves, corncobs etc.

Use this information for Part II(b)

Other factors that might affect the characteristics of the sludge
The composition of sludge will vary with age: the older the sludge, the more dense and viscous.
The composition of sludge will vary throughout the pit: the deeper the sludge, the more dense and viscious
High rainfall and groundwater table might lead to water ingress into the pit.

FIGURE 6. Pit emptying decision tree part II(a) (Color figure available online).

Parts I, II(b), and III use key criteria to determine technically feasible options for emptying and transport (Table 3 shows the options considered at each part of the decision tree). In particular, a distinction is made between access to the settlement and within the settlement to reflect varying conditions. This distinction can be especially important for slum settlements where roads are much narrower within the settlement than on main roads. The decision tree only eliminates unfeasible solutions for the given technical

TABLE 3. Options considered at each stage of the decision tree

Part I: Access to pit	Part II: Emptying of pit	Part III: Transport of sludge*
	Vacuum tanker	
Tractor-trailer	Mechanized vacuum pump	Tractor-trailer and tank
Animal-driven cart or pedal cart	Manual vacuum pump	Animal-driven cart or pedal cart with tank
Self-propelled pump unit	Manual direct pump	Pushcart and tank
Pushcart	Manual emptying	On-site disposal
Carried		

Note. A recommendation of providing an intermediate transfer station is also included.

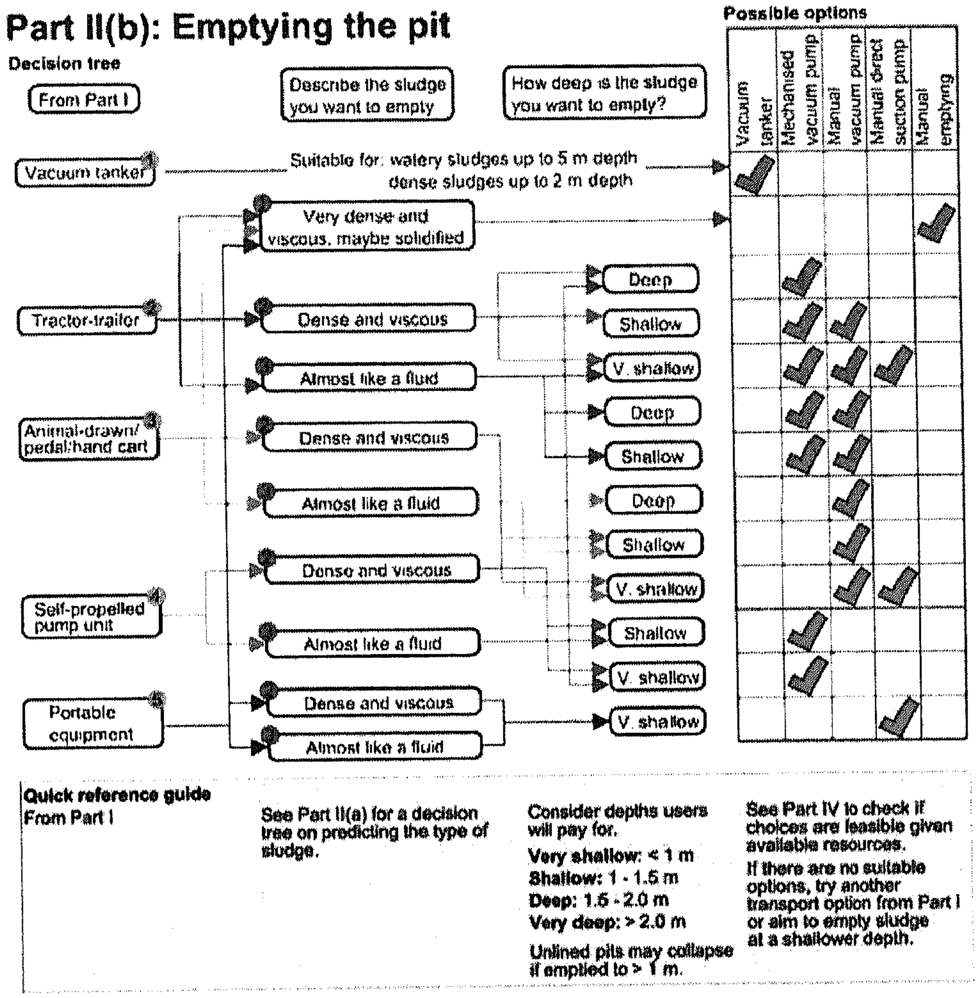


FIGURE 7. Pit emptying decision tree part II(b) (Color figure available online).

