Lesson B1

RESOURCE MANAGEMENT SANITATION

Authors:
Holger Gulyas
Deepak Raj Gajurel
Ralf Otterpohl

Institute of Wastewater Management
Hamburg University of Technology
Hamburg, Germany

Revised by Dr. Yavuz Özoguz
data-quest Suchi & Berg GmbH

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Overview and summary

Human excreta contain valuable plant nutrients as well as organic matter and can be converted into fertiliser and soil conditioner for agriculture. Thus, **reuse of human excreta reduces the production of chemical fertiliser** which is energy intensive, causes environmental problems and draws on very limited fossil resources. Additionally, the **surface water is preserved** which is otherwise polluted by discharging human excreta into it. Because of high dilution, it is hardly possible to recover good amount of nutrients in conventional sanitation systems. Even modern wastewater treatment plants that are hardly affordable for developing countries emit nutrients into water bodies where they cause eutrophication. Also, pathogens contained in faeces can spread to the aquatic environment causing disease to people.

A high amount of nutrient recovery is possible with source control in households. With the application of Resource Management sanitation it is possible to keep human excreta in non-diluted or little diluted form which provides good condition for high levels of nutrient recovery as well as for effective sanitisation. The systems that are applied in Resource Management sanitation for the source control are **composting/dehydration toilets, sorting or no-mix toilets as well as vacuum toilets**. In composting/dehydration toilet systems either a toilet with urine diversion or no urine diversion is used. In case of no urine diversion toilet, faeces and urine with or without toilet paper depending on the user’s habit drop into the composter located just below the toilet. In urine diversion toilet, urine is collected separately and kept in a storage tank until it is ready for use in agriculture. Urine diversion is crucial for dehydration toilets. The non-diluted faecal materials are dehydrated with the help of heat (solar radiation), ventilation and the addition of dry materials.

The no mix toilet usually has two bowls, the front one for urine and the rear one for faeces. Each bowl has its own outlet from where the respective flow is piped out and treated separately. Urine is stored in an underground tank for sanitisation prior to its reuse in agriculture whereas faeces with toilet paper if used are discharged either into Aquatron system or Rottebehaelter system for solid liquid separation and treatment. The end product of both systems requires post-treatment prior to its reuse. The vacuum toilet uses only 1 litre flush water to flush faeces, urine and toilet paper and the mixer called black water is transported to the biogas plant with the help of a vacuum system. Biogas can be used for heating and lighting whereas sludge can be used in agriculture after sanitisation. Resource Management sanitation systems have been increasingly used around the world. In this lesson, some applications worldwide are presented as well. Also treatment methods for other domestic wastewater that originates from kitchen, shower, wash basin and laundry are discussed.

1. Material flows in domestic wastewater

1.1 Different sources

Different particular wastewater streams are forming the domestic wastewater (see figure 1). The wastewater originating from toilets is called black water and can be further divided into yellow water (urine with or without flush water) and brown water (toilet wastewater without urine). Additionally, grey water is that part of domestic wastewater which originates from kitchen, shower, wash basin and laundry (for more details see Lesson A1).

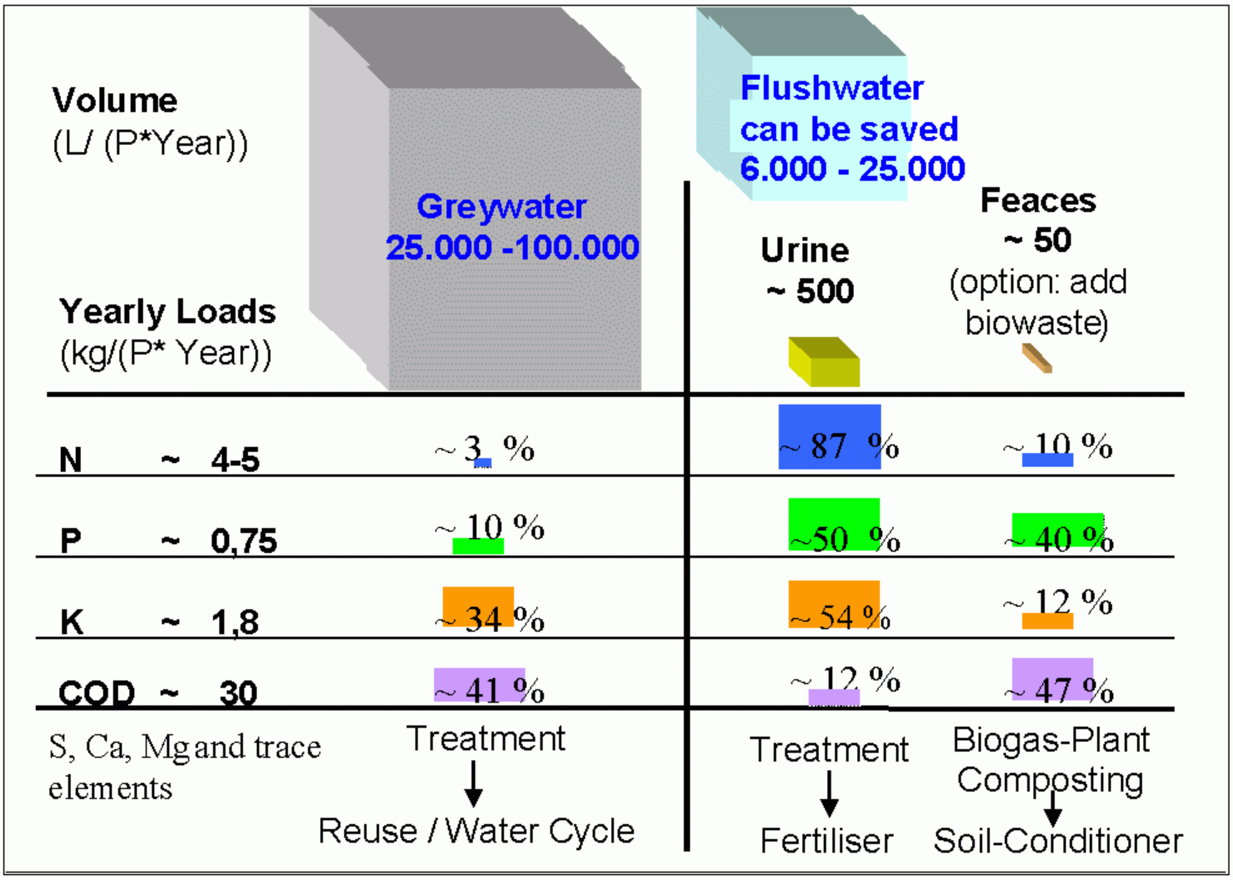
Figure 1: Sources of domestic wastewater (Samwel 2005)

1.2 Characteristics of different streams

The typical characteristics of the streams of domestic wastewater, shown in table 1 clearly characterize that yellow and brown water contain most of the nutrients discharged to sewers in the conventional sanitation. This means that they are generally wasted instead of being used as fertilizers (except the small portion of nutrients being contained in sludge which is used sometimes as fertilizer after sanitisation).

Due to pathogens, brown water poses high health risk, but it represents a very small volume flow in domestic wastewaters (only 50 litres are excreted per person per year). In conventional systems, this small volume is mixed with other streams of domestic wastewater with higher volume flows: yellow water (tenfold volume flow compared to faeces) and grey water. Grey water volume flows depend on habits. That is why a wide range is given for grey water volume flow: 25,000 to 100,000 litres per person per year. Table 1 is related to Central European patterns. Of course, also extremely smaller grey water volume flows per person can be found, especially in regions with water scarcity. Additionally toilet flush water has to be taken into consideration (which might be up to 10 litres per toilet use).

Table 1: The typical characteristics of the streams of domestic wastewater (Compiled from: Geigy, Wissenschaftliche Tabellen, Basel 1981, Vol.1, Larsen and Gujer, 1996 and Fittschen and Hahn, 1998)



It is very impressive that the large volume flow of grey water is accompanied by comparably small nutrient mass flows (about 3 % of the total nitrogen mass flow and 10 % of the total phosphorus mass flow (phosphorus concentration can still be lowered by using phosphorus free detergents) discharged with domestic wastewater). However, about one third of the potassium (which is also important for plant growth and a limited fossil fertilizer component) mass flow of domestic wastewater is contained in grey water. Because of the large volume flow of grey water (compared to yellow and brown water), its potassium concentration is quite low (commonly below 10 mg/l), however. Because of its low contribution to mass flow of the nitrogen and phosphorus in domestic wastewater and its high volume flow grey water turns out to belong to the ***water cycle*** and represents a splendid source for wastewater reuse. As grey water contains nearly half of the organic load of domestic wastewater, this is the main group of pollutants to be removed from grey water before its eventual reuse. Therefore, treatment of grey water is far cheaper than treatment of total domestic wastewater as there is no need of costly nitrification and denitrification processes mostly practiced in modern municipal wastewater treatment plants.

The scheme clearly demonstrates that greatest part of the nutrients nitrogen, phosphorus and potassium of domestic wastewater are contained in the comparably small volume flow of yellow water. Moreover, urine contains trace metals required for plant growth. Only about 10 % of the organics of domestic wastewater are urine borne. From these reasons, yellow water has to be taken into consideration as fertilizer, and is thus related to the ***food cycle*** rather than to the water cycle.

Brown water contributes greatly to the phosphorus load of domestic wastewater and can thus also be considered as fertilizer. Moreover, the organic solids make brown water a splendid candidate as a soil conditioner after suitable treatment. Therefore, also brown water is belonging to the ***food cycle.***

1.3 Yellow water as fertilizer

Separate collection of yellow water is possible with sorting toilet (see figure 7 and 8). Among the flows of wastewater, yellow water contains most of the nutrients (table 1). One person produces on average 3.92 kg of nitrogen, 0.38 kg of phosphorous and 0.97 kg of potassium per year. These nutrients, such as nitrogen in the form of urea, phosphorus as super phosphate and potassium as an ion, are in a form which are ideal for uptake by plants (Esrey et al.; 1998). Beneficially, urine contains very low levels of heavy metals and pathogens. These heavy metal concentrations are much lower than those of most chemical fertiliser. In Sweden, for instance, urine contains less than 3.2 mg cadmium per kg of phosphorus compared to 26 mg Cd/kg of phosphorus in commercial fertiliser and 55 mg Cd/kg of phosphorous in sludge (Esrey, 2000).

In the conventional wastewater treatment systems, instead of utilising the yellow water for plant nutrition, it is wasted. In modern municipal wastewater treatment plants, nitrogen compounds (most of them originating from yellow water) is removed with the costly nitrification and denitrification process. Even with the high inputs of money, a reasonable amount of nitrogen compounds (especially nitrate) escapes with the effluents of treatment plants and causes eutrophication in water bodies. In high-tech treatment plants, most of the nitrogen compounds are converted to N_2, which is itself a raw material for high energy consuming nitrogen fertilizer synthesis (e.g. in natural-gas based ammonia plants).

Even the best affordable treatment plants discharge over 20 % of nitrogen, over 5 % of phosphorus and more than 90 % of potassium to the aquatic environment where they are lost for ever and cause severe problems (Otterpohl et al., 1997). Those nutrients, which are captured in sludge are often contaminated with heavy metals such as Cadmium (Cd) and organic compounds such as PCB (polychlorinated Biphenyle), which pose potential toxic risks to plants, animals and humans (Metcalf and Eddy, 1991). Therefore, large amounts of sewage sludge are disposed of in landfills or incinerated. Only a smaller part is applied to agricultural land.

Due to following reasons wasting of yellow water is not sustainable:

1st: Production of fertiliser is energy intensive, draws on very limited fossil resources and causes environmental problems. Generating nitrogen (N) from air requires a considerable amount of energy. Mining and refining the raw materials for phosphate production generates a huge amount of hazardous wastes. Reserves of phosphate (P) and potassium (K) are definitely limited on a time scale of only a couple of human generations especially with regard to economic constraints. Moreover, also sulphur is a limited fossil resource and is required by plants. Also sulphur is contained in yellow water. Therefore, we should use the human resource "Anthropogenic Nutrient Solution" (ANS; Larsen and Gujer, 1996) yellow water as fertiliser which contains reasonable amounts of these nutrients.

2nd: If yellow water is wasted (i.e. it is added to municipal wastewater), it will either contribute to eutrophication of surface waters because of its nutrient content or it will even lead to groundwater contamination (high nitrate concentrations can be generated by transformation of ammonia, and sometimes high nitrate concentrations are detected in ground waters contaminated with domestic wastewater - they can lead to lethal methemoglobinemia of babies drinking water from such contaminated sources).

3rd: Even if domestic wastewater is treated in modern treatment plants, adding yellow water to wastewater is disadvantageous Residual nitrogen compounds (mainly nitrate) escape with the effluents even of very efficient wastewater treatment plants and contribute to surface water eutrophication. But the main disadvantage of adding yellow water to municipal wastewater is that a great deal of energy consumption for operating activated sludge tanks is required for ammonia removal (aeration for nitrification). Removal of phosphate from municipal wastewater requires an additional biological stage and/or precipitation stages (addition of iron or aluminium salts). It is assumed that nutrient removal requires about 50 % of energy consumption in German wastewater treatment plants (Rakelmann 2002). It is clear that production of electric power is contributing to the greenhouse effect and leads to emission of air pollutants.

4th: Because of its content of nutrients, yellow water can substitute a reasonable amount of synthetic fertilizers. It is assumed that about 50 % of crops needed by human beings can be fertilized with human excreta. When yellow water is wasted, this means additional energy consumption for fertilizer production.

(See definitions of "sustainable development" under: http://www.gdrc.org/sustdev/definitions.html)

1.4 Brown water as soil conditioner

It can be seen in a map (figure 2) provided by the FAO that Soil degradation caused by human activities is alarming worldwide. About 38 % of globally used agricultural land is degraded- mostly in Asia, Africa and South and Central America (Esrey, 2000). The main causes of soil degradation are: erosion, fertility decline, overcropping and use of synthetic fertiliser. Since synthetic fertiliser does not contain organic matter which prevents soil erosion, reuse of brown water as soil conditioner plays important role to reduce the soil degradation as brown water contains most of the organic solids in domestic wastewater (see table 1).

Like yellow water, separate collection of brown water is possible with sorting toilet (See figure 7 and 8). As faeces are the predominant source of pathogens of all streams of domestic wastewater, they have to be sanitised prior to their use as soil conditioner. However, killing of pathogens is facilitated when faeces are collected separately. Possible treatment techniques are dehydration (utilization of solar energy) or composting. Together with organic solids helping to prevent soils from desertification, also nutrients are transferred to agricultural fields with processed brown water.

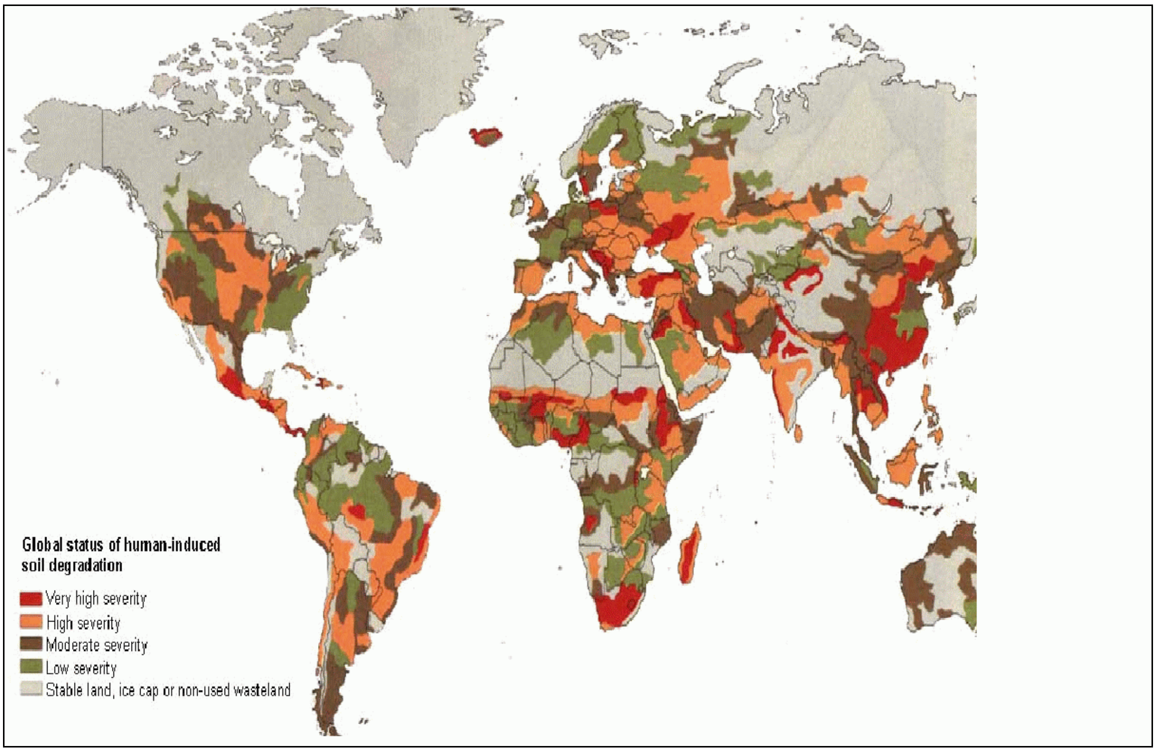


Figure 2: Map of global status of human-Induced soil degradation

2. Conventional sanitation systems and their limitations

Due to disease risks caused by faecal wastewater, in large European cities sewers were constructed to drain the wastewater away from the people's surroundings to the nearby water courses, and ultimately into the sea. Later, it was found that discharging raw wastewater had deteriorated aquatic environment of the receiving water body and at the same time it caused diseases to the people who received their drinking water from the same river downstream. Because of drinking water contamination, epidemics of cholera had periodically caused heavy loss of life in the large European cities (Evans, 1987). The outbreak of cholera in 1892 , for instance, took place all over in Hamburg where drinking water supply was extracted from the river Elbe. To protect these rivers from the pollution as well as the public health from water borne diseases, the wastewater was since then treated at the end of the sewer before discharging it into the river. This tradition has been widely established as a standard way of managing wastewater worldwide. However, most of the wastewater is discharged without any treatment mostly in developing countries.

