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Ecological Sanitation and Associated Hygienic Risk

An overview of existing policy making guidelines and research

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Ecological Sanitation and Associated Hygienic Risk

An overview of existing policy making guidelines and research

Deepak Raj Gajurel, Dr.-Ing.

Claudia Wendland, Dipl.-Ing.

Contents

1 | 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 (Cooper, 2001). 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 (Kluge and Schramm, 1986). 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. 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 still 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).

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 ground water 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. Even with the high inputs of money for construction, maintenance and operation, this end-of-pipe concept is producing linear mass flows (Figure 1). It shows clear deficiencies in recovery of nutrients and organic matter, which are valuable fertiliser and soil conditioner. 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; Presnitz, 2001). Therefore, large amounts of sewage

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.

There are many existing decentralised wastewater treatment systems such as pit toilets, septic tanks etc. which have been widely used worldwide and most of them are low-cost and low- tech. 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

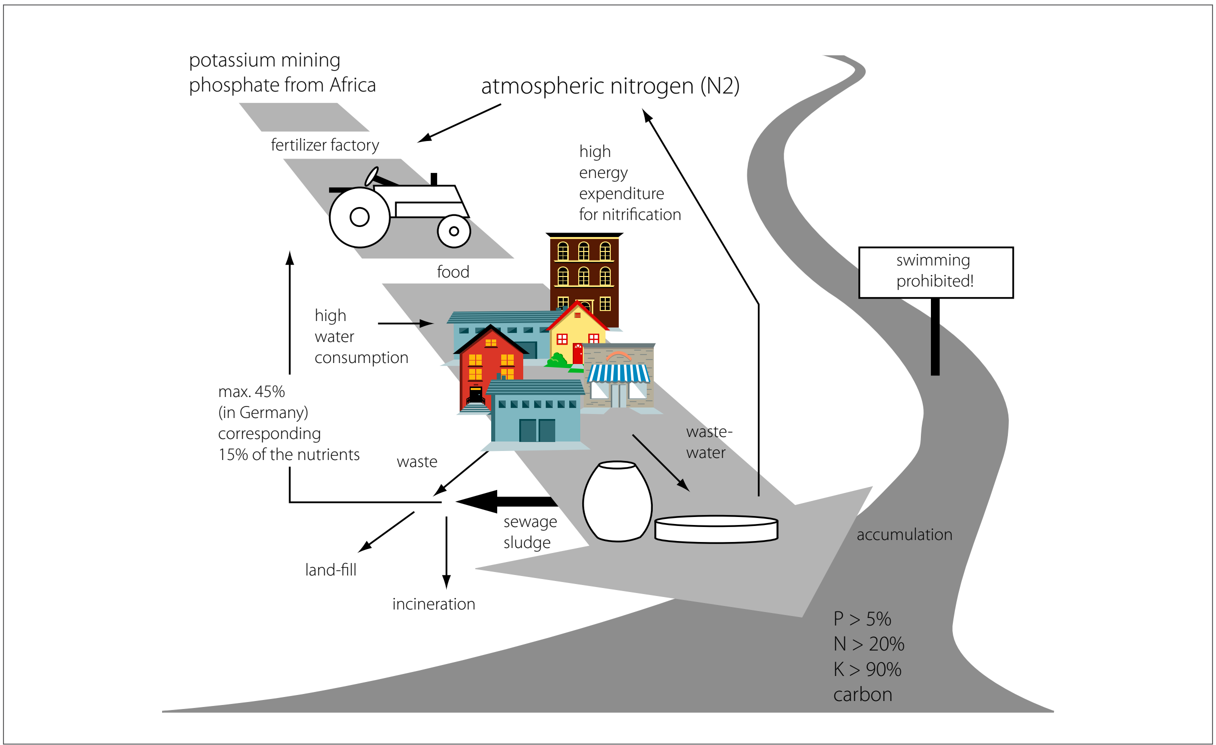

Figure 1: Material flows in the conventional sanitary concept (Source: Otterpohl et al., 1997)

sludge are disposed of in landfills or incinerated. Only a smaller part is applied to agricultural land.

Decentralised sanitation systems have following benefits compared to the centralised system:

- there is no need of laying sewers for the transportation

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

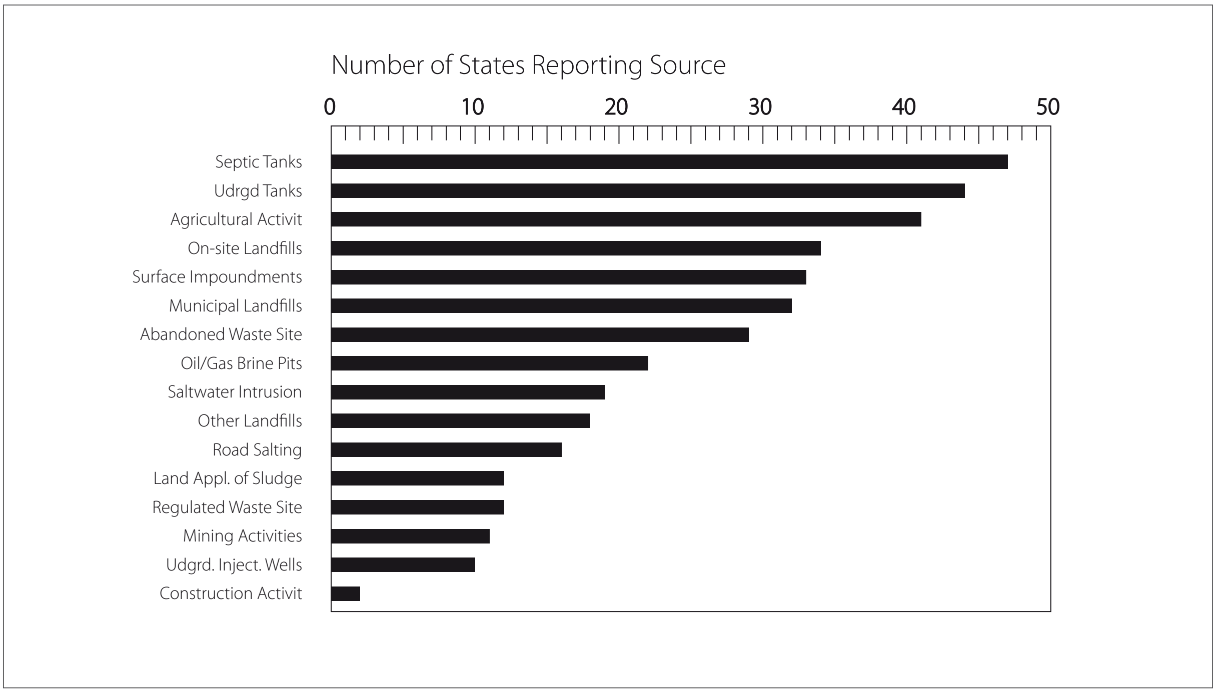

Figure 2: Reported sources of groundwater contamination in the United States (Jenkins, 1994)

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 andically 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 2), 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.

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 (Gray, 1989).

2 | Ecological sanitation

2.1 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, 2001). 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 3 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 ecological sanitation, base on ecological principal. There are numerous advantages of ecological

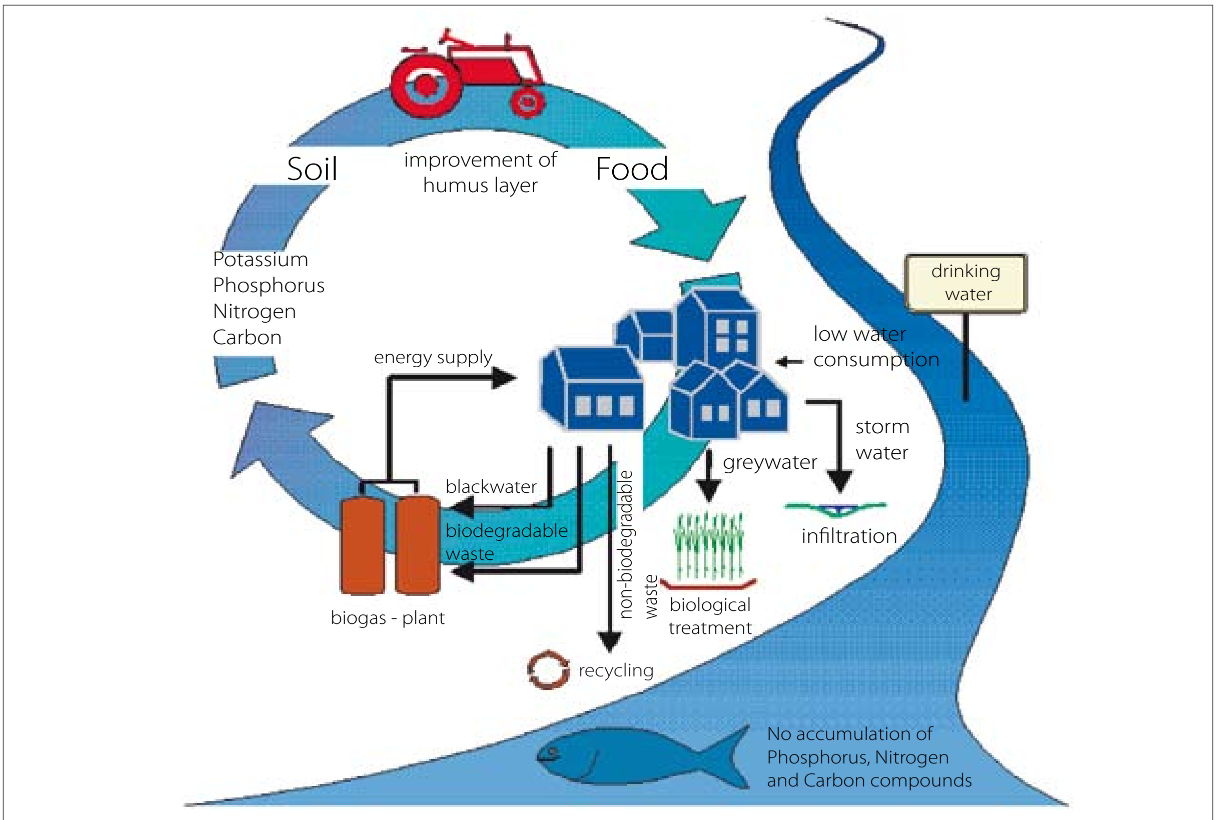

Figure 3: Material flows in ecological sanitation (Source: Otterpohl et al., 1997)

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.