conditions so that an appropriate choice may be made based on other social, economic, and political factors. Part II(a) is a supplementary decision tree for the user to predict the likely characteristics of the sludge within the pits to be emptied. It is not included within the main decision-making process and does not have to be used if the characteristics of the sludge can be determined more accurately such as by direct observation.

Qualitative instead of quantitative parameters are used for two reasons. First, parameters are likely to be specific to the local conditions. For example, the assessment of distances as being very far, far, near, or very near would depend to an extent on topography and road conditions. Second, it reflects the lack of quantitative data and understanding of the performance of pit emptying methods under different conditions.

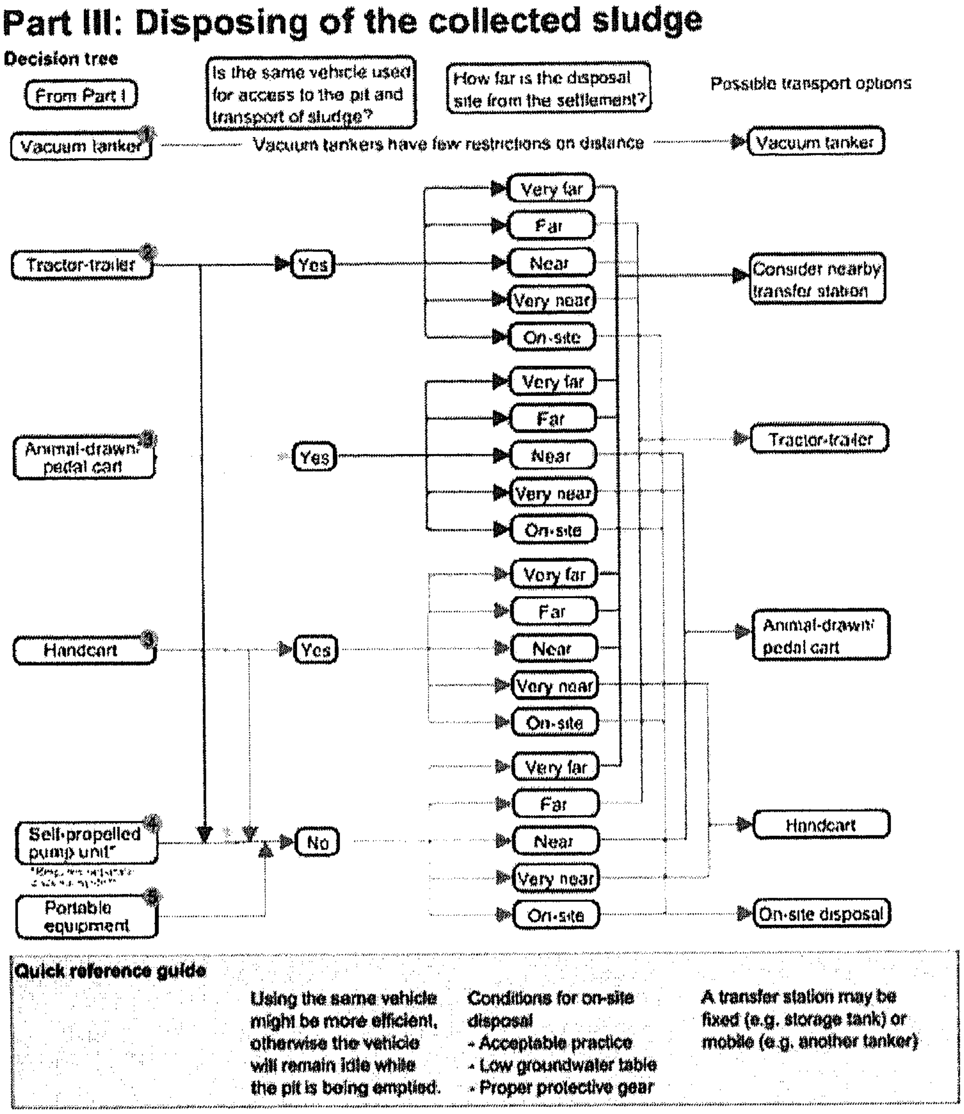


FIGURE 8. Pit emptying decision tree part III (Color figure available online).

Part I is used to determine the feasibility of using a vacuum tanker, tractor, animal-driven or pedal cart, and hand cart to reach the settlement, and whether the storage facility is located within the settlement so that emptying devices can be carried to the pit. It is assumed that the settlement is not large enough for distance within the settlement to be a constraint.

Part II(a) is used to answer question two of Part II(b), describe the sludge you want to empty, if the user does not know the characteristics of the sludge. The type of sludge is simplified into two components: viscosity and density. The series of questions in Part II(a) is used to determine these two parameters. Due to the complexity of the processes that occur inside the pit that are not fully understood and the many factors that affect the composition of sludge, a number of assumptions are made:

- Density and viscosity are directly correlated. In practice this is not always true, as seen from the Botswana trials.
- Conditions throughout the depth of the pit are uniform. In reality, the density and viscosity increase with depth.
- Density and viscosity increase as the ratio of water content and solid material in the pit decreases.

In practice, it is very difficult to predict the type of sludge in the pit. Larger solid material in the sludge such as bottles and rags are not considered as no technology can satisfactorily deal with it. Instead, sticks or rakes are usually used to manually remove large solids.

Part II(a) determines whether the pit is likely to contain more or less watery sludge. Wet pits such as pour flush latrines and septic tanks have more watery sludge than dry pits such as pit latrines because water is used for flushing.

