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Review article

Ecological Sanitation—a way to solve global sanitation problems?

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Abstract

Today about 2.4 billion people in rural and urban areas do not have access to adequate sanitation services. Within 20 years, it is expected that an additional 2 billion will live in towns and cities, mainly in developing countries, demanding sanitation. Still over 90% of sewage in developing countries is discharged untreated, polluting rivers, lakes and coastal areas. Conventional sanitation concepts, based on flush toilets, a water wasting technology, are neither an ecological nor economical solution in both industrialized and developing countries. The water-based sewage systems were designed and built on the premises that human excreta are a waste; suitable only for disposal and that the environment is capable of assimilating this waste.

A sanitation system that provides Ecological Sanitation (EcoSan) is a cycle—a sustainable, closed-loop system, which closes the gap between sanitation and agriculture. The EcoSan approach is resource minded and represents a holistic concept towards ecologically and economically sound sanitation. The underlying aim is to close (local) nutrient and water cycles with as less expenditure on material and energy as possible to contribute to a sustainable development. Human excreta are treated as a resource and are usually processed on-site and then treated off-site. The nutrients contained in excreta are then recycled by using them, e.g., in agriculture.

EcoSan is a systemic approach and an attitude; single technologies are only means to an end and may range from near-natural wastewater treatment techniques to compost toilets, simple household installations to complex, mainly decentralised systems. These technologies are not ecological per se but only in relation to the observed environment. They are picked from the whole range of available conventional, modern and traditional technical options, combining them to EcoSan systems.

The paper presents an introduction to EcoSan principles and concepts including re-use aspects (available nutrients and occurring risks), and case studies of EcoSan concepts in both industrialized and developing countries.

Keywords: Ecological Sanitation; Global sanitation; Closed-loop system

Contents

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1. Introduction

Since the UN Earth Summit 1992 in Rio de Janeiro, Brazil, people have been discussing seriously about environmental pollution, exploitation and limitation of natural resources all over the world. The intake capacity and overloading of the natural environment with emissions and waste are reaching a critical point strengthened by rapid urbanisation, fast population growth and migration into urban centres. The effects are manifold, but the most affected are the poorest in society. Especially women and children in developing countries suffer most from water-related diseases and the damaged environment (WHO/UNICEF, 2003).

The main burdens are the consequences of inadequate drinking water sources and lack of sanitation facilities, which causes undeniable health and environmental problems especially water pollution (Fig. 1). Worldwide, one in five persons does not have access to safe and affordable drinking water and every second person does not have access to safe and sufficient sanitation (WHO/UNICEF, 2000). The majority of people, which have to struggle with contaminated drinking water and accompanying illnesses, live in Asia and Africa (UN, 2003; Gordon et al., 2004).

The World Health Organisation (WHO/UNICEF, 2003) stated that, “around 1.1 billion people globally do not have access to improved water supply sources whereas 2.4 billion people do not have access to any type of improved sanitation facility. About 2 million people die every year due to diarrhoeal diseases; most of them are children less than 5 years of age. The most affected are the populations in developing countries, living in extreme conditions of poverty, normally peri-urban dwellers or rural inhabitants. [. . .] Providing access to sufficient quantities of safe water, the provision of facilities for a sanitary disposal of excreta, and introducing sound hygiene behaviours are of capital importance to reduce the burden of disease caused by these risk factors.”

Fig. 1. Water pollution, Kampala, Uganda.

The UN Millennium Development Goals (UN, 2000), agreed at the UN Summit 2000, encourage that half of the people without access to safe drinking water today should have access by 2015. This goal was completed at the UN World Summit 2002 in Johannesburg, South Africa, with the formulation of the demand for access to basic sanitation (UN, 2002).

But sanitation is not only a problem concerning developing countries. However, different problems have to be solved in industrialized countries: Over the decades, the main focus of sanitation has changed from health aspects to the reduction of environment impacts (e.g., Gujer, 1999; Cooper, 2001). Over the past decades, mainly centralized systems have been built to serve the densely populated areas (Wilderer, 2001). These centralized systems result in large investment costs especially for the sewer lines required (Lettinga et al., 2001). For rural areas that still suffer from adequate sanitation, sustainable solutions modelled on decentralized systems are required (Wilderer, 2001).

To approach these goals, the concept of Ecological Sanitation (EcoSan) is presented as a way to tackle the problem of lacking sanitation worldwide. An introduction to the main EcoSan principles, concepts, re-use aspects and health hazards is given. Case studies present EcoSan concepts which are applied in industrialized and in developing countries.

