sustainable sanitation alliance

SuSanA factsheet

Sanitation systems and technology options

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1 Summary

To address the great sanitation challenge in developing countries, numerous technological innovations have been developed. But with so many innovations and a wide range of existing technologies for different settings, difficulties with knowledge dissemination hinder informed decision making and the integration of all sanitation elements.

This factsheet makes a plea for a sanitation system approach where technologies are categorised based on their "product-process" characteristics and then linked into logical systems using a "Flowstream" concept. Technologies are grouped and used to construct seven logical systems. This method for organising and defining sanitation systems helps facilitate informed decision making and consideration of an integrated approach.

By using the sanitation system and its technology configurations from user interface to reuse and disposal, other aspects can now be further highlighted such as the inherent implications for operation and management (O&M), business and management models, service and supply chains, possible involved stakeholders, and finally the associated health risks by exposure of different groups of people to waste products. Such a health risk assessment for different sanitation systems has recently been published by Stenström et al. (2011).

2 Introduction: the need for a systems approach

Technology choice should be based on determining the best possible and most sustainable solution within an urban or rural context. There is often a prevailing assumption that centralised water-based sewer system can be the solution in all urban and peri-urban contexts. Site specific considerations such as the scarcity of fresh water, farmers' demand for treated wastewater or excreta-based fertiliser, or lack of technical skill and institutional or socio-economic barriers to such centralised sewer systems are often neglected (Luethi et al., 2011).

Sanitation programmes and projects often ignore the impacts of different waste inputs on the treatment processes, and on the quality of the final products (sludge and final effluents). A typical example is the implementation of waterborne sanitation with sewer systems without consideration of water availability and reliability or an appropriate wastewater treatment technology of adequate size to accept the additional raw sewage inputs. Consequently, subsequent poor operation of the system has potentially severe impacts on the environment, resulting in health risks to those served as well as of downstream populations.

On the other hand, on-site sanitation, like in the South Asian rural context, consists of the widespread promotion of pour flush latrines with on-site disposal pits which in many cases are not able to cope with the hydraulic or organic loads due to certain geological, groundwater and climatic conditions.

Figure 1: Schematic of school toilets connected to biogas settler and anaerobic baffled reactor at Adarsh College, in Badlapur, India (source: N. Zimmermann, 2009)[1].

The options: to change the basic design or to consider alternative sanitation technologies to take into account the specific on site conditions are often overlooked or not investigated. As a result, in spite of significant investments, a number of latrines are found to be either dysfunctional or malfunctioning and the unsatisfied users have reverted to open defecation or the use of unsanitary pits latrines. In addition, the focus is often on the construction of *toilets* alone with little consideration given to the management of the generated *faecal sludge*, including its collection, transport, treatment and possible reuse or disposal.

There is a great need for sanitation practitioners to plan sanitation from a more holistic perspective, for example by considering the entire municipal area and the sanitation chain in order to come up with an overall sanitation concept. A holistic perspective includes components such as technical, (socio-) economic, institutional and financial feasibility studies, consultation with the users in which the whole life cycle of different sanitation options are presented and discussed, quality assurance during implementation,

[1]See SuSanA case study for details: www.susana.org/lang-en/library?view=ccbktypeitem&type=2&id=38

and ongoing institutional support during the O&M phases. Training is another very crucial aspect as even the most inexpensive or sophisticated technologies eventually fail if they are not accompanied by a trained service provider.

One of the challenges for improving sanitation in low and middle income countries involves acquiring a sound knowledge of the wide range of sanitation options to ensure informed decision making. The most feasible sanitation systems and technologies - for the different habitats in urban and rural areas, which can achieve the objectives of improved health, changed hygiene practices, minimal impact on the environment, improved quality of life, and are best suited to the site specific context - can be chosen when decision making is informed.

Commonly asked questions when faced with deciding on a sanitation option are: What are the available sanitation systems? Which sanitation systems are appropriate for which kind of faecal waste inputs? What kinds of waste products are produced from the technologies that transform waste inputs? This factsheet summarises and highlights previous work conducted by various authors who worked on the categorisation of sanitation systems (Cruz et al., 2005; IWA, 2005; Tilley and Zurbruegg, 2007; DWA, 2010; Tilley et al., 2008).

