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Faecal SludgeTreatment

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Acronyms, Abbreviations and Glossary

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Acronyms

AIT	Asian Institute of Technology, Bangkok, Thailand
EAWAG	Swiss Federal Institute for Environmental Science & Technology, Duebendorf, Switzerland
EU	European Union
SANDEC	Dept. of Water & Sanitation in Developing Countries at EAWAG
WRI	Water Research Institute (Council for Scientific and Industrial Research, CSIR), Accra, Ghana (formerly Water Resources Research Institute, WRRI)
USEPA	United States Environmental Protection Agency

Abbreviations

BOD	Biochemical Oxygen Demand	SS	Suspended Solids
COD	Chemical Oxygen Demand	TKN	Total Kjeldahl Nitrogen
CW	Constructed Wetlands	TOC	Total Organic Carbon
FC	Faecal Coliforms	TS	Total Solids
FS	Faecal Sludge	TVS	Total Volatile Solids
NH_4-N	Ammonium Nitrogen	WSP	Waste Stabilisation Ponds
NH_3-N	Ammonia Nitrogen	WWTP	Wastewater Treatment Plant

Glossary

Faecal sludge	Sludges of variable consistency collected from so-called on-site sanitation systems; viz. latrines, non-sewered public toilets, septic tanks, and aqua privies
Septage	Contents of septic tanks (usually comprising settled and floating solids as well as the liquid portion)
Public toilet sludge	Sludges collected from unsewered public toilets (usually of higher consistency than septage and biochemically less stabilised)
Percolate	The liquid seeping through a sludge drying bed and collected in the underdrain

1. Current Practice and Problems in Faecal Sludge Management

In urban areas of Asia, Africa and Latin America, the excreta disposal situation is dramatic: every day, worldaround, thousands of tons of sludges from on-site sanitation (OSS) installations, i.e. unsewered family and public toilets and septic tanks – so-called faecal sludges – are disposed of untreated and indiscriminately into lanes, drainage ditches, onto open urban spaces and into inland waters, estuaries and the sea.

OSS systems are the predominant form of excreta disposal installations in urban centers of industrializing countries. From 65 to 100 % of dwellers in towns and cities of Africa and Asia who do avail of adequate sanitation installations and services are linked to unsewered or so-called on-site sanitation facilities (Table 1 and Fig. 1). These comprise family and public latrines, aqua privies and septic tanks. Only smaller portions of cities' central business districts are linked to sewers (Strauss et al., 2000). In Latin America, more than 50 % of houses in cities are connected to a sewerage system. In medium sized and smaller towns, however, most houses are served by on-site sanitation systems, notably septic tanks. OSS systems are also common in peri-urban areas of high-income countries. 25% of houses in the U.S., e.g., are served by septic tanks.

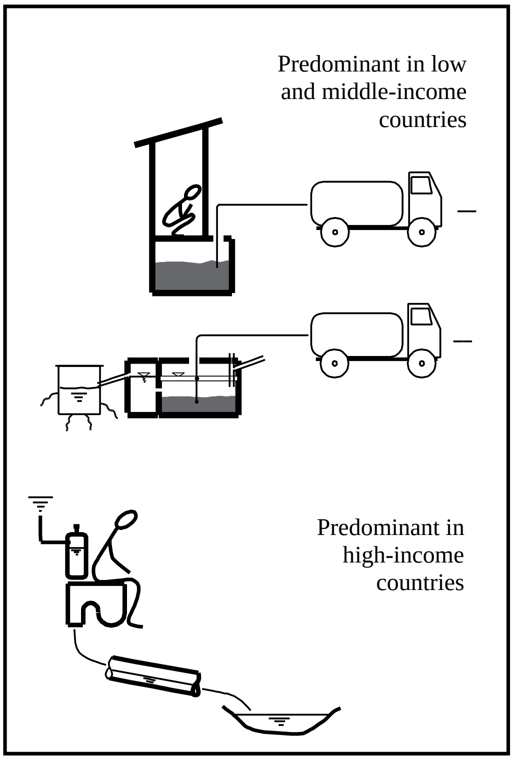


Table 1
Percent urban households served by on-site sanitation systems

Manila	78
Philippines (towns)	98
Bangkok	65
Ghana	85
Tanzania	> 85
Latin America	23
Metro Buenos Aires	36

Fig.1 Excreta disposal systems predominant in urban areas of low and high-income countries

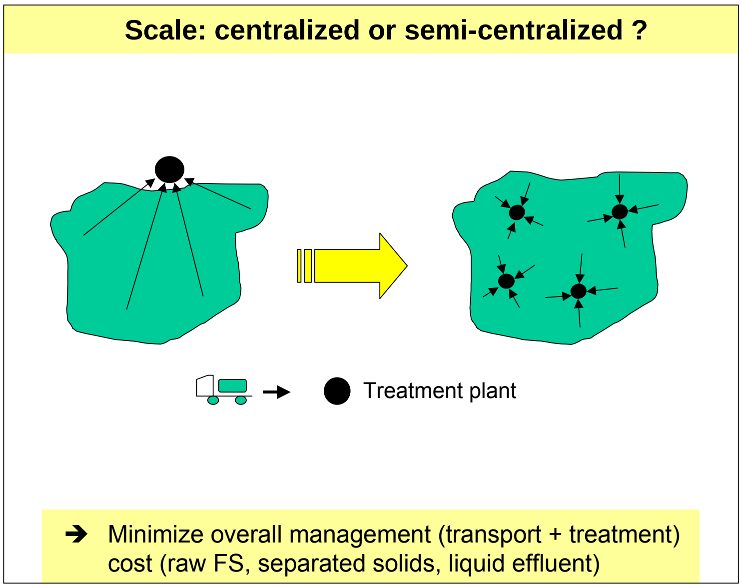
Faecal Sludge (FS) collection and haulage in larger cities is faced with immense difficulties: Emptying vehicles circulating in towns and cities often have no access to pits. Traffic congestion prevents efficient emptying and haulage. Emptying services are poorly managed particularly where the responsibility lies with government authorities. Suitable sites for treatment and use or for final disposal may be found at the outskirts of cities only. Hence, haulage distances tend to be large. The haulage of relatively small faecal sludge volumes (5-10 m3 per truck) through congested roads over long distances in large urban agglomerations is not sustainable, neither from an economic nor from an ecological viewpoint. The current widespread practice is for vacuum tankers to discharge their load at shortest possible distance from the points of collection to render collection services and earnable income more effective.

FS are disposed of or used in agriculture untreated in the majority of cases, creating enormous health risks, eye and nose sores and water pollution. In many cities, dumping sites and open defecation grounds are close to formally or informally 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. In China, traditional excreta disposal practices consist of collecting the excreta from individual houses and public toilets by buckets and vacuum tankers for use in agriculture and aquaculture. Most of the 30 million tons of sludges that are reportedly collected in China's cities every year are used untreated. Concern regarding the potential health impact of this practice has led Chinese authorities and research institutions to embark on action research in faecal sludge treatment (Ministry of Construction, 1993).

2. *Strategic Aspects of FS Management*

The use of double-pit latrines should allow – if they are operated adequately – to eliminate pathogens before pit emptying and hence to reduce potential health risks related to sludge handling and disposal or reuse. Sludge transport to a treatment site would not be necessary anymore; it could be used directly as soil conditioner on the nearest agricultural plots. However, the principle of alternate use of pits requires a change in behavior. All projects involving the construction of double-pit latrines must therefore allow for a prolonged support program (Franceys et al, 1992).

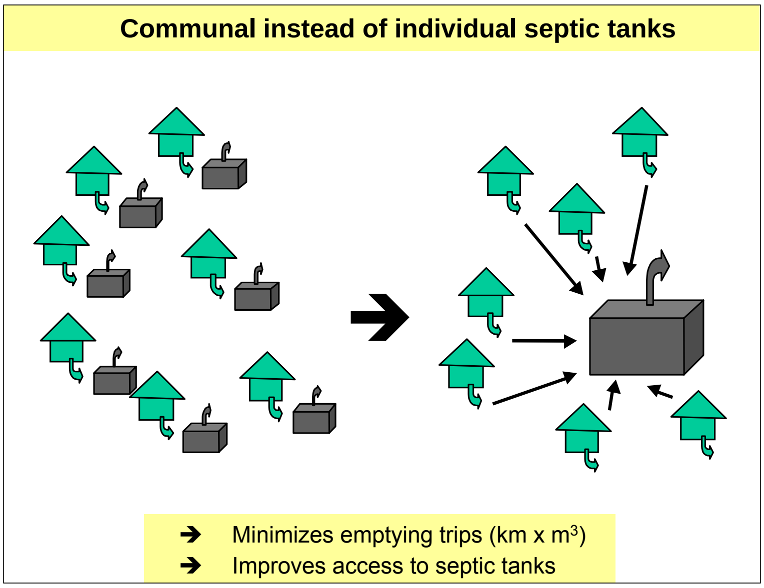
Using small to medium-size, semi-centralised FS treatment plants may help to minimize faecal sludge haulage volumes and mileage. As an example, the plants might comprise solids-liquid separation and dewatering. The separated liquid either might be treated at the same site or be transported away in solids-free sewers for centralised treatment. Sludge volumes are inversely proportional to the solids content. Assuming that the dewatering process (e.g. by sludge drying beds) yields a reduction of the water content from 98 % to 75 % (equivalent to an increase of the solids content from 2 % to 25 %), the dewatered sludge volume to be transported would be 12 times smaller than the raw FS volume. These treatment systems could also include co-composting of faecal sludge (separated solids) and organic solid waste.


Scale: centralized or semi-centralized ?

