The challenge of faecal sludge management in urban areas – strategies, regulations and treatment options

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Water Science and Technology **Vol 46 No 10 pp 285–294** © IWA Publishing 2002

Abstract In urban centres of industrialising countries, the majority of houses are served by on-site sanitation systems such as septic tanks and unsewered toilets. The faecal sludges (FS) collected from these systems are usually discharged untreated into the urban and peri-urban environment, posing great risks to water resources and to public health. Contrary to wastewater management, the development of strategies to cope with faecal sludges, adapted to the conditions prevailing in developing countries, have long been neglected. The authors describe the current situation and discuss selected issues of FS management. A proposal is made for a rational setting of sludge quality or treatment standards in economically emerging countries. The authors stipulate that regulatory setting should take into account local economic, institutional and technical conditions. Defining suitable treatment options as critical control points in securing adequate sludge quality is better than setting and relying on numerical sludge quality standards. A separate section is devoted to the practice and to regulatory aspects of (faecal) sludge use in Argentina. An overview of treatment options, which may prove sustainable in less industrialized countries is provided. Planted sludge drying beds are one of these options. It has been piloted in Thailand for four years and details on its performance and operation are presented along with data on the hygienic quality of treated biosolids.

Keywords Faecal sludge; hygienic quality; septage; sludge; standards; treatment

Current practice and problems in faecal sludge management

In urban areas of many developing countries, the excreta disposal situation is dramatic. Every day, all around the world, thousands of tons of sludges from on-site sanitation (OSS) installations, i.e. from unsewered ("dry") family and public toilets and from septic tanks, are disposed of untreated. They are either used in agriculture or aquaculture or discharged indiscriminately into lanes, drainage ditches, onto open urban spaces and into inland waters, estuaries and the sea, causing serious health impacts, water pollution and eye and nose sores. OSS systems are the predominant form of excreta disposal for the majority of urban dwellers in Africa and Asia as well as for a considerable proportion in Latin America (Table 1 and Figure 1; Strauss *et al.*, 2000).

Faecal sludge subsumes sludges of various consistencies accumulating in and evacuated from so-called on-site sanitation systems, viz. septic tanks, aqua privies, family latrines and unsewered public toilets. In larger cities, faecal sludge (FS) collection and haulage are faced with great challenges: emptying vehicles often have no access to pits; traffic congestion prevents efficient emptying and haulage; emptying services are poorly managed.

Suitable sites for treatment and use or for final disposal may be found at the outskirts of cities only. Vacuum tankers discharge their load at shortest possible distance from the points of collection to save time and cost. In many cities, dumping sites for FS are close to squatter or formally inhabited low-income areas where they threaten the health of this ever-growing segment of population. Children, in particular, are at greatest risk of getting into contact with indiscriminately disposed excreta.

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Improving on faecal sludge management

Given the immense problems and challenges in FS management, a large array of technical, economic and institutional/organizational measures are required to improve the situation. The authors consider the use of semi-centralized (as against centralized) FS treatment and of neighbourhood septic tanks as particularly expedient. Both measures may contribute significantly to reducing indiscriminate dumping of FS and, hence, to reducing health and pollution risks. However, every city has to be taken at its own merits, given the great variability of spatial settings, sanitation infrastructure and planning mechanisms, which influence sanitation planning and the allocation of suitable sites for either condominial septage tanks or FS treatment plants.

Semi-centralized faecal sludge treatment

Faecal sludge haulage volumes and mileage are to be minimised. Using, in larger cities, semi-centralised FS treatment plants may help to attain this (Figure 2). Compared with wastewater collection in sewers, the advantage of FS collection and transport is its adaptability to any type of topography. Semi-centralised treatment may consist of solids-liquid separation and solids dewatering (ref. Section on treatment options below). Assuming that the dewatering process yields a reduction of the water content from 98 to 75% or an increase of the solids content from 2 to 25%, the dewatered sludge volume to be transported would be one twelfth the raw FS volume.