3 Systemising sanitation systems

The main objective of a sanitation system is to protect and promote human health by providing a clean environment and breaking the cycle of disease transmission, as well as to preserve the dignity of users - particularly women and girls. In order to be sustainable, a sanitation system has to be not only economically viable, socially acceptable, and technically and institutionally appropriate, it should also protect the environment and the natural resources (SuSanA, 2008).

A sanitation system - contrary to a sanitation technology - considers all components required for the adequate management of human excreta. Each system represents a configuration of different technologies that carry out different functions on specific waste inputs or waste products. The sequence of function-specific technologies through which a product passes is called a “Flowstream”. Each system is therefore a combination of inputs, function-specific technologies, and products designed to address each flowstream from origin to reuse or adequate disposal.

Technology components exist at different spatial levels, each with specific management, operation and maintenance conditions as well as potential implications for a range of stakeholders. A system can include waste generation, storage, treatment and reuse of all products such as urine, excreta, greywater, organic solid waste from the household and agricultural activities such as manure from cattle at or near the source of waste generation. However, the requirement to effectively contain the wastes and prevent the spread of diseases and the pollution of the environment can often not be solved at the household level alone.

Households “export” waste or environmental contaminants generated by the wastes to the neighbourhood, town, or downstream population. In such cases, it is crucial that the sanitation system is extended to include these larger spatial areas and take into account technology components for storage, collection, transport, treatment, and discharge or reuse at all levels.

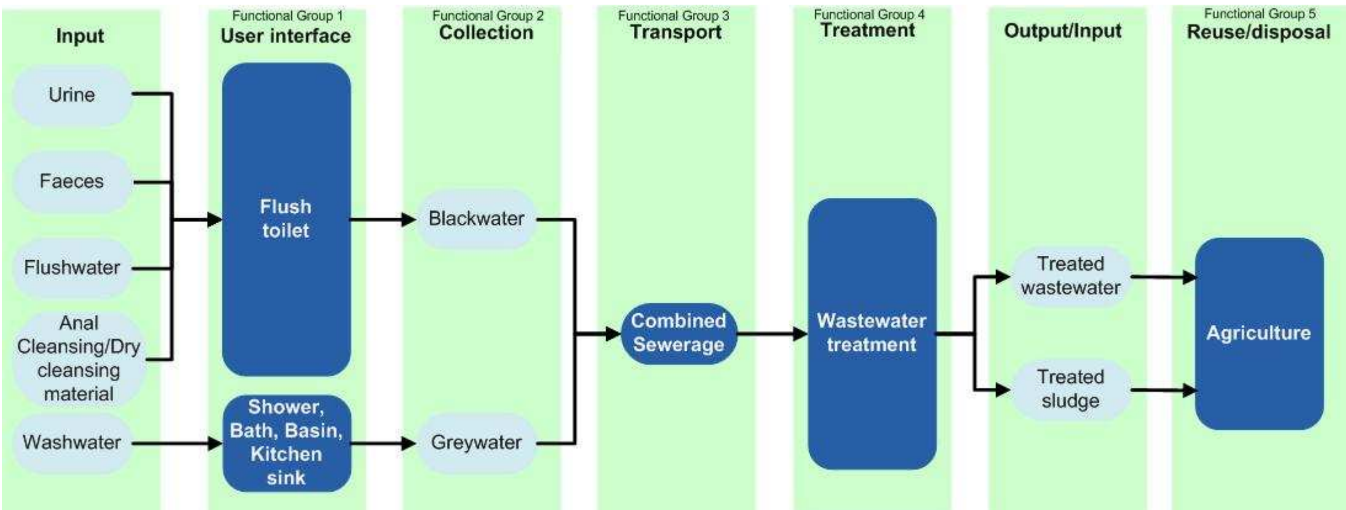

Figure 2: System template providing a schematic overview of the specific inputs of a sanitation system (left column), their transformation in the four functional groups “user interface”, “collection”, “transport” and “treatment“, the specification of two outputs for the fifth functional group “reuse/disposal” (in this example “nutrient reuse in agriculture”) (source: Luethi et al, 2011).