➔ Minimize overall management (transport + treatment) cost (raw FS, separated solids, liquid effluent)

Fig.2 Semi-centralised FS treatment – A strategic tool to minimise cost, indiscriminate dumping, health risks and water pollution

Use of neighborhood or condominial septic tanks would be particularly suitable for densely populated urban districts. The problem of inaccessibility of septic tanks or latrines would be reduced, as the tanks could be located at easily accessible sites.



Communal instead of individual septic tanks

➔ Minimizes emptying trips (km x m^3)
➔ Improves access to septic tanks

Fig.3 The use of communal septic tanks – A strategic tool to facilitate effective FS collection

3. FS Treatment and Regulations

In the majority of less-industrialized countries, effluent discharge legislation and standards have been enacted. The standards usually apply for both wastewater and faecal sludge treatment. They are often too strict to be attained under the unfavorable economic and institutional conditions prevailing in many countries or regions. Quite commonly, effluent standards are neither controlled nor enforced. Examples for faecal sludge treatment standards are known from China and Ghana. In the Province of Santa Fé, Argentina, e.g., current WWTP effluent standards also apply to FS treatment. For sludges used in agriculture, a helminth egg standard has been specified (Ingallinella, 1998).

Standards setting – appeal for a sensible approach

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 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 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 vs. use scenarios; types of soils on which treated human wastes are spread; influence on the crops; health aspects; financial and economic factors, and institutional settings. Clearly, distinct standards and a distinct selection of treatment parameters should be stipulated depending on whether treated wastes would be used in agriculture or discharged into the environment. For reuse, hygiene-related variables (helminth eggs in biosolids and faecal coliforms in wastewater) and nitrogen are the relevant criteria whereas for discharge, variables such as COD or BOD and NH4 are of prime importance. Where WSP are used to treat faecal sludges or co-treat FS and wastewater and treated effluent is discharged into surface waters, effluent standards for BOD or COD should be stipulated for filtered rather than for unfiltered samples. This is due to the fact that in the order of 70 % of the BOD in the effluent of well-functioning WSP consists of algal cells. Algal BOD is different from untreated wastewater or FS BOD in its potential impact on the receiving waters. Algae produce oxygen during daylight hours and are likely to be consumed by the zooplankton before they may exert their BOD (Mara, 1997).

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).

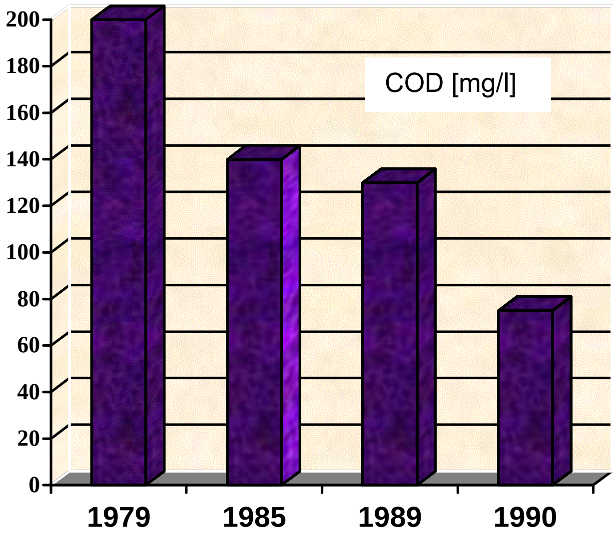


Figure 4

Gradual development of the effluent discharge standard in Germany For sewage treatment plants > 100,000 p.e. (Bode, 1998)

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[1]. (Ingallinella et al., 2001)

In Table 2, a set of effluent and plant sludge quality guidelines for selected constituents is listed. The suggested values are based on the considerations outlined above.

Table 2 Suggested effluent and plant sludge quality guidelines for the treatment of faecal sludges (Heinss et al., 1998)

	BOD [mg/l]		**NH_4-N** [mg/l]	**Helminth eggs** [no./liter]	**FC** [no./100 ml]
	total	filtered			
A: Liquid effluent ***1. Discharge into receiving waters:***					
Seasonal stream or estuary	100-200	30-60	10-30	≤ 2-5	$\leq 10^4$
Perennial river or sea	200-300	60-90	20-50	≤ 10	$\leq 10^5$
2. Reuse:					
Restricted irrigation	n.c.		1)	≤ 1	$\leq 10^5$
Unrestricted irrigation	n.c.		1)	≤ 1	$\leq 10^3$
B: Treated plant sludge					
Use in agriculture	n.c.		n.c.	≤ 3-8/ g TS 2)	3)

1) ≤ Crop's nitrogen requirement (100 - 200 kg N/ha·year)

2) Based on the nematode egg load per unit surface area derived from the WHO guideline for wastewater irrigation (WHO, 1989) and on a manuring rate of 2-3 tons of dry matter /ha·year (Xanthoulis and Strauss, 1991)

3) Safe level if egg standard is met

n.c. – not critical

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[1] 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.

4. Faecal Sludge Characteristics

4.1 Resource Value of Human Excreta (Heinss et al., 1998)

Table 3 contains relevant characteristics and per capita quantities of human excreta, including its resource elements, viz. organic matter, along with phosphorus, nitrogen and potassium as major plant nutrients. Average nutrient contents of plant matter and cattle manure are also included for comparison's sake. Faecal sludges, if adequately stored or treated otherwise, may be used in agriculture as soil conditioner to restore or maintain the humus layer or as fertiliser.

Table 3 Human excreta: per capita quantities and their resource value (Strauss 1985)

	Faeces	**Urine**	**Excreta**
Quantity and consistency			
• Gram/cap·day (wet)	250	1,200	1,450
• Gram/cap·day (dry)	50	60	110
• Including 0.35 litres for anal cleansing, gram/cap·day (wet)			1,800
• m^3/cap·year (upon storage and digestion for $\geq$ 1 year in pits or vaults in hot climate)			0.04-0.07
• Water content [%]			50 - 95
Chemical composition		**% of dry solids**	
• Organic matter	**92**	**75**	**83**
• C	48	13	29
• N	**4-7**	**14-18**	**9-12**
• P_2O_5	**4**	**3.7**	**3.8**
• K_2O	1.6	3.7	2.7
For comparison's sake:		**% of dry solids**	
	N	**P_2O_5**	**K_2O**
• Human excreta	9-12	3.8	2.7
• Plant matter	1 - 11	0.5 - 2.8	1.1 - 11
• Pig manure	4 - 6	3 - 4	2.5 - 3
• Cow manure	2.5	1.8	1.4

In many places, faecal sludges are traditionally used in agriculture, often untreated or stored for insufficiently long periods, though, to ensure adequate hygienic quality. For a large number of vegetable farmers in China for example, excreta collected in urban areas are still the favoured form of soil conditioner and fertiliser although the sludges may still contain considerable loads of e.g. viable intestinal worm eggs. Many urban consumers in China prefer excreta-fertilised vegetables to crops cultivated with mineral fertilisers.

4.2 Faecal Sludge Quality and Variability

Characteristics of faecal sludge and wastewater differ widely as is shown in Table 4.

Table 4 Faecal sludges from on-site sanitation systems in tropical countries: characteristics, classification and comparison with tropical sewage (after Strauss et al. 1997 and Mara 1978)

Item	**Type "A" (high-strength)**	**Type "B" (low-strength)**	**Sewage - for comparison's sake**
Example	Public toilet or bucket latrine sludge	Septage	Tropical 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 Type "A"	
COD mg/l	20, - 50,000	< 15,000	500 - 2,500
COD/BOD	5 : 1 .... 10 : 1		2 : 1
NH_4-N mg/l	2, - 5,000	< 1,000	30 - 70
TS mg/l	≥ 3.5 %	< 3 %	< 1 %
SS mg/l	≥ 30,000	≅ 7,000	200 - 700
Helm. eggs, no./l	20, - 60,000	≅ 4,000	300 - 2,000

Table 4 shows typical FS characteristics. It is based on results of FS studies in Accra/Ghana, Manila/Philippines and Bangkok/Thailand. The characteristics of typical municipal wastewater as may be encountered in tropical countries are also included for comparison's sake.

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 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 pattern are parameters which influence the sludge quality and are therefore responsible for its high variability. Unlike digested sludge produced in activated sludge treatment plants, the organic stability of FS attains varying levels. This variability is due to the fact that the anaerobic degradation process, which takes place in on-site sanitation systems, depends on several factors, among others the ambient temperature, the retention period, and the presence of inhibiting substances. The dewaterability is a varying parameter as well, which is related to the degree of stability. Fresh, undigested faecal sludge as produced in public toilets does not lend itself to dewatering.