Neighbourhood (condominial) septic tanks

This strategic option (Figure 3) is particularly suitable for densely populated urban districts with narrow lanes. The problem of inaccessibility of septic tanks or latrines would be alleviated, as the tanks could be located at easily accessible sites.

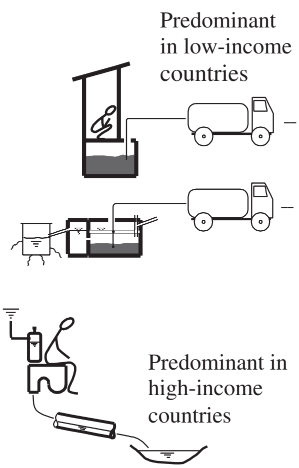

Figure 1 Excreta disposal systems in urban areas of low and high-income countries

Table 1 Per cent urban households served by on-site sanitation systems

Manila	78
Philippines (towns)	98
Bangkok	65
Ghana	85
Tanzania	> 85
Latin America	> 50

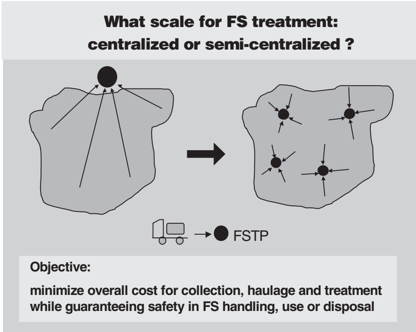

Figure 2 Semi-centralized FS treatment – a strategic tool to minimize cost, indiscriminate dumping, health risks and water pollution

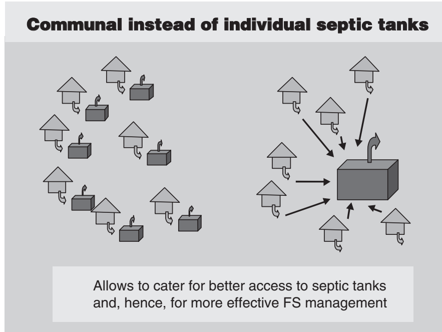

Figure 3 The use of communal septic tanks – a strategic tool to facilitate effective FS collection

Agricultural sludge use and regulations

In many places, faecal sludge has been used in agriculture and in aquaculture for centuries already. Its content of organic matter and nutrients and the usually low level of chemical contamination such as heavy metals make it a valuable resource. FS management strategies should therefore aim at rendering FS apt for use in agriculture.

Sludge hygienic quality

In many areas of Africa, Asia and Latin America, helminth, notably nematode infections (*Ascaris, Trichuris, Ancylostoma, Strongyloides*, etc.) are highly prevalent. Among the pathogens causing gastro-intestinal infections, nematodes, *Ascaris* in particular, tend to be more persistent in the environment than viruses, bacteria and protozoa. The bulk of helminth eggs contained in wastewater or in faecal sludge end up in the biosolids generated in treatment schemes. Hence, nematode eggs are the indicators-of-choice to determine hygienic quality and safety where biosolids are to be used as a soil conditioner and fertilizer. The concentration of helminth eggs in the biosolids is largely dependent on the prevalence and intensity of infection in the population from which FS or wastewater is collected. Depending on the duration of biosolids storage and type of treatment, a distinct proportion only of the helminth eggs remains viable. Table 2 shows values for helminth egg counts and viability in untreated human wastes and in biosolids as reported in published and unpublished literature for a few selected treatment schemes.

Standards setting – appeal for a sensible approach

Basic aspects. According to Vesilind (2000), "the responsibility of the regulator is to incorporate the best available science into regulatory decision-making. But problems arise when only limited scientific information is available. The complexity of the environmental effect of sludge on human health leads to scientific uncertainty and makes sludge disposal difficult". The same author indicates that the standards elaborated recently by USEPA are based on the "principle of expediency" formulated by Phelps in 1948. The principle is "an ethical model that calls for a regulator to optimise the benefits of health protection while *minimising costs within the constraints of technical feasibility*" (Vesilind, 2000).