Part II(b) considers characteristics of the sludge in the pit as well as the depth of the sludge to be emptied. The two parameters must be considered together because it is the combination of the density (and viscosity) and depth of the sludge that governs the performance of a vacuum-based technology. The parameters eliminate emptying technologies unfeasible for the sludge characteristics based on the following assumptions:

- Vacuum-based pumps have more difficulty dealing with dense and viscous sludge than less dense and more watery sludge.
- Vacuum-based pumps have increasing difficulty emptying deeper sludge.
- Manual pumps are worse than mechanized pumps for a given depth and type of sludge because it generates a smaller vacuum in the tank.
- Direct suction pump is not limited by the characteristics of the sludge but by its depth (very shallow). This is based on the Gulper, which can empty to a depth of approximately 1 m.
- Very dense and viscous sludge cannot be removed by any existing technology or method apart from manual emptying.

All large pits with sludge more than two years old are likely to contain very dense and viscous sludge toward the bottom of the pit due to decomposition processes. However, this irremovable sludge is not considered for manual emptying when it is overlain by fresher sludge due to the health risks and effort involved.

VII. CONCLUSIONS AND RECOMMENDATIONS

Pit emptying is a serious challenge in slums and informal settlements where there are a large number of pit latrines situated in highly dense, urban areas. A fully adequate solution to pit emptying such places has yet to be developed, with the main challenges being the following:

- Traditional vacuum-based methods cannot empty dense and viscous sludge.
- The composition of sludge varies widely between and within pits, requiring a technology, or a combination of technologies, able to tackle these variations.
- The high densities within slum settlements make it very difficult to develop a product that is accessible and yet has the ability to remove sludge effectively.
- The method must address subsequent components of the fecal sludge management chain including transport, storage, treatment, and disposal.
- The technology must not only satisfy the previous requirements but also must be technically and financially sustainable in developing country contexts.

It is crucial that the pit emptying method selected from the presently available choices is appropriate to the local situation in order to maximize the benefits to the user and the service provider. It is hoped that this critical review and the accompanying decision-making framework may help to disseminate knowledge and aid the technology selection process.

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