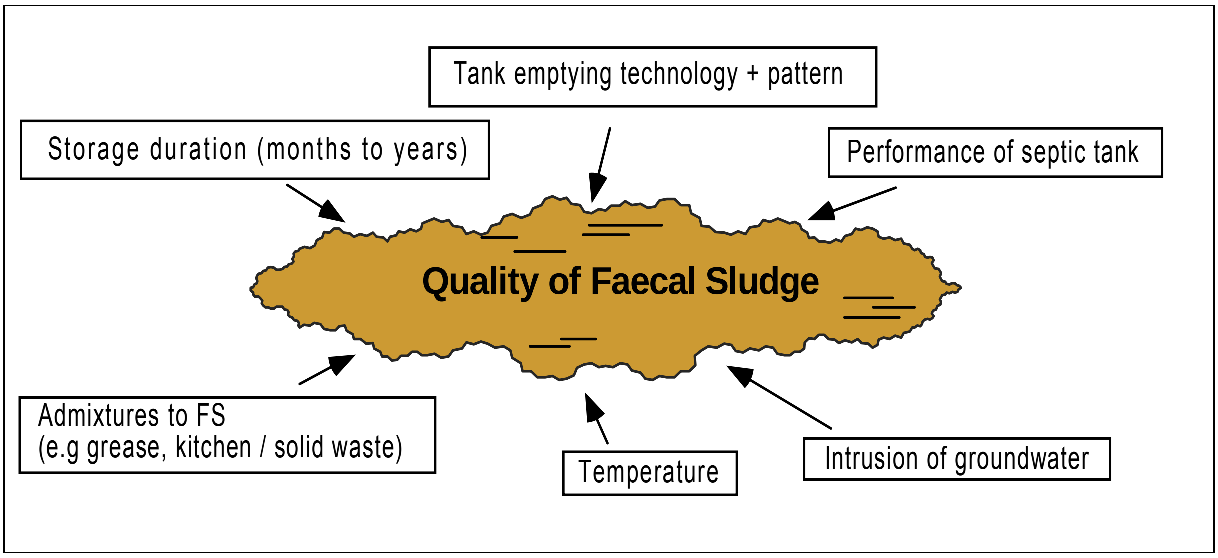

Fig. 5 Factors Influencing Faecal Sludge Quality

Sludge hygienic quality (Ingallinella et al., 2001)

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 5 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.

Table 5 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	600-6,000 (septage; nematodes)		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)

Heavy metals

When intending to use raw or treated faecal sludge for soil amendment in agriculture or to restore soil fertility in damaged soils, it is important to take heavy metals into account. A restriction in sludge application may become necessary to limit heavy metal accumulation in soils and crops through the repeated application of sludge. There exist, in many countries, regulations regarding the maximum yearly load (kg/ha·year) of specified heavy metals which may be applied to soils, and standards for maximum heavy metal concentrations in sludge applied onto land (Matthews 1996).

Table 6 Heavy metal concentrations in septage and EU standard for admissible levels in sludges used in agriculture

	Heavy metal concentrations in septage, mg/kg TS			
	Bangkok (15 samples)	**Manila** (12 samples)	**U. S.** average	**EU** tolerance values for sludge
Cd	2.8	5.3	18	20 - 40
Pb	6.8	84	216	750 - 1,200
Cu	289	64	165	1,000 - 1,750
Zn	2,085	1,937	1,263	2,500 - 4,000
Cr	20	16	28	1,000 - 1,500

Table 6 shows heavy metal (HM) concentrations in faecal sludges collected in Bangkok and Manila. FS are usually “cleaner” than sewage treatment plant sludges, as they tend to contain less heavy metals or refractory organics. Exceptions may be found in places where septage is also collected from septic tanks serving cottage or small industrial enterprises. Also listed in Table 6 are the tolerance values for HM concentrations in sewage sludge used in agriculture as stipulated by the European Union. These reflect the fact that sewage sludge often carries considerable loads of heavy metals originating from industrial wastewater discharges (Heinss et al., 1998).

4.3 Faecal Sludge Quantities (Heinss et al., 1998)

Table 7 contains the daily per capita volumes and constituent contributions in faecal sludges collected from septic tanks and pit latrines, as well as from low or zero-flush, unsewered public toilets. Values for fresh excreta are given as reference. The figures are overall averages and may be used for planning and preliminary design. Actual quantities may, however, vary from place to place. The daily per capita BOD for septage appears to be very low when compared with the figures for fresh excreta. The phenomenon can be explained with the fact that more than 50 % of the BOD load entering the septic tank is removed by anaerobic digestion during the storage of the faecal sludge. A further portion of the BOD is "lost" through the discharge of the supernatant into soil infiltration systems or into surface drains.

The reliability of the sludge collection has certainly also an effect of the amount of BOD which finally arrives with the septage on the treatment plant.

Table 7 Daily per capita volumes; BOD, TS, and TKN quantities of different types of faecal sludges

Variable	Septage [1]	Public toilet sludge [1]	Pit latrine sludge [2]	Fresh excreta
• **BOD** g/cap·day	1	16	8	45
• **TS** g/cap·day	14	100	90	110
• **TKN** g/cap·day	0.8	8	5	10
• **Volume** l/cap·day	1	2 (includes water for toilet cleansing)	0.15 - 0-20	1.5 (faeces and urine)

[1] Estimates are based on a faecal sludge collection survey conducted in Accra, Ghana.

[2] Figures have been estimated on an assumed decomposition process occurring in pit latrines. According to the frequently observed practice, only the top portions of pit latrines (~ 0.7 ... 1 m) are presumed to be removed by the suction tankers since the lower portions have often solidified to an extent which does not allow vacuum emptying. Hence, both per capita volumes and characteristics will range higher than in the material which has undergone more extensive decomposition.

4.4 Influence of Faecal Sludge Characteristics on Treatment Schemes

It can be concluded that **FS is a highly concentrated and variable material**. This implies that FS cannot be considered as a kind of wastewater. **Treatment thus calls for specific treatment schemes and design criteria**. Because of the high variability of this material, the design of a treatment system should not be based on standard characteristics but rather on the results obtained on a **case-to-case basis**. While substantial resources have been invested into the development of wastewater technologies, both low and high-cost, sustainable FS treatment technologies still require large inputs of field research, development and testing before they may be propagated as “state-of-the-art” options.

Based on the mentioned FS characteristics, a few aspects pertaining to the design of FS treatment systems can be summarized as follows:

- ♦ A first treatment step consisting in the separation of the solids from the liquid part (e.g. drying beds or sedimentation ponds/tanks) appears meaningful as most of the organic matter is contained in the solids part. Besides, it allows concentrating the helminth eggs in the separated solids fraction.
- ♦ The fresh, undigested sludge should be stabilized (e.g. through primary, anaerobic treatment in a pond or a reactor). Sludges which have already attained a high level of stabilization could be

directly dewatered (e.g. on planted or unplanted drying beds, sedimentation/thickening ponds) and further mineralized (on the beds/ponds or through thermophilic composting).

- If the main objective is to reduce environmental pollution (e.g. of the surface waters), the treatment system should attain high removal efficiencies for organic matter (TOC, COD) and nutrients (N and P).
- However, high N and P removal efficiencies lead to a “loss” of valuable nutrients. As these nutrients were originally taken up in the human body through food consumption, a sustainable resource management system should consist in closing the loops, i.e. allowing the nutrients to go back to the soil and be utilised for crop production. In this case, the treatment system should aim at creating valuable products for agricultural reuse. It should allow to stabilise and hygienise the biosolids (the solids fraction of the faecal sludge) while limiting nutrient losses[2].
- Faecal sludges and even more so the biosolids produced during solids/liquids separation processes, contain high levels of pathogens. Attention should therefore be paid to their safe handling (septic tanks emptying, haulage and treatment) and disposal. The treatment system should allow to hygienise the biosolids in such a way that its use as soil conditioner/fertilizer or its disposal does not involve health risks.

A viable treatment system should also be adapted to the specific conditions prevailing in a city or country. The system should:

- be low in capital and operating cost
- require low or modest levels of mechanization
- require minimum external energy input
- be compatible with the expertise available
- be compatible with the institutional framework

Low capital and operating cost treatment options are usually associated with large land requirements. When selecting a treatment option, a balance between economic and technical feasibility on the one hand and land requirement on the other hand must be found suiting the conditions and specific needs of the particular situation.

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[2] The liquid fraction of FS will exhibit, in most cases, too high a conductivity (dissolved solids concentration) to be suitable for irrigation.

5 Faecal Sludge Treatment

5.1 Overview of FS Treatment Options

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

Fig. 6 gives an overview of potential modest-cost options for 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 and will be presented in the following chapters.

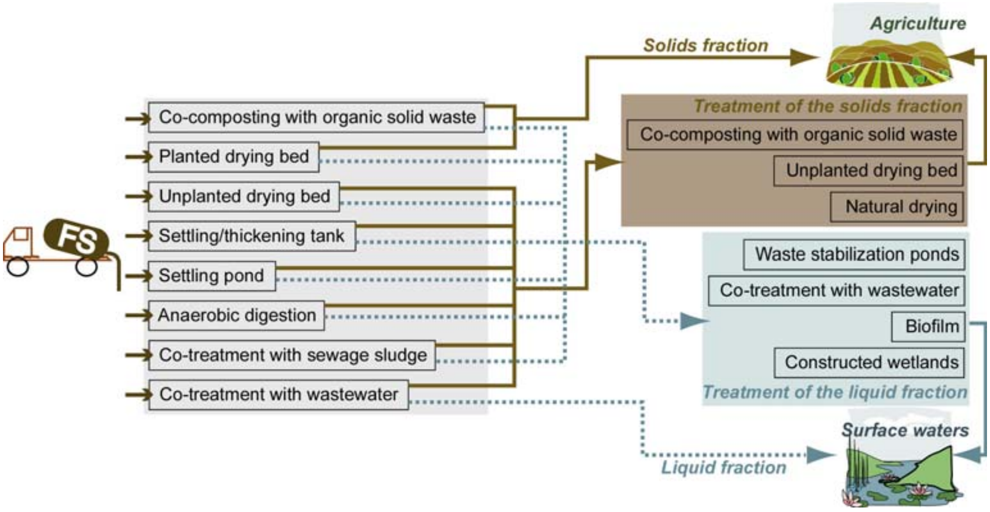

Figure 6 Overview of potential modest-cost options for faecal sludge

5.2 Solids-Liquid Separation

Faecal sludges typically exhibit total (TS) and suspended solids (SS) contents, which are very high, compared to wastewater. The separation of the solids and the reduction in volume of the fresh FS might be desirable e.g. when treating FS in ponds, be it separately or in conjunction with wastewater; as an option to produce biosolids conducive to agricultural use, and when intending the joint composting of FS solids and solid organic wastes.