If this paradigm – basing environmental regulations on available technology and on (local) economic and institutional resources – has been adopted in industrialised countries, it should even more be applied to Latin American and other, economically less advanced countries. There, the development of monitoring and enforcement systems is still lagging far behind and is more difficult to organise and implement than in industrialized countries. Therefore, replicating the strict standards or limits established in industrialized countries

Table 2 Helminth eggs in biosolids from faecal sludge and wastewater treatment schemes

Place and scheme	No. of helminth eggs per litre of untreated . . .		Helminth eggs in biosolids		Reference
	Faecal sludge	Wastewater	No. of eggs/g TS	Egg viability	
Extrabes, Campina Grande (Brazil); experimental WSP scheme	–	1,000 (nematodes)	1,400–40,000 (as distributed in sludge in a primary facult. pond; avg.= 10,000, approx.)	2–8% (period of biosolids storage not reported but probably several years)	Stott *et al.* (1994)
Chiclayo (Peru); WSP schemes	–	10–40 (mostly nematodes)	60–260 (in sludge from a primary facult. pond)	1–5% (biosolids stored for 4–5 years)	Klingel (2001)
Asian Institute of Techn. (Bangkok); pilot constructed wetland plant (planted sludge drying beds) for septage dewatering +stabilisation (septage; nematodes)	600–6,000		170 (avg. nematode levels in dewatered biosolids accumulated over 3.5 years in planted sludge drying beds)	0.2–3.1%	Koottatep and Surinkul (2000); Schwartzbrod (2000)

without taking into account the regional characteristics or necessary data pertaining to the local conditions is entirely inappropriate. In many instances, the numerical values of certain parameters are established without defining locally appropriate management and treatment options for wastewater and biosolids. Such options would have to take into account disposal or use scenarios, type of soils on which they are spread, influence on the crops, health aspects, financial and economic factors, etc. Treatment aiming at use of the treatment products, biosolids in this case, would clearly have to meet different standards than if aiming at final disposal or discharge.

A sensible strategy for public health protection in biosolids use has been adopted by the EU. The general principle is to define and set up a series of barriers or critical control points, which reduce or prevent the transmission of infections. Sludge treatment options, which were found to inactivate excreted pathogens to desirable levels, are the prime element in this (Matthews, 2000). "Barrier points" such as the sludge treatment works, can be easily controlled with respect to design and operations, thereby securing the compliance of the treated biosolids with stipulated quality standards. In contrast to this, the controlling of numerical quality criteria for wastewater or biosolids requires regular monitoring. In economically less developed countries, such monitoring is often difficult and very costly to perform. Results may not be reliable and replicable as adequate routine, quality control and cross-referencing are lacking.

In industrialised countries, pollution laws have been made more stringent in a stepwise manner over many decades. Concurrently, wastewater and sludge treatment technology has been upgraded stepwise to cope with an increasing number of constituents and to reduce pollution loads discharged into the environment (Johnstone and Horan, 1996). A suitable strategy would consist in also selecting a phased approach, under the paradigm that "something" (e.g. 75% instead of 95–99% helminth egg or COD removal) is better than "nothing" (the lack of any treatment at all or the often totally inadequate operation of existing treatment systems) (Von Sperling, 2001).

Numerical values – at the base of the barrier principle. Following the principle of defining and setting up barriers against disease transmission, which can be used as critical control points for securing safe biosolids quality, technically and economically appropriate options for the treatment of faecal sludges and biosolids must be defined, which will guarantee a defined quality level. Hence, numerical quality values need to be used to define process specifications, yet they do not have to be regularly monitored once the processes are in place. Xanthoulis and Strauss (1991) proposed a guideline value for biosolids (as produced in faecal sludge or in wastewater treatment schemes) of 3–8 viable nem. eggs/g TS. This recommendation is based on the WHO guideline of £1 nematode egg/litre of treated wastewater used for vegetable irrigation (WHO, 1989), and on an average manuring rate of 2–3 tons TS/ha·year. For comparison, the standard to comply with in Switzerland, e.g. is 0 helminth eggs/g TS and 100 Enterobacteriaceae/g TS. This standard is extremely strict and can be attained through high-cost, sophisticated heat treatment (pasteurization) only. It is an option, which constitutes proven technology and is widely applied in Switzerland and other industrialized countries. For the majority of economically less advanced countries, however, such treatment is not sustainable nor is such a strict standard epidemiologically justified (moreover, Enterobacteriaceae also comprise bacteria which do not live in the human or animal intestine, hence, it is not an expedient criterion for sludges, which were not treated by in-vessel processes, such as pasteurisation).