2. Global sanitation problems

In most parts of the world, basically two options to tackle sanitation problems are applied which can be described as “drop and store” and “flush and forget” (Winblad, 1997; Esrey et al., 2001; GTZ, 2003). These conventional forms of wastewater management and sanitation systems are based on the perception of faecal material, which is considered as repulsive and not to be touched (Stenström, 1997). The design of the technologies is furthermore based on the premise that excreta are waste and that waste is only suitable for disposal (Esrey et al., 2001).

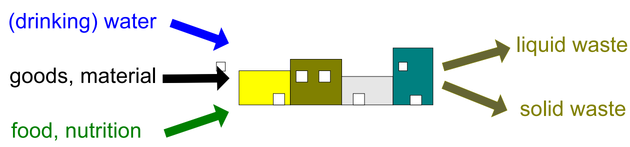

Fig. 2. Linear flows in a conventional sanitation system.

Water-borne sanitation as used in conventional sanitation systems (Fig. 2) is based on the collection and transport of wastewater via a sewer system, using (drinking) water as transport medium (Lettinga et al., 2001). The system mixes comparatively small quantities of potentially harmful substances with large amounts of water and the magnitude of the problem is multiplied. In addition, both the construction, and operation and maintenance of the necessary hardware for the "flush and discharge" options (sewer, wastewater treatment, drinking water treatment) are a heavy financial burden. Even in developed countries, these conventional systems are directly cross subsidised and the chances to ever become financially sustainable are low (Hauff and Lens, 2001).

Conventional sanitation systems have even more fundamental shortcomings than their high costs such as over-exploitation of limited renewable water sources, pollution of soil and groundwater, waste of valuable components in wastewater and the difficulty for an effective removal of pollutants (GTZ, 2003; Wilderer, 2001). Also in the European Union (before the EU enlargement in May 2004), still 37 of the 527 cities with more than 150,000 inhabitants discharge their sewage without adequate treatment—Brussels is a well-known example (EC, 2004).

Looking on conventional on-site wastewater disposal systems applying the "drop and store" principles the pit latrine in its various forms is still the dominantly used device in developing countries (Esrey et al., 2001). The obvious disadvantages, like soil and groundwater contamination with pathogens, bad odour, fly/mosquito breading, pit collapse or the distance from the house make clear that this cannot be a viable alternative. However, in densely populated areas, the limits are obvious: Digging a new pit when the old one is full often leads to the question; where to build the new one? (Werner et al., 2004a).

Further problems greatly concern the agricultural sector. The produced nutrients on farms (in terms of food) are transported on a one-way flow to municipalities and discharged as waste. At present, this steady loss of nutrients on farms is compensated for by mineral fertiliser of fossil origin (e.g., Vinnerås, 2002). Also, the UN realizes the limits of conventional systems and the urgent call for action: "The fact is that in contrast to the water supply system where even in urban areas the supply can be augmented through local spot sources, the sanitation problem does not have any low cost environmentally safe solution and so, focus on eco-sanitation needs to be considered" (UN, 2003).

3. Ecological Sanitation

Ecological Sanitation is an alternative approach to avoid the disadvantages of conventional wastewater systems (Werner et al., 2004a). The EcoSan paradigm in sanitation is based on ecosystem approaches and the closure of material flow cycles (Fig. 3). Human excreta and water from households are recognised as a resource (not as a waste), which should be made available for re-use. According to Werner et al. (2004b), EcoSan:

- reduces the health risks related to sanitation, contaminated water and waste,
- prevents the pollution of surface and groundwater,
- prevents the degradation of soil fertility and
- optimises the management of nutrients and water resources.

EcoSan represents a holistic approach towards ecologically and economically sound sanitation and is a systemic approach as well as an attitude. Single technologies are only means to an end and are not ecological per se but only in relation to the observed environment. The applied technologies may range from natural wastewater treatment techniques to compost toilets, simple household installations to complex, mainly decentralized systems (Otterpohl, 2004). Therefore, EcoSan is not just a poor people solution, with