In centralised wastewater management systems, household wastewater together with municipal and industrial wastewater, storm water as well as infiltration/inflow water is collected and transported a long way to central treatment plants where it is treated and disposed/reused (figure 3). This system has been built and operated for more than hundred years. In the mean time, because of advanced technological development, the wastewater management has reached high standard in many industrialised countries. However, in developing countries the present situation is still similar to that of the currently industrialised countries in the 19th century in many respects. About 95 % of wastewater in developing countries is discharged without any treatment into the aquatic environment (WIR, 1992). This contributes largely about 1.2 billion people without access to clean drinking water. Almost 80 % of diseases throughout the world are water-related. Water-borne diseases account for more than 4 million infant and child deaths per year in developing countries (Lubis, A.-R., 1999). In New Delhi, India, more than 50 % of the raw wastewater is still discharged into the river Yamuna, from where the city draws its water supply (Narain, 2002).

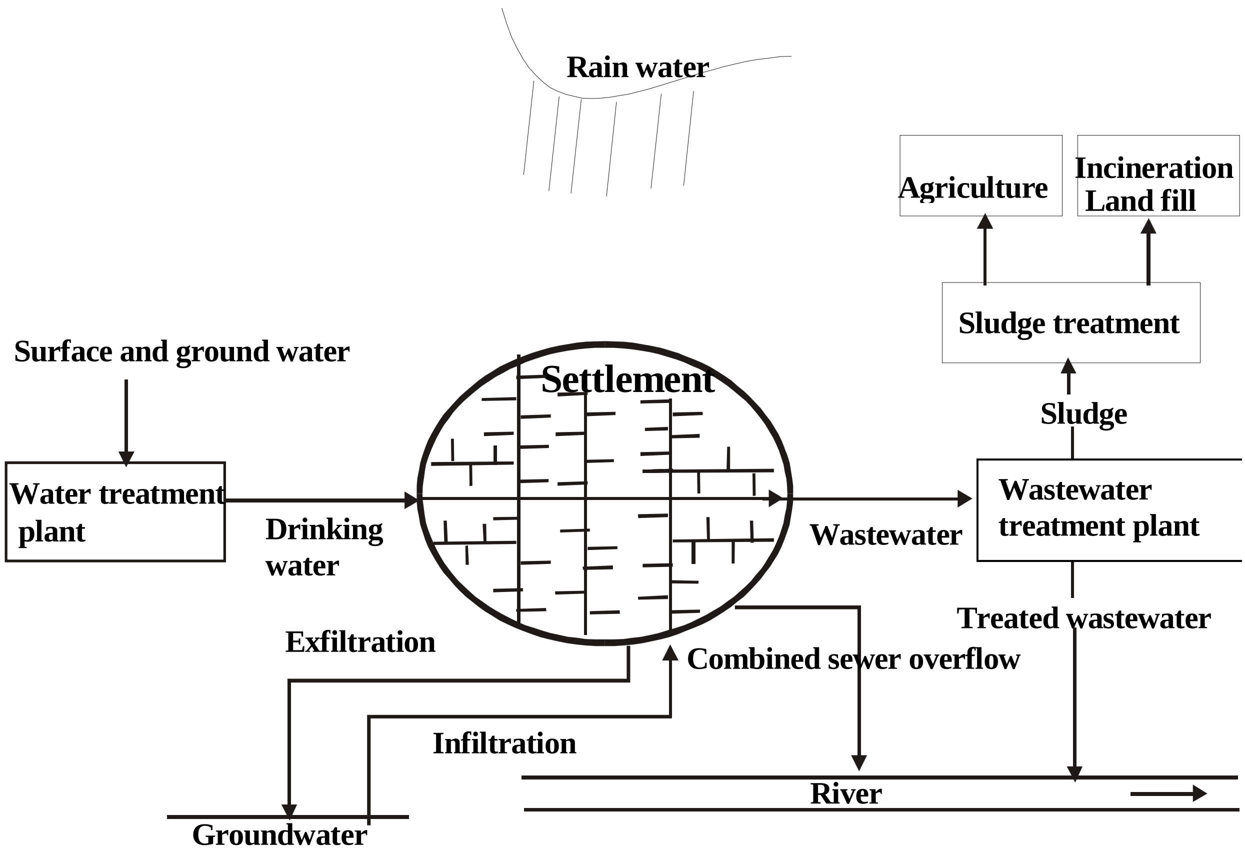


Figure 3: Traditional centralized system of water supply and wastewater treatment

In households, the nutrients that are brought in in the form of food are converted into human excreta and kitchen waste. In conventional sanitation systems, a huge amount of fresh water is used as a transport medium and a sink to dispose of these wastes. In this process a small amount of human faeces is diluted with a huge amount of water. Therefore, it is hardly possible to prevent contaminants from emitting into surface and groundwater bodies. As a result a huge amount of fresh water is contaminated and deemed unfit for other purposes. Moreover, due to the pollution and hygienic problems in receiving waters, surface water can no longer be used as a source for drinking water supply. Huge investments have to be made to improve the surface water quality in order to use it as drinking water.

In the industrial countries, a large amount of money has been already spent to build up and maintain these conventional sanitation systems. In Germany it has been estimated that large investments are still necessary for repairing, rebuilding and extending existing systems in the coming years (Hiessl, 2000). About 80 % of the overall expenditures for sewerage systems go to the collection and transportation of wastewater to the central treatment plant, where only about 20 % of the overall expenditures is spent.

Although construction, maintenance and operation of sewers are very costly parts of the centralised wastewater treatment systems, more than 90 % of the population in Germany are already connected to sewer systems (Wilderer and Schreff, 2000). Experience shows that centralised sewerage systems can be extremely expensive for regions with a low population density, since costs of construction, operation and maintenance of long sewers are to be covered by a small number of inhabitants. These costs are obviously unaffordable for the major part of the population mostly living in developing countries. Thus, it is irrational to plan central sewerage for all rural and peri-urban regions of developing countries. Even in the USA, the complete coverage with sewerage systems is not possible or desirable, for both geographical and economical reasons (Crites and Tchobanoglous, 1998).

Even with the high inputs of money for construction, maintenance and operation, this end-of-pipe concept is producing linear mass flows (figure 4). It shows clear deficiencies in recovery of nutrients and organic matter, which are valuable fertiliser and soil conditioner. As it is already mentioned that even the best affordable treatment plants discharge considerably large amount of nutrients to the aquatic environment where they are lost for ever and cause severe problems. Those nutrients, which are captured in sludge are often contaminated with heavy metals such as Cadmium (Cd) and organic compounds such as PCB (polychlorinated Biphenyle), which pose potential toxic risks to plants, animals and humans. Therefore, large amounts of sewage sludge are disposed of in landfills or incinerated. Only a smaller part is applied to agricultural land.

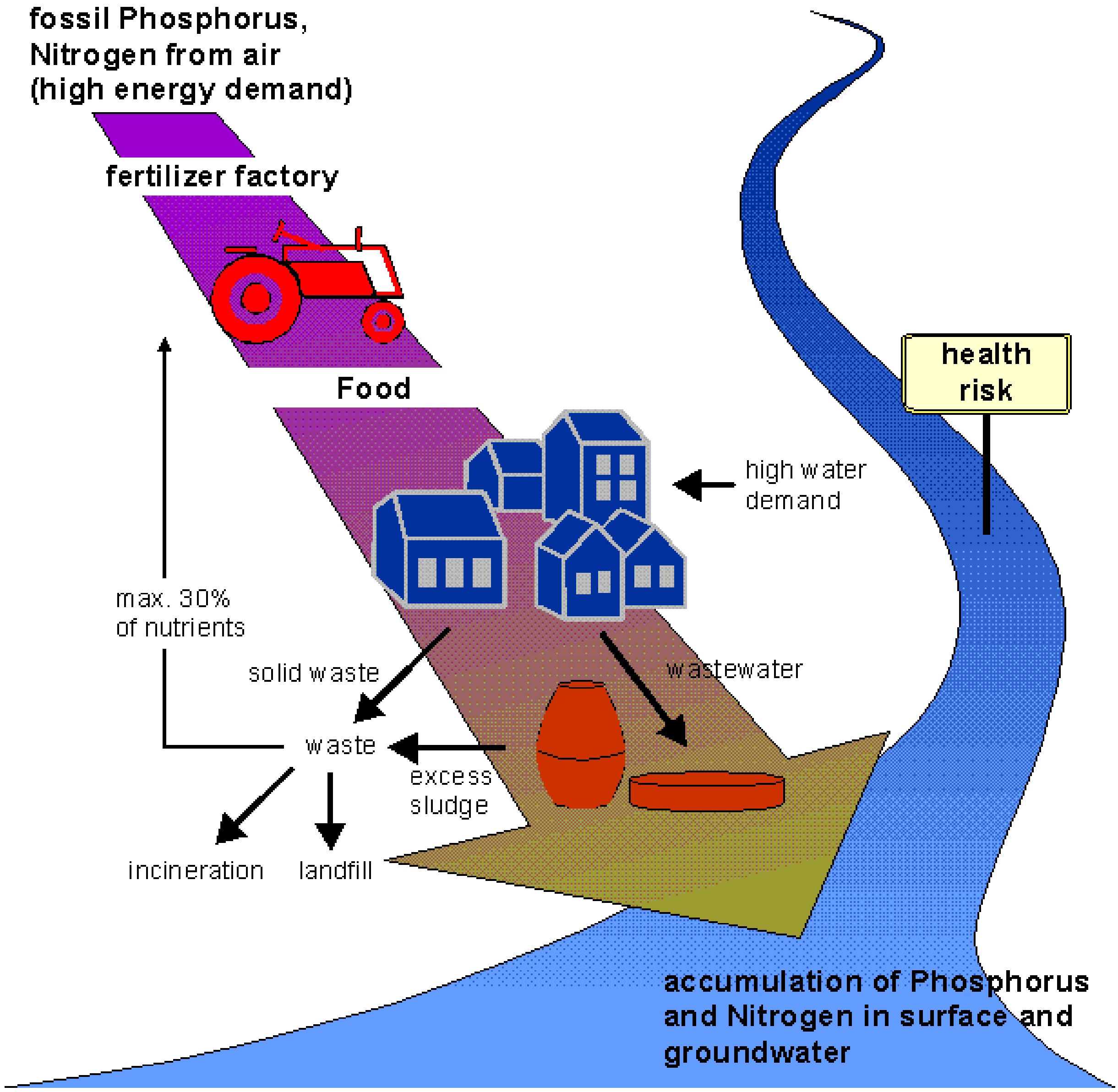


Figure 4: Material flows in the conventional sanitary concept (source Otterwasser GmbH)

3. Conventional decentralised sanitation systems – benefits and limitations

In decentralised systems, wastewater from individual houses is collected, treated and disposed / reused at or near the point of its origin. The most important benefits of this system compared to the centralised system are:

- there is no need of laying sewers for the transportation of sewage as in the centralised treatment plant, which is normally located far from the point of the origin of the sewage; construction, maintenance and operation of sewers are very costly parts of sanitation systems;
- there is far lower dilution of sewage than in the centralised system, which creates possibilities to reuse treated wastewater and nutrients.

Therefore, decentralised wastewater treatment technologies will play a significant role, if they are low-cost and allow reuse. There are many existing decentralised wastewater treatment systems which have been widely used worldwide. However, all of them cause pollution i.e. nutrients and pathogens seeping from these systems contaminate the groundwater and nearby surface water, they cannot destroy pathogens and deprive agriculture of valuable nutrients and soil conditioner from human excreta. Moreover, some systems require expensive tanker-trucks to pump and transport the sludge deposited at the bottom of the system far away. In large cities, transportation distances are normally long, since suitable sites for treatment and disposal can mostly be found at the outskirts of cities. Transportation of relatively small faecal sludge volumes (5 - 10 m^3 per truck) through congested roads over long distances in large urban agglomerations is not suitable, neither from an economical nor from an Ecological point of view (Montangero and Strauss, 2002).

Most of the people in urban and peri-urban areas of Asia, Africa and Latin America and peri-urban areas of industrialised countries use conventional decentralised sanitation systems (On-site sanitation systems), notably septic tank systems. Even in the USA, 25 percent of the houses are served by septic tank. Basically septic tanks are designed only to collect household wastewater, settle out the solids and anaerobically digest them to some extent, and then leach the effluent into the ground, not to destroy pathogens contained in wastewater. Therefore, septic tank systems can be highly pathogenic, allowing the transmission of disease causing bacteria, viruses, protozoa and intestinal parasites through the system. It is reported that there are 22 million septic system sites in the USA issuing contaminants such as bacteria, viruses, nitrate, phosphate, chloride, and organic compounds into the environment (Jenkins, 1994). Another problem is home chemicals with hazardous constituents which are discharged to toilets and contribute to severe groundwater contamination in sanitation using septic tanks. According to the EPA, states of the USA reported septic tanks as a source of groundwater contamination more than any other source, with 46 states citing septic systems as sources of groundwater pollution (figure 5), and nine of them to be the primary source of groundwater contamination in their state. It has to be noted that occasionally problems with broken septic tanks occur leading to infiltration of nearly untreated wastewater.

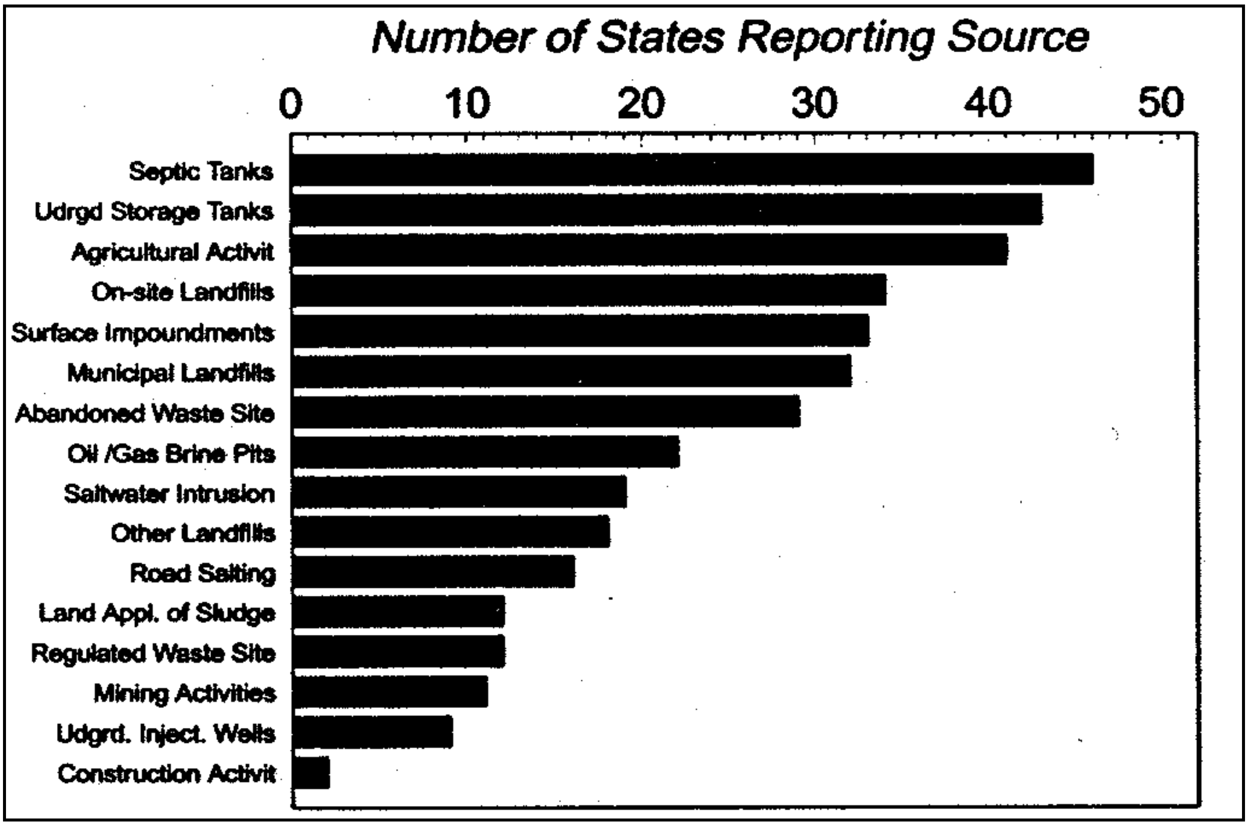


Figure 5: Reported sources of groundwater contamination in the United States (Jenkins, 1994)

The incomplete anaerobic decomposition in septic tanks results in unpleasant odour that spreads in the surrounding. Many households often add chemicals into septic tank to reduce odour. These chemicals have adverse effects on the decomposition process and ultimately in environment.