The case of Argentina

How are excreta disposed of? Of the total population of 37 million inhabitants (1991 census), 89% live in urban areas; i.e. in communities of 2,000 or more inhabitants. About 54% of the population are connected to sewer systems and the remaining 46% are served by individual, on-site sanitation systems, mainly septic tanks. In large cities, the vacuum trucks discharge the faecal sludge into the sewer system through manholes designated for this purpose, thereby causing numerous complaints from neighbours due to unpleasant odours and other nuisances (noise, obstruction of the traffic, etc.).

Most of the existing wastewater treatment plants generally accept septage delivered by vacuum trucks and this is one of the reasons for the malfunctioning of the them. In cities of up to 50,000 inhabitants, the use of stabilization ponds for treatment of septage is slowly spreading in order to pretreat the faecal sludge in co-treatment schemes or in systems designated exclusively for these liquids in the case of absence of sewerage systems (Ingallinella *et al*., 1996). CIS, the centre for sanitary engineering at the University of Rosario, Argentina, and EAWAG/SANDEC are conducting collaborative field research on the co-treatment of septage and wastewater in a full-scale waste stabilisation pond scheme (Ingallinella *et al*., 2000). One of the objectives of this project is to determine treatment performance with respect to the hygienic and agronomic quality of the biosolids generated in the pre-treatment ponds, which cater for solids–liquid separation in septage and for the thickening and stabilisation of the biosolids so generated.

Use of organic fertilisers in Argentina. The different organic fertilisers currently marketed originate from composting processes and/or vermiculture grown on household waste. These products have to be registered. However, the existing regulations do not stipulate any quality standards. Sewage sludge generated in wastewater treatment plants is being supplied to farmers in various locations. However, this activity is not based on any legal provisions or on sludge quality control measures. Horticulturists also use organic fertilisers such as poultry and pig manure, an activity that is neither registered nor controlled.

Existing regulations. The only existing legislation at national level, which may apply to faecal sludge disposal, is the Law on Hazardous Waste (República Argentina, 1992). According to this law, sludges, among them FS, may be accepted in sanitary landfills.

There, they have to be discharged in specifically designed separate cells. Sludge designated for sanitary landfilling has to meet tolerance limits set for, among others, pH, total solids, volatile solids, combustibility, cyanides and sulphides. Furthermore, tolerance limits in the leachate have been established for 25 parameters, including heavy metals and organic substances. Microbiological sludge quality standards have not been established. Agricultural sludge use is permitted in the said law but not legally regulated. No special reference is made to faecal sludges, i.e. the sludges collected from on-site sanitation systems, such as septic tanks and latrines. Sludge disposal and use regulations were established in Santa Fé Province (Argentina), recently (Ente Regulador de Servicios Sanitarios de la Pcia. de Santa Fé, 2000). Quality criteria are stipulated for various use categories, similarly to the Class A and B standards established by USEPA (USEPA, 1993). The helminth standard for biosolids used in agriculture is set at ≤1 viable eggs/4 g TS. This standard may prove rather strict if having to be enforced in areas where helminth infestation is high.

Treatment options

Today's practices

Proper FS treatment, either in combination with wastewater or separately, is being practiced in a few countries only to date (e.g. Argentina, Ghana, Benin, Botswana, South Africa, Thailand, Indonesia, China). Treatment options used comprise batch-operated settling-thickening units; Imhoff tanks; non-aerated stabilization ponds; combined composting with municipal organic refuse; extended aeration followed by pond polishing; anaerobic digestion. In the USA, most of the septage (the contents of septic tanks) is co-treated in wastewater treatment plants. In some states, though, pond systems are used to separately treat septage. They typically consist of an anaerobic sedimentation pond followed by an infiltration pond.