Sanitation systems can be distinguished by being water-reliant or non-water reliant for the transport of excreta and wastewater (Cruz et al., 2005; Tilley and Zurbruegg, 2007). Some manuals on technology options have used the type of anal cleansing (anal cleansing with water or dry anal cleansing material), water availability and affordability as distinguishing factors for on-site sanitation technologies.

Another common categorisation divides sanitation systems into on-site and off-site (i.e. whether treatment of the wastes occurs on-site or the wastes are transported off-site for treatment).

In addition to water-reliant or non-water reliant, or on-site or off-site, another distinction can be made in the various degrees of separation of incoming wastes. Urine diverting sanitation systems keep urine separate from faeces from the very beginning. On the other hand sewered sanitation systems mix faeces, urine, flushing water, greywater as well as wet or dry anal cleansing materials resulting in a waste product called wastewater. Depending on the degree of waste separation, various flowstreams can be distinguished, which must be accounted for in the subsequent functional components of the sanitation system.

It is also important to note the similarity in the naming convention between products and flowstreams. For example, blackwater is a product, but the entire process of collecting, treating and disposing of blackwater is referred to as the blackwater flowstream. Similarly, greywater can be managed separately as an independent product, but when it is combined and treated along with blackwater, the flowstream is referred to as the "blackwater mixed with greywater" flowstream (Tilley et al., 2008).

"Wet" and "dry" indicate the presence of flushing water for the transport of excreta or the use of water for facilitating the treatment of the wastes. This however only gives a certain indication of how wet or dry the collected waste materials will be. Although flushing water might not be used it would not necessarily qualify as a "dry system" as it may nevertheless contain anal cleansing water or even greywater. Also, it should be remembered that wet systems also contain solids, like faecal material and anal cleansing materials. In wet systems the solids flowstream must be taken into account and treated accordingly with its own set of specific technologies for reuse or disposal.

In this factsheet seven distinctly different sanitation systems are described based on the categorisation from the EU-funded NETSSAF project (Network for the development of Sustainable approaches of large-scale implementation of Sanitation in Africa[2]). They all have their place and application, and not one of them is per *se* better than the other.

[2]Information about NETSSAF and its outputs: www.susana.org/library?search=netssaf

a) Wet mixed blackwater and greywater system with offsite treatment

In this system, all wastewater which is created by households and institutions, also partly industries and commercial establishments is collected, transported through gravity sewers or pumping mains, and treated without stream separation. There are different user interface technologies available for the collection of blackwater. These can be cistern-flush toilets or pour-flush toilets.

After collection, the blackwater is mixed with household greywater as it leaves the house; the mixture (referred to as "wastewater") is transported to a centralised treatment plant. Then a wide array of technology options for wastewater treatment can be applied. These treatment processes are generally biological reactors that convert the organic matter into bacterial cells, CO_2, and other non-noxious carbonaceous products. Some of the nutrients such as nitrates and phosphates can also be removed in the treatment process. The treated effluent is then discharged into the environment while the sludge produced is dried and disposed of on land or used as a soil conditioner.

The most common transport technology for "system" is sewer pipes with gravity flow. This system is generally called conventional sewer system. Occasionally, non conventional vacuum systems are used as a transport technology.

For this system new approaches and technologies have also been developed to take into account the limited financial capacities of low and middle income countries. Simplified sewers, also called condominial sewers, have less stringent design criteria, are located in backyards or sidewalks rather than under the roads, and can be constructed together with the community, although operational challenges have to be considered. This is a type of technology for wastewater transport which is used for example in Brazil.

b) Wet mixed blackwater and greywater system with semi-centralised treatment

This system, like the previous one, is characterised by flush toilets (cistern flush, pour flush or vacuum toilets) at the user interface. Here however, the treatment technology is located closer to the source of wastewater generation. Depending on the plot size, the treatment technology will be appropriate for one house, one compound or a small cluster of homes or an entire settlement.