4. Resource Management Sanitation

4.1 Background

All conventional wastewater treatment systems usually deprive agriculture, and hence food production, of the valuable nutrients contained in human excreta, since the design of these systems is based on the aspect of disposal. In households, resources are converted into wastes. When the systems we have designed fail to reconvert the waste back into resources, they don't meet the important criteria of sustainable sanitation (Esrey, 2000). Thus, the future sanitation designs must aim for the production of fertiliser and soil conditioner for agriculture rather than waste for disposal (Otterpohl, 1999). Nutrients and organic matter in human excreta are considered resources, food for a healthy ecology of beneficial soil organisms that eventually produce food or other benefits for people. One person can produce as much fertiliser as necessary for the food needed for one person (Niemcynowicz, 1997). Therefore, the new approach should be designed in such a way that it could reconvert the waste we produce into resources free of pathogens in reasonable costs without polluting aquatic environment.

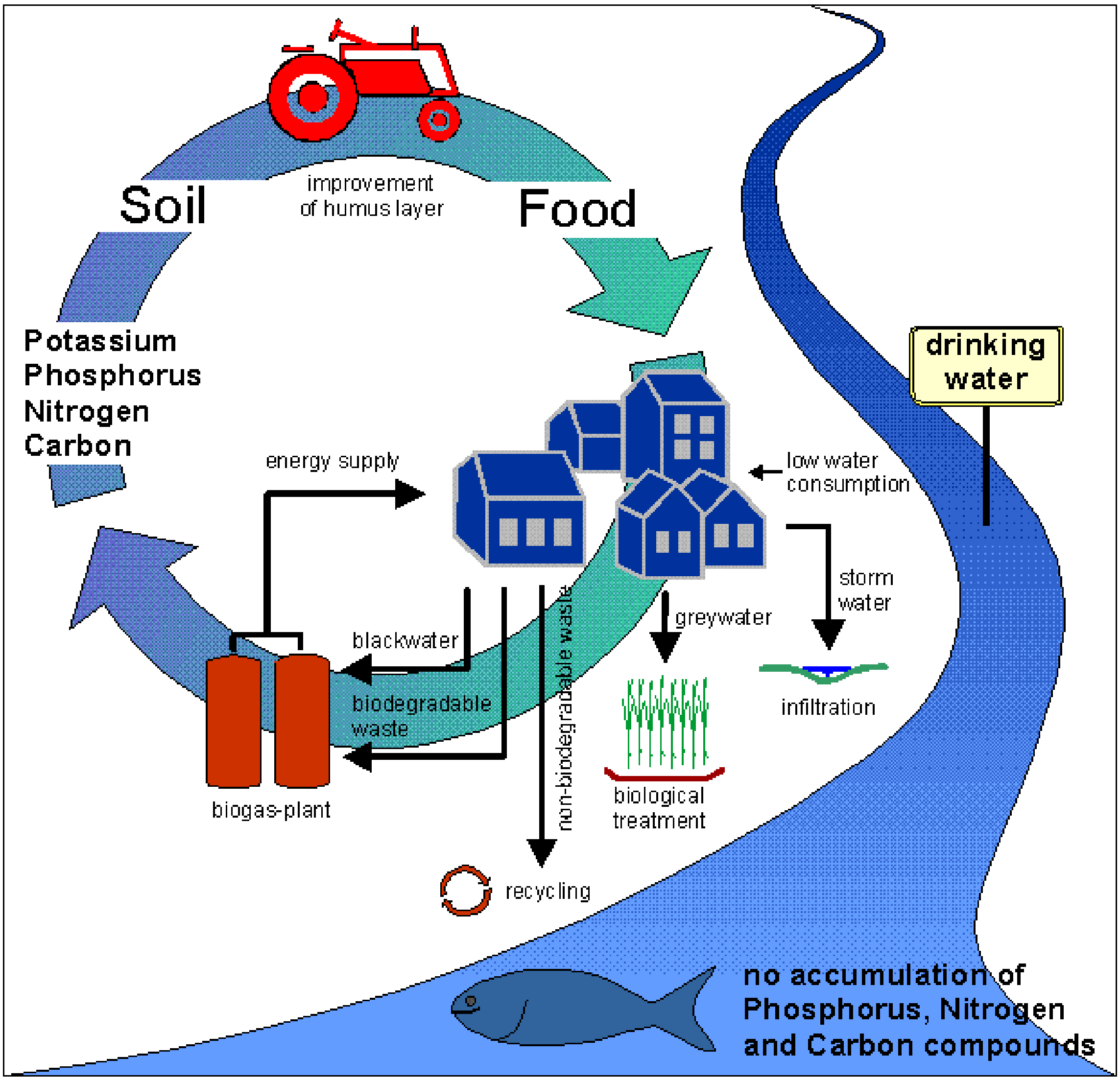


Figure 6: Material flows in resource management sanitation (Source: Otterpohl et al., 1997)

Figure 6 illustrates a possible scenario for closing the nutrients cycles and simultaneously preserving fresh water from pollution. This scenario can be achieved with the application of resource management sanitation, base on ecological principal. There are numerous advantages of resource management sanitation compared to conventional sanitation (Werner et al., 2002; Otterpohl, 2001; Esrey et al., 1998). The major advantages of them are :

- reuse of human excreta as fertiliser and soil conditioner; water and energy;
- preservation of fresh water from pollution as well as low water consumption;
- preference for modular, decentralised partial-flow systems;
- design according to the place, environment and economical condition of the people;
- hygienically safe;
- preservation of soil fertility;
- food security;
- low cost (ecological, economical and health cost);
- reliable.

Resource management sanitation bases on the concept of source control. High levels of nutrient recovery are possible with the concept of source control in household (Otterpohl et al., 1999; Henze et al., 1997; Esrey et al., 1998). The technologies to realise source control have already been developed (Otterpohl, 2001; Esrey et al., 1998). **Sorting toilet** is a suitable technology to separate the urine and faeces at source (see figure 7). Usually, the toilet has two bowls, the front one for urine and the rear one for faeces. Each bowl has its own outlet from where the respective flow is piped out. The flush for the urine bowl needs little water (0.2 l per flush) or no water at all, a mechanical device closes the urine pipe when users stand up whereas flushing water for faeces bowl can be adjusted to the required amount (about 4 to 6 l per flush). However, in the present system separate collection is efficient only when men sit down while urination. Recently, there is a new development in Norway for separating urine even when men stand up while urination.

Figure 7: Sorting toilet (Source: Ruediger)

Figure 8 : Vacuum toilet (Source: Ruediger)

Vacuum toilets as shown in figure 8 has been used in aeroplanes and ships for many years and is increasingly used in trains and flats for water saving. It uses 1 l water per flush and is independent of gravity. The black water is transported by air and pressure differential (vacuum) instead of water and gravity to bio-gas plant. Water is used only for rinsing the bowl, not for transporting the faeces. Limited vertical lifts and long horizontal transportation of the black water are possible. Noise is a concern with vacuum toilets but modern units are not much louder than flushing toilets and give only a short noise.

Composting / dehydrating toilet needs 0.2 l water per flush, only for cleaning the toilet seat. There are also urine diversion composting or dehydration toilets (figure 9). These low-flush and non-flush toilets save not only water, but also produce low diluted or dry faecal material that is easier to manage than highly diluted faecal wastewater as in conventional systems.

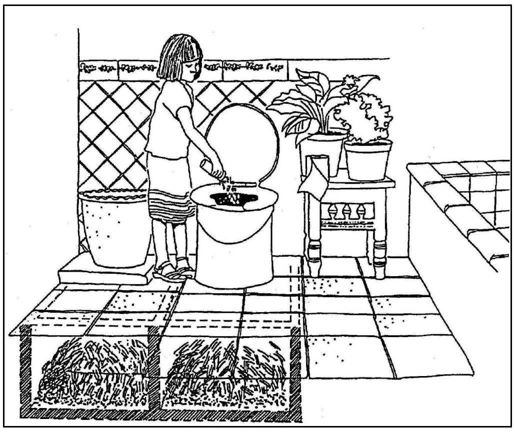


Figure 9: Double-vault toilet with urine diversion (Source: Esrey et al., 1998)

4.2 Bellagio statement

In February 2000, there has been an experts consultation arranged by the Water Supply and Sanitation Collaborative Council (WSSCC) which resulted in the formulation of the so-called ***"Bellagio Statement"*** ("Clean, healthy and productive living: a new approach to environmental sanitation"), which gives some insight into philosophy and basics of Resource management sanitation. The statement contains the following principles (EAWAG/SANDEC 2000):

1st: “Human dignity, quality of life and environmental security at household level should be at the centre of the new approach, which should be responsive and accountable to needs and demands in the local and national setting.“

2nd: “In line with good governance principles, decision-making should involve participation of all stakeholders, especially the consumers and providers of services.“

3rd: “Waste should be considered a resource, and its management should be holistic and form part of integrated water resources, nutrient flows and waste management processes.“

- “Inputs should be reduced so as to promote efficiency and water and environmental security.“
- “Exports of waste should be minimised to promote efficiency and reduce the spread of pollution.“
- “Wastewater should be recycled and added to the water budget.“

4th: “The domain in which environmental sanitation problems are resolved should be kept to the minimum practicable size (household, community, town, district, catchment, city) and wastes diluted as little as possible.“

Also a ***Workshop on "Ecological Sanitation in a Recycling Society"*** in August 2000 organized by the associations Sida, UNDP, and SIWI addressed the potential of resource management sanitation to overcome water scarcity and wasting resources:

- "Water is an increasingly scarce resource and to continue to use clean *drinking water as a means to transport human waste* ***is not environmentally sustainable***."

- "Linear approaches to problems, in which *resources* are used and converted into wastes, only *to be disposed of*, represent a *failure in human ingenuity* and a flaw in technology design."

This statement emphasizes that linear matter flows (i.e. they end in disposing of any matters as waste in the end instead of organizing matter flows in cycles realizing reuse achieving almost "zero emission" scenarios) should be changed - also in sanitation schemes.

- "In order to *create a recycling society*, we need to *capture the wastes*, *render them safe and return them to productive resources again*. Resource management sanitation is based on natural ecosystems. It contributes to environmental health and human well-being by reducing disease transmission and disposal of wastes, by recovering and recycling water and nutrients for increasing food security."

- "Most cities and towns in the Third World will neither have access to the required quantities of water, nor will they be able to generate financial resources for investments in extensive sewerage networks and treatment plants. ***Resource management sanitation is far more feasible financially and ecologically than conventional approaches to sanitation*** by reducing external inputs into a closed-loop system and by empowering people, providing for local livelihoods, and enhancing community cohesion."

This statement also points out that resource management sanitation helps to save financial resources, because it is a closed-loop system.

- "If coverage can be increased, *resource management sanitation can serve as the missing link to sustainable urban development*, reverse the unconscious pattern of linear thinking and actions, and be a technical solution that protects ecosystems and harmonises with natural systems."
- "There is a *big need for research to further develop affordable and sustainable solutions*, based on an eco-system approach, *for the management of human excreta*."

As resource management sanitation scenarios are discussed since last few years, it is clear that research is needed in this field. However, how many research activities have been developed in conventional sanitation?

Finally, an introduction to Resource management sanitation given by Steven A. Esrey also renders the most important characteristics of Resource management sanitation:

“Why do people want sanitation today? The most common reason given is for better health. People also want it for convenience, privacy, efficiency, dignity and status among other reasons. We want cars too for transportation. We want convenience, privacy, efficiency, dignity and status as well.

Just like a car and a highway system reflect our culture and values, the toilets and sanitation systems installed around the world also reflect our culture and values. Unfortunately, they reflect a culture of linear flow of resources, waste generation and disposal.

Resource management sanitation is also reflective of a culture and values, albeit an alternative one. It is an alternative philosophy, one with ecological design and systems thinking. Thus, resource management sanitation is more than a toilet or a technology. It is an alternative view of life of how we should live on this planet. It is about restoring communities, protecting cultures, preserving resources, and protecting biodiversity. This is how most of humanity lived until last century.

Resource management sanitation systems are designed on the cyclical principles of natural ecosystems. External inputs into the system, like water, and ‘wastes‘ that exit the system, like nutrients, are reduced to a minimum or eliminated. Thus, resource management sanitation systems are designed to render pathogens harmless close to where people excrete them, use no or little water, and recover and recycle nutrients**.**

By adhering to these principles, resource management sanitation systems help to solve some of society's most pressing problems - infectious disease, environmental degradation, water scarcity and the need to recover and recycle nutrients for plant growth. In doing so, it also helps to restore soil fertility, conserve fresh water and protect marine environments.

Those promoting and resource management sanitation systems take an ecosystems approach to the problem of human excreta. Urine and faeces are considered valuable resources, with distinct qualities, that are needed to restore soil fertility and increase food production. Prior to recycling nutrients, urine and/or faeces may need to be processed. Many of the plant nutrients in urine are readily available to be taken up by plants, while most of the pathogens causing illness are in the faeces. Thus, it makes sense to divert urine from faeces to keep urine relatively sterile, while making it easy to process and treat feaces to render them harmless. Faeces, which contain most of the carbon in excreta, can be rendered harmless by several processes and returned to the land as a soil conditioner as well as returning other valuable nutrients."

4.3 Issues of resource management sanitation

The four issues addressed by resource management sanitation (microbial risks and environmental degradation, water scarcity, malnutrition, and wasting of financial resources) lay down the tasks of Ecosan schemes:

Excreta must be handled safely and also chemical contaminants from domestic wastewater must be contained in compartments as small as possible (again: "dilution is no solution"), water scarcity has to be overcome by reusing the reclaimed part of domestic wastewater related to the water cycle (i.e. greywater), nutrients from human excreta should be recycled for increasing agricultural yields, and saving money (not only by avoiding high investment for sewers, but also needing less synthetic fertilizers because of utilizing nutrients from human excreta).

4.4 Source separation as a key issue in resource management sanitation

The aforementioned aims can be achieved by source control in sanitation! Source separation of different streams of domestic wastewater helps to prevent pathogens from faecal matter to be spread in the environment, utilizing nutrients from yellow water, and preventing grey water from being further contaminated with nutrients, faecal pathogens, and contamination with hazardous substances from industrial wastewaters making it a suitable source for being reused - even for high quality demand like groundwater recharge.

The issue of source control requires some special pre-requisites: separate pipes for yellow, brown and grey water, no-mix toilets for separate collection of yellow and brown water and low volumes for toilet flushing.

Generally, there are different options for source separation. A simple scheme would be the separation of grey water from black water, requiring two separate pipe systems in the home (one for grey water, one for black water). Low volumes of toilet flush water are helpful in further treatment of black water solids in order to sanitise them. For certain sanitation techniques (dehydration, composting), the black water solids have to be separated from the liquid phase. One possibility for sanitisation the entire black water is anaerobic digestion, which also offers the possibility of harvesting biogas.

The second option is to collect all three sources of domestic wastewater separately: grey water, yellow water, and brown water. This option requires three different types of pipes in the home (for grey water, yellow water, and brown water). In such a scheme, the excellent fertilizer “yellow water“ is collected very purely.

Source separation of different particular domestic wastewater flows (related to the nutrient as well as to the water cycle) facilitates sanitisation of human excreta as well as nutrient recovery from excreta – and also purification of the grey water stream.

4.5 Treatment systems for brown and black water

There are two types of treatment systems, namely dry and wet systems for the treatment of brown and black water. Dry systems use no flush water whereas wet systems use flush water, but only very low amounts just to transport faecal matter to the treatment plant located close to the origin of faecal matter. The non-diluted or less diluted faecal matter has to be sanitised before reuse in agriculture. This can be done with composting, dehydration, vermicomposting and anaerobic fermentation/digestion. In the following sections the theoretical background of these processes is briefly discussed.

4.5.1 Composting

Composting is the biological decomposition of the organic matter under controlled aerobic conditions. The basic composting process is shown in figure 10. The main factors affecting the aerobic decomposition of organic matter by microorganisms are oxygen, moisture and nutrients. Carbon and nitrogen are essential for microbial growth and activity. Carbon is the principal source of energy, and nitrogen is needed for cell synthesis. Other important factors that can slow down the composting process are temperature and pH. Temperature is the result of the microbial activity as well as the influence of the surrounding temperature, mass of the composting materials and heat loss.