Faecal sludge characteristics

Table 3 illustrates the substantial differences between faecal sludge and sewage on the one hand and between the different types of faecal sludges on the other hand. Organic and solids contents, ammonium and helminth eggs concentrations measured in FS are normally higher by a factor of 10 or more than in wastewater. Moreover, FS differs from wastewater and sludge produced in wastewater treatment plants by the fact that its quality is subject to high variations. Storage duration, temperature, intrusion of groundwater in septic tanks, performance of septic tanks, and tank emptying technology and patterns are parameters which influence the sludge quality.

Table 3 Characteristics of faecal sludges and comparison with tropical sewage (Heinss *et al.*, 1998)

	Public toilet sludge	Septage	Sewage
Characterisation	Highly concentrated, mostly fresh FS; stored for days or weeks only	FS of low concentration; usually stored for several years; more stabilised than public toilet sludge	Tropical sewage
COD (mg/l)	20,–50,000	< 10,000	500–2,500
COD/BOD	2:1 . . . 5:1	5:1 . . . 10:1	2:1
NH_4-N (mg/l)	2,–5,000	< 1,000	30–70
TS	≥ 3.5%	< 3%	< 1%
SS (mg/l)	≥ 30,000	≈ 7,000	200–700
Helminth eggs (no./litre)	20,–60,000	≈ 4,000	300–2,000

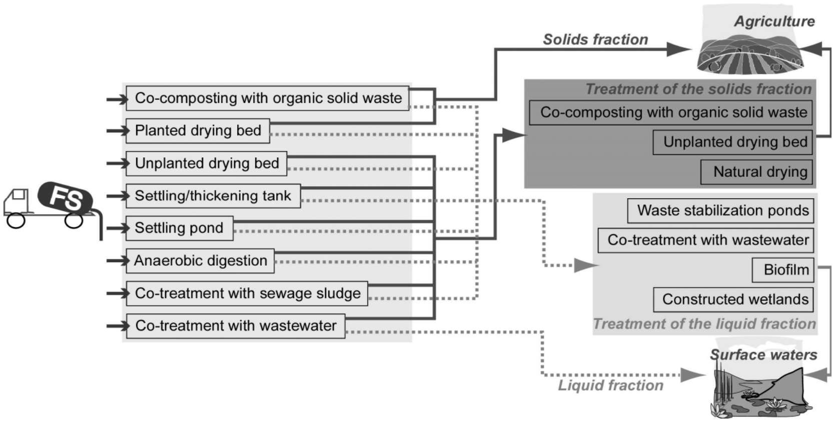

Figure 4 Overview of potential, modest-cost treatment options for faecal sludge

Overview of treatment options

Figure 4 is an overview of potential modest-cost options for the treatment of faecal sludge. Some of them have already been or are being investigated by EAWAG/SANDEC and its partners in Argentina, Ghana, Thailand and The Philippines. The most appropriate option(s) must be determined on a case-to-case basis by taking into account the specific conditions prevailing in a particular city (economic, institutional, climatic, legal, etc.), the existing excreta management system and the (often highly variable) characteristics of FS.

While substantial resources have been invested over the past decades into the development of both low and high-cost wastewater technologies, sustainable treatment technologies for faecal sludges still require large inputs of field research, development and testing before they may be propagated as "state-of-the-art" options. One option is presented in the following paragraph with an emphasis on treated biosolids quality.