Process disturbance by improper design and operation for solids separation has been repeatedly observed (Hasler, 1995; Mara et al., 1992). The settleability of FS can, as a first approach, be determined by settling tests in graduated cylinders at laboratory scale. Thereby, approximate information can be gained regarding (1), the rate of settling, (2), the density of the separated solids and (3), the quality of the liquid supernatant produced during the separation process. Settling conditions in cylinders or columns are usually more quiescent and thus more favorable than in full-scale units. Therefore, a scale-up or security factor must be applied when using settling test results to size full-scale settling-thickening units. The settleability of faecal sludges varies considerably depending on the type of sludge and specific location (U.S. EPA, 1984; Heinss et al., 1998). Results from FS settling tests carried out at the Water Research Institute (WRI) in Accra have shown that Accra's septage, which has an average TS contents of 12,000 mg/l (thereof, 60 % volatile solids, TVS), exhibits good solids-liquid separability (Larmie, S.A., 1994; Heinss et al., 1998). Separation under quiescent conditions is complete within 60 minutes (Fig. 7). This holds also for FS mixtures containing up to 25 % by volume of fresh, undigested sludge from unsewered public toilets.

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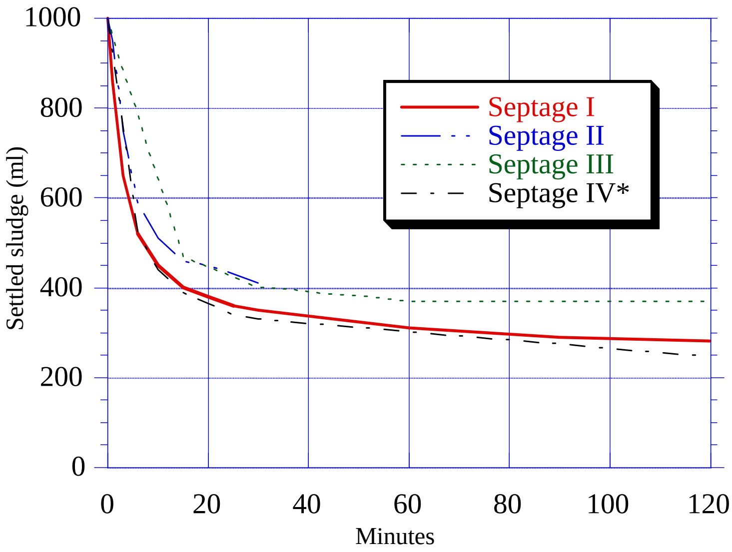

Fig. 7 *Results of settling tests performed in 1-litre cylinders (septage I-III) and in a cylinder of 20 cm diameter and 2 m height (septage IV*)*

The settling tests conducted at WRI with 4:1 mixtures of septage and public toilet sludge (SS = 4,500-18,400 mg/l), showed that theoretical SS removals of 80 % can be achieved. This resulted in SS concentrations in the supernatant of 1,200-3,500 mg/l. Investigations conducted at the full-scale settling tanks in the Achimota FSTP (see chapter 6.1) revealed that clear-liquid SS concentrations of ≤ 4,000 mg/l were achieved. The scale-up or safety factor would thus amount to 2 to 3. For septage, the cylinder tests simulated a 67-94 % removal of SS, resulting in supernatant SS of 150-700 mg/l (Larmie, 1994).

Settling tests were also conducted at AIT in Bangkok using septage of the City of Bangkok exhibiting an average SS concentration of 12,000 mg/l. Cylinder settling tests showed that separation is complete in 30-60 minutes and that SS concentrations in the supernatant of 400 mg/l are achieved (Koottatep, 2001; Kost and Marty, 2000).

The rate of accumulation of settleable solids, hence, the required solids storage volume, is the decisive design criteria for preliminary settling/thickening units or for solids storage compartments in primary ponds. The specific volume occupied by separated solids may be assumed as 0.10 – 0.15 m^3/m^3 of raw FS, depending on FS composition and on the period allowed for solids consolidation and thickening (Heinss et al., 1998).

Thickened solids densities in the settling/thickening tanks of the Achimota FSTP in Accra range from 14% TS in the settled solids layer to 16% TS in the scum layer by the end of the 4-8 weeks loading cycles (Larmie, 1994). The fairly thick scum layer is due to the share of undigested, high-strength sludges from unsewered public toilets and their associated intensive gas production causing buoyancy. In the septage settling ponds of the Alcorta (Argentina) pond scheme, TS in the settled solids amounts to about 18% after 6 months of septage loading (Ingallinella et al., 2000). Septage collected in Alcorta exhibits a SS content of approx. 8,000 mg/l (which might be associated with an estimated TS content of 12,000-15,000 mg/l). The specific volume of accumulated solids was only 0.02 m^3/m^3 of fresh septage, hence, 5-7 times less than that found in the settling/thickening tanks of the Achimota FSTP in Accra. This is due to the higher hydraulic (and solids) loading rates applied to the settling tanks in Accra (~ 0.7 m/d and 10 kg SS/ $m^2\cdot$day) as compared to the settling ponds in Alcorta (~ 0.1 m/d and 0.8 kg SS/$m^2\cdot$day).

5.3 Pond Treatment

5.3.1 The Use of Anaerobic Ponds

Given the high organic strength frequently encountered in faecal sludges, anaerobic ponds - with or without prior solids removal in separate settling units - are a feasible option as primary units in pond treatment schemes in warm climate. Use of facultative ponds for raw faecal sludges may often not be possible due to the high ammonia levels in the sludges accumulating in unsewered public toilets with zero or low-flush installations or in latrines with so-called watertight pits. Excessive ammonia (NH_3) contents will impair or suppress algal growth (see the section below on ammonia toxicity). Also, with the organic strength of faecal sludges being much higher than in wastewater, uneconomically large land requirements would result. Faecal sludges from unsewered public toilets emptied at intervals of 1-3 weeks only, are often little conducive to solids separation.

Primary treatment in anaerobic ponds might be the method-of-choice in developing countries to render such FS conducive to further treatment, viz. solids-liquid separation, dewatering/drying of the biosolids and polishing of the liquid fraction.

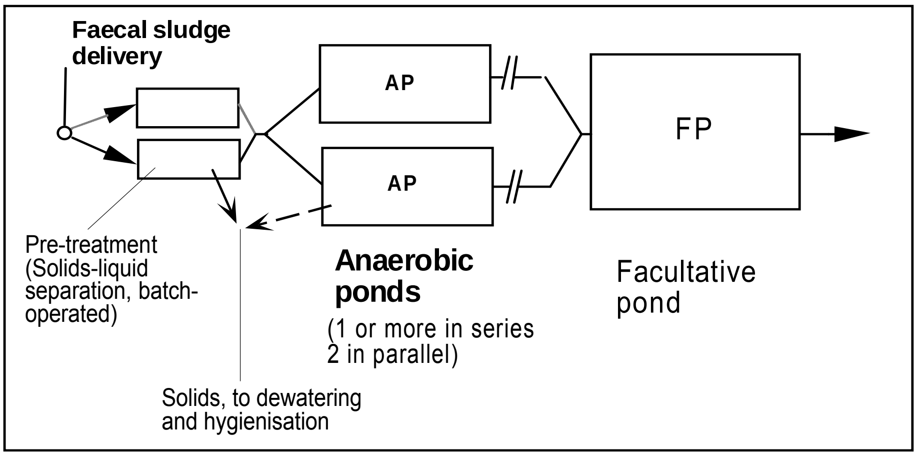

Fig. 8 Schematic Drawing of a WSP System Treating Low to Medium-Strength Faecal Sludges (Strauss et al., 2000)

Fig. 8 shows a WSP system suitable to treat low to medium-strength faecal sludges. It comprises pre-treatment units (tanks or ponds) for solids-liquid separation followed by a series of one or more anaerobic ponds and a facultative pond. This allows to produce a liquid effluent apt for discharge into surface waters. Effluent use in agriculture is not possible due to its high salinity.

5.3.2 Anaerobic pond loading and performance

The upper limit of the volumetric BOD loading rate for anaerobic ponds is determined by odour emissions and minimum pH threshold value at which methane formation ceases to work. It is, however, not possible to establish a commonly valid maximum BOD loading rate for anaerobic ponds at which odours will not become a problem. For high-strength waste such as FS, multi-stage pond systems comprising two or more anaerobic ponds in series each operated at the highest permissible BOD loading rate, will result in lowest land requirements (Uddin, 1970; McGarry and Pescod, 1970). Mara et al. (1992) suggest a safe volumetric BOD loading rate of 300 g BOD/m^3·d for anaerobic wastewater ponds at temperatures above 20 °C. A tolerance value of $\leq$ 400 g BOD/m^3·d is given at which odour emissions can still be avoided. More practical research is required to establish the maximum safe loading rates for wastes such as septage and septage/high-strength FS mixtures in warm climate. It is hypothesized that organic loading rates of $\geq$ 400 g/m^3·d might be admissible.