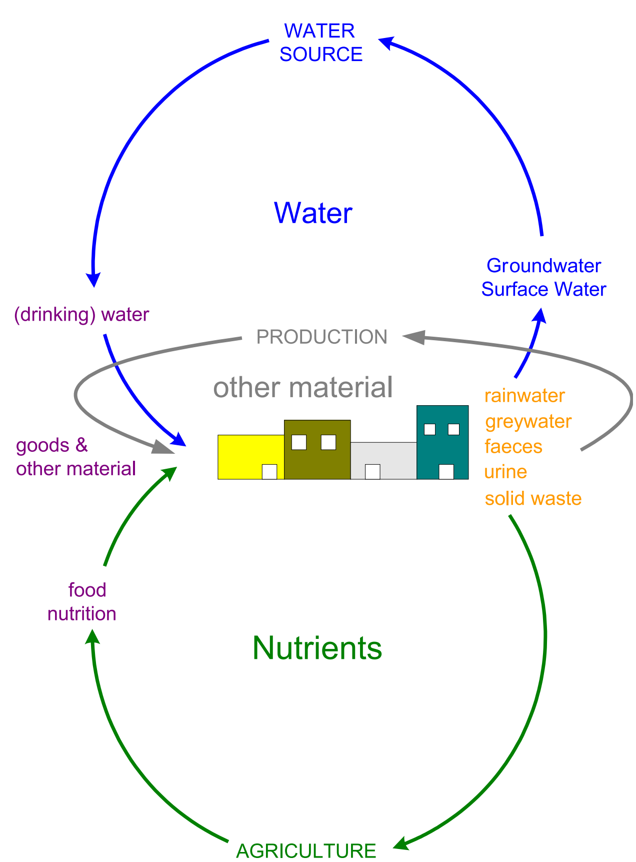

Fig. 3. Circular flows in an EcoSan system.

low standard; it is more a number of appropriate solutions for different specific local situation.

3.1. Requirements for EcoSan systems

The principles underlying EcoSan are not novel. In different cultures, sanitation systems based on ecological principles have been used for hundreds of years. EcoSan systems are still widely used in parts of East and Southeast Asia. In Western countries, this option was largely abandoned as “flush and discharge” became the norm. Only in recent years, there has been a revival of interest in EcoSan (Esrey et al., 1998).

According to Niemczynowicz (2001), the basic motivation behind the need to reshape the management of nutrients and streams of organic residuals in the society may be found in the so-called “basic system conditions for sustainable development” for water and sanitation management, formulated in the Agenda 21 (UN, 1992):

- The withdrawal of finite natural resources should be minimised.
- The release of non-biodegradable substances to the environment must be stopped.
- Physical conditions for circular flows of matter should be maintained.
- The withdrawal of renewable resources should not exceed the pace of their regeneration.

For the successful implementation of an EcoSan concept, a detailed understanding of all the components of the sanitation system is required. The concept should consider the whole system, consisting of social and natural components in consideration of a real and temporal material flows (ADC, 2004). For every local situation, the specific parameters have to be valuated again, always with strong involvement of the stakeholders. Planning and decision making processes should be participatory, by providing the users with information to enable an informed choice. It is generally agreed that awareness rising brings better results, if people are more involved and participate actively in decision making (GTZ, 2003).

A participatory planning process alone can miss a gender perspective of sanitation. Women and men, both should be involved because they benefit differently from improvements in sanitation. Also, their needs and priorities are often not the same (van Wijk-Sijbesma, 1995). Therefore, it is not enough to involve all stakeholders as one homogenous group, the different roles of women and men (and girls and boys respectively) have to be seen and the various activities have to be adjusted (Hannan and Andersson, 2001).

The technologies themselves have to be appropriate for the local and users’ circumstances and should be flexible as well as affordable. Different framework conditions, involved stakeholders and motivating factors ensure that no two EcoSan projects are alike (GTZ, 2003). Especially the choice of the toilet itself is a critical point, because the water flush toilet has had a strong impact on the general view of what is a good sanitation system, to the extent that it is perceived as the best. Therefore, any alternative has to be at least as comfortable and easy to maintain as the flush toilet if it is going to be accepted by the people and therefore to be successful (Drangert, 2004). Rational arguments for EcoSan concepts are manifold and well understandable by looking at the drawbacks of conventional sanitation solutions. However, rationality alone may not convince the users to decide for EcoSan concepts. Decisions are, i.e., influenced by emotions with the aim to raise the personal living standard (e.g., an in-door sanitation facility, privacy and comfort) by changing from one sanitation system to another (Holden, 2004).

3.2. Wastewater is a resource

Wastewater has for a long time been regarded as a problem as it involves hygienic hazards, as well as containing organic matter and eutrophying substances in the form of nitrogen and phosphorus. These substances cause problems in seas, lakes and streams, but on the other side, they would be valuable for agriculture purpose (Esrey et al., 2001). Especially the macronutrients nitrogen (N), phosphorus (P) and potassium (K) in urine and faeces can be utilized instead of artificial fertilizer (Vinnerås et al., 2004) produced mostly by fossil resources, on which cannot be relied securely in a long-term perspective (Palmquist and Jönsson, 2004). According to Jönsson (2001), “All nitrogen, phosphorous and potassium from urine and faeces can be recycled to agriculture, except for some small losses of nitrogen in the form of ammonia. A lot of energy is conserved since a lot of chemical fertilisers can be replaced by urine and faeces.” Furthermore, the organic material increases the humus content and thus the water holding capacity of the soil and prevents the degradation of soil fertility (Esrey et al., 2001; GTZ, 2002).