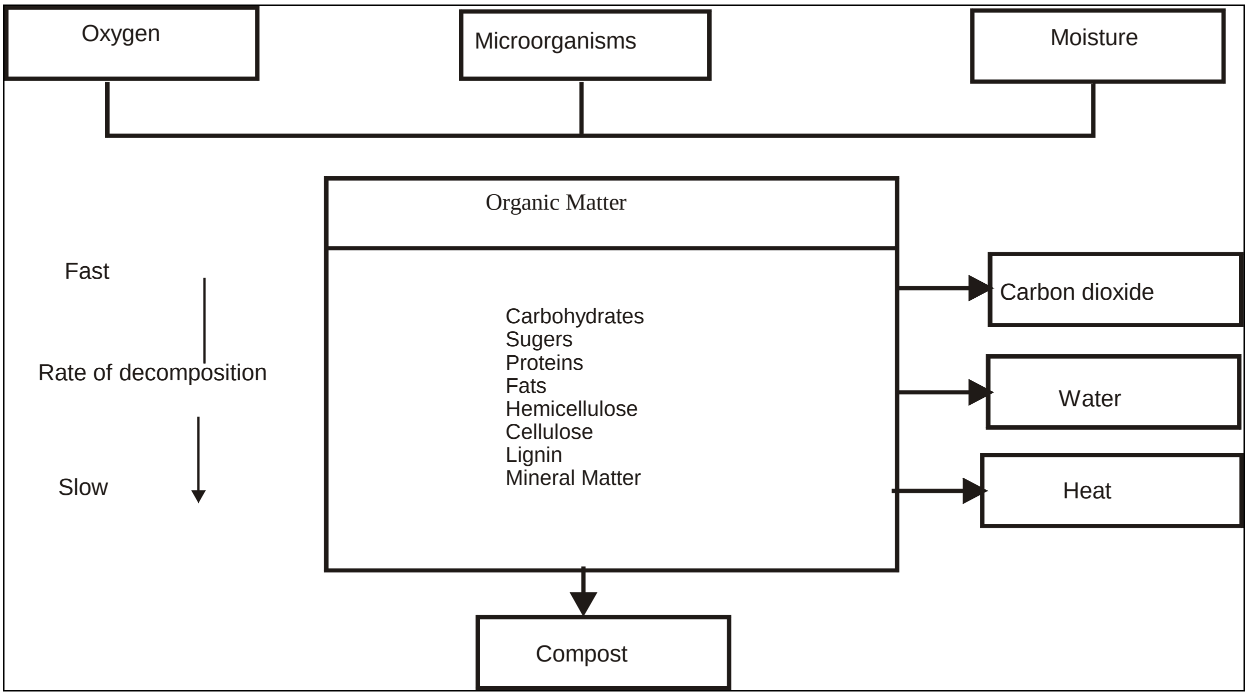


Figure 10: The composting process (Source: Epstein, 1997)

In the process of composting, microorganisms break down organic matter and produce carbon dioxide, water, heat, and compost. In addition, ammonia and other volatile compounds are emitted to the atmosphere. However, in comparison to CO_2 and H_2O these represent a very small amount.

All organic material will eventually decompose. The rate at which it decomposes depends on the physical as well as chemical factors. The optimal condition for composting is shown in table 2.

Table 2: Overview of optimal condition for composting

Parameters	Optimal level for household organic waste	Optimal level for Fibrous or bulky materials such as straw or wood chips
Moisture	50 - 60 %	For straw: 75 - 85 %, for wood chips: 75 - 90 %
C:N ratio	25 - 30: 1	For woody materials: 35 - 40 : 1
pH	6 - 8	
Temperature	Thermophilic (> 45 ℃)	
Oxygen	5 - 15 % of air	
Particle size	Good Structural stability	
Time	Depend on temperature Longer for temperature<45 ℃ Shorter for temperatur > 45 ℃	

4.5.1.1 Composting of faecal materials

The composting of faecal materials follows the same biological processes as the composting of other organic waste. Therefore, the optimal conditions for the composting of faecal matter are a C:N ratio of 25 - 30:1 and a moisture content of 50 - 60 % (Table 3). However, the composition of human faeces shows low C:N ratio and a high water content. Besides, human faeces have a low structural stability. Therefore, only materials with a high C:N ratio, low moisture content and high structural stability should be added to faecal materials. Straw, bark and wood chips are considered to be good bulking agents.

Table 3: Overview of conditions for composting in sanitation

Condition → Parameters ↓	**No or little functioning**	**Slow functioning**	**Optimal functioning**	**Slow functioning**	**No or little functioning**
Moisture	< 25 %	< 35 – 40 %	50 – 60 %	70 %	70 % anaerobic
C:N ratio		< 25:1 (nitrogen loss)	25 – 30: 1	> 30:1	
Temperature	< 15 ℃	< 45 ℃	> 45 – 60 ℃ <	70 ℃	> 75 ℃
pH		> 8 (nitrogen loss)	6-8	5 - 6	< 5
Oxygen		< 5 % of air anaerobic	> 10 % of air		
Time			< 45 ℃ 1 year > 45 ℃ 2 month		
Particle size			structural materials: bark, wood chips, straw etc.		

4.5.1.2 Dehydration

Dehydration means to remove water. Therefore, unlike composting, dehydration is the controlled physical process of dewatering moist materials. Dehydration is effective if faecal materials are separated at source without any dilution, since a great part of the liquid phase of faecal materials has not to be evaporated off at all. Therefore, urine diversion is crucial for dehydration. Esrey et al. (1998) claimed that treatment methods based on dehydration can reduce pathogens effectively. There is a rapid pathogen destruction at moisture contents below 25 %. Dehydration processes can be accelerated with the help of heat (solar radiation), ventilation and the addition of dry materials.

4.5.1.3 Vermicomposting

Vermicomposting is the process in which organic materials are converted into humus using earthworms that break down the organic materials. Earthworms are voracious feeders on organic wastes and while utilising only a small portion for their body synthesis they secrete a large part of these consumed waste materials in a half digested form. Since the intestines of earthworms harbour wide ranges of microorganisms, enzymes, hormones etc., these half digested vermicasts decompose rapidly and are transformed into a form of vermicompost that is homogenous, rich in plant nutrients with superior plant growth characteristics and increases water holding capacity of the soil (Appelhof, 1997; Edwards, 1995). Moreover, pathogens cannot survive the vermicomposting process (Edwards, 1995).

The earthworms species: Eisenia fetida and Eisenia andrei are most commonly used for the vermicomposting. Other suitable species include Lumbricus rubellus, Eudrillus eugenie and Perionyx excavatus. The latter two species are from Africa and Asia and cannot withstand low temperatures.

In the composting process, the organic materials have to be turned regularly or aerated in some way in order to maintain aerobic conditions. In vermicomposting, the earthworms, which survive only under aerobic conditions, take over both the roles of turning and maintaining the organic materials in an aerobic condition, thereby lessening the need for expensive engineering. The major constraint to vermicomposting is that, in contrast to composting, vermicomposting systems must be maintained at temperatures under 35 ℃. Exposure of the earthworms to temperat ures above this, even for short periods, will kill them. To avoid such overheating careful management is required. The processing of organic materials occurs most rapidly at temperatures between 15 ℃ and 25 ℃, at moisture content of 70 to 90 % and pH of 6.5 - 7.5 (Edwards, 1995). Outside these limits, earthworm activity and productivity, and thus the rate of waste processing, falls dramatically.

4.5.1.4 Anaerobic digestion/ fermentation

Anaerobic fermentation is an oxidation process, in which organic compounds, such as e.g. livestock manure and toilet waste, are converted by microbiological processes in absence of oxygen (O_2) to methane (CH_4) and carbon dioxide (CO_2). The produced biogas (~ 55 - 75% CH_4) can be used for cooking, heating and light. The methane production contributes to the BOD reduction in digested sludge. It is possible to apply high loading rates to the digester and even recalcitrant materials (e.g. lignin) can be degraded.

Anaerobic digestion produces lower amounts of sludge (3 - 20 times less than aerobic processes), since the energy yields of anaerobic bacteria are relatively low. Most of the energy derived from substrate breakdown is found in the final product, CH_4. As regards to cell yields, 50% of organic carbon is converted to biomass under aerobic conditions. The net amount of cells produced per metric ton of COD destroyed is 20 - 150 kg [44.1-330.75lbs], as compared to 400 - 600 kg [882-1323lbs] for aerobic digestion. (http://www.united-tech.com/wd-anaerobicdigestion.html). But the process is slower than the aerobic digestion, it is much more sensitive to upsets by toxicants, and the start-up of the process requires a long period of time.

Anaerobic digestion is affected by temperature, retention time, pH, chemical composition of wastewater, competition of methanogens with sulfate-reducing bacteria, and the presence of toxicants. The complete anaerobic digestion is considered to take place in three phases (figure 11):

Hydrolysis: particulate material is converted to soluble compounds that can be hydrolyzed further to simple monomer that are used by fermentation performing bacteria.

Fermentation (also acidogenesis): amino acids, sugars, and some fatty acids are degraded further to acetate, hydrogen, CO_2, and propionate and butyrate.
Methanogenesis (carried out by methanogens): acetate is split into methane and CO_2; CO_2 reacts further with hydrogen to methane; and acetic acids that are produced in this phase are also transformed to methane.

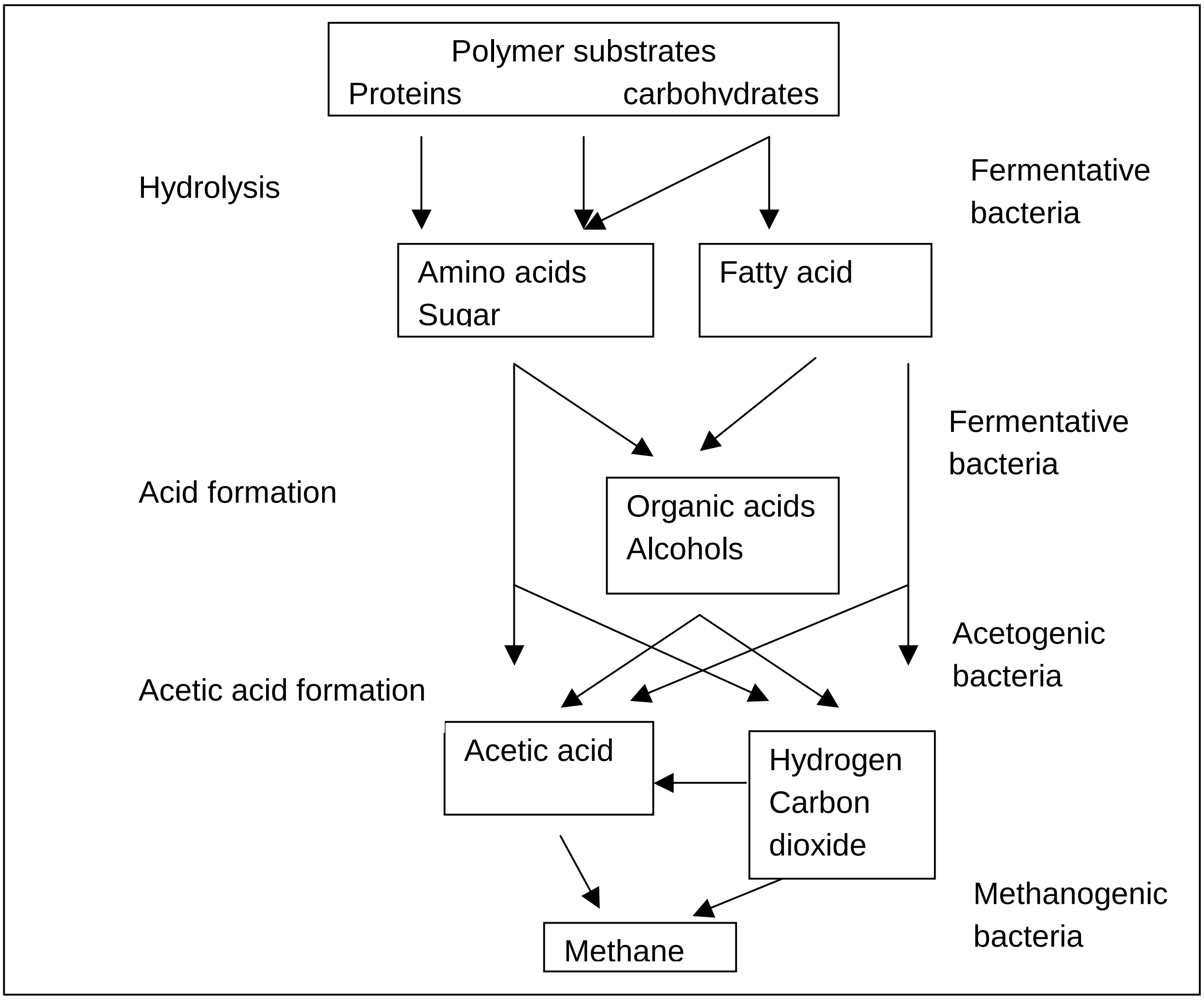


Figure 11: Steps of anaerobic digestion (Bilitewski et al., 1994)

Process temperature affects the rate of digestion and should be maintained in the mesophillic range 35 - 40 ℃ (95 - 105 ℉) with an optimum of 100 ℉. It is possible to operate in the thermophillic range 55 - 65 ℃ (135 to 145 degrees F), but the digestion process is subject to upset if not closely monitored.

Thermophilic digestion operates at temperature ranges of 50-65℃ [122℉-149℉]. It allows higher loading rates and is also conductive to greater destruction of pathogens. One drawback is its higher sensitivity to toxicants. Because of their slower growth as compared with acidogenic bacteria, methanogenic bacteria are very sensitive to small changes in temperature.

The hydraulic retention time (HRT), which depends on wastewater characteristics and environmental conditions, must be long enough to allow metabolism by anaerobic bacteria in digesters. The retention times of mesophilic and thermophilic digesters range between 25 and 35 days but can be lower.

Most methanogenic bacteria function in a pH range between 6.7 and 7.4. Acidogenic bacteria produce organic acids, which tend to lower the pH of the bioreactor. Under normal conditions, this pH reduction is buffered by the bicarbonate that is produced by methanogens. Under adverse environmental conditions, the buffering capacity of the system can be upset, eventually stopping the production of methane. Acidity is more inhibitory to methanogens than of acidogenic bacteria. An increase in volatile acid levels thus serves as an early indicator of system upset. Monitoring the ratio of total volatile acids (as acetic acid) to total alkalinity (as calcium carbonate) has been suggested to ensure that it remains below 0.1.
(http://www.united-tech.com/wd-anaerobicdigestion.html)

A wide range of toxicants is responsible for the occasional failure of anaerobic digesters. Inhibition of methanogenesis is generally indicated by reduced methane production and increased concentration of volatile acids.

4.5.2 Composting and dehydration toilet systems

In composting toilet systems either a toilet with urine diversion or no urine diversion is used (see overview in figure 12). In case of no urine diversion toilet, faeces and urine with or without toilet paper depending on the user's habit drop into the composter located just below the toilet. In urine diversion toilet, urine is collected separately and kept in a storage tank until it is ready for use in agriculture or just treated in a soak pit or evapotranspiration bed. However, leaching from soak pit can cause heavy groundwater pollution. Faecal materials are composted or dehydrated for a long time and reused as fertiliser and soil conditioner in agriculture.

In composting toilets, low temperature composting occurs because only a small amount of materials enters every day, which is not sufficient to prevent the heat loss from the heap (Gajurel, 1998). Moreover, aeration, which is a very important factor in the composting process, is poor inside the material of the composting toilet, even if material with high structural stability is added, because structural material cannot be mixed with faeces properly unless they are turned mechanically. As a result, aerobic micro-organisms cannot find proper environment to work actively. Because of low temperatures in composting toilets, other methods such as a long retention time and ash as an additive among others are applied to kill pathogens.

Urine diversion is crucial for dehydration toilets. The non-diluted faecal materials (faeces and toilet paper if used) drop into the dehydrating vault located just below the toilet and are dehydrated with the help of heat (Solar radition), ventilation and the addition of dry materials.