Transport to the treatment plant is limited to short distances mostly by gravity sewers. There are various technology options for on-site wastewater treatment, which differ from those typically used for centralised, off-site technologies. These may or may not treat the wastewater to the same effluent standard as a centralised treatment facility, but due to the smaller volumes this can still be acceptable in environmental terms. Examples include anaerobic baffled reactors, constructed wetlands, DEWATS[3] and biogas plants (Gutter et al., 2009). Although it is commonly practiced, pits

[3]DEWATS stands for Decentralised Wastewater Treatment Systems, see www.borda-net.org

should not be used as disposal sites for mixed wastewater systems.

Figure 3: Vertical flow constructed wetland in the “Olympic forest park” located north of the city centre of Beijing, Peoples Republic of China, 2008 (source: J. Germer, 2008)[4].

c) Wet blackwater system

In this system, urine, faeces and flushing water (together called blackwater) are collected, transported and treated together. However, greywater is kept separate. Since greywater accounts for approximately 60% of the wastewater produced in homes owning flush toilets, this separation simplifies blackwater management. A common example of this system is the double-pit pour flush toilet; this technology allows users to have the comfort of a pour-flush toilet and water seal. Another technology option is anaerobic treatment for blackwater with biogas production.

In this system, a separate process for greywater management must be implemented. Since separated greywater contains few pathogens, and usually low concentrations of nitrogen and phosphorus, it does not require the same level of treatment as blackwater or mixed wastewater. Greywater can be treated with soil filters and recycled for irrigation, toilet flushing, cleaning around the house etc.

d) Wet urine diversion system

In this system, faeces, flushing water and greywater are collected, transported and treated together but urine is kept separate. The diversion of urine from the other flowstreams requires a specific user interface, known as a urine diversion toilet. Urine can be either collected with or without flushing water (see von Muench and Winker, 2011, for a detailed description of this concept).

The objective of the urine separation is to keep the urine free of pathogens and to ultimately facilitate its reuse in agriculture. In wet urine diverting systems, the faeces are flushed with water to an off-site treatment facility. Sometimes the urine is mixed with a small amount of flushing water. Due to the novelty of the user interface and the complicated infrastructure required for this type of system, it is not widely used yet and exists only in some demonstration projects[5].

e) Dry excreta and greywater separate system

Here excreta, a mix of urine and faeces, are discharged at the user interface without using any flushing water. Greywater is collected separately. Consequently, although the mixture of urine and faeces is wet, the system is referred to as “dry” because there is no flushing water. Depending on the cultural habits, anal cleansing water may or may not be included although odour and flies are minimised if the mixture is kept as dry as possible. This is particularly true for the simple composting toilets (such as Arborloo, Fossa alterna) that can become smelly if too much water is added.

Generally, the system is characterised by “drop and store” latrines that are emptied or abandoned when full. The separate greywater should be treated close to where it is generated (on-site-treatment). The faecal sludge may be further treated off-site. Generally, off-site treatment of faecal sludge for pathogen removal is difficult to organise properly and unfortunately often neglected. Households who do not have sufficient space to move their latrine over a new pit once it is full will often revert to emptying the pits by hand and burying the sludge in shallow pits nearby. It is possible to either reuse the recovered resources (greywater or treated faecal sludge) or to dispose of them when interest in reuse is lacking.

Figure 4: Faecal sludge being discharged from trucks into treatment beds in Cotonou, Benin (source: S. Blume, 2010).

[4] See SuSanA case study for details: www.susana.org/lang-en/case-studies?view=ccbktypeitem&type=2&id=36

[5] See SuSanA case studies with urine diversion flush toilets in Linz (Austria) www.susana.org/lang-en/case-studies?view=ccbktypeitem&type=2&id=66 and in Eschborn (Germany) - www.susana.org/lang-en/case-studies?view=ccbktypeitem&type =2&id=63

Certain innovations of this type of system have incorporated an enhanced drying process for the pit contents, producing dry compost that is simple to handle and dispose of. These latrines, also called desiccating latrines, generally use passive air flow enhancers and/or solar heat to speed up the drying process.

f) Dry urine, faeces and greywater diversion system

This system is characterised by the separation of urine, faeces and greywater into three different flowstreams, and, where anal cleansing water is used, a fourth flowstream. In this way, each flowstream can be separately managed in terms of its volumetric flow, nutrient and pathogen content and handling characteristics. This diversion can facilitate more targeted treatment and end use for the different fractions. This system requires a urine diversion dehydration toilet (UDDT) and a separate greywater treatment system.