EcoSan systems therefore greatly help in saving limited resources. This is particularly urgent with regard to fresh water and mineral resources—for example, current estimates for phosphorus state that economically extractable reserves will be exhausted within the next 100 years (Steen, 1998). Some researchers assume that within a century, the severity of the phosphorus crisis will result in increasing food prices, food shortages and geopolitical rifts. The reserves of sulphur and oil (used for production of nitrogen fertilizer) are even less and are calculated to last for about 30 and 40 years, respectively (EcoSan Res, 2003).

An applied strategy for EcoSan projects in practice is based on collecting and treating the different wastewater flows separate to optimise the potential for reuse (Esrey et al., 1998; Wilderer, 2001; GTZ, 2003):

- Blackwater (wastewater from the toilets, a mixture of urine and faeces).

- Greywater (wastewater without excreta respectively from kitchen, bathroom and laundry).
- Yellowwater (separately collected urine).
- Separately collected faeces are called brownwater or faecal matter, respectively, depending on if flash water is used or not.

Rainwater harvesting, treatment of organic domestic, garden wastes and animal manure are often also integrated into EcoSan concepts (GTZ, 2003). Fig. 4 shows different treatment and utilisation options for the separated streams of wastewater and waste.

To identify the resources in wastewater are closer look on the separate fractions is needed: One person produces about 500 l of urine and 25–50 kg dry matter of faeces per year (Vinnerås, 2002; Palmquist and Jönsson, 2004). The same person additionally produces up to 100,000 l of greywater (Wilderer, 2001). If no piped water is available the amount of greywater produced is much lower. Blackwater and greywater have very different characteristics (Table 1, valid for developed countries), whereby most of the nutrients essential in agriculture (N, P, K) occur in urine. Several studies have been investigated in the fertilising effect of human urine and have shown satisfying results (Kirchmann and Pettersson, 1995; Johansson et al., 2001; Simons and Clemens, 2004). Faeces contain smaller amounts of nutrients, while the quantities in greywater are insignificant (Johansson et al., 2001; Vinnerås, 2002). However, the contents depend on the individual washing habits and if phosphorus detergents are used (Jefferson et al., 2001). Separately collected blackwater contains more than 95% of the total nitrogen in waste and about 90% of the total phosphorus. Therefore, collection of blackwater with low (or ideally no) dilution gives the potential for the conversion to safe natural fertiliser, replacing synthetic products and preventing spread-out of pathogens and other pollutants to receiving waters.

The exact wastewater composition, however, depends on the diet and habits of the population (Jönsson, 1997). Even

Table 1
Typical characteristics of the main components of household wastewater (source: Lange and Otterpohl, 2000)

		Greywater	Urine	Faeces
Volume (l p^{-1} $year^{-1}$)		25,000–100,000	~500	~5
Yearly loads (kg p^{-1} $year^{-1}$)				
N	~4–5	~3%	~87%	~10%
P	~0.75	~10% (P-free detergents)	~50%	~40%
K	~1.8	~34%	~54%	~12%
COD	~30	~41%	~12%	~47%

between different population strata in the same country, between men, women and children, the nutrient content varies (Jönsson and Vinnerås, 2004). Table 2 shows values for the excreted nutrients in the different countries calculated from food uptake. In developing countries, e.g., Haiti, the excreted nutrients per person are far less compared to industrialized countries (Table 2).

Urine separating toilets are the technical solution applied for separating the streams of wastewater. They have two different bowls: The one in the front collects the urine and the rear bowl the faeces and used toilet paper. Both bowls can either be flushed or non-flushed. Urine separating toilets are available in a number of designs depending on the habits of the people (Fig. 5).

It has been clearly demonstrated that these toilets are feasible (e.g., Sweden with more than 3000 installations; Johansson et al., 2001). With urine separating toilets, one major problem is left: Men are often reluctant to sit down for urinating. This would cause a loss of urine and a mixing of urine with faeces (Johansson et al., 2001). A luxury solution for this problem would be a private waterless urinal. If urine-diverting toilets are installed indoors, they can match the water flush toilet for socio-cultural features like comfort, hygiene, smell and maintenance (Drangert, 2004). They also compare quite favourably with the flush toilet as for environmental sustainability, e.g., by saving of flush water, no spreading of pathogens into the environment