Ecological sanitation bases on the concept of source control. High levels of nutrient recovery are possible with the concept of source control in household (Henze et al., 1997; Esrey et al., 1998; Jönsson et al., 1999; Larsen and Udert, 1999; Otterpohl, 2001). A vision of source control for household wastewater is based on the fact of very different characteristics of grey, yellow and brown water (Table.1). The typical characteristics of the flows of household wastewater, shown in table 2, clearly reveal that urine contains most of the soluble nutrients, whereas grey water, despite a very large volume compared to urine, contains only a small amount of nutrients. Furthermore, faeces, which are about 10 times smaller in volume than urine, contain nutrients, high organic load and the largest part of pathogens. Although grey water due to personal hygiene and yellow water due to contamination in sorting toilet contain pathogens, they can easily be eliminated. But, faeces contain as much as 100 million bacteria per gram; some of them are pathogen to human (Wolgast, 1993).

If urine is separated and reused in agriculture, not only nutrients will be reused, but also a high level of water protection will be reached. Unlike wastewater containing urine and faeces, grey water can be treated with simple and low cost processes and reused. There are many cost efficient biological treatment and membrane technologies that can produce high quality water.
If faeces are separated and kept in small volumes with non or low-flush toilet, it will provide a good condition for sanitisation of faeces and these sanitised faeces can be used as a soil conditioner in agriculture. Therefore, separated treatment of different flows according to their characteristics can lead to full reuse of resources and a high hygienic standard.

Wastewater fraction	Description
Grey water	Washing water from kitchen, shower, washbasin and laundry
Black water	Toilet wastewater (urine, faeces, toilet paper (if used and put in the bowl) and flush water)
Yellow water	Urine with or without flush water
Brown water	Faeces, toilet paper (if used and put in the bowl) and flush water (toilet wastewater without urine)

Table 1: Definition of wastewater fractions in households

The technologies to realise source control have already been developed (Otterpohl et al., 2001; Esrey et al, 1998). Sorting toilet is a suitable technology to separate the

Volume (L / (P*Year))		Grey water 25.000 - 100.000	Flush water can be saved 6.000 - 25.000	
Yearly Loads (kg / (P*Year))			Urine ~ 500	Faeces ~ 50 (option: add biowaste)
N	~ 4-5	~ 3 %	~ 87 %	~ 10 %
P	~ 0,75	~ 10 %	~ 50 %	~ 40 %
K	~ 1,8	~ 34 %	~ 54 %	~ 12 %
COD	~ 30	~ 41 %	~ 12 %	~ 47 %
S, Ca, Mg and trace elements		Treatment ↓ Reuse / Water / Cycle	Treatment ↓ Fertiliser	Biogas-Plant Composting ↓ Soil-Conditioner

Table 2: Typical characteristics of household wastewater components (Compiled from: Geigy, Wissenschaftliche Tabellen, Basel 1981, Vol.1, Larsen and Gujer, 1996; Fittschen and Hahn, 1998)

urine and faeces at source (Figure 4). 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 whereas flushing water for faeces bowl can be adjusted to the required amount (about 4 to 6 l). 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.

Vacuum toilet as shown in figure 5 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 flush water. Noise is a concern with vacuum toilets but modern units are not much louder than flushing toilets and give only a short noise.

Figure 4:
Left: sorting toilet (Source: Roediger) and Right: urine diverting squatting-pan (design: Lin Jiang, China)

Figure 5: Vacuum toilet (Source: Roediger)

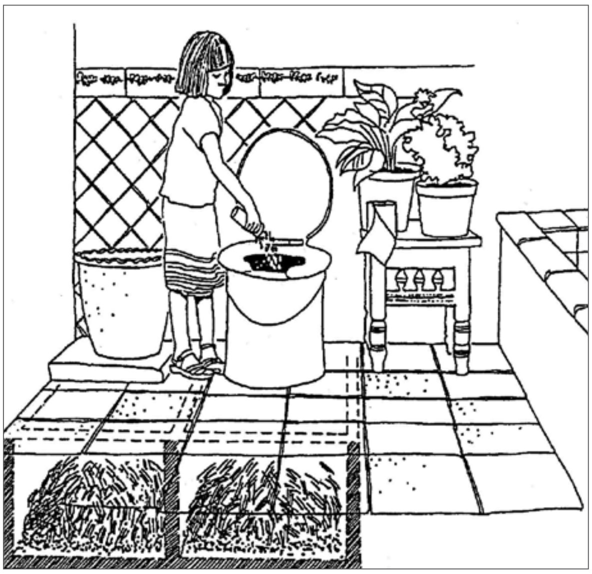

Figure 6: Double-vault toilet with urine diversion (Source: Esrey et al., 1998)

Composting toilet needs 0.2 l per flush, only for cleaning the toilet seat. There are also urine diversion composting or dehydration toilets (Figure 6 and 4 right). 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.

2.2 Microbial Hygienic Aspect of Ecological Sanitation

2.2.1 Background

Human faeces contain most of the pathogens with a potential of causing diseases. Therefore, source control of faeces from household wastewater prevents these disease-causing pathogens gaining access to water bodies where they survive longer than on land (Esrey et al., 2000) and pose a long-term threat to human health. The most beneficial is when it is kept separated at source which avoids dilution of faeces. The separated solid fractions, which are easily biodegradable, can be treated biologically. When the organic matters decompose, due to self heating capacity heat is produced. This self produced heat will create self-hygienisation of the matter. Among others parameters, amount of essential nutrients and moisture, pH, the presence / absence of oxygen are crucial for the process rates of waste treatment and sanitisation.