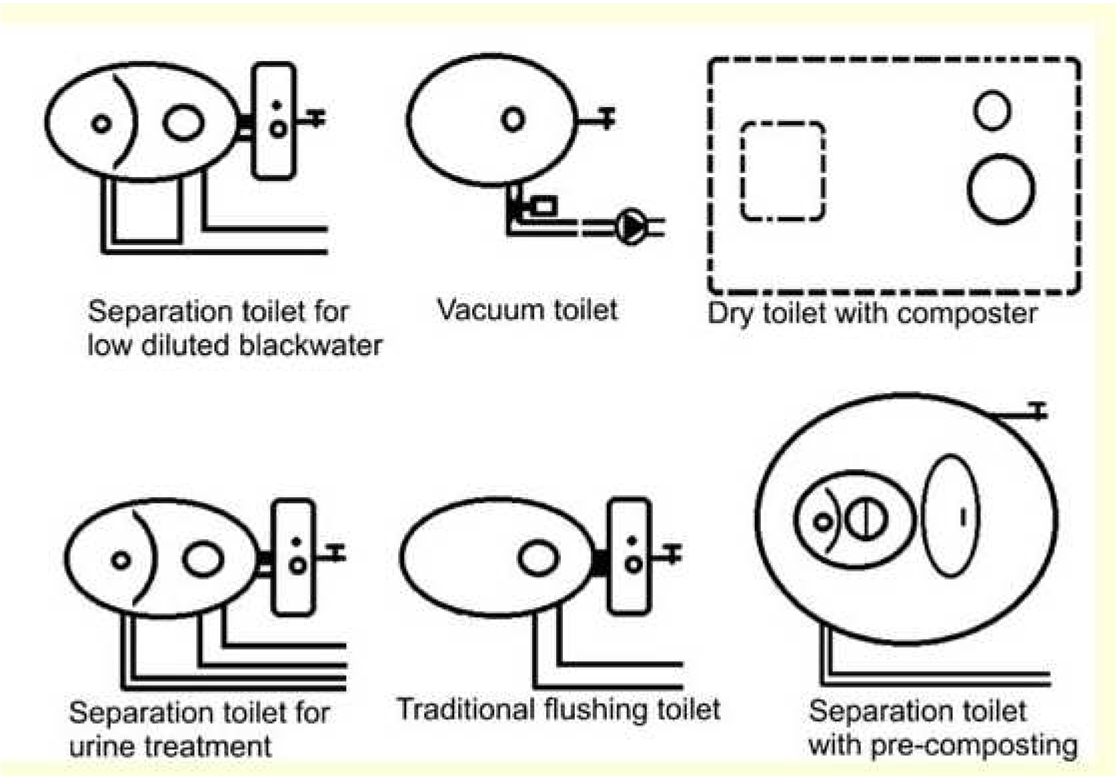
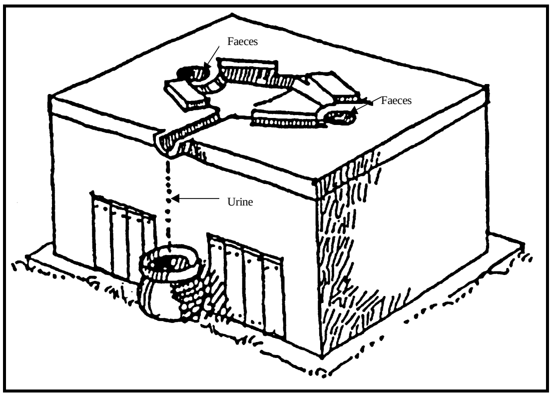


Figure 12: Overview of toilet systems for source control sanitation (Otterpohl 1999 - www.gdrc.org/uem/waste/oldenburg.html)

4.5.2.1 Existing dehydration toilet systems

Different forms of dehydration toilets have been in used in many parts of the world. However, all use the same basic principle of dehydration. Dehydration toilets are mostly used in Vietnam, Mexico, China, El Salvador, Ecuador, Yemen, South Africa and India. Double-Vault dehydrating toilets as shown in figure 13, which consist of two alternately used vaults constructed above the ground, have been widely used in Northern Vietnam since 1954, and adapted models were implemented in Mexico, Central America and Sweden (Esrey et al., 1998). In this toilet, urine is diverted to a collection tank or soak pit under the toilet vault or outside the toilet and faeces drop into one of the two vaults located below the toilet's seat. When one vault is full, it is sealed and another vault is used. Dry materials like ash or soil or a mixture of sawdust/lime or soil/lime are added after the defecation. The added dry material assists the desiccation process and raises the pH, which aids in pathogen reduction.

Central American and Mexican version of Vietnamese double-vault toilets have been successfully applied in urban areas of El Salvador and Mexico (Moe et al., 2001 and 2003). These toilets are usually attached to the house, sometimes even placed inside the house. The double-vault toilet as shown in figure 9 is built in a bathroom of a modern, high standard house in the city of Cuernavaca, Mexico. A urine diverting mobile toilet bowl is placed just above the opening of one of the two chambers located below the bathroom. When the first vault is full, it is sealed and the bowl is moved to the opening of another empty vault. The vaults are accessible from outside the house.



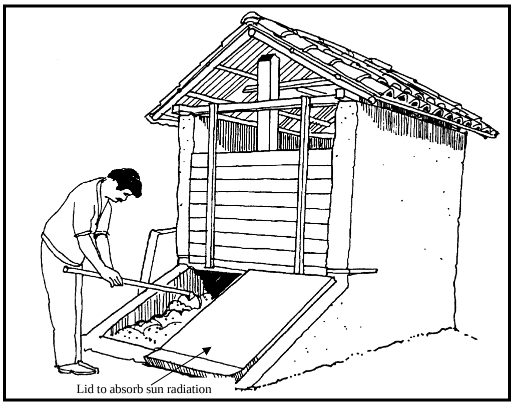


Figure 13: Vietnamese double-Vault Dehydrating toilet (left) and double-vault toilet with solar heater (right) (Source: Esrey et al., 1998)

The double-vault toilet without urine diversion has been used in a dry region of Ecuador. The vault is covered with a lid made up of a wooden frame covered with thin galvanised iron painted black in order to absorb the sun's radiation and increase the vault temperature and rate of dehydration (figure 13 right). Sawdust or ash is added after every defecation as in the urine diversion system.

The single-vault dehydrating toilet uses a passive solar panel to increase the chamber temperature and rate of dehydration. The addition of dry materials after defecation is required as in the double-vault dehydrating toilet. In this system, the faecal materials that are accumulated below the toilet's seat are shift to the rear of the chamber with a hoe or rake. There are also systems, which have been equipped with a pusher to shift the faecal materials to the rear of the vault (figure 14). After some months, the dry materials which are collected at the rear of the chamber are shovelled into a sack and stored outside the toilet until reuse.

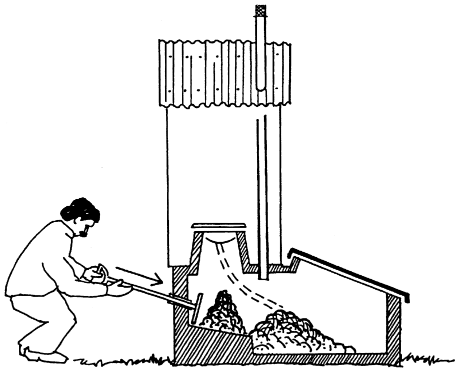


Figure 14: Single-vault toilet equipped with a pusher (Source: Esrey et al., 1998)

German Technical Co-operation (GTZ) with the company Otterwasser has implemented some dehydrating toilets in Mali, West Africa (see figure 15).

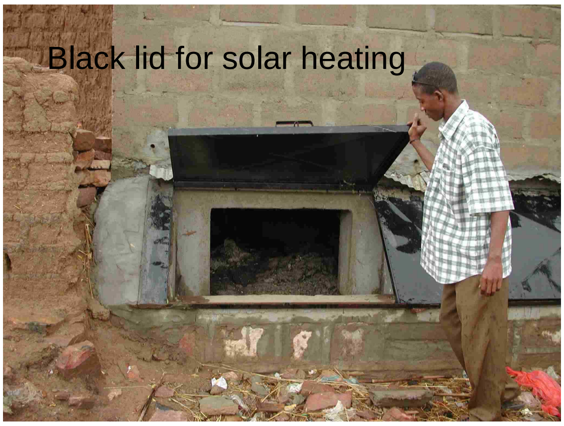


Figure 15: Dehydration toilet in Male, West Africa

Dehydration toilet is very beneficial for regions of warm climate. However, also in Sweden there are a number of dehydration toilets on the market for many years (Del Porto and Steinfeld, 1999). WM Ekologen system, for example, is based on urine diversion and dehydration. This system has been used in indoor bathrooms.

By now tens of thousands of urine diversion ecosan toilets have been built in China (Xianghong and Jiang, 2003; Jiang, 2000). Ash, soil and lime are added after the use of the toilet. The urine-diversion squatting pan and mechanical ash dispensers are provided in the systems (figure 16). Many of the toilets are built inside the dwelling, and often upstairs.

Figure 16: Squatting pan urine diverting toilet with double-vault from China

The main principles for good functioning of dehydration toilets are:

- it should be built above the ground to avoid entering and contamination of groundwater;
- urine diversion is beneficial;
- two vaults system with alternative usage is advantageous;
- vault should be heated with solar by covering each chamber with black lids;
- wash water has to be kept out;
- post-composting after collecting the dehydrated faecal materials can be required.

4.5.2.2 Effectiveness of existing dehydration toilet systems

Sanitation based on dehydration prevents pollution, destroys pathogens and recycles human excreta as fertiliser . These systems seem to be an effective method to deal with human excreta because they keep faeces that contain pathogen causing diseases in a small volume in a closed environment for a long time in order to be sanitised before re-use. Not only they prevent pathogens and nutrients entering into water bodies, but they also produce an end product that is rich in nutrient and is a good soil conditioner.

As mentioned before, these systems have been increasingly applied in many parts of the world mostly in rural areas and small communities. Experts working in the field have made mostly positive experiences. Especially in dry climates dehydration toilets have been found effective regarding pathogens destruction, volume reduction of faecal material and maintenance. In dehydration toilets there is less chance of flies breading and odour development since faecal materials are dried by solar heater and by adding dry materials.

Many years of practical experience, technological development have shown that resource management sanitation based on dehydration is an effective means to convert human excreta into fertiliser and soil conditioner as well as to destroy pathogens. To maximise efficiency, both of pathogen destruction and of nutrient reuse the systems should be provided with separate collection of urine and faeces at source. So far the effective methods for pathogens destruction in faecal material are dehydration and high pH. By the addition of dry materials (ash, soil, lime) moisture is absorbed and pH is raised. Solar heating accelerates the dehydration.

4.5.2.3 Existing composting toilet systems

The Clivus Multrum composting toilet shown in figure 17 is a continuous system and features a single chamber, in which combined processing of urine, faeces and organic household waste takes place (Del Porto and Steinfeld, 1999). The composting chamber is provided with a slanting floor, air conduits and at the lower end a storage space. A tube connects the toilet seat riser with the receptacle. There is a constant draught due to natural convection from an air intake in a vault, through which the air conduits, and out via a vent pipe. This system has a separate chute for the household organic waste. Because of the slopping floor, the content of the vault slowly slides down from the fresh deposits at the upper end to the storage part of the vault.

Figure 17 : Clivus Multrum composting toilet (Source: Clivus Multrum)

The TerraNova composting toilet system of Berger Biotechnik, Germany is also a single chamber continuous system. Based on the Clivus Multrum, this system has been increasingly used in single family houses and ecological settlements in Germany (figure 18). In the ecological settlement Waldquelle near the city of Bielefeld there are about 70 systems in operation for single family and terraced houses as well as multi-storey buildings even up to the 5th floor.

Another type of the composting toilet called twin-bin net composting toilet was used first time on the Pacific Islands (Del Porto and Steinfeld, 1999). It consists of two chamber constructed above the ground and inside each chamber a fishing net is suspended by hooks from the side of the chamber (figure 19 left). On the fishing net, a mat woven from coconut palm fronds is placed in order to separate the solid from liquids. The net also allows air to enter into the composting materials from all sides. In the chamber, coconut husks, small wood chops, leaves or vegetable food scrapes are added through the seat riser or drop hole periodically. The liquid that accumulates on the floor of the composting chamber is evaporated by air flow and wicks made from old clothing or is drained to an evapo-transpiration bed adjacent to the composting chamber. Air flow inside the chamber is provided with a large diameter vent pipe that draws air up through the pile from an intake opening located below the net along the rear wall of the vault.

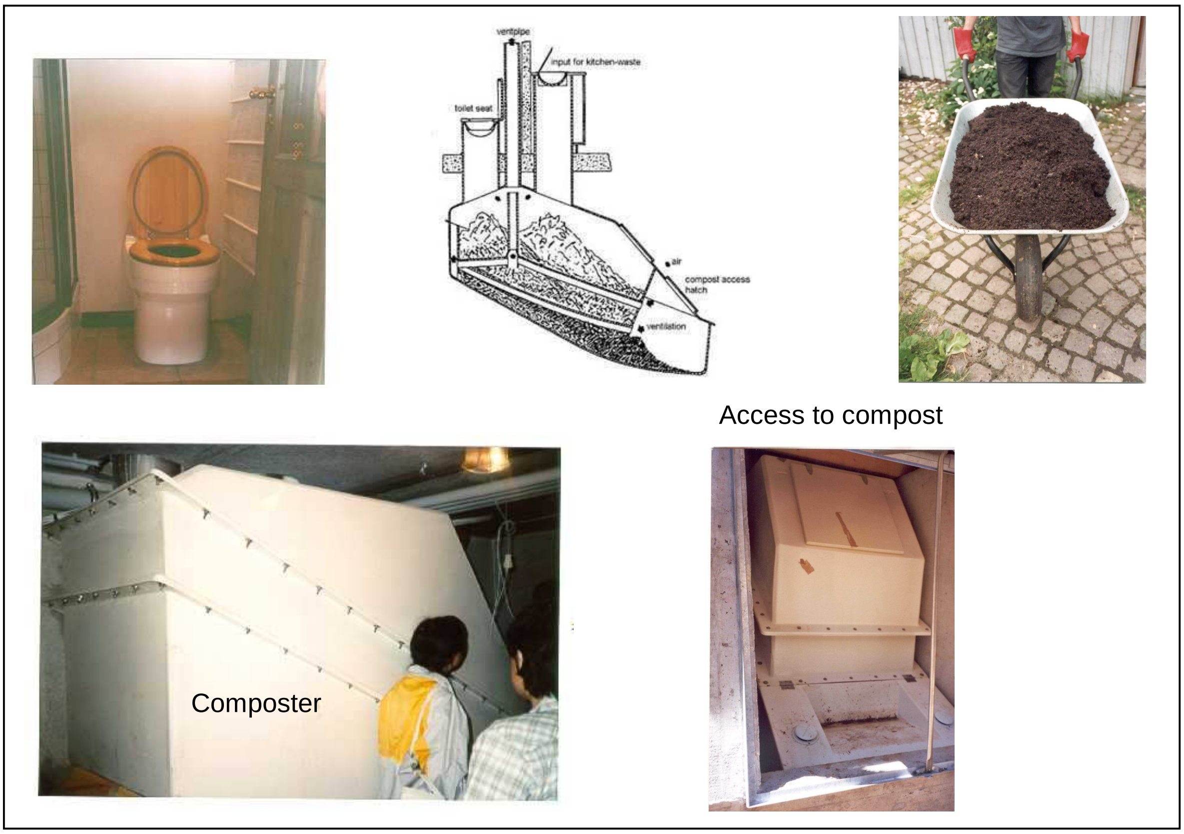


Figure 18: Composting toilet in Eco-settlement Braamwisch, Hamburg

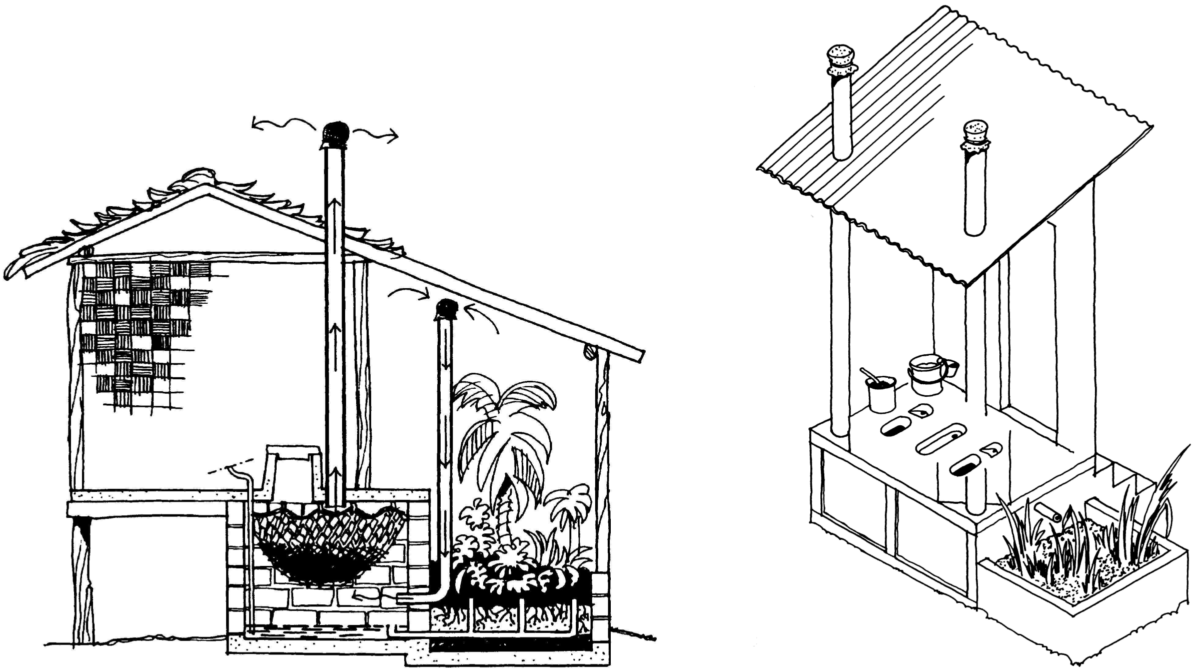


Figure 19: Twin-bin net composting toilet in the pacific islands (left) and Kerala double-vault toilet developed by Paul Calvert (right) (Source: Esrey et al., 1998)

In Kerala, India, the Vietnamese type double-vault composting toilet with urine diversion as shown in figure 19 (right) has been applied. Since most of the Indian people are washers, water used for anal cleaning is diverted along with urine to the evapo-transpiration bed. Over each vault there is a drop hole for faeces and a funnel for urine. Between the two vaults there is a trough over which anal cleaning is performed. The materials added for enhancing composting are straw, leafy material and paper scraps. A handful of ashes is sprinkled over the faeces after each uses.