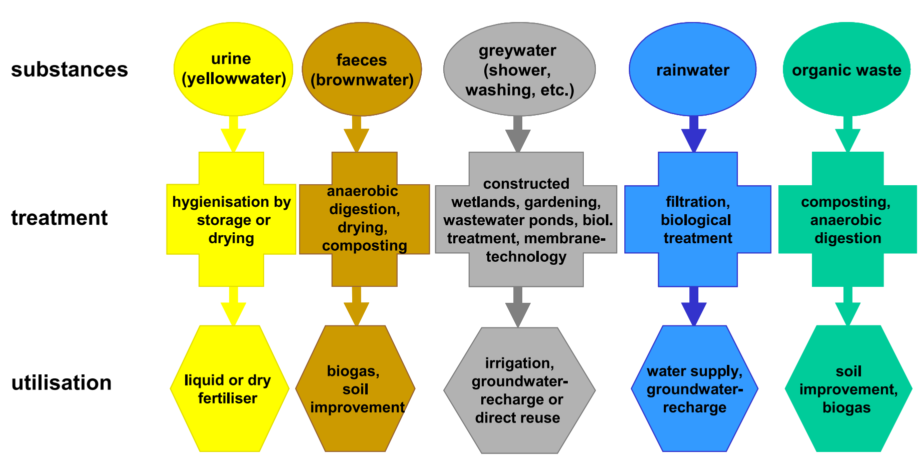

Fig. 4. Treatment and utilisation options for the separated streams of wastewater and waste (GTZ, 2002).

Table 2
Calculated estimation of the yearly nutrient excretion per person in different countries (source: Jönsson and Vinnerås, 2004)

Country	Nutrient								
	Nitrogen (kg p^{-1} year^{-1})			Phosphorus (kg p^{-1} year^{-1})			Potassium (kg p^{-1} year^{-1})		
	Total	Urine	Faeces	Total	Urine	Faeces	Total	Urine	Faeces
China	4.0	3.5	0.5	0.6	0.4	0.2	1.8	1.3	0.5
Haiti	2.1	1.9	0.2	0.3	0.2	0.1	1.2	0.9	0.3
India	2.7	2.3	0.3	0.4	0.3	0.1	1.5	1.1	0.4
South Africa	3.4	3.0	0.4	0.5	0.3	0.2	1.6	1.2	0.4
Uganda	2.5	2.2	0.3	0.4	0.3	0.1	1.4	1.0	0.4

and the re-use of nutrients and water (e.g., Jönsson et al., 1997; Höglund et al., 1998; Wilsenach and van Loosdrecht, 2003; Drangert, 2004).

3.3. Hygienic hazards

Pathogens and parasites found in human excreta are widely responsible for a variety of diseases in developing countries (Prüss et al., 2002). The majority of pathogens can be found in the human faeces (Feachem et al., 1983). Therefore, the main risk lies in the contamination of the environment by faeces spread next to places where people and animals live and especially next to drinking water sources (Esrey et al., 1998). The risk of transmission of infectious diseases via the abundance of pathogens can be reduced essentially by keeping the magnitude of the problem as small as possible by preventing mixing of the critical fraction—faeces—with urine or water (Esrey et al., 2001).

An essential step within an EcoSan concept is the sufficient hygienisation and handling of the materials before their recovery and re-use. The sources of hygienic hazards are:

- *Human faecal excreta* may be harmless but can contain large amounts of pathogenic organisms. The risk is dependent on the frequency of infected persons in the population. Anyway, human faecal excreta are the main source of pathogenic organism and are therefore responsible for the major hygienic hazards (e.g., Esrey et al., 1998; Vinnerås, 2002).
- *Human urine* normally does not contain pathogens that will transmit enteric disease to other individuals. Only in special cases, e.g., a systemic infection with fever or faecal cross-contamination, pathogenic organisms will be present in urine (e.g., Schönning, 2004).
- *Greywater* normally contains low amounts of pathogenic organisms, which are normally deemed to be of no major hygienic concern. However, due to a relatively high load of easily degradable organic substances a re-growth of pathogens may occur (e.g., Ottoson and Stenström, 2003; Ottosson, 2004).
- *Stormwater* may have a high load of faecal contamination (Leeming et al., 1998). This is of special concern in areas of the world where open-air defecation is practiced, as high loads of pathogens, as in wastewater, may occur. Stormwater may also contain high loads of zoonotic pathogens originating from animal or bird faeces (Leeming et al., 1996).
- In *municipal wastewater*, all micro-organisms originating from human excreta will occur in amounts reflecting their occurrence in infected persons or carriers connected to the system. Their concentrations also depend on the dilution in water and possible die-off. Untreated wastewater should always be regarded as potentially containing high concentrations of pathogenic organisms (Esrey et al., 1998).