Methanogenesis is the rate-limiting step in anaerobic metabolism. Products from the preceding acetogenesis reaction may accumulate and lead to a pH decrease. Optimum pH for methanogenesis amounts to 6.8 - 7.8. Based on various anaerobic digestion studies, McGarry and Pescod (1970) found that pH 6.0 probably constitutes the absolute, lowest limit for anaerobic ponds in the tropics when treating high-strength wastes. Determination of the maximum BOD loading rate beyond which pH is likely to drop below this threshold value is, therefore, important. A reason why anaerobic ponds treating FS might be loaded at higher rates than anaerobic ponds treating wastewater is the high alkalinity of FS imparted by the formation of ammonia bicarbonate (NH_4HCO_3) during the hydrolysis of urea (H_2NCONH_2). A high buffer capacity results. This acts as a safeguard against the drop in pH caused by the potential predominance of acid over methane-forming bacteria induced by excessive organic loading rates.

5.3.3 Ammonia Toxicity

Ammonia levels in faecal sludges

Average concentrations of ammonia (NH_4 + NH_3-N) in the faecal sludges collected in Accra, Ghana, range from 330 mg/l in septage to 3,300 mg/l in high-strength, rather fresh faecal sludges from unsewered, low or zero-flush public toilets (Heinss and Larmie, 1998). Hasler (1995) found average (NH_4 + NH_3)–N concentrations of 1,300 mg/l in FS from so-called watertight pits in Cotonou, Bénin. TKN levels in sludges collected from watertight pits in Ouagadougou ranged from 1,000 to 5,000 mg/l (Rehacek, 1996). NH_4 and NH_3 are in a temperature and pH dependant relationship. At 30 °C and pH 7.8, NH_3 amounts to approximately 5 % of (NH_4 + NH_3)–N. At pH 8.2, the share of NH_3 is 10 %. NH_3 is the potentially toxic component in anaerobic processes (inhibition of the methanogenic bacteria) and in facultative ponds (inhibition of algal growth).

The faecal sludge treatment plant (FSTP) at Achimota in Accra comprises settling-thickening tanks followed by a series of 4 stabilisation ponds, all operating anaerobically. In the primary pond, average (NH_4 + NH_3)–N concentrations amounted to 1,000 mg NH_4-N/l during the monitoring campaigns conducted from 1994-1997. Average maximum air temperatures were 30 °C and average pH was 8. The corresponding NH_3-N level was 75 mg NH_3-N/l. The average (NH_4 + NH_3) –N concentration in the pond 4 effluent was 700 mg/l. Natural NH_3 stripping, a very slow process, may explain the loss of NH3 betwen pond 1 and 4 (total retention = 25 days). Mean NH_3–N levels in ponds 2-4 ranged from 50-70 mg/l.

Ammonia Toxicity to Methane-Forming Bacteria

Siegrist (1997) found a 50 % growth inhibition of methane-forming bacteria in digesters treating wastewater treatment plant sludge at NH_3-N/l concentrations of 25-30 mg/l. Whether these results equally apply to anaerobic ponds remains to be examined.

Ammonia Toxicity to Algae

Tolerance limits for *Chlorella vulgaris* and *Scendesmus obliquus* are 6 and 31 mg NH_3-N/l, respectively (Kriens, 1994). These algae commonly form an important share of the algal biomass in facultative ponds. Some algal species are reportedly able to adapt to and withstand concentrations of up to 50 mg NH_3-N/l under specific conditions (Mara and Pearson, 1986). In the Achimota FSTP in Accra, excessive ammonia NH_3-N concentrations of 50-70 mg/l in ponds 2 through 4 were the likely cause for the suppression of algae and, hence, of the development of facultative pond conditions with an upper, aerobic layer.

The (NH_4+NH_3)-N concentration in the influent to a pond supposed to work in the facultative mode, should not exceed 400 mg/l (Heinss and Strauss, 1999).

Possible methods to counteract ammonia toxicity to algae include intermittent, forced surface aeration to oxidize, lime dosing and recirculation, or a mixture thereof. The aim is to lower the ammonia concentrations and, hence, to eliminate NH_3 toxicity effects.

5.3.4 Problems encountered when co-treating FS and wastewater in waste stabilisation ponds

Where waste stabilisation ponds exist to treat municipal wastewater, and where these are used to co-treat FS, a number of problems may arise. In many cases, the problems are linked to the fact that the wastewater ponds were not originally designed and equipped to treat additional FS load. Common problems are:

- Excessive organic (BOD) loading rates may lead to overloading of the anaerobic and facultative ponds. This overloading causes odour problems and prevents the development of aerobic conditions in the facultative pond.

- Ponds may fill up with solids at undesirably fast rates due to the high solids content of FS.

- Fresh, undigested excreta and FS contain high NH_4 concentrations. These may impair or even prevent the development of algae in facultative ponds.

Preventative measures, such as the addition of a solids separation step ahead of the first pond, and the consideration of a maximum admissible FS load can avoid the aforementioned problems. Like in pond schemes exclusively treating FS, the (NH_4+NH_3)-N concentration in the influent to a pond supposed to work in the facultative mode, may not exceed 400 mg/l.

6. Specific treatment options

6.1 Sedimentation/Thickening Tanks – Accra/Ghana

Field studies were conducted at the Achimota Faecal Sludge treatment plant in Accra/Ghana from 1993-97 to assess the performance of two parallel sedimentation/thickening tanks and a series of four ponds treating the supernatant from the solids-liquid separation step (see chapter 5.2). The treatment plant receives around 150 m3 FS/day loaded by vacuum trucks; 20 to 40 % of which originate from unsewered public toilets and 60 to 80% from septic tanks.

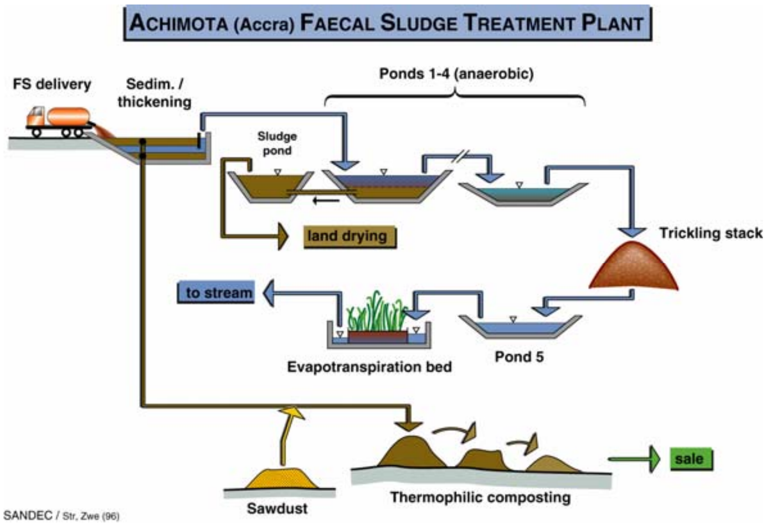

Figure 9 Scheme of the Achimota Faecal Sludge Treatment Plant

The first treatment step consists of a solids-liquid separation in two parallel, batch-operated settling/thickening tanks. The settled sludge is stored in the tank and the supernatant flows from the tank into the following pond. The intensive anaerobic degradation of the fresh public toilet sludge which has been stored for 1-2 weeks only prior to collection taking place in the settling tank causes the solids to rise to the surface and thus hinders effective settling. Results of 4 years of monitoring reveal that the performance of the sedimentation tanks strongly depends on the plant’s state of maintenance and operation. The loading and resting periods should not exceed 4 to 5 weeks each. In practice, the tanks are emptied every 4 to 5 months, only. This reduces the efficiency of the solids-liquid separation process considerably. Settling tanks removal efficiencies are shown in Figure 10. Design recommendations for settling/thickening tanks are found in Heinss et al. 1998.

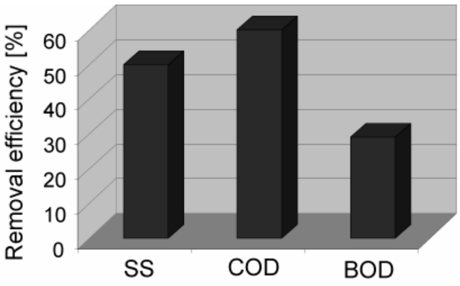

Figure 10 Removal efficiency of the settling tank (Heinss and Larmie, 1998)

6.2 Drying Beds – Accra/Ghana (Heinss et al., 1998)

Sludge drying beds, if suitably designed and operated, can produce a solids product, which may be used either as soil conditioner or fertiliser in agriculture, or deposited in designated areas without causing damage to the environment. In most cities, the solids removed from the drying beds after a determined period (several weeks to a few months) require further storage and sun drying to attain the hygienic quality for unrestricted use. Where dried sludge is used in agriculture, helminth (nematode) egg counts should be the decisive quality criterion in areas where helminthic infections are endemic. A maximum nematode (roundworm) egg count of 3-8 eggs/g TS has been suggested by Xanthoulis and Strauss (1991).

Although drying bed treatment is usually not classified as a solids-liquid separation process, it serves to effectively separate solids from liquids and to yield a solids concentrate. Gravity **percolation** and **evaporation** are the two processes responsible for sludge dewatering and drying. In planted beds, **evapotranspiration** provides an additional effect. Unplanted and planted sludge drying beds are schematically illustrated in Fig. 11. A frequently observed phenomenon is the fact that when fresh, anaerobic sludges are loaded onto the drying beds, the sludge solids rise to the surface due to degasification. This enhances the solids-liquid separation process and reduces resistance to seepage. Evaporation causes the mud to crack, thereby leading to improved evaporative water losses and enhanced drainage of the sludge liquid and rainwater.