In UDDTs, urine is collected through the front outlet and conveyed to a collection vessel (a tank in larger, more expensive systems or a jerrycan in smaller, simpler systems), or a soak pit if the urine is not reused. Through the second outlet the faeces are collected in a container located underneath the toilet pan or seat. The urine diversion squatting pan or seat can also be equipped with an additional outlet for anal cleansing water which is then treated in a separate flowstream. More information on UDDTs is available in Rieck et al. (2012).

g) Dry excreta and greywater mixed system

Urine, faeces and greywater are mixed in the same on-site collection, storage and treatment technology. Although this type of system with a simple soak pit for excreta and greywater together can be found in rural and peri-urban areas of many developing countries, it is not considered to be good practice in densely populated areas, or areas with high groundwater tables or unfavourable soil conditions. The difference between this system and the dry excreta and greywater separate system is the lack of separation of greywater. The performance of these systems has been enhanced through the incorporation of a sealed chamber into which all the wastes are disposed (a digester or type of septic tank system) with a filter at the outlet before the effluent enters a soak-away. The digester provides an environment for the partial treatment of the wastes.

Box 1: Note on reuse of sanitation sludge

Care should be taken in promoting the direct reuse of sanitation sludge for agricultural purposes. The digestion of wastes, even over long periods, may not render the compost-looking sludge completely free of pathogens. In particular the ova (eggs) of many protozoan parasites are not easily rendered non-viable even under good composting conditions. Users should always be informed on the safe use of the sludge including use of protective clothing (boots and gloves), and which crops it can be applied to.

4 Description and evaluation of technology components

In all the recent publications that have described sets of typical sanitation systems (Cruz et al., 2005; IWA, 2005; Tilley and Zurbruegg, 2007; Tilley et al., 2008; DWA, 2010) a certain procedure was applied to characterise technologies: along with the description of the sanitation system, each technology (or technological component) is discussed and described. The technology is grouped according to its role in the process (i.e. the function that it serves) while on the other hand it is also sub-divided according to the flowstreams that it deals with.

Table 1: List of sustainability criteria that can be used to evaluate and compare technological components and complete sanitation systems

Health issues	
reduces exposure (and thus health risks)	of users
	of waste workers
	of resource recoverers /reusers
	of “downstream” population
hygienisation rate	
increases health benefits	
Impact on environment / nature	
use of natural resources	needs low land requirements
	needs low energy requirements
	uses mostly local construction material
	low water amounts required
low emissions and impact on the environment	surface water and groundwater
	ground water
	soil / land
	air
	noise, smell, aesthetics
good possibilities for recovering resources	nutrients
	water
	organic matter
	energy
Technical Characteristics	
allows simple construction and low level of technical skills required for construction	
has high robustness and long lifetime/high durability	
enables simple operational procedures and maintenance; low level of skills required	
Economical and financial issues	
has low construction costs (unit cost per household) and low operation and maintenance costs	
provides benefits to the local economy (business opportunities, local employment, etc.)	
provides benefits or income generation from reuse	
Social, cultural and gender	
delivers high convenience and high level of privacy	
requires low level of awareness and information to assure success of technology	
requires low participation and little involvement by the users	
takes special consideration of issues for women, children, elderly and people with disabilities	

The technological components and the complete sanitation systems need to be discussed and evaluated with respect to specific sustainability criteria. Examples for such criteria are given in Table 1. This can lead to a comparison of the sustainability of different systems. Examples of such evaluations are given in Section 12 of each SuSanA case study (www.susana.org/case-studies).

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Authors and contributors

Main authors:

- Christian Zurbruegg, Eawag/Sandec, Switzerland (christian.zurbruegg@eawag.ch)
- Arne Panesar, GIZ, Germany (arne.panesar@giz.de)
- Soeren Rued, GIZ, Germany (soeren.rued@giz.de)

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For questions or comments please contact the SuSanA secretariat at info@susana.org or susana@giz.de. We invite you to join the SuSanA discussion forum: www.forum.susana.org. This document is available at www.susana.org.

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