Separation of urine and faeces cannot be a zero-risk solution, rather a search for new possibilities. Contamination with pathogenic organisms as well as organic and

Fig. 5. Examples of urine separating toilet (sitting and squatting).

inorganic pollutants cannot be excluded, although the probability is lower compared to conventional "flush and discharge" solutions (Wittgren et al., 2004). Prevention, diversion at the source, adequate treatment, awareness of the risks and appropriate handling assure the minimisation of health risks, whereby treatment of the excreta is the most important barrier to prevent spreading of pathogens (Schönning, 2004). For safe use of human excreta in agriculture, guidelines have been published (WHO, 1989, to be updated by 2005). Recommendations how to sanitise human excreta before use have been developed and are continuously extended and updated (e.g., Schönning, 2004; Jönsson et al., 2004).

Remaining pathogenic organisms in urine, caused by a faecal cross-contamination (e.g., Jönsson et al., 1999; Esrey, 2001), are found to die off during storage (Höglund, 2001; Vinnerås, 2002). The recommended storage period depends on the storage conditions (temperature and pH), the fertilised crops and scale of the system (for a household's own consumption or for commercial use). Recommendations for reusing human urine are given by Höglund (2001) and Schönning (2004). Höglund (2001) states that "for single households the urine mixture is recommended for all type of crops, provided that the crop is intended for the household's own consumption and that one month passes between fertilising and harvesting, i.e. consumption. Incorporation of the urine into the ground is also recommended, but only for crops where the edible parts grow above the soil surface. For crops growing under the surface it is, from a hygiene point of view, more beneficial not to work the urine into the ground since inactivation of potential pathogens by heat, UV-radiation and desiccation is faster on the surface." The removal of other substances found in urine, like micropollutants such as medical residues and endocrine disruptors (de Mes and Zeeman, 2004), is still a matter of discussion (e.g., Janssens et al., 1997). Research is needed to describe the fate and removal of these substances before safe use in agriculture can be guaranteed (Fürhacker et al., 2004).

For safe re-use of human faeces, the destruction of pathogens is compulsory (Peasey, 2000; Esrey et al., 2001). Various treatment methods have been tested (Vinnerås, 2002): storage, composting, digestion, chemical treatment and incineration. Storage is the simplest method but it is not reliable; faecal material has to be treated actively to attain hygienically safe conditions (Vinnerås, 2002). According to Esrey et al. (1998) and Moe and Izurieta (2004) a high pH, a long storage time and high temperatures are the critical factors affecting microbial inactivation. The addition of an absorbent and pH increasing agent after excretion, such as ash, lime or similar additives should help to destroy the pathogens and to decrease the risk of odours and flies (Jönsson et al., 2004).

Clean drinking water and safe excreta disposal is not enough for a sustainable diseases control and preservation of health. The spreading of pathogenic organisms can be reduced or stopped by using barriers to prevent pathogens moving from one place to another. A primary barrier (like dry toilets) prevents faeces from coming in contact with liquids, foods and environment. Secondary barriers are as important as a hygienic and adequate sanitation system, like washing hands after toilet use, adequate cooking of food, food hygiene or water disinfection (Howard, 2002).

Summarising the characteristics of wastewater and the sources of hygienic hazards, the following conclusions can be drawn:

(1) Most of the directly plant available and soluble nutrients are found in urine, which deemed to be hygienically uncritical, but may contain medial residues and hormones, as well as pathogens from faecal cross-contamination. If urine is separated, treated and converted to agricultural usage, the biggest step towards nutrient re-use and highly efficient protection against water eutrophication will be taken.
(2) The hygienic hazards of wastewater originate mainly from faecal matter. Separation opens the way to hygienisation and finally to a valuable end-product. However, faeces are hygienically critical and for any reuse a sufficient treatment for pathogen destruction is inevitable.
(3) Wastewater that is not mixed with faeces and urine (greywater) is a great resource for high-quality re-use of water, provided that only environmentally friendly chemicals and no environmentally hazardous ones are used.
(4) Source control should include evaluating all products that end up in the water. High-quality re-use will be far easier when household chemicals are not only degradable (original substance disappears, even if metabolites do not degrade) but can be mineralised with the available technology. Additionally, the system infrastructure should not emit pollutants (e.g., copper or zinc).
(5) To reduce storm water runoff local infiltration and/or trenches to surface waters for relatively unpolluted rainwater can be used. Prevention of pollution includes avoiding copper or zinc gutters and roof materials that can cause heavy metal pollution of the rainwater runoff.