The mostly applied methods for the sanitisation of separated faecal waste are composting and dehydration. Esrey et al. (1998) claimed that treatment method based on dehydration can reduce pathogens effectively because there is a rapid pathogen destruction at moisture content below 25 %. Composting of a sufficient amount of fresh and easily degradable organic materials can produce heat which raises the temperature of the materials. At the temperature of 60 °C and above, most of the pathogens are destroyed. Low temperature composting takes long time to kill the pathogens. The rate of reduction of pathogens is significantly dependant on time and temperature (Stubgaard, 2001; Feachem et. al., 1983). The higher the temperature of the materials, the shorter the time for destroying the pathogens and vice versa. The factors such as high pH, competition for food, antibiotic action and the toxic by-products of decomposing organism play a significant role in eliminating or reducing pathogens (Naudascher, 2000; Del Porto and Steinfeld, 1999).

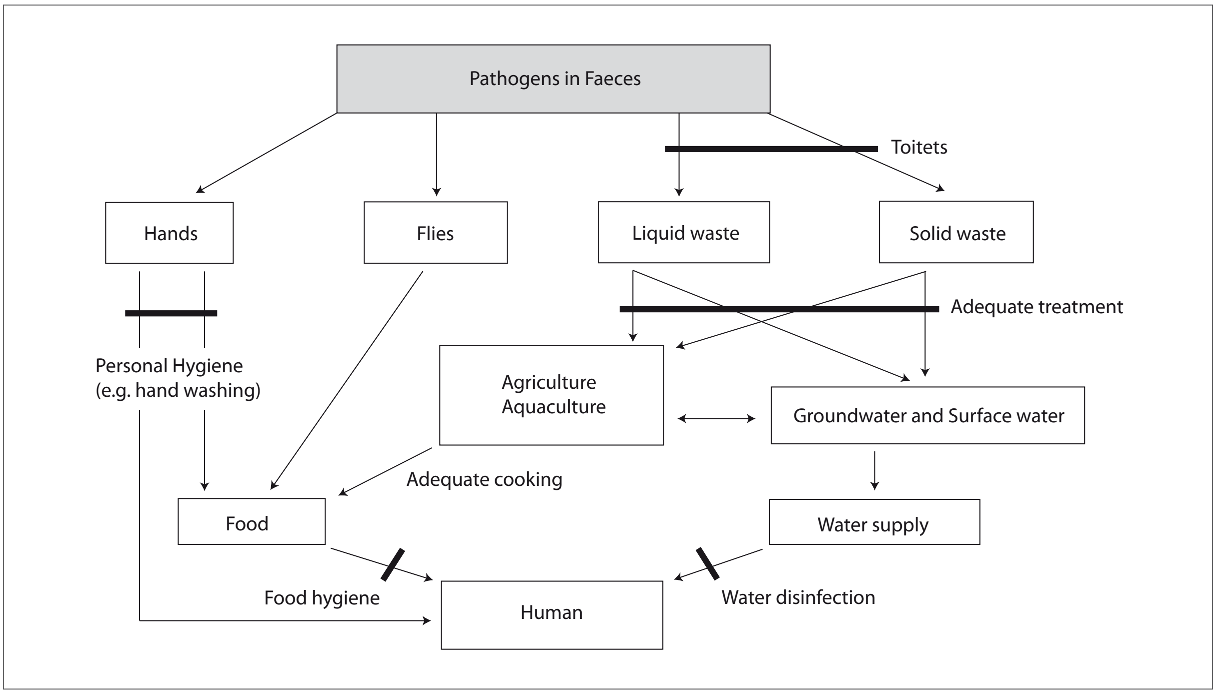

Figure 7: Routes of Pathogens transmission from faeces to human (Adopted from Franceys et al., 1992 and modified)

2.2.2 Pathogens and transmission routes

Pathogens that are responsible for the transmission of diseases are mostly bacteria, viruses, protozoa and helminths. The routes of infection with these Pathogens found in faeces are illustrated in figure 7. The arrows indicate the routes of pathogens transmission whereas the crossing bars represent barriers to prevent the spread of pathogens. The physical barriers can be applied to intercept the routes of transmission. An effective primary barrier can prevent pathogens spreading. However, secondary barrier like personal hygiene and food hygiene must be sufficiently implemented to prevent spreading diseases. Before the pathogens gain access to the environment, there are many primary prevention facilities, which can effectively block their pathway.

2.2.3 Survivability rate of pathogens in environment

Survival of the pathogens in the environment is of great concern in the management of faecal waste. Within the environment and treatment methods, they have varying survivability rate (Table 3). Survivability rate of pathogens is controlled by many factors (Del Porto and Steinfeld 1999) such as:

- competition for food (limited food sources limit microbial numbers);
- predator-prey relationships (some organisms consume others for food sources);
- antagonism (some organisms produce toxic substances which inhibit other organisms);
- environmental conditions (oxygen concentration, nutrient levels, temperature, moisture, pH).

In order to eliminate the pathogens, faecal containing waste must be treated in a controlled environment where the above mentioned factors act effectively. This can be done in many ways. However, low-tech and low-cost are the deciding factors.