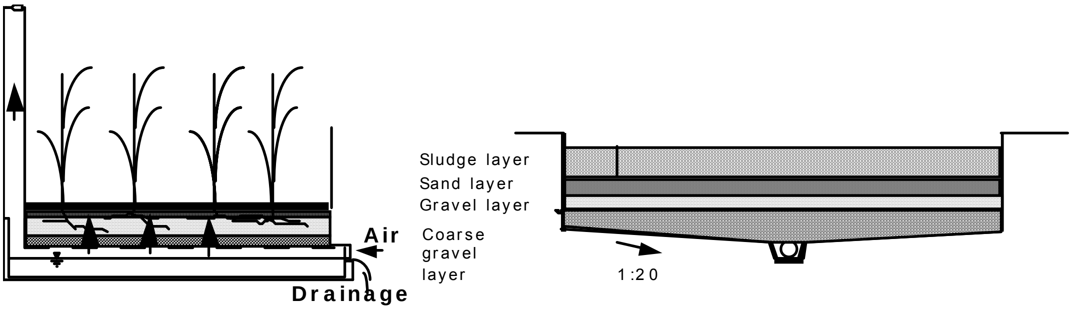

Fig. 11 Planted and unplanted sludge drying beds (schematic)

From 50 - 80 % of the faecal sludge volume applied to unplanted drying beds will emerge as **drained liquid** (percolate). The ratio between drained and evaporated liquid is dependent on type of sludge, weather conditions and operating characteristics of the particular drying bed. In planted drying beds, this ratio is likely to be much lower. Drying bed percolate tends to exhibit considerably lower levels of contaminants than settling tank supernatant. This liquid will, nevertheless, also have to be subjected to a suitable form of treatment (e.g. in facultative ponds).

Pescod (1971) conducted experiments with unplanted sludge drying beds in Bangkok, Thailand. According to the experiments, maximum allowable solids loading rates can be achieved with a sludge application depth of 20 cm. To attain a 25 % solids content, drying periods of 5 to 15 days are required depending on the different bed loading rates applied (70 - 475 kg TS/m^2·yr).

Results from pilot sludge drying beds obtained by the Ghana Water Research Institute (WRI) in Accra/Ghana indicate their suitability for public toilet sludge, septage/public toilet sludge mixtures and primary pond sludge (TS = 1.6 - 7 %). Experiments were conducted during the dry season with sludge application depths of ≤ 20 cm.

Sludge dewatered to ≤ 40 % TS in the Accra/Ghana experiments, still exhibited considerable **helminth egg** concentrations. This is not surprising as the drying periods amounted to 12 days at the most. In the few experiments where ≥ 70 % TS contents were attained, no helminth eggs were recovered. The database is, however, yet too scarce to ensure complete egg elimination at this level of dryness. Based on current knowledge of *Ascaris* egg survival, several months of storage at temperatures of ≥ 25 °C or sludge water contents of ≤ 5 % (TS ≥ 95 %) (Feachem et al. 1983) must be attained to ensure complete egg inactivation. High ambient temperatures will yield high levels of dryness fairly rapidly. In such a situation, a few weeks of storage in layers ≤ 20-30 cm on drying beds or on open ground may suffice to attain the desired level of residual egg concentration. To guarantee a hygienically safe product for use in agriculture, further controlled sludge drying experiments should be conducted to determine safe drying periods and required sludge dryness.

When the contaminant levels in the drained liquid of the pilot beds in Accra were compared with the levels in the raw sludges applied, the following average removal rates were calculated from 12 bed loadings:

- Susp. solids: ≥ 95 %
- COD: 70-90 %
- Helminth eggs: 100 %
- NH_4: 40-60 %

6.3 Land Requirement for Sedimentation/Thickening Tanks and Sludge Drying Beds (Heinss et al., 1998)

Approximate land requirements for settling/thickening tanks and for unplanted sludge drying beds can be estimated, based on the monitoring results obtained in Accra/Ghana (see chapters 6.1 and 6.2 above). Table 8 provides an estimate of plant size in terms of square meters required per capita.

Table 8 Land requirements for settling/thickening tanks and drying beds

	Attainable TS %	Assumed Loading cycle	TS loading kg TS/m^2·yr	Required area m^2/cap[1)]
Sedimentation/ Thickening Tank	≤ 14	8-week cycle (4 weeks loading + 4 weeks consolidating; 6 cycles annually); two parallel settling tanks	1,200	**0.006**
Sludge Drying Bed (unplanted)	≤ 70	10-day cycle (loading-drying-removing; 36 cycles annually)	100 - 200	**0.05**

1) Assumed parameters: FS quantity = 1 litre/cap·day; TS of the untreated FS = 20 g/l
The dewaterability and thickenability of the faecal sludges are important factors determining area requirements.

Sedimentation/thickening tanks require a much smaller per-capita area than sludge drying beds, as the process of separating settable solids requires relatively short hydraulic retention. The space required to store the separated solids bears little on the area requirement. In contrast to this, dewatering and drying of thin layers of sludge on sludge drying beds calls for comparatively long retention periods. Organic and solids loads in the percolate of drying beds are significantly lower than in the effluent of sedimentation/thickening tanks. Hence, less extensive treatment is necessary. Percolate (underdrain) flows from drying beds will amount to 50-80 % of the raw FS deliveries only, whereas the supernatant flows from settling/thickening tanks amount to 95 %, approximately, of the raw sludge discharged into the tanks.

6.4 *Constructed Wetlands for the Treatment of Septage – Bangkok/Thailand*

Constructed Wetlands consist of gravel/sand/soil filters planted with emergent plants such as reeds, bulrushes or cattails. Three pilot constructed wetlands – planted with cattails – have been investigated since early 1997 at the Asian Institute of Technology (AIT) in Bangkok. The 3x25 m^2 pilot plant is equipped with drainage and ventilation systems (Fig. 12) and it treats the septage from approximately 3,000 people. It was first acclimatised with wastewater and gradually fed with Bangkok septage in a vertical-flow mode of operation. The percolate is collected and pumped into an attached-growth waste stabilisation pond system. The objectives of the project were to assess the suitability of this option for the treatment of septage and establish design and operational guidelines.

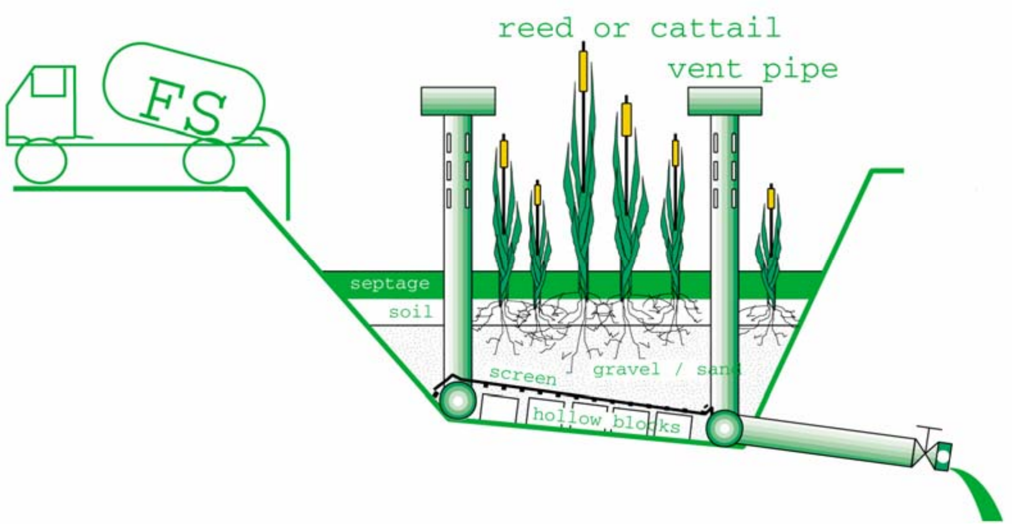

Figure 12 Pilot plant constructed wetlands at the Asian Institute of Technology

The system was monitored under different operating conditions. Parameter tests comprised variations in solids loading rate, sludge loading frequency and percolate ponding period. Ponding of the percolate water was initiated to reduce the plant wilting observed especially during the dry season. Operating conditions under which maximal removal efficiencies were measured and cattails didn't show any wilting symptoms are the following:

"Optimum" operating parameters

• Solids loading rate	250 kg TS/m^2*a
• Sludge loading frequency	1/week
• Percolate ponding	6 days

A 6-day percolate ponding has a positive impact on plant growth and shows the highest N removal efficiencies as it creates conditions which promote nitrification and denitrification reactions. However, as earlier mentioned, a high nitrogen removal efficiency may not be considered as a positive effect if agricultural reuse of the percolate is desired. In this case, the shortest ponding period guaranteeing a healthy plant growth should be chosen so as to reduce nitrogen losses. Besides operating conditions, operation time also influences the CW removal efficiency. It was observed that the solids removal efficiency increased after four months of operation. This is probably due to the increase of the sludge layer and hence in filter efficiency.

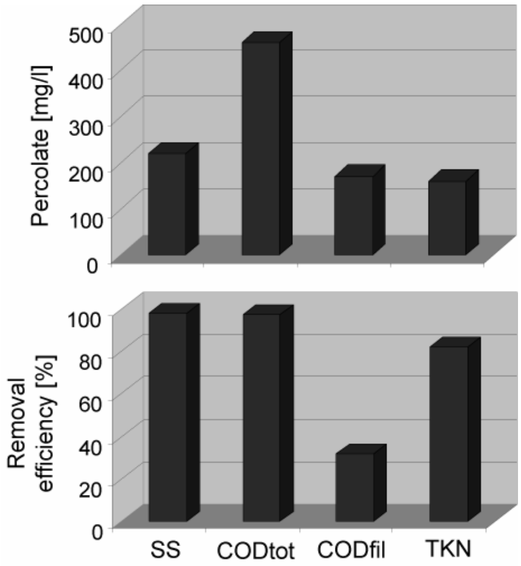

Figure 13 Percolate concentration and removal efficiency of the constructed wetlands (average data based on 12 composite samples)

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 to maintain the dewatering capacity of the filter during several years. Sludge is due to be removed from the filters only after 5 to 6 years. Besides, aerobic conditions prevail and support mineralisation and nitrification. The investigations conducted at AIT allowed establishing recommendations for the design and mode of operation of such treatment systems (Koottatep et al., 1999a, Koottatep et al., 1999b). They also allowed identifying cattail growth as an aspect, which has to be given particular care (acclimatization, water balance).