4. Case studies

4.1. Introduction

All over the world—in both developing and industrialized countries—a steadily increasing number of case studies exist for rural, peri-urban and urban areas (e.g., Werner et al., 2004c; Jenssen et al., 2004). The concepts applied vary from simple dry toilets to sophisticated high-tech concepts. Examples for EcoSan concepts in Austria are the "Bettelwurfhütte" (PAP, 2003)—a sanitation concept including public urine separation toilets for a mountain hut in Tyrol—and the "Christophrous Haus" (Lechner and Müllegger, 2004; EcoSan Club, 2003)—an office building with a water/wastewater concept for sustainable (re)use. Some case studies are discussed in more detail.

4.2. Kisoro, Uganda

In 1996, the South Western Towns Water and Sanitation Programme (swTws) was initiated by the Austrian Development Cooperation (ADC) together with the Ugandan Directorate of Water Development (DWD). The project was designed to cover small towns and rural growth centres in the southwest of the country with the aim to provide safe water and improved sanitation facilities (ADC, 2004).

Kisoro Town was chosen as a case study community for an EcoSan pilot project due to the local conditions concerning the (hydro-) geological situation, the poor sanitation coverage and the absence of an operating sewerage system. At the beginning of the project, an elaborate feasibility study was undertaken with a strong focus on local conditions as well as user participation. In order to reach the majority of the community members, the project emphasised the use of drama, rallies and meetings. Political leaders were contacted to gain their commitment for supporting the project in form on an official implementation agreement.

Various options were discussed. The final decision was in favour of a solution based on EcoSan principles, which were best adapted to the local circumstances in order to avoid further demand of water, to protect ground water from faecal contamination and to re-use the different types of residues for agricultural purposes (Fig. 6). The main components are:

- Water-born sanitation, sewer, treatment plants (constructed wetland) and re-use of the outflow.
- Water-born sanitation, septic tanks, cesspool emptier and treatment plant.
- Pit latrines as basic sanitation.
- Composting and dry toilets on private and public level and re-use of compost, urine and/or faeces as manure in agriculture.

In 1999 and 2000, more than 250 dry toilets have been built for private households, institutions as well as public facilities. Private toilets have been more accepted than public ones. The proper use of the toilets increases with better "know-how" of the technology and the feeling of property. Public dry toilets have been found often in bad condition and highly misused.

4.3. "Lübeck-Flintenbreite", Germany

Source separation in a housing estate is realized firstly in Germany at "Lübeck-Flintenbreite", for 350 inhabitants in a densely populated rural area (Wendland and Oldenburg, 2004; Flintenbreite, 2003). The installed system comprises a strict separation of blackwater, greywater and stormwater. The treatment of stormwater and greywater takes place in swales respectively in constructed wetlands. It was planned but up to now not implemented that blackwater together with organic waste should be treated anaerobically (producing biogas for energy and heat production).

Despite of the rather high technical approach the operating costs have been found to be much lower than for conventional sanitation systems. The monthly operating costs (also including the costs for electricity and solid waste) are 1.44 EUR/m^2 compared to 2.22 EUR/m^2 in the neighbouring houses with conventional systems.

The vacuum toilet system has been running for 2 years with only minor technical problems. The flushing system which has been optimised during operation needs only about 0.7 l per flush. The daily mean drinking water consumption of 77 l per person therefore is significantly low compared to the German average 129 l. Peaks in spring and summer time are caused by garden irrigation. After a time of accustoming the vacuum toilets are accepted and are seen more hygienic than conventional flushing toilets.

Fig. 6. Dry toilet (left) and reuse field trials (right) in southwest Uganda.

4.4. "*Lambertsmühle*", *Germany*

The "Lambertsmühle" is an ancient watermill, which is nowadays operating as a museum. In connection with the restoration of the building, a progressive sanitation concept has been developed for the museum and the flat in the mill house (Oldenburg et al., 2004). Due to the local conditions, a connection to a sewer network system was not possible. Therefore, an own wastewater treatment was necessary and it was intended to install a source separating concept (Otterwasser, 2003). The separate collection of urine, faeces and greywater is the prerequisite for the concept. For the separation of urine and faeces, different toilets are installed. Two of these toilets are diluting the urine with flushing water; the third one does not dilute the urine. According to Gajurel et al. (2003), the water content of the retained material in the Rottebehaelter used is very high. Therefore, the operation of the Rottebehaelter has to be optimized. During the first year of operation, no problems regarding the separation occurred. The first results of the agricultural investigations are demonstrating a good efficiency of the fertilizer on various plants.

4.5. "*Svanholm Community*", *Denmark*

The Svanholm Community in Denmark is an ecological village with its own wastewater treatment (la Cour Jansen and Koldby, 2004). The main objectives of the performed study were to test urine for fertilisation and to investigate the effect of urine separating toilets on the existing wastewater treatment plant.