Planted drying beds – "constructed wetlands" – for the treatment of septage

Constructed wetlands consist of gravel/sand filters planted with emergent plants such as reeds, bulrushes or cattails. The advantage of planted over unplanted sludge drying beds is that the root system of the cattails creates a porous structure in the beds and thus enables them to maintain prolonged permeability of the filter body. Sludge is due to be removed from the beds at intervals of several years only. A pilot plant – planted with cattails – has been investigated at the Asian Institute of Technology (AIT) in Bangkok since early 1997. The $3 \times 25\ m^2$ plant is equipped with drainage and ventilation systems (Figure 5) and treats the septage produced by 3,000 people. The percolate is collected and pumped into an attached-growth waste stabilization pond system. The investigations carried out at the AIT

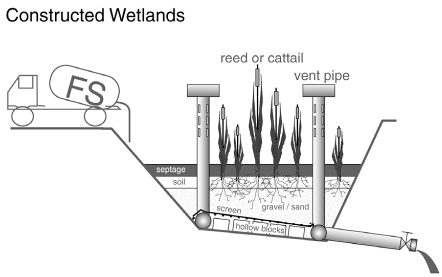

Figure 5 Pilot-scale constructed wetlands treating septage at the Asian Institute of Technology (Bangkok/Thailand)

enabled us to establish preliminary recommendations for the design and mode of operation of such treatment systems (Koottatep *et al.*, 1999a, 1999b).

Table 4 illustrates the characteristics of the accumulated sludge layer, as it was determined after three and a half years of operation. Nitrogen and phosphorus contents of the sludge accumulating on the planted drying beds compare very favourably with the ones found in matured compost. Helminth eggs analysis showed that the use of the accumulated biosolids in agriculture would not result in a risk to public health. Even though the number of nematode eggs counted was high (170 g/TS on avg.), only a small fraction (2/g TS on avg. or 1.2%) was found to be viable (Schwartzbrod, 2000). Average viable nematode egg concentrations are thus below the suggested quality guideline of 3–8 eggs/g TS (ref. sect. on standards setting). The fate of heavy metals in constructed wetlands is of prime importance as a high content of heavy metals in the dried sludge layer could damage the cattail plants which play a crucial role in maintaining the long-term permeability of the filter body. Further to this it could render the biosolids inadequate for agricultural use (soil accumulation). Heavy metal concentrations in raw septage were found to be very low and accumulation in the dewatered biosolids is insignificant. However, zinc concentration measured in septage collected from Chatuchak district in Bangkok was found to be much higher than in septage samples from other city districts. In spite of the high Zn concentration, agricultural use of dewatered biosolids from the AIT pilot plant applied at a dose of 1 to 10 tons/hectare·year would not lead to an unacceptable increase of the soil concentration (Staelens *et al.*, 1999). As the high zinc concentration in the Chatuchak septage appears to result from a point source pollution (possibly galvanizing or cosmetics industry), an on-site or decentralised treatment of the polluted septage could avoid contaminating the non polluted septage from the other areas and hence the treated biosolids intended to be used as soil conditioner.

Conclusions and recommendations

Contrary to wastewater management, the development and implementation of strategies and options to cope with faecal sludges (FS) adapted to the conditions prevailing in developing countries has long been neglected. Future planning for the upgrading of urban sanitation compulsorily should cater for improvements in FS management inclusive of collection, haulage, treatment and use or disposal. Treatment options considered feasible for developing countries are at hand; yet, more field research and monitored testing of pilot and demonstration schemes are required to render them “proven options”. The following elements are fundamental in FS management: The diligent siting of an adequate number of FS treatment sites in order to minimise transport mileage and hence indiscriminate dumping of untreated FS; the formulation of treatment standards which are sound, enforceable and adapted to a country’s economic, institutional and technological setting; the choosing of the “best” FS treatment options on a case-to-case basis. As in industrialized countries, a strategy of starting off with lenient standards and of introducing modest-cost treatment options as disease barriers and critical control points should be adopted.

Table 4 Agronomic characteristics of the biosolids accumulating in the AIT constructed wetland plant treating septage (Kost and Marty, 2000). Nutrient levels in matured compost are also included for comparison’s sake (FAO, 1987)

	TS (%)	TVS (%TS)	Total N (%TS)	Total P (%TS)	Total K (%TS)
Dried sludge layer	35–45	60–65	3	1.2	0.2
Matured compost			0.4–3.5	0.1–1.6	0.4–1.6

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