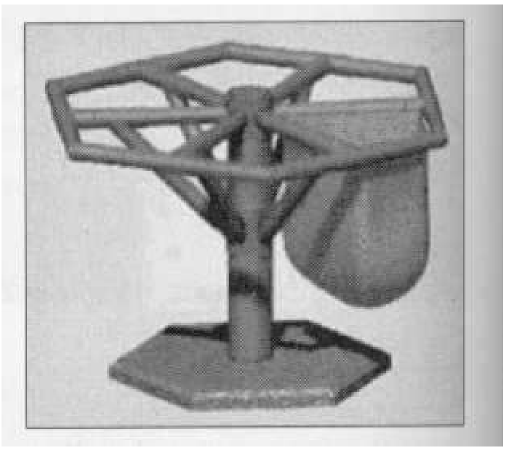


Figure 20: Dryloo composting toilet (Source: Del Porto and Steinfeld, 1999)

Dryloo composting system as shown in figure 20 consists of a rotating PVC frame upon which six woven polyethylene bags are hung. These bags are used alternately and serve as faecal matter composter. It is placed in a watertight container just below the toilet stool. A fan and a vent pipe are provided in the system.

There are also other types of composting toilet systems either batch or continuous systems such as Minimus, Weelie Batch, Nature-loo and Rota-loo. They are increasingly used in Australia (Pollard et al., 1997).

4.5.2.3 Effectiveness of existing composting toilet systems

Like dehydration toilet, sanitation systems based on composting are an effective method to deal with human excreta because they keep faeces that contain disease causing pathogens in a small volume in a closed environment for a long time in order to be sanitised before reuse. They also produce compost that is rich in nutrients and is a good soil conditioner.

These systems have been increasingly applied in many parts of the world, mostly in rural areas and small communities. However, very few investigations on the composting toilets have been carried out so far (Naudascher, 2000). Investigations on pre-composting of faeces along with toilet paper and bark in small scale composting toilets showed that decomposition takes place in composting toilets, but only slowly because many factors that influence the composting process are, unlike in the pile system, difficult to be optimised in the composting toilet (Gajurel, 1998). Turning of the pile in the pile system helps for air circulation. It may not be practical in the present design of composting toilets. Moreover, because of the small amount of material entering every day and heat loss from the system, the temperature in composting toilets is more or less same to ambient temperature. The maximum temperature measured in the Multrum composting toilet was 32 ℃ (Jenkins, 1994). Anothe r study by Redlinger et al. (2001) in the state of Chihuahua, Mexico, showed that temperature measured in single-vault solar composting toilet was equal to or similar to ambient temperature. The reasons they found were 1) the composting pile in the toilet was not large enough to trap heat to maintain the high temperature required for aerobic thermophilic bacterial growth, 2) users did not regularly adjust the moisture levels of the compost pile with water or soak materials, and 3) users did not regularly adjust pile oxygen content by stirring or turning over the pile.

Because of low temperature and slow decomposition, the materials in composting toilets should be kept in the vault for a long time in order to kill pathogens and to stabilise the composting materials. The pre-composted faecal material from the composting toilet has self heating capacity of about 60 ℃. Therefore , it can be further composted in pile systems with other organic waste, in which many parameters influencing thermophilic composting can be optimised, so that high temperature can be obtained in the pile. Pathogen free stable compost is desirable for its application as fertiliser and soil conditioner.

Especially in dry climates dehydration toilets have been found more effective than composting toilets regarding pathogens destruction, volume reduction of the faecal material and maintenance. In dehydration toilets, because of dry conditions there is less chance of flies breading and odour development. However, the end product produced by the composting process is an excellent soil conditioner, free of pathogens when the optimal conditions are achieved and sufficient retention time is given. Therefore, development of composting toilets that can maintain optimal condition for composting of faeces is required.

4.5.2.4 Vermicomposting toilet system

Some toilets use earthworms to decompose faecal matter and kitchen organic waste (figure 21). The Dowmus system in Australia is partially filled with active compost at the time of installation and inoculated with beneficial soil organisms in particular tiger and red composting worms (Ho and Mathew, 1998). There is no heating element and the system is not intended to operate above 35 ℃, to p rotect the worms. The process depends more on soil organisms and worms rather than on the thermophilic microorganisms for composting. It can also take other household organic matters provided they are cut into small pieces.

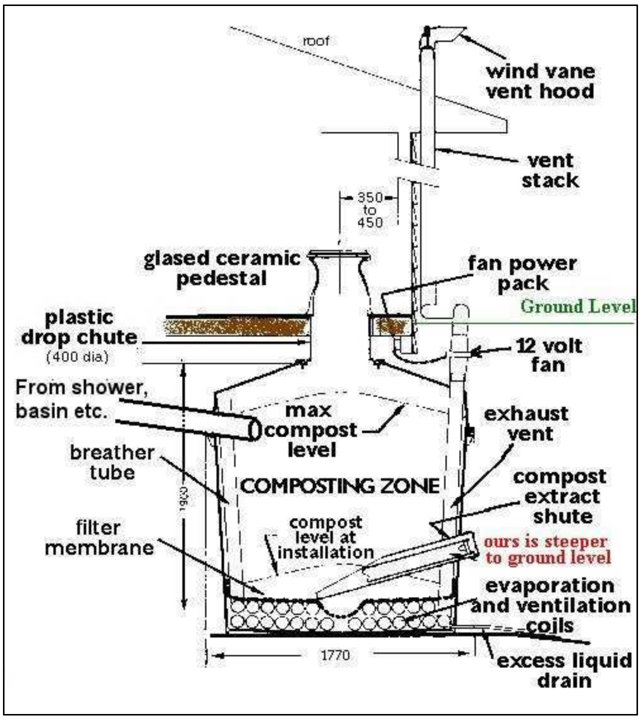


Figure 21: Dowmus composting system with worms (Source: Dowmus)

A Vermi-processing toilet has been field tested for 8 years in India and was found to be a novel low water-use toilet for safe processing of human excreta without odour and fly problem. It is started off by putting 5 kg of vermicastings in the pit. The operation of the toilet employing the pit is very simple and hygienic as the human excreta will be completely converted to vermicastings (Bhawalkar and Bhawalkar, 1991). In the USA, Redworm (Eisenia and Lumbricus rubellus) has been added in the Clivus Multrum composting toilet (Rockefeller, 1995). Because of low moisture in the toilet, daily misting with water is required for maintaining optimal moisture content. The effect of redworms on the degradation process in the toilet has been remarkable. Most of the faecal matters and kitchen wastes were flat, worm castings covered the entire surface. Recently, the Dowmus vermifiltration system has been developed for domestic wastewater and kitchen organic waste treatment in Australia (Bajsa et al., 2002). This system has a composting tank from which the liquid is drained. Vermicomposting is used for the treatment of the tank contents. However, since ammonia is sensitive to worms, urine should be diverted.

4.5.2.5 Vacuum toilet-biogas plant system

Vacuum toilets produce little diluted black water which is transported by the vacuum system to a bio-gas reactor in which black water is treated anaerobically together with bio-waste from kitchens. A well managed anaerobic digester should produce 1 m^3 gas/m^3 volume. The biogas mixture is about 70 % methane and 30 % carbon dioxide (Doelle, 1998). The methane can be used as a source of renewable energy and can be used to produce electricity as well as cooking and lighting gas. The sludge, which is rich in nutrients and organic matter can be used after sanitisation in agriculture as a fertiliser. Vacuum toilet-biogas plant systems have been applied in following projects:

Settlement Flintenbreite, Luebeck, Germany: An integrated sanitation concept with vacuum toilets, vacuum sewers and a bio-gas plant developed by OtterWasser GmbH has been implemented in the settlement Flintenbreite, peri-urban area of the city of Luebeck (figure 22). The settlement was planned for 350 inhabitants and is connected to a bio-gas reactor for black water treatment (Otterpohl et al., 2001). Vacuum toilets and vacuum pipes are used for black water collection and transportation. The little diluted black water is transported to the bio-gas reactor in which black water is treated together with bio-waste from kitchens. The bio-gas is used to operate the heat and power generator. After the treatment the hygienic end product is used as fertiliser.

Black water mixed with shredded bio-waste is sanitised by heating the feed to 55 °C for 10 hours. The energy is further used by the digester that is operated mesophilic at around 37 °C. The relatively small amount of water added to the black water keeps the volumes small enough for transportation. There is a 2-weeks-storage tank for the collection of the digester effluent. Bio-gas is stored in the same tank within a balloon that gives more flexibility in operation. The fertiliser will be pumped off by a truck and transported to a farm that has a seasonal storage tank for 8 months.

Solar Passive Building „Wohnen & Arbeiten“, Freiburg-Vauban, Germany: about 40 inhabitants in the 4-storey-building „Wohnen & Arbeiten“, are connected to the sanitation system as in Flintenbreite (Panesar and Lange, 2003). Black water is collected with vacuum toilets and transported to the bio-gas plant by vacuum sewers. In the biogas plant, organic wastes are added to the black water with the help of a feeding device. The biogas plant is connected to the internal gas system of the house; it provides cooking gas for the households. The sludge is stored in a storage tank for the fertiliser. At the beginning grey water was treated with an aerated sand filter, but due to technical problems, it was later replaced by a membrane-filter-module.

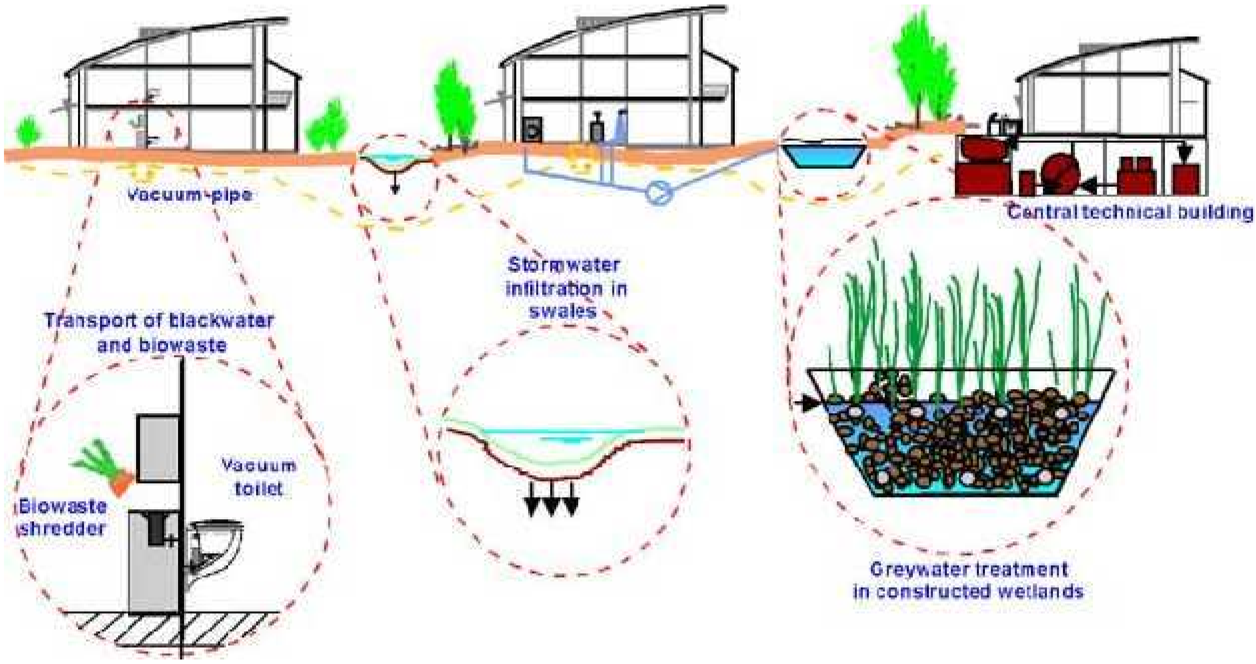


Figure 22: Vacuum -bio-gas system, greywater bio-filter and rainwater infiltration (Otterpohl, 2001)

Norwegian experience with water saving toilet - storage tank - thermophilic aerobic reactor: in Norway, unlike in the projects in Germany, a different type of toilet is used for black water collection (Skjelhagen, 1999). The toilet does not need water for transportation, only about 0.2 l per flush for cleaning the toilet. The black water is stored under the toilet bowl until it contains 20 - 25 l and is flushed by gravity to a storage tank that is located not farther than 10 m from the toilet. Grey water is treated in a compact treatment plant consisting of sludge collecting filter bag, filter and UV. The organic waste is stored in a closed sub-surface tank in which bio-mass produces acids that lowers pH below 5. As a result the waste remains conserved. There is no production of gases.

After a year of storage, the black water, grey water sludge and semi-liquid organic waste are pumped by a truck-tanker and transported to a pre-storage tank. The tank content is sanitised and stabilised in a thermophilic aerobic reactor with a processing temperature of 55 - 60 ℃ and kept in a post-storag e tank before application in agriculture. No energy is added for heating the bio-mass.

Also, at the agricultural university of Norway 24 student apartments have been connected to a recycling system based on aerobic sanitisation of black water with organic household waste, collected using a vacuum toilet system and rendering an odourless and sanitised fertiliser slurry (Jenssen, 2001).

Picture from Tan Lap village, close to Hanoi (figure 23) shows an anaerobic digester for decomposing the manure of at least 5 pigs and black water of one family. The biogas is used for cooking and light, the effluent is used as fertilizer. The biogas can be transported via PVC-tubes to houses up to 100 meters away. It can be directed by valves to the gas stove or the gas lamp in the kitchen. The methane produced displaces the use of firewood (estimated at 2500 kg per family per year, for which families spend between $ 5 and $ 10 per month). The plants also improve sanitation and promote cleaner air.

Figure 23: Biogas production and use in Vietnam

4.5.3 Solid-liquid separation systems

With the sorting toilet, faeces with toilet paper (if used and put in the bowl) is flushed with 4 - 6 l water to the tank where the solid and the liquid phase are separated and treated separately. There are many varieties of processes used in liquid-solid separation. They are usually based on two principal modes of separation: 1) filtration (gravity, vacuum, pressure and centrifugal), in which the solid-liquid mixture is directed towards a filter medium (screen, woven cloth, membrane etc.). The liquid phase flows through the filter medium while solids are retained, either on the surface or within the medium and 2) sedimentation or settling in a forces field (gravitational and centrifugal) whereby advantage is taken of differences in phase densities between the solid and the liquid. The solids are allowed to sink in the fluid under controlled conditions. In the reverse process of flotation, the particles rise through the liquid, by virtue of a natural or induced low solids densities.

In decentralised wastewater treatment systems, septic tanks, which are based on the principal of sedimentation are widely used for solid-liquid separation (Crites and Tchobanoglous, 1998). A new development is Aquatron (figure 24) which is manufactured and applied in Sweden for separating solid matters from toilet wastewater (Del Porto and Steinfeld, 1999). When the toilet is flushed, the flush water with faeces and toilet paper enters the top of the polyethylene module, which is constructed to initiate a whirlpool effect in the upper container. Here, by centrifugal force, part of the liquid, which moves to the outer wall and ultimately out of the system, is separated while the solids drop down in the middle into the composter beneath it.

Figure 24: The whirlpool, surface tension separator Aquatron and its function where the faecal water (FW) is separated into liquids and solids (Vinnerås, 2002, http://www.aquatron.se***)***

The Aquatron is a commercial separation system adopted for separation of faeces from faecal water. The efficiency of the system depends on correct installation. The disintegration of faecal particles should be minimised. An easy way to reduce disintegration is by shortening the length of the system, especially by decreasing the vertical drop and a smoother bend between vertical and horizontal transport of the faecal water. When using the system in a multi-storey building, one way of doing this is to install an Aquatron on each floor.

4.5.4 Rottebehaelter systems

Rottebehaelter as a component of decentral systems has been increasingly used in Austria, Germany and Switzerland for domestic wastewater pre-treatment. Since its application is until now only limited to German speaking countries, there is no English word for it, but can be called pre-composting tank. However, in this work the term "Rottebehaelter" is used to make clear to which system it refers. It was first introduced by Dr. Joachim Niklas, OEKOTEC, and Mr. Peter Stolz, AREAL, in Germany. Today there are also other companies including Mall-Beton offering this system.

A Rottebehaelter consists usually of an underground monolithic concrete tank having two filter beds at its bottom or two filter bags that are hung side by side and used alternately in an interval of 6-12 months (figure 25) (Gajurel, 2003).