2.2.4 Elimination of pathogens from faecal matter

There are two aspects for faecal waste treatment: stabilisation and sanitisation. Both can be achieved by thermophilic composting and dehydration. Thermophilic composting above a temperature of 55 °C can kill all pathogens in some days (Epstein, 1997). But this range of temperature has not been achieved in composting toilets so far. Because of low temperature composting,

Condition	**Bacteria**	**Viruses**	**Protozoa***	**Helminths*** *
Soil	400	175	10	Many months
Crops	50	60	not known	Not known
Night soil, faeces, sludge 20-30 °C	90	100	30	Many months
Composting Anaerobic at ambient temperatures	60	60	30	Many months
Thermophilic composting 50-60 °C maintained for several days	7	7	7	7
Waste stabilisation ponds Retention time > 20 days	20	20	20	20

* excluding Cryptosporidium parvum
** mainly Ascaris; other parasitic eggs tend to die quicker

Table 3: Survival time (d) of pathogens in day by different disposal/treatment conditions (adapted from Esrey et al., 1998)

Pathogens	Composting Toilet (3 months retention time)	Thermophilic Composting
Enteric Viruses	Probably eliminated	Killed rapidly at 60 °C
Salmonellae	A few may survive	Killed in 20 hrs at 60 °C
Shigellae	Probably eliminated	Killed in 1 hr. at 55 °C
E.coli	Probably eliminated	Killed rapidly above 60 °C
Cholera vibrio	Probably eliminated	Killed rapidly above 55 °C
Leptospires	Eliminated	Killed in 10 min. at 55 °C
Estamoeba histolytica cysts	Eliminated	Killed in 5 min. at 50 °C
Hookworm eggs	May survive	Killed in 5 hrs. at 50 °C
Roundworm(Ascaris)eggs	Survive well	Killed in 2 hrs. at 55 °C
Schistosome eggs	Eliminated	Killed in 1 hr. at 50 °C
Taenia eggs	May survive	Killed in 10 min. at 59 °C

Table 4: Pathogens survival by composting (Feachem et al., 1983)

retention time should be long enough in order eliminate or inactivate pathogens. Feachem et al. (1983) stated that three months retention time will kill all of the pathogens in a low-temperature composting toilet except for worm eggs (Table 4).

Low temperature in composting toilet can be due to:

- small portion of material entering into the container which is not large enough to trap sufficient heat produced inside heap to increase the temperature;
- lack of oxygen inside the material due to not turning pile time to time;
- not adjusting moisture content to optimal level (50 - 60 %) by adding dry a material or water regularly;
- not maintaining optimal C:N (20-30:1), which is required for successful composting by adding bulking agents regularly.

There is a synergistic correlation between time and temperature (Figure 8). The hatched areas refers to safety zone, where due to the combination of time and temperature all pathogens will be killed. Also the factors such as competition for food, predator-prey relationships and antagonism help to reduce or eliminate pathogens. But there are no data available on effect of these factors on die-off rate of pathogens. However, most of the composting toilets in Europe and some parts of USA rely on retention time and above mentioned biological factors to eliminate or reduce pathogens (Naussadar, 2000; Del port and Steinfeld, 1999). In countries such as Vietnam, China, El Salvador, Mexico, South Africa etc. additional measures such as raising pH with adding ash and/or lime, desiccation by solar heating and adding dry materials etc. are used to destroy pathogens.

Chien et al. (2001) evaluated the die-off rate of the indicator organisms: Salmonella typhymurium phages 28 B and Ascaris suum eggs in faecal material in urine-diverting Eco-San toilets in Vietnam. Ash was added in all the toilets and some of them were heated with solar heater too. The shortest die-off of Salmonella typhymurium phages 28 B was 23 days and longest was 151 days whereas the shortest die-off of Ascaris suum eggs was 51 days and longest was 169 days. Their survival time was shorter in the toilets with solar heater. In the low-temperature toilets, high pH and low moisture had a significant effect on the reduction of the indicators pathogens.

In El Salvador, Moe et al.(2001 and 2003) studied the microbiological safety of the end product from double-vault urine-diverting and solar toilets. Additives used in the toilets varied from household to household. Most of the household used ash while other used lime, soil, sawdust. Their study has shown that some of the toilets achieved conditions that promote microbial inactivation and produced biosolids with low or no detectable level of pathogens indicators. Other toilets were not functioning properly. Pathogens elimination or inactivation in these system was a function of the temperature, pH, moisture and retention time. Double-vault urine-diverting and solar toilets were associated with lower prevalence of less persistent pathogens, including hookworm, Giardia and E. histolytica. However, double-vault urine-diverting toilets were associated with higher prevalence of Ascaris and Trichuris.

Desiccation by drying and adding high-alkaline additives is the best way to kill pathogens. Addition of ash helps in raising pH and decreasing moisture of faecal material. Both of them shorten the surviving time of pathogens (Austin, 2001; Chien et al., 2001). There are also other additives such as saw dusk, dry soil etc. Jiayi et al.(2001) has evaluated survival time of pathogens in faecal material with different additives They have come up with the result that plant ash was the most effective additive to eliminate the pathogens within two and half months.

Redlinger et al. (2001) investigated the reduction of faecal coliforms over a 6-month time and methods of this reduction (desiccation and biodegradable) in dry-composting toilets installed on the U.S-Mexico border. The end product was classified with respect to faecal