Two urine separating toilets were established in connection with the common dining hall of the community. Computer simulation of the wastewater treatment plant with nutrient removal was used to evaluate the impact of urine separation and for estimation of the possible savings in wastewater treatment. The potential savings in operation of the wastewater treatment plant are small and cannot cover the costs for installation of the system. After a successful test period, a plan to install urine separation for all 32 toilets of the community was established. Financial potentials will be substantially higher in new building projects, where costs of a urine separation system will be lower, and where the significant reduction of contents of nitrogen and phosphorous in sewage enable simpler and cheaper treatment plants.

4.6. *Sund, Finland*

The municipality of Sund in Åland (Finland) is a rural area with small villages surrounded by the sensitive Baltic Sea (Malmén et al., 2003). The overall objective was to move the most concentrated fraction of wastewater from the coastal area to batch-wise treatment, followed by agricultural use. The results indicate that the wet composting process reduces indicator bacteria sufficiently. Normally, this also means that conventional pathogens are reduced sufficiently. However, since treatment of only two batches has been monitored additional batches has to be evaluated before conclusions can be drawn.

From a technical point of view, the installed system was a success. The project has faced no major technical problems. As a result, the Government of Åland is discussing the introduction of the system in other places. It is also encouraging that over 80% of the phosphorus and nitrogen in the wastewater from the households have been diverted to agricultural use, instead of discharged to the environment.

5. Summary and conclusion

The underlying aim of Ecological Sanitation is to close local nutrient and water cycles to contribute to a sustainable development. Single technologies are only means to an end to reach the EcoSan goals. EcoSan technologies therefore may range from natural wastewater treatment techniques to separating toilets, simple household installations to complex, mainly decentralised systems. Technologies are not ecological per se but only in relation to the observed environment.

The main objectives for sanitation systems are that they have to minimise hygienic risks and protect the environment. EcoSan systems additionally have to return nutrients to the soil, and conserve valuable water resources. They have to be affordable, acceptable, aesthetically inoffensive and consistent with cultural and social values, simple and robust in design and operation, and as comfortable as conventional systems. To make sanitation systems work, all their components such as the natural environment, the society, the occurring processes and the device for defecation have to be considered together.

The advantages of EcoSan can be summarised as follows (GTZ, 2002):

- EcoSan improves health by minimising the introduction of pathogens from human excreta into the water cycle.
- EcoSan promotes a safe and hygienic recycling to use valuable nutrients in human excreta.
- EcoSan conserves the natural resources through reducing the water consumption, substitution of chemical fertilisers and minimises the water pollution.
- EcoSan gives preference to modular, decentralised, separated-flow systems for more appropriate and cost-effective solutions.
- EcoSan helps to preserve soil fertility by hindering the steady loos of nutrients and organic material.
- EcoSan improves agricultural productivity and contributes food security.
- EcoSan promotes a holistic and interdisciplinary approach.

To promote EcoSan concepts, 10 Recommendations for Action (Werner et al., 2004b) have been proposed which include a strong emphasis on the development of EcoSan concepts for urban areas, agricultural re-use, as well as education and training. A number of associations and organisations are building up a worldwide network for promotion of EcoSan concepts. Among these are, e.g., the EcoSan Club (Austria; www.ecosan.at); GTZ (Germany; www.gtz.de/ecosan); EcoSanRes (Sweden; http://www.ecosanreshome.org); the Water and Sanitation Program of the World Bank (http://www.wsp.org); and the Specialist Group on Ecological Sanitation (http://www.iwahq.org.uk/template.cfm?name=sg52) of the International Water Association (IWA).

The problems that have to be solved in developing and industrialized countries are different: In developing countries, the main focus of action is to reduce health risks in urban, peri-urban and rural areas. EcoSan concepts save water resources and due to their re-use orientation have benefits for agriculture. In industrialized countries, the main focus is on rural areas and on the reduction of environmental impacts. The comparison of investment and operating costs shows that conventional systems for rural areas are the most expensive option mainly due to the sewer lines needed (e.g., Lechner and Langergraber, 2004). Especially the operating costs of source separating systems are lower compared to conventional systems where all the wastewater is collected and treated (e.g., Müllegger et al., 2004). In addition to the more ecological sound sanitation and their sustainability re-use oriented systems are therefore also economically advantageous.

It can be concluded that EcoSan concepts are a way towards a more ecological sound sanitation. There are many different EcoSan concepts available that can be appropriate in different socio-economic and geographical situations. EcoSan concepts are also in accordance with the UN Millenium Development Goals due to their accessibility also to the world's poorest people. There are so many technological options that most social and economic conditions can be met. Creativity is needed to find the appropriate technology and the best way of implementing, operating and financing.

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