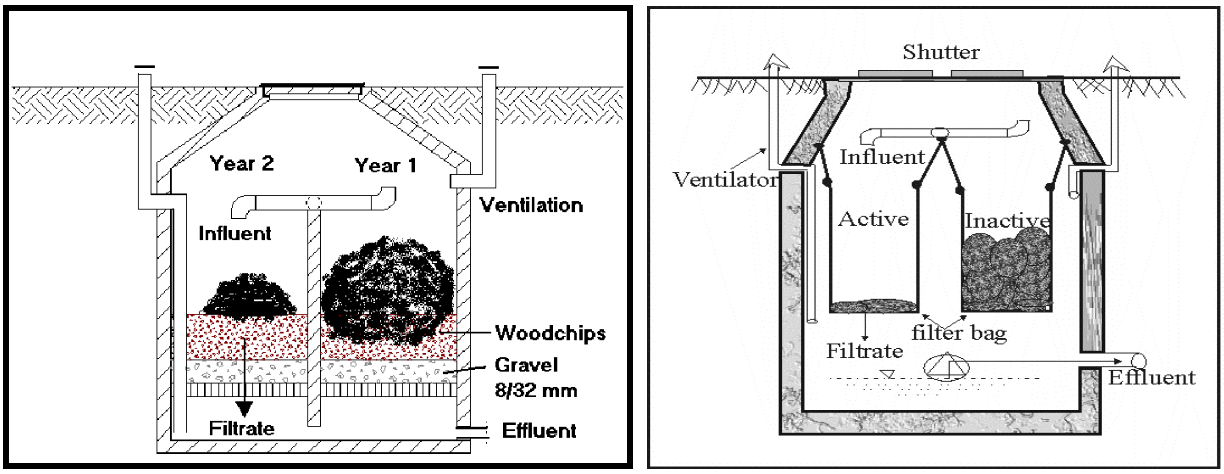
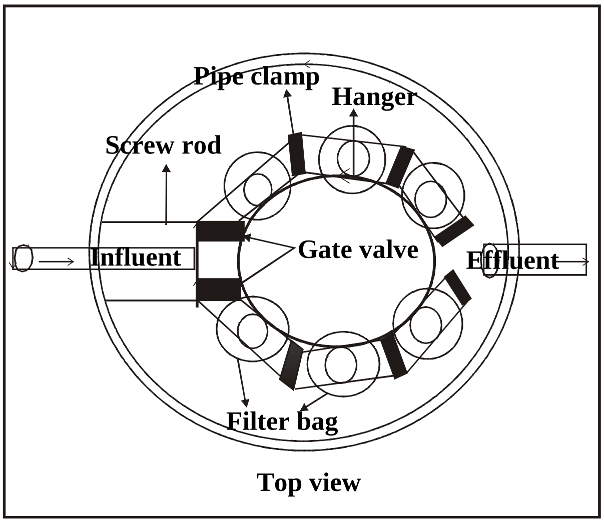


Figure 25: Rottebehaelter systems (left: filter bed system, right: filter bag system)

It is watertight and structurally sound in order to avoid entering of extraneous groundwater in it and leakage of the filtrate into the groundwater which would cause groundwater pollution. The top opening is covered by a prefabricated concrete slab and provided with ventilation so that air can enter. A shutter for changing the filter bag or emptying treated material, adding bulking agents such as straw, bark etc. into the retained materials, inspection and cleaning has been provided on the covering of the tank.

The influent is discharged into one of the two filter beds or filter bags retaining solid materials while draining the liquid. The principal role of the filter medium (filter bed or filter bag) is to cause a clean separation of particulate solids of the influent with no additional energy consumption. The filter medium is designed to recover a valuable solid product. Therefore, attempts are made to create a surface deposition of the solids in a recoverable form. When the influent is discharged into the filter bed or filter bag a filter cake is formed at the bottom. Its depth increases during the filtration due to deposition of solid material on its surface.

There is also another kind of Rottebehaelter, in which six filter bags are hung side by side. This is used only in Austria (figure 26 and 27). Unlike the previously described Rottebehaelter, two pipes with a slope of 5 % are clamped inside the Rottebehaelter, under which filter bags are hung side by side in their mountings. There are three filter bags for each pipe. The influent is alternately distributed to both pipes by a means of diversion. The influent is first diverted into one of two pipes where three empty filter bags are hung in such a way that when one is full, the influent flows to next filter bag and so on. The solid materials in the influent are retained while liquid passes through the filter bag and is collected at the bottom of the Rottebehaelter.



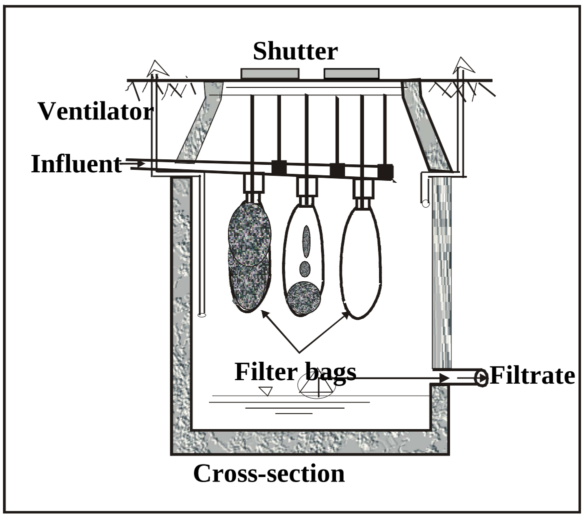


Figure 26: Rottebehaelter with several filter bags system (left: top view , right: cross-section)

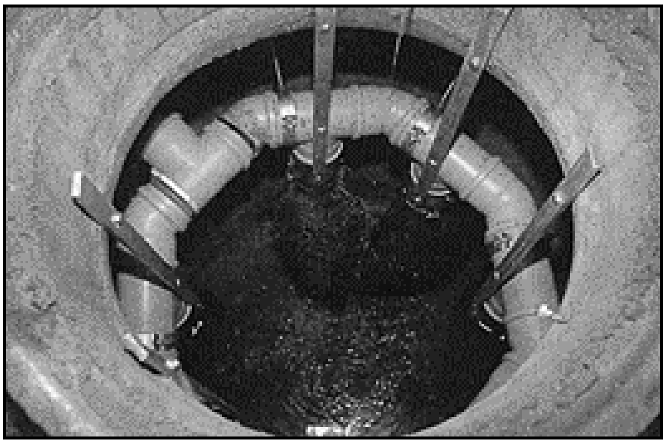


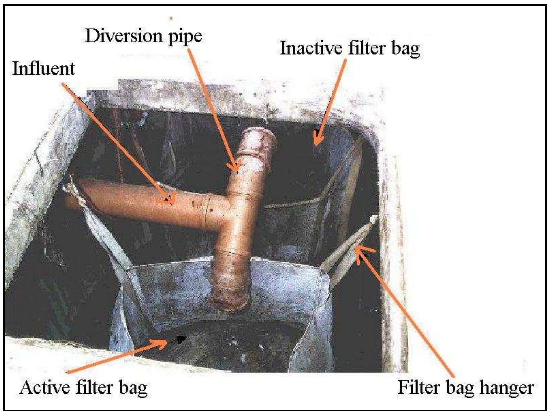
Figure 27: Existing Rottebehaelter with several filter bags in Austria (Ambros et al., 1998)

The filtrate that is collected at the bottom of the Rottebehaelter is periodically pumped or piped (at a good gradient) for further treatment. Normally, the pre-treated filtrate in the Rottebehaelter is further treated in constructed wetlands adjacent to the Rottebehaelter and then discharged into the water bodies nearby. For reuse tertiary treatment is needed. The solid materials, which are retained in the filter medium, are bio-degradable and during the filling phase and silence phase (the filled one is left in a silence phase for degradation) decomposition takes place. Because of the degradation, the volume of the material in the filter bag or filter bed will be reduced.

Compared to Rottebehaelter with a filter bed at its bottom, the filter bag system has some advantages. In the filter bag the outer part of the material is always in aerobic condition, because it has a continuing contact with air. Therefore, there is no or only little odour nuisance. Moreover, handling of treated material is not so difficult as in filter bed systems because material is collected in the filter bag which can be taken out easily. Regarding the handling, Rottebehaelter with several filter bags is simpler than other systems. Because the material is distributed into 6 filter bags instead of only two, each bag is 3 times lighter than in other systems. However, since the filter bag is attached to the influent pipe, there is no opening in the filter bag. Therefore, adding bulking agents like straw or bark, which is important for composting of retained materials, is not possible unless they are added through the toilets.

4.5.4.1 Existing Rottebehaelter systems in Germany

Rottebehaelter with two filter bags or two filter beds system has been increasingly used in rural areas of Germany for the domestic wastewater treatment (figure 28). This system is mostly installed in individual houses for 4 - 40 inhabitants. There are a couple of places where the system is connected to more than 200 inhabitants. However, in Belzig a system with filter bed was installed for several hundred people.



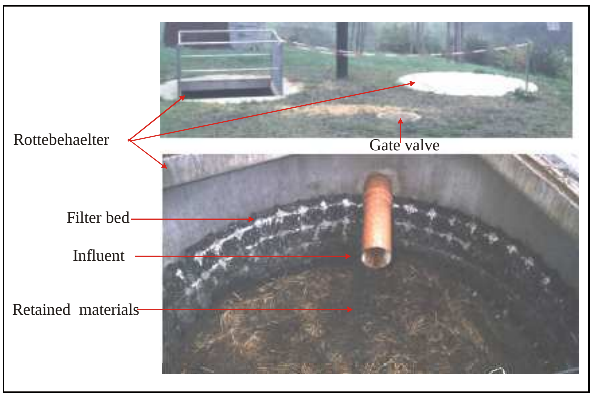


Figure 28: Rottebehaelter with filter bags (Left) and with filter beds (Right)

Most of the Rottebehaelter systems are constructed near residential buildings. The domestic wastewater is discharged into one of the two empty filter bags having a pore size of 1 - 2 mm and made up from non-biodegradable material. The solid materials are retained in the filter bag which is usually filled up in 6 – 8 months. As soon as the filter bag is full, the flow is diverted manually to the next empty filter bag. The filled bag is left for further dewatering and degradation in order to get volume and pathogens reduction as well as a dry material. After 6 - 8 months, the bag with pre-treated materials is taken out through the shutter located on top of the Rottebehaelter and further composted with other household and garden organic waste in a local composter for a year prior to its use in the garden. The filtrate drops down to the bottom of the Rottebehaelter. The collected filtrate is pumped periodically or piped (for a site of good gradient) to the constructed wetland. After treatment in the constructed wetland, it is discharged into the water courses nearby. At some places it is collected in a pond in the garden.

This system has also been implemented in the pilot project in Lambertsmuehle near Cologne city in Germany as a component of resource management sanitation in 2000 (figure 29). The Lambertsmuehle, a historical water mill, has been put under preservation since 1983. It has been reconstructed to a museum. Due to the restoration of the building the wastewater treatment had to be reconstructed as well. The new concept of source control and reuse has been installed for the treatment of wastewater from residents and museum visitors. The flow of nutrients and water in the system is shown in figure 30.

Figure 29: Rottebehaelter with two filter bags in the pilot project Lambertsmuehle

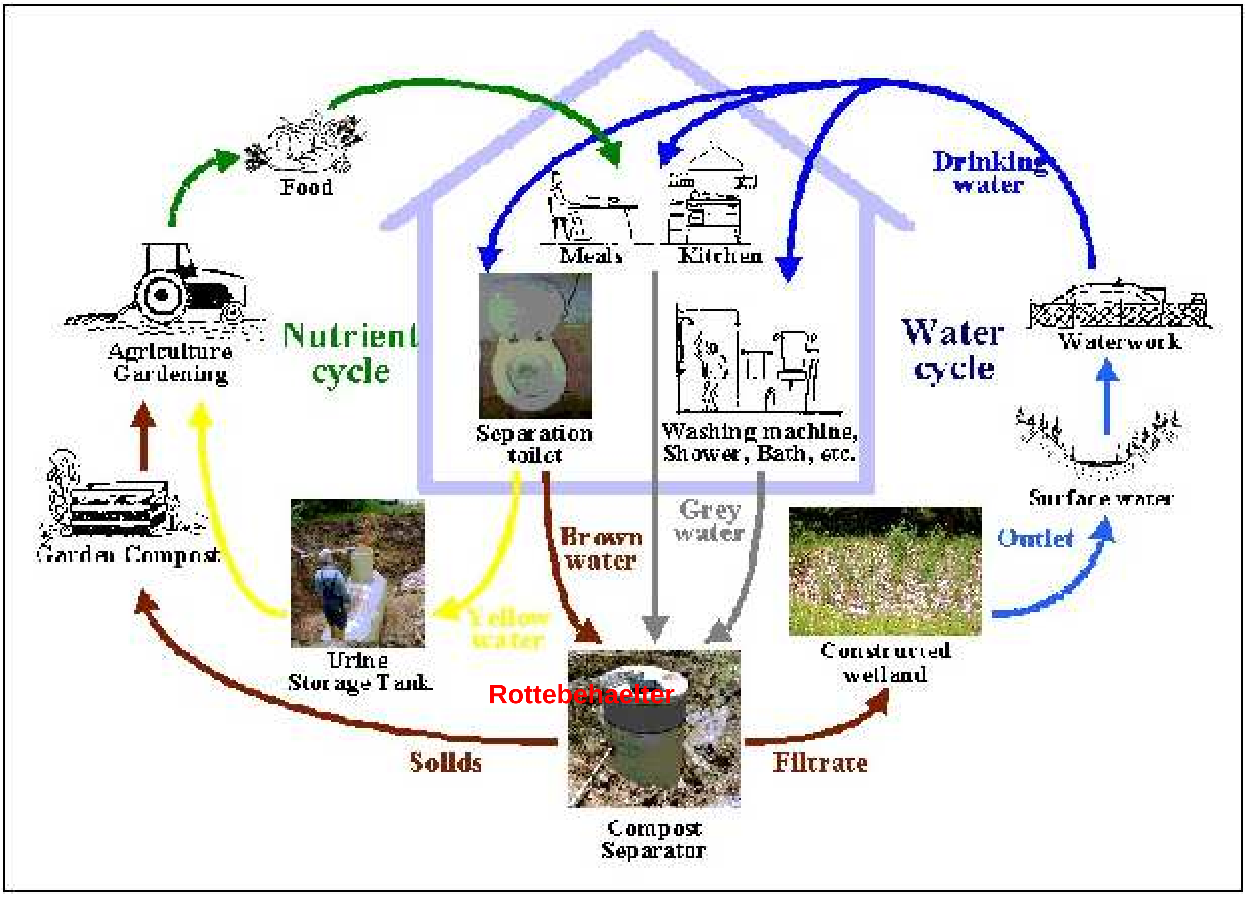


Figure 30: Flow scheme of water and nutrient recycling in the Lambertsmuehle pilot project (Oldenburg et al., 2003)

The wastewater is now separately captured at the source. The source separated flows are treated separately outside of the building. Newly developed sorting toilets where no water is needed for the urine flushing, a mechanical device closing the urine pipe when users stand up and water free urinals have been installed. Yellow water is collected and stored in the storage tank until it is used for agricultural purposes. For brown water, a Rottebehaelter system is used. The filtrate, due to urine separation, is nutrient poor, and is mixed with grey water at the bottom of the Rottebehaelter and treated in a constructed wetland. The effluent is discharged into the nearby water course .

4.5.4.2 Effectiveness of Rottebehaelter systems

The major advantages of the Rottebehaelter system over other systems such as septic tanks are that it does not deprive agriculture of the valuable nutrients and soil conditioner from human excreta and does not require expensive tanker truck. The system is low-cost and allows reuse of nutrients and soil conditioner in agriculture. Relatively dry and stable retained materials can be obtained in the Rottebehaelter with composting by adding sufficient amount of bark regularly as well as with vermicomposting by adding worms. The latter was more effective to reduce the moisture content and to accelerate the degradation of the retained materials. However, low temperature composting took place which needs more than a year to kill all pathogens specially Ascaris. Vermicomposting, however, is an effective process to sanitise faecal materials. The final product is hygienically safe as the human excreta will be completely converted to vermicastings. The typical analysis of the vermicast of wastewater sludge in Australia revealed that pathogens such as enteric viruses, parasite eggs and bacteria such as E.coli have been reduced to safe levels for use in the garden.

Figure 31: Fresh material (Left) and finished material after 3 months of vermicomposting

Compared to composting with adding bark in retained materials, vermicomposting has several benefits. In the Rottebehaelter, moisture content is too high for composting of the retained materials that are structurally poor, whereas this range of moisture content is optimal for worms to work effectively. Structural materials such as bark have to be added for composting. Adding bark regularly and sufficiently is not an easy job.

In a good functioning Rottebehaelter system, solid-liquid separation, dewatering, low temperature composting or vermicomposting can be achieved in one unit. It can be implemented where people use flush toilets. Therefore, the septic tank systems can be replaced by the ecologically and hygienically advantageous Rottebehaelter system for household wastewater treatment. There is no need to construct a new tank, since the existing tank can be modified, if the tank is watertight at least at the bottom where the filtrate is collected. The Rottebehaelter systems are most beneficial when they are integrated in resource management sanitation for rural and peri-urban areas where local post treatment and reuse is possible. This has ecological, economical and hygienic benefits.