Table 9 *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

Table 9 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 (see chapter 3). 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 to contaminate the non polluted septage from the other areas and hence the treated biosolids intended to be used as soil conditioner (Ingallinella et al, 2001).

6.5 Waste Stabilization Ponds for the Treatment of FS Supernatant – Accra/Ghana

The treatment system – two twin batch-operated sedimentation tanks followed by a series of ponds treating septage and public toilet sludge – is described under chapter 6.1. Average performance of the treatment system are illustrated in figure 14:

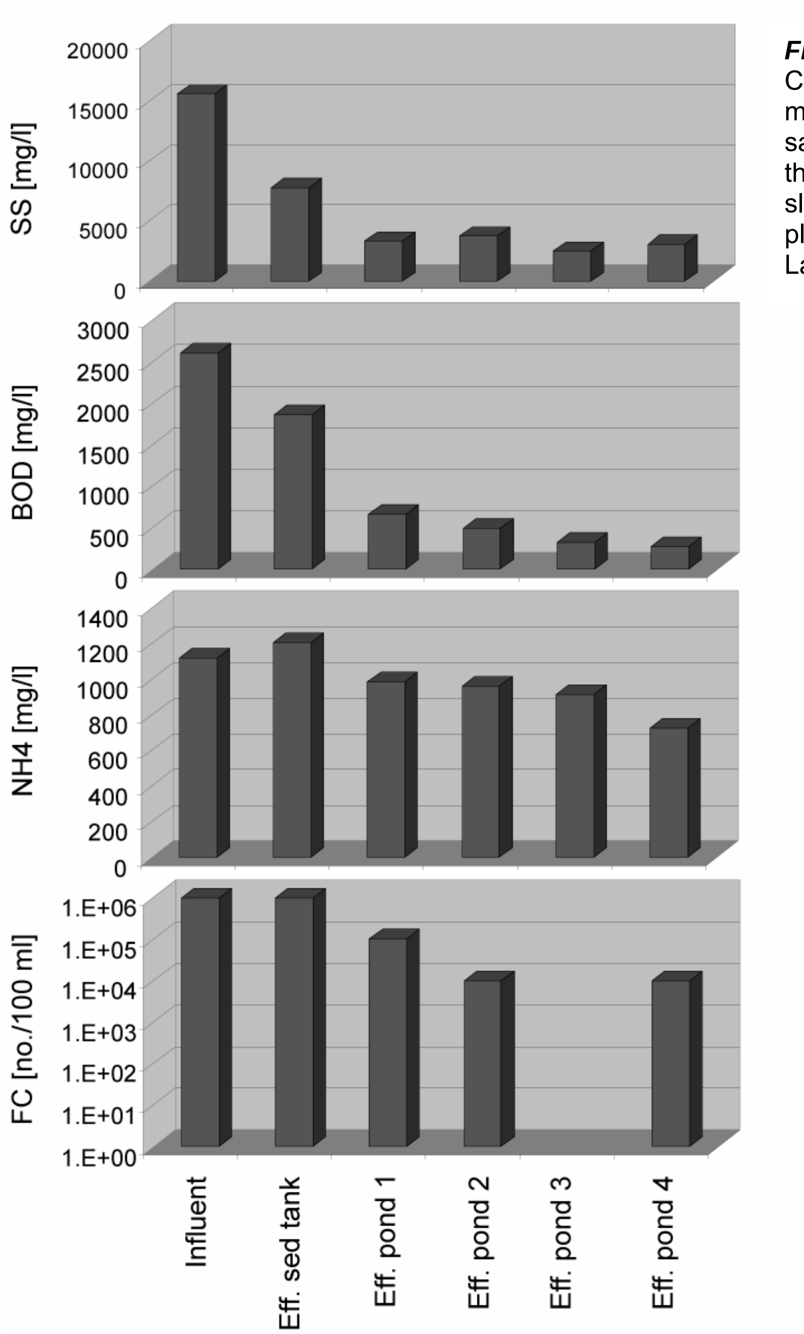

Figure 14
Concentrations measured at different sampling points at the Achimota faecal sludge treatment plant (Heinss and Larmie, 1998)

In addition to its bad settling behavior (see chapter 6.1), public toilet sludge is characterized by the fact that it exhibits very high ammonia concentrations. The average NH_4 concentration in the settling tank effluent amounts to more than 1,000 mg/l, corresponding to more than 60 mg/l NH_3. Such high ammonia levels are toxic for algae. Therefore, facultative pond conditions comprising algae as oxygen suppliers and allowing further removal of organic matter and inactivation of pathogens do not develop. Open questions thus relate to the development of measures aiming at reducing ammonia levels to below the critical threshold.

6.6 Co-Treatment of Septage and Wastewater in Ponds –Alcorta/Argentina

In large cities of Latin America, the majority of households, which avail of sanitation systems, are usually served by sewered sanitation. Many small towns, however, are largely or even fully served by on-site sanitation systems.

In Alcorta (Santa Fé), a town of 4,000 inhabitants, 35% of the population are connected to a sewer system whereas 65% use septic tanks and cesspools which are emptied by vacuum trucks. A series of two stabilisation ponds was put in operation in 1987 to treat both wastewater and septage. A monitoring program of the system (93-95) revealed that the capacity of the first pond had been reduced in half due to the high solids content of septage. Based on these investigations conducted by the University of Rosario, a septage pre-treatment consisting of two sedimentation ponds was constructed in July 98 (Fig. 15). The two ponds are operated alternatively: one pond is loaded while the sludge accumulated in the other one is drying. The idea is that the settled sludge should be easy to handle and partly mineralised/hygienized at the end of the drying cycle. A monitoring program was initiated by the Sanitary Engineering Centre of the University of Rosario (Ingallinella et al., 2000). Loading and drying cycles were chosen to be half a year each and the average organic loading rate amounted to 80-600 g BOD/m3*d. The effluent of the sedimentation ponds is co-treated with wastewater in a series of two waste stabilisation ponds.

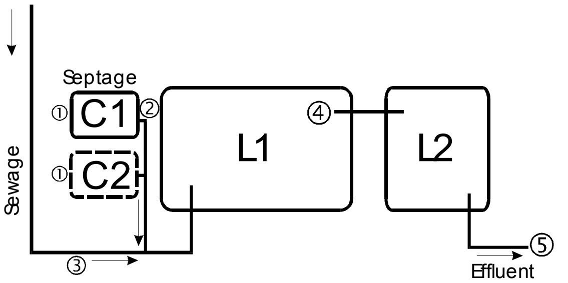

Figure 15
Co-treatment of septage and wastewater (schematic)

The sedimentation ponds were designed according to the following criteria:

- The accumulated sludge layer should be less than 0.5 m
- The sludge accumulation rate amounts to 0.02 m3/m3

A monitoring program aiming at assessing the feasibility of using sedimentation ponds as a pre-treatment for septage in a septage/wastewater co-treatment system started in January 99. The results of this three-year monitoring period show that the efficiency of the ponds treating septage (sedimentation and degradation) is such that the effluent quality is similar to the wastewater quality by low as well as by high BOD loading rate. Raw septage, sedimentation pond effluent and wastewater quality are illustrated in figure 16.

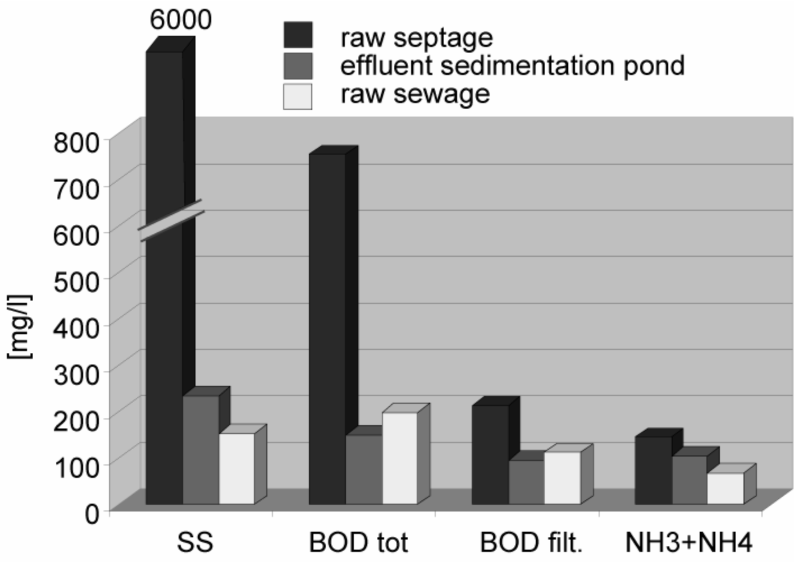

Figure 16

Raw septage, effluent of the sepatge pond and raw sewage concentration measured in Alcorta during the first monitoring cycle (14 campaigns). (Ingallinella et al., 2000)

Analyses of the dewatered sludge show that the level of humidity reached at the end of the drying cycle enables an easy handling of the sludge. Open questions concerning pond behavior by very high BOD loading rate (ca. 800 g/m3*d), system efficiency with regard to pathogens removal and feasibility of reusing biosolids in agriculture will be dealt with in the next project phase.