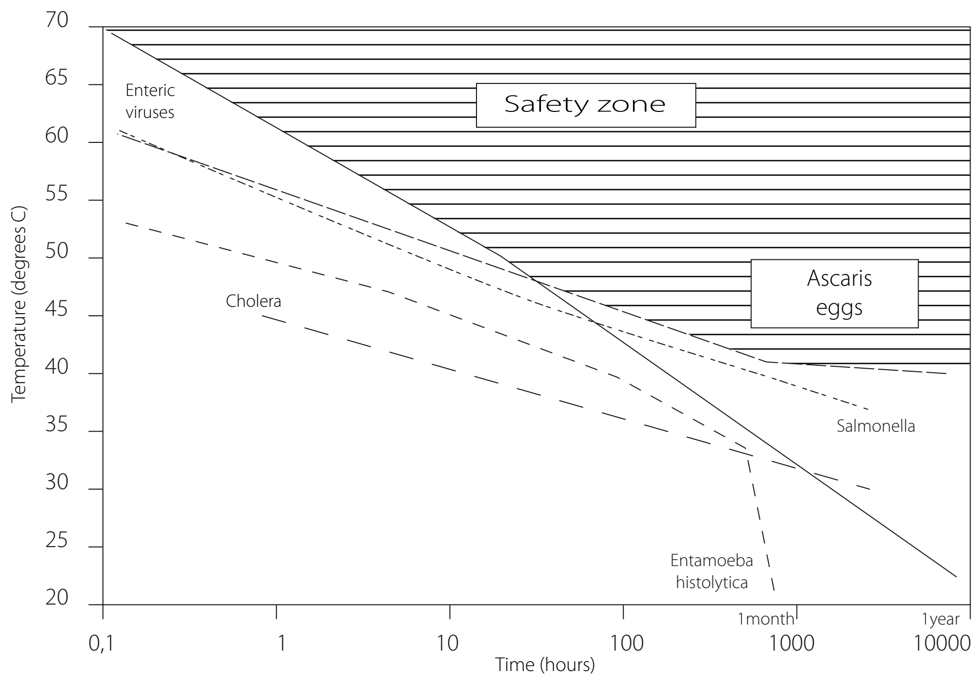

Figure 8: Combination of time and temperature of pathogens elimination. Hatch area represents complete pathogens elimination due to the combined effect of time and temperature (Feachem et al., 1983)

coliforms according to US EPA. According to EPA class A end product should contain safe and acceptable levels of pathogens and is a safe soil amendment for food and non-food plants and Class B end product should be a safe soil amendment for ornamental plants. In their study only 35.8 % of 90 composting toilets' compost samples fulfilled the class A requirement after 6 months. In 3 months only 19.4 % was class A compost. There was significant increase in 3 months. By 6 months 60.5 % of compost samples attained class B and 3.7% was not able to determine any class. There was no class C compost sample after 6 months. In the study it was found that reduction of faecal coliform was primarily due to desiccation. There were two reasons to support it. One, 54 % of the compost had low moisture content, which was sub-optimal for biodegradation and of these, 73.8 % were class A. Another, only 9.5 % of the compost samples, which had optimal moisture content for aerobic biodegradation, fulfilled class A. 16.7 % of the compost samples, which had high moisture content (>60 %), was class A. This reduction was most probably due to anaerobic bio-degradation, since moisture content above 60 % and emission of unpleasant odour were noted.

Above mentioned studies from various authors show that desiccation is the best way so far to eliminate or reduce pathogens from the faecal solid waste. Desiccation can be achieved with solar drying and dry additives. Plants ash is the best additive not only to reduce moisture content but also to raise pH. Both are able to destroy pathogens. However, composting has advantages of achieving high temperatures, which will destroy many pathogens that desiccation cannot (Del port and Steinfeld, 1999). But, as mentioned above, in composting toilet high temperature has not been achieved so far.

Study of Stenström (2001) on reduction efficiency of index pathogens in ecological sanitation and conventional sanitation concluded that "if requirements of time, temperature and pH level are met, ecological sanitation can be as effective as, or superior to, conventional wastewater treatment in bringing about pathogen reduction". However, studies so far are few and on a small scale. More studies are required. Also selection of an index organism to measure is critical. The use of bacterial indicators to evaluate die-off of pathogens is not fully sound. The survival rate of viruses and parasites is greater than of faecal coliforms or other bacteria. Ascaris (roundworm) is among the most resistant, and therefore destruction of ascaris ova could be seen as a one of the most important indicators of the safety of sanitised faeces (Stenström, 2001).

In practice, complete elimination of pathogens may not be possible in any kind of sanitation. Therefore, secondary barrier such as personal, food and domestic hygiene must be included to destroy the pathogens completely. Therefore, hygiene awareness and proper education are the crucial points for on-site faecal waste management.

In summary, the die-off rate of the pathogens depends on the environmental condition of the place where they reside. The following factors are lethal to most of the pathogens:

- high pH (> 9)
- Low moisture contain (< 25%)
- High temperature (> 55 °C) over more than 10 hours
- Long retention time (> 6 months)
- Ammonia and high salt content
- Limited nutrients (competition for food)
- predator-prey relationships
- antagonism

High pH can be obtained by adding alkaline material such as ash or lime (but lime is not preferable) that reduces the moisture additionally. Moisture can be lowered by drying. Solar dryer can be used for this purposes, also high temperatures can be achieved at least part of the year in hot climate regions. High ammonia and salt can be obtained from urine. Long retention time, ammonia and high salt content, limited nutrients availability, predator-prey relationships and antagonism can be obtained in multi-chamber batch composting process.

The hygiene risk associated with urine is very small compared to that with faeces. The fate of the pathogens entering into urine collection tank due to faecal contamination in urine diversion toilets is of vital importance for the hygiene risks related to the handling and reuse of the urine. To determine the duration and conditions for sufficient storage of the urine mixture before its use as a fertiliser, it is necessary to estimate the survival of various microorganisms in urine as a function of time (Höglund, 2001). For the urine mainly temperature and the elevated pH (~9) in combination with ammonia has been concluded to affect the inactivation of microorganisms (Schönning, 2003). Bacteria like Salmonella (i.e. gram-negative bacteria) were inactivated rapidly, whereas viruses was hardly reduced at all at low temperatures (4-5°C)(Table 5).

These are the established processes used for eliminating or reducing pathogens until now. These are few regarding so many lethal factors to pathogens. Thus, more studies are needed to make use of combining factors to find new processes as well to improve the existing ones.