It has to be stated that because maintenance is a crucial factor, removal and handling of the retained material has to be improved. In addition, proper procedures of further composting and usage should be established. The loss of water level does make it more appropriate for sites with a good gradient, otherwise an additional pump may be required. Compared to other systems such as septic tanks, there are major advantages.

4.6 Treatment systems for grey water

4.6.1 Biological treatment systems

Biological treatment methods are required to remove organic contamination. The mostly used methods are constructed wetlands, Sequence Bach Reactors, membrane bioreactors and biological aerated filter. Grey water treatment with vertical constructed wetlands with sizes of 2 m^2 per inhabitant in the Flintenbreite settlement, Luebeck has shown good performance (figure 32).

Constructed wetlands are cheap in construction and operation. Therefore, it has been widely used in Europe and transferred successfully to some developing countries. However, because of space scarcity, it is not always appropriate for densely populated urban areas. For these areas, sequence batch reactor (SBR), membrane bioreactors and biological aerated filter can be suitable. Treatment of grey water in small scale showed that SBR can greatly reduce organic matter, nutrients and turbidity SBR (Li et al., 2001).

In other investigations Shin et al. (1998) have found the performance of SBR on treating grey water satisfactory. Biological aerated filter (BAF) followed by membranes are installed at the Millennium Dome in London for the treatment and reuse of hand basin grey water (Hills et al., 2001).

- *top layer:* 10 cm gravel 8/10
- *filter layer:* 75 cm sand 2/8
- textile ("Geovlies")
- drain layer: 10 cm gravel 8/16

intermittent feeding
aerobic conditions in soil filter

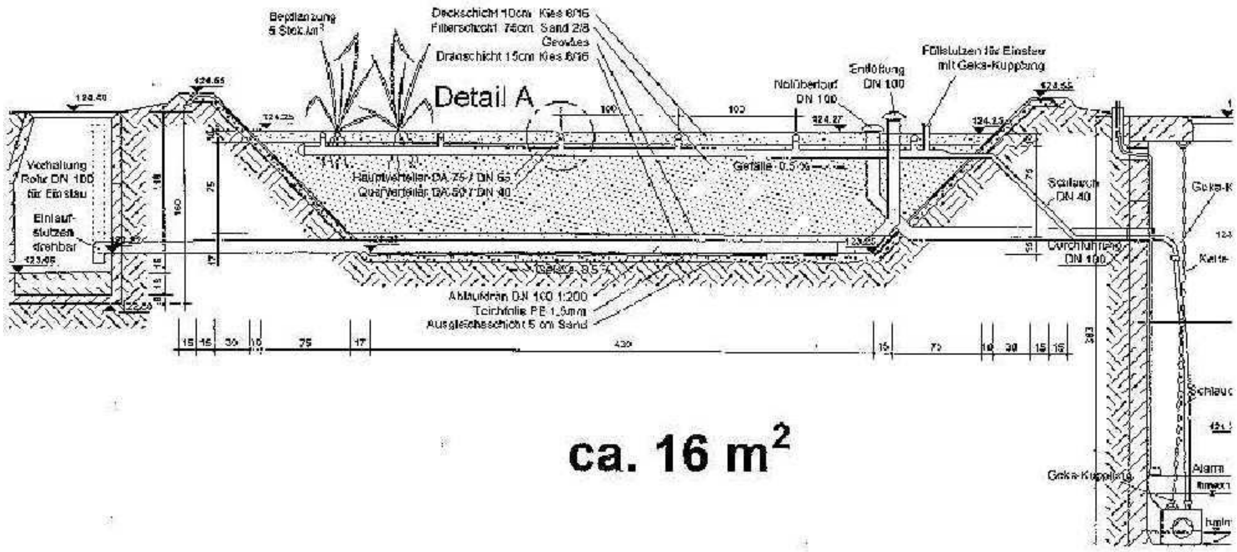


Figure 32: Constructed wetlands for grey water treatment in Flintenbreite-Luebeck

The biological process must be followed by a physical process in order to retain active biomass and to prevent the passage of solids into the effluent, if the effluent is for reuse purposes. Treatment with the membrane-bioreactors (MBR) will probably be the choice of the future, especially if reuse is intended. The MBR is the amalgamation of a suspended growth reactor and membrane filtration device into a single unit process. The process represents an intensification of traditional biological processes with the added advantage that the membrane retains particles including bacteria and viruses. Effluent from MBR treated grey water is typically solid-free, low in organic pollution and contains non-detectable levels of coliforms (Stephenson et al., 2000).

4.6.2 Physical and chemical treatment systems

Physical methods used for grey water treatment are sand filter, ultrafiltration, micro-filtration, reverse osmosis. Small scale experimental results have shown that grey water treated with combination of SBR (Sequence Batch Reactors) and slow sand filter has achieved the quality required for groundwater recharge (Li et al., 2001). In the study of Shin et al. (1998), the grey water treated with a combination of SBR and micro-filtration was suitable for reuse. Moreover, grey water treated with the combination of constructed wetlands and chemical process (TiO_2–based photocatalytic oxidation) has achieved the European bathing water quality (Li et al., 2002).

4.7 Treatment systems for yellow water

4.7.1 Storage and reuse

Urine is relatively sterile and can be reused without further treatment (Wolgast, 1993). However, due to faecal contamination, pathogens have been found in yellow water; but in low concentration, which will pose low hygienic risk of using yellow water as a fertiliser, if it is stored at least for 6 months before being used in agriculture land (Jönsson et al., 1999; Hellström and Johansson, 1999). Since the practising of separated collection of yellow water, farmers in Sweden have been collecting it in underground storage tanks for applying to their agricultural land (Jönsson et al., 1999).

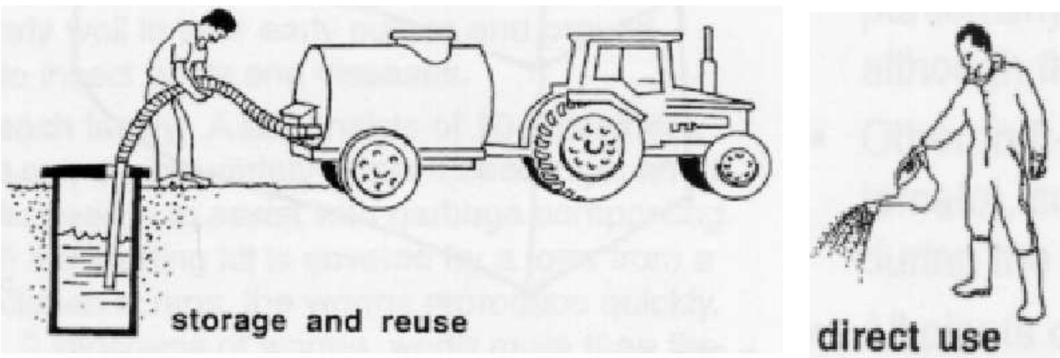


Figure 33: Practice of urine: storage and reuse or direct reuse

In Eco-village, Understenhöjden, Sweden, urine of 160 inhabitants is separated with urine separating toilets and collected in a collection tank. The collected urine is transported by tanker truck, once a year, to the storage tank, where it is sanitised prior to its use in agriculture. Similar to Eco-village Understenhöjden, 160 inhabitants in the Palsternacken housing state, Enskede in Sweden are connected to a urine separating system. Collected urine is transported once a year to a storage tank, where also the urine from eco-village, Understenhöjden is stored. Once the tank is full, it is closed and stored until it is ready for application in agriculture.

During the storage and transportation of urine, a large amount of unionised ammonia is formed due to decomposition of urea which also increases pH. The high pH causes precipitation of calcium, phosphate, struvite and calcite resulting 90 % of total nitrogen is present as ammonia, the pH is about 9 and 30 % of phosphorus is precipitated (Udert et al., 2003). The ammonia can evaporate while transportation and application in agriculture as fertiliser of urine solution (Hellström and Johansson, 1999). However, nitrogen loss can be prevented by ammonia oxidation; with the biological nitrification, urine can be stabilised (Udert et al. 2003). In the Pilot project Lambertsmuehle in Germany, urine from a family and museum visitors is separated with a newly developed sorting toilet where no water is needed for the urine flushing, a mechanical device closes the urine pipe when users stand up. The separated urine is collected and stored in the storage tank near the building until it is sanitised before it is applied in agriculture. Unlike in Sweden, in Lambertsmuehle, acidification is also used for sanitisation. In the storage tank the urine is acidified (pH< 5) with sulphuric acid to reduce microbial contamination, ammonia emissions and plant damage; however, it should not be used in excess to avoid yield losses due to high inputs of sodium choride (Simons and Clemens, 2003). Experiences from Sweden have shown that nitrogen loss during the storage is small and does not cause odour problem. The urine storage has been carried out without any extra conditioning.

In Mexico city, vegetables have been grown in containers using human urine as a fertiliser (Esrey et al., 1998). Urine is stored in a container for 3 weeks and is applied to the vegetables after diluting it with water on a ratio of 1:10. After several years of study it showed that plants fertilised with urine grew more rapidly and healthier than those grown with conventional agricultural techniques.

In a lab scale experiment, nutrient removal by different plants with different dilution of urine was studied (Prasapati and Gajurel, 2003). Results showed that Green Pea, Black Gram, Broad Bean, Cress, Spinach, Tintel, Mustard and Rape had high nutrients removal efficiency while using a ratio of 1:10 and 1:15. With the applied dilution, effluent still contained traces of N, P, K. Therefore, further dilution of source-separated urine could be applied for total nutrient recovery. This practice is good for a region where the farmland is near to the housing area; otherwise, transportation of large amounts of urine solution for longer distance has many negative environmental impacts (Hellström and Johansson, 1999).

4.7.2 Volume reduction and reuse

Recently, many methods for treatment and volume reduction of collected yellow water have been studied. One method is dewatering by evaporation with and without nitrification and freeze concentration (Gulyas, 2004). By freezing, it is possible to concentrate 80 % of nitrogen and phosphorus in 25% of the original volume (Ban et al., 1999). By nitrification in combination with drying, it is possible to concentrate over 70 % of the nitrogen in 10 % of the original volume (Hellström and Johansson, 1999). The production of Isobuthylaldehyde-di-urea IBDU and ammonia water from urine is possible. Urea can be converted to IBDU only after concentrating urine. With air stripping and absorption ammonificated urine can be treated very effectively and a solution of 10 % w/w of ammonia can be obtained (Behrendt et al., 2002). These methods could be beneficial, when a larger volume of urine solution has to be transported a long way to the agriculture farm. However, these methods have been investigated only in small scale so far.

4.8 Benefits of source separation in sanitation

Most of the benefits of Resource management sanitation should be clear from the preceeding sections. In the following, the advantages of Resource management sanitation toward conventional sanitation are summarized again.

Resource management sanitation combats hygienic risks (for details please refer Lesson A2)

Highest concentrations of pathogenic microorganisms are contained in brown water. As sanitisation of small volumes is easier than of the highly diluted entire wastewater streams, and source control sanitation leads to catchment of brown water with a far out lower water content than in domestic wastewater in conventional sanitation, resource management sanitation is a good means to reduce sickness and deaths from diarrhoea because of safe containment and hygienization of brown (or black) water (solids). This is a clear advantage. Separately collected faeces can be hygienized by dehydration (when there is no water available for pathogenic organisms, they will die). A good way to take the water away is utilization of solar heat. For this purpose, the solids of brown water are stored in a chamber which is covered with a black lid. This way is preferably feasible for warm regions. It has to be noted that faeces in Resource management sanitation schemes have to be safely kept away from eventually occurring stormwater (special care is required e.g. in regions with monsoon).

Another possibility to kill pathogens in faeces is composting. In this process the killing agent is heat. The diagram (figure 33) shows that the compost process has to last longer the lower the generated temperature is. As fungi are important actors for the composting process, aerobic conditions have to be ensured in the heap of faeces. For this purpose, addition of structured material like woodchips is helpful. A too high moisture content of the solids hinders oxygen to diffuse through the heap of excreta. Therefore, composting requires sufficiently dried blackwater solids (optimum moisture content for composting: 50 to 60 %). Addition of worms ("vermicomposting") loosens the material and enables better access of air into the heap. As too high concentrations of nitrogen inhibits the composting process (optimum C:N ratio: 25-30:1), divertion of urine makes composting of faeces more efficient.

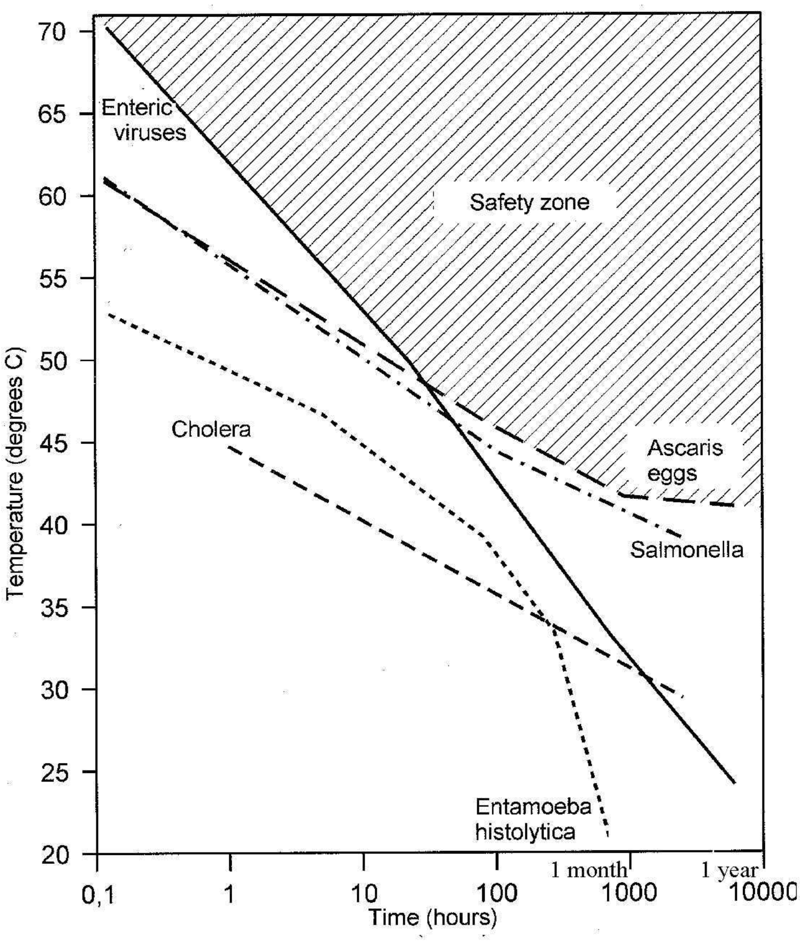


Figure 33: Combination of time and temperature of pathogens elimination. Hatch area represents complete pathogens elimination due to the combined effect of time and temperature (Feachem et al., 1983)

EcoSan helps to overcome malnutrition

The safe nutrients obtained from Resource management sanitation can be reused in agriculture and thus help to increase harvest yields and to combat malnutrition.

The nutrient cycle – closed

With implementation of Resource management sanitation, the food cycle can be closed leading to less environmental degradation and also to socio-economic advantages.

Wastewater reuse in Resource management sanitation

Wastewater reuse is facilitated because of using the less contaminated greywater which belongs to the water cycle (this can help to combat water scarcity). For example, in constructed wetlands, the separately collected greywater can be purified in a relatively simple way to a high quality.

Resource management sanitation avoids pollution of the aqueous environment

Pollution of the aqueous environment is reduced in resource management sanitation, as excreta flows do not come into contact with surface waters. Moreover, pharmaceuticals are not discharged to the water cycle-related greywater and can thus not enter surface waters. Groundwater contamination with pharmaceuticals by agricultural use of yellow water (and of hygienized brown water solids) will have to be investigated more intensively in future. But as concentrations of pharmaceuticals in separately collected yellow water are decreasing during storage (mainly at low pH; Strompen et al. 2003), this pathway is not thought to be threatening aquifers.

⇨ "If coverage can be increased, resource management sanitation can serve as the missing link to sustainable urban development, reverse the unconscious pattern of linear thinking and actions, and be a technical solution that protects ecosystems and harmonises with natural systems" Statement of the Sida/UNDP/SIWI Workshop 2000).

Socio-economic benefits of EcoSan

Also in socio-economic aspects, Resource management sanitation may contribute to some improvement:

- Jobs can be created (e.g. caretakers for resource management sanitation facilities, yellow and processed brown water transportation firms).

- There will be financial benefits (no sewers needed, energy necessary in wastewater treatment plants in conventional sanitation schemes is saved, a great deal of energy for fertilizer production can be saved).

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6. Ecosan internet links

A revised and enlarged edition of the book "Ecological Sanitation" can be downloaded from here:

http://www.ecosanres.org/PDF%20files/Ecological%20Sanitation%202004.pdf

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