7. Evaluation of Treatment Options

Prior to conducting an evaluation of treatment options for a selected city, a comprehensive faecal sludge management concept must be established. It will describe the organisational/institutional, financial, legal and technical aspects of the entire FS management scheme from the sanitary facility to the final disposal or reuse of treatment products and include a description of adequate

- sanitary infrastructure types,
- collection system,
- transport system,
- treatment goals, level of decentralisation and selected potential sites and
- reuse/disposal schemes of the treatment products

The management concept will be based on the assessment of:

- current management practices and their shortcomings,
- existing sanitary infrastructure and trends
- stakeholders customs, needs and wishes and on
- the prevailing socio-economic, institutional, legal and technical conditions as well as
- the general urban development concept

Based on the management concept, treatment goals in particular, an evaluation of options (see chapter 5.1 for a sketch of potential treatment options) can be conducted.

The first step – pre-selection – consists in excluding unfeasible options. For example, if the city does not avail of a sewer system, the option “co-treatment with wastewater” will be excluded. The option anaerobic digestion with biogas use must be excluded if, for example, technical expertise is lacking.

The second step consists in comparing the potentially feasible options chosen during the pre-selection step according to selected criteria, for example:

Table 10 Criteria for selecting FS treatment options for Nam Dinh (Klingel et al, 2001)

Performance criteria	**Process simplicity and reliability criteria**	**Cost-related criteria**
• Consistency and biochemical stability of biosolids • Hygienic quality of solids • Quality of liquid effluent	• O+M requirements • Skills required for operation and supervision • Risk of failure related to installations or to managerial or procedural measures:	• Land requirement. • Investment costs • Operation and maintenance cost

The following table illustrates the evaluation process of three pre-selected options that has been conducted for the city of Nam Dinh, Vietnam:

Table 11 Evaluation of treatment options for Nam Dinh (Klingel, 2001)

Criteria	**Constructed Wetlands**	**Drying Beds**	**Settling tanks + pond**
Performance			
a) Physical quality of solids	Sludge mass of initial m.: 3 % Water content: 70% (+) high volume reduction (+) low water content, solids easy to handle (spadable)	Sludge mass of initial m.: 4.5 % Water content: 60 % (+) low water content, solids easy to handle (spadable)	Sludge mass of initial m.: 14 % Water content: 85 % (-) water content too high, settled sludge neither pumpable nor spadable, bulking agent needed, resulting in volume increase
b) Hygienic quality of solids	(+) safe for reuse without post - treatment	(-) post-treatment required for safe reuse	(-) post-treatment required for safe reuse
c) Quality of liquid effluent	(-) Vietnamese discharge standard not met (+) Quality relatively close to standard, minimal polishing treatment required	(-) Vietnamese discharge standard not met	(-) Vietnamese discharge standard not met
Simplicity and Reliability of process			
d) O+M requirements	(+) Sludge removal only once every 2 years (every 4 years for each unit) (-) Pumping required for septage loading and percolate evacuation (-) Care for plant growth, periodical harvest and control of bed humidity	(-) Sludge removal 2-3 times a week (once every 10-15 days for each unit) (-) Pumping required for septage loading and percolate evacuation (-) Regular replenishment of sand	(+) No pumping required (+/-) Sludge removal from tanks every 4 weeks (-) Sludge removal difficult because of high water content, mixing with bulking agent (-) Regular supplying of bulking agent (rice husks) required
e) Skills required for operation and supervision	(+) Day to day operation: unskilled labor Supervision: technical degree	(+) Day to day operation: unskilled labor Supervision: technical degree	(+) Day to day operation: unskilled labor Supervision: technical degree
f) Risk of failure	(-) Problems with healthy plant growth, e.g. because of bad regulation of bed humidity, have neg. impact on filter permeability.	(-) Loss of filter property if sand is not replenished regularly (-) Increased drying time because of wet climate (-) If post-treatment is not properly executed, reuse is not safe	(-) Loss of settling capacity if the tanks are not desludged in the designed intervals (-) Sludge removal might be difficult and avalability of bulking agent might be limited, leading to prolonged desludging intervals (-) If post-treatment is not properly executed, reuse is not safe
Cost			
g) Land requirement	Net treatment area: 200 m^2	Net treatment area: 250 m^2 (-) highest land requirement	Net treatment area: 200 m^2 (+) more land-use efficient with higher septage load
h) Investment costs	23,200 $	24,350 $	24,100 $
i) Operation and maintenance	1,400 $/year	2,010 $/year	6,180 $/year

The third step consists in the weighing of the different criteria by decision-makers and the determination of the most appropriate option(s) that fit into the faecal sludge management concept.

8. Cost and Land Requirements

8.1 Cost

Investment and O+M cost of FS collection and treatment must be determined on a case-to-case basis, as local conditions are decisive. The following factors play a role:

- Economic indicators (land price, labour cost, interest rates, gasoline prices)
- Possible income from sales of treatment products (e.g. hygenised biosolids or compost; biogas)
- Site conditions (permeability, groundwater table)
- Haulage distances and traffic conditions
- Economy of scale (plant size)
- Legal discharge standards

Further to this, the availability and choice of construction material, whether produced locally or imported, play a role.

There is no published literature on FS management cost and no systematic search or review of construction and O+M cost for FS management schemes has been made by SANDEC to date. Consequently, only scarce information on cost is available. Below, some limited cost information is provided for septage treatment in constructed wetlands; for the treatment of septage + public toilet sludge in two pond systems in Ghana (Annoh, 2001), and for the treatment of septage/public toilet sludge mixtures by sludge drying beds (Annoh 1995).

Heinss (1999) estimated the annualised cost per ton of TS treated (investment and O+M) for constructed wetland plants treating septage from 10000-30000 inhabitants. The calculations are based on experience made with a pilot plant installed and tested by AIT, Bangkok, during the past four years. The plant treats septage from approximately 3000 inhabitants (Heinss, 1999). Further to this, he estimated the cost of polishing treatment of the wetlands percolate by waste stabilisation ponds. Whenever possible, FS treatment cost should be evaluated in conjunction with collection cost, considerations of optimal plant size and availability of land of required size. As discussed in Chpt. 2, the strategic option-of-choice in FS management is to plan, in large towns or cities, for multiple, semi-centralized rather than for single, centralized treatment sites. FS collection becomes uneconomical and indiscriminate dumping of FS proliferates if haulage distances are too long. There probably exists economy-of-scale with larger treatment plants, but this may be less pronounced than commonly assumed. For the ideal situation where a FS constructed wetlands plant would be located in the centre of a chosen urban district, the cost were estimated as shown in Table 12. For this, the following assumptions were made or real cost figures used:

Depreciation period:	20 years
Interest rate:	5 %
Skilled worker's salary:	US $ 350 p. year
Land price:	US $ 8/m^2
Daily per capita TS contribution:	14 g/cap•day

Item	**Annual cost (US $ per ton TS)**
Constructed wetlands:	
- O+M	**47**
- Capital cost (plant)	**32**
- Capital cost (land)	**3**
Total constructed wetlands	**82**
Polishing of percolate in ponds	
- capital and O+M	**10**
FS collection	
- km-dependant cost	**6**
- Capital cost for vacuum tanker	**32**
Overall annual cost per ton of TS treated:	**US $ 130**

Table 12 *Annual cost of FS collection and treatment of septage by constructed wetlands (Heinss 1999)*

Annoh (2001) has reported the following investment cost (excluding land) for the Teshie FSTP in Accra (commissioned in 1996) and for the Buobai FSTP constructed in Kumasi in 2001. Both plants consist of ponds. At Teshie, a preliminary settling/thickening tank is used for solids-liquid separation, while at Buobai, the primary anaerobic ponds are used for this.

Teshie FSTP, Accra (1996)

US $ 900 per m^3/d of treated FS (approx. 4:1 septage/public toilet sludge mixture), excluding treatment of the biosolids. Assuming an average TS content of 25 kg/m^3, 20 years of depreciation and 5 % interest rate:

→ Cost per ton of TS ≅ US $ 14

Buobai FSTP, Kumasi (2001)

US $ 2200 per m^3/d of FS treated (septage: PTS ≅1:1) excluding treatment of the biosolids. Assuming an average TS content of 25 kg/m^3, 20 years of depreciation and 5 % interest rate:

→ Cost per ton of TS ≅ US $ 35

Although these figures are not directly comparable wit the ones presented above for constructed wetlands, they appear reasonable, as CW constitute a more complete FS treatment system, viz. dewatering and biochemical stabilisation, than ponds. Hence, the higher unit cost for CW.

Investment cost for pilot sludge drying beds measuring 3.5 x 3.5 m installed in Accra in 1995 amounted to US $ 70/m^2 net bed surface (Annoh, 1995). Assuming a sludge loading thickness of 30 cm, TS = 25 kg/m^3, a loading and drying cycle of 3 weeks and, hence, 17 loading cycles per year, this results in annualised investment cost of US $ 140 per ton TS, approximately. The cost is high compared to the ones estimated for the above-mentioned systems. Yet, considerable economies-of-scale might be expected when upscaling the small pilot drying beds to real-size installations.

9.2 Land requirements

Limited information on total land requirements for low-cost FS treatment options have been collated to date. Information received and extrapolations made for the systems described above (pond and constructed wetlands treatment) yielded land requirements ranging from

0.02 – 0.07 m2 per capita

(Heinss et al., 1998). The figures may serve for order-of-magnitude estimates. They may, however, not be used for detailed costing as they were calculated for widely differing situations in Africa (Ghana) and Asia (Bangkok).

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