	Bacteria Gram-negative	**Bacteria Gram-positive**	**C.parvum**	**Rhesus rotavirus**	**S. typhimurium phage 28B**
4°C	1	30	29	172 [a]	1466 [a]
20°C	1	5	5	35	71

[a], *Survival experiments performed at 5°C .*

Table 5: Inactivation of microorganisms in urine, given as T90-values (time for 90% reduction) (Höglund, 2001)

3 | WHO Guidelines for the Safe Use of Wastewater, Excreta and Greywater

3.1 Introduction

In 2006, the World Health Organisation released Guidelines for the Safe Use of Wastewater, Excreta and Greywater (WHO, 2006) which replaced the former guidelines from 1989 (WHO, 1989). The 4 volumes of the new guidelines give a detailed description of the present state of knowledge regarding the impact of wastewater, excreta and greywater in agriculture and aquaculture on public health. Health hazards are identified and appropriate health protection measures to mitigate the risks are discussed. Within ecological sanitation concepts, volume 4 "Excreta and greywater use in agriculture" is of major importance . It provides an integrated preventive management framework for safety applied from the point of household excreta and greywater generation to the consumption of products grown with treated excreta applied as fertilizer or treated greywater used for irrigation purposes. They describe reasonable minimum requirements of good practice to protect the health of the people using treated excreta or greywater or consuming products grown with these for fertilization or irrigation purposes.

3.2 Health based targets

The assessment of health risk is based on three parts: microbial analysis, epidemiological studies and quantitative microbial risk assessment (QMRA). Human faeces contain a variety of different pathogens, reflecting the prevalence of infection in the population. In contrast, only a few pathogenic species may be excreted in urine. The risks associated with both reuse of urine as a fertilizer and the use of greywater for irrigation purposes are related to cross-contamination by faecal matter. Epidemiological data for the assessment risk through treated faeces, faecal sludge, urine or greywater are scarce and unreliable, while ample evidence exists related to untreated faecal matter. In addition, microbial analyses are partly unreliable in the prediction of risk due to a more rapid die-off of indicator organisms such as E. coli in urine, leading to an underestimation of the risk of pathogen transmission. The opposite may occur in greywater, where a growth of the indicator bacteria on easily degradable organic substances may lead to an overestimation of the risks. Based on the above limitations, QMRA is the main approach taken, due to the range of organisms with common transmission characteristics and their prevalence in the population.

The 2006 WHO guidelines provide health-based targets and health protection measures for developed and less developed countries world wide.

Health-based targets define a level of health protection that is relevant to each hazard. A health-based target can be based on a standard metric of disease, such as a disability adjusted life year or DALY (i.e. 10-6 DALY), or it can be based on an appropriate health outcome, such as the prevention of exposure to pathogens in excreta and greywater anytime between their generation at the household level and their use in agriculture. To achieve a health-based target health protection measures are developed. Usually a health-based target can be achieved by combining health protection measures targeted at

different steps in the process.
1 DALY loss means 1 year of illness or 1 year lost due to premature death. 10-6 DALY loss pppy are suggested to be tolerable which means to be ill for 32 seconds per year due to the use of greywater, faeces or urine in agriculture.

The health-based targets may be achieved through different treatment barriers or health protection measures. The barriers relate to verification monitoring, mainly in large-scale systems, as illustrated in Table 6 for excreta and greywater. Verification monitoring is not applicable to urine. The health-based targets may also relate to operational monitoring, such as storage as an on-site treatment measure or further treatment off-site after collection. This is exemplified for faeces from small-scale systems in Table 7.

For collected urine, storage criteria apply that are derived mainly from compiled risk assessment studies. The information obtained has been converted to operational guidelines to limit the risk to a level below l0-6 DALY, also accounting for additional health protection measures. The operational guidelines are based on source separation of urine (Table 8). In case of heavy faecal cross-contamination, the suggested storage times may be lengthened.
If urine is used as a fertilizer of crops for household consumption only, it can be used directly without storage. The likelihood of household disease transmission that results from the lack of hygiene is much higher than that of transmission through urine applied as a fertilizer.

For all types of treated excreta, additional safety measures apply. These include, for example, a recommended withholding time of one month between the moment of application of the treated excreta as a fertilizer and the time of crop harvest. Based on QMRA, this time period has been shown to result in a probability of infection well below l0-4, which is within the range of a 10-6 DALY level.

	Helminth eggs (number per gram total solids or per litre)	**E coli (number per 100 ml)**
Treated faeces and faecal sludge	< 1/g total solids	< 1000g/total solids
Greywater for use in: • Restricted irrigation	< l/litre	$< 10^5$ [a] Relaxed to $<10^6$ when exposure limited or regrowth is likely
• Unrestricted irrigation of crops eaten raw	< l/litre	$< 10^3$ Relaxed $<10^4$ for high- growing leaf crops or drip irrigation

[a] *These values are acceptable due to the regrowth potential of E. coli and other faecal coliforms in greywater*

Table 6: Guideline values for verification monitoring in large-scale treatment systems of greywater, excreta and faecal sludge for use in agriculture (WHO, 2006).

Treatment	Criteria	Comment
Storage; ambient temperature 2 - 20 °C	1,5 - 2 years	Will eliminate bacterial pathogens; regrowth of *E- coli* und *Salmonella* may need to be considered if rewetted will reduce viruses and parasitic protozoa below risk levels. Some soil-borne ova may persist in low numbers.
Storage; ambient temperature > 20 - 35 °C	> 1 year	protozoa; inactivation of schistosome eggs (< l month); inactivation of nematode (roundworm) eggs, e.g. hookworm (*AncylostomalNecator*) and whipworm (*Trichuris*); survival of a certain percentage (l0-30%) of *Ascaris eggs* (> 4 months), whereas a more or less complete inactivation of *Ascaris eggs* will occur within 1 year
Alkaline treatment	pH > 9 during > 6 months	If temperature >35 °C and moisture <25%, lower pH and/or wetter material will prolong the time for absolute elimination.

[a] *No addition of new material.*

Table 7: Recommendations storage treatment of dry excreta and faecal sludge before use at the household municipal levels[a] *(WHO, 2006)*

3.3 Health protection measures

A variety of health protection measures can be used to reduce health risks for local communities, workers and their families and for the consumers of the fertilized or irrigated products.
Hazards associated with the consumption of excreta-fertilized products include excreta-related pathogens. The risk from infectious diseases is significantly reduced if foods are eaten after proper handling and adequate cooking. The following health protection measures have an impact on product consumers:

- excreta and greywater treatment;
- crop restriction;
- waste application and withholding periods between fertilization and harvest to allow die-off of remaining pathogens;
- hygienic food handling and food preparation practices;
- health and hygiene promotion;
- produce washing, disinfection and cooking.

For all types of treated excreta, additional safety measures apply. These include, for example, a recommended withholding time of one month between the moment of application of the treated excreta as a fertilizer and the time of crop harvest. Based on QMRA this time period has been shown to result in a probability of infection well below l0-4, which is within the range a l0-6 DALY level. Workers and their families may be exposed to excreta-related and vector-borne pathogens (in certain locations) through excreta and greywater use activities. Excreta and greywater treatment is a measure to prevent diseases associated with excreta and greywater but will not directly impact vector-borne diseases. Other health protection rneasures for workers and their families include:

- use of personal protective equipment;
- access to safe drinking-water and sanitation facilities at farms;
- health and hygiene promotion;
- disease vector and intermediate host control:
- reduced vector contact.

Storage temperature (°C)	Storage time (months)	Possible pathogens in the urine mixture after storage	Recommended crops
4 °C	≥ 1	Viruses, protozoa	Food and fodder crops that are to be processed
4 °C	≥ 6	Viruses	Food crops that are to be processed, fodder crops [d]
20 °C	≥ 1	Viruses	Food crops that are to be processed, fodder crops [d]
20 °C	≥ 6	Probably none	All crops [e]

[a], *Urine or urine and water. When diluted, it is assumed that the urine mixture has a pH of at least 8.8 and a nitrogen concentration of at least I g/1.*

[b], *Gram-positive bacteria and spore-forming bacteria are not included in the underlying risk assessments, but are not normally recognized as a cause of any infections of concern.*

[c], *A larger system in this case is a system where the urine mixture is used to fertilize crops that will be consumed by individuals other than members of the household from whom tie urine was collected.*

[d], *Not grasslands for production of fodder.*

[e], *For food crops that are consumed raw, it is recommended that the urine be applied at least one month before harvesting and that it be incorporated into the ground if the edible parts grow above the soil surface.*

Table 8: Recommended storage times for urine mixture [a] based on estimated pathogen content [b] and recommended crops for larger systems [c] (WHO, 2006)

Local communities are at risk from the same hazards as workers. If they do not have access to safe drinking-water, they may use contaminated irrigation water for drinking or for domestic purposes. Children may also play or swim in the contaminated water. Similarly, if the activities result in increased vector breeding, then vector-borne diseases can affect local communities, even if they do not have direct access to the fields. To reduce health hazards, the following health protection measures for local communities may be used:

- excreta and greywater treatment;
- limited contact during handling and controlled access to fields;
- access to safe drinking-water and sanitation facilities in local communities;
- health and hygiene promotion;
- disease vector and intermediate host control:
- reduced vector contact.

3.4 Other aspects

3.4.1 Monitoring and system assessment

Monitoring has three different purposes: *validation*, or proving that the system is capable of meeting its design requirements; *operational monitoring*, which provides information regarding the functioning of individual components of the health protection measures; and *verification*, which usually takes place at the end of the process to ensure that the system is achieving the specified targets. The three functions of monitoring are each used for different purposes at different times. *Validation* is performed when a new system is developed or when new processes are added and is used to test or prove that the system is capable of meeting the specified targets. *Operational monitoring* is used on a routine basis to indicate that processes are working as expected. Monitoring of this type relies on simple measurements that can be read quickly so that decisions can be made in time to remedy a problem. *Verification* is used to show that the end product (e.g. treated excreta or greywater; crops) meets treatment targets and ultimately the health-based targets. Information from verification monitoring is collected periodically and thus would arrive too late to allow managers to make decisions to prevent a hazard break-through. However, verification monitoring in larger systems can indicate trends over time (e.g. if the efficiency of a specific process was improving or decreasing). The most effective means of consistently ensuring safety in the agricultural use of excreta and greywater is through the use of a comprehensive risk assessment and risk management approach that encompasses all steps in the process from waste generation to treatment, use of excreta as fertilizers or use of greywater for irrigation purposes and product use or consumption. Three components of this approach are important for achieving the health-based targets: system assessment, identifying control measures and methods for monitoring them and developing a management plan.

3.4.2 Socio-cultural aspects

Human behavioural patterns are a key determining factor in the transmission of excreta-related diseases. The social feasibility of changing certain behavioural patterns in order to introduce excreta or greywater use schemes or to reduce disease transmission in existing schemes needs to be assessed an individual project basis. Cultural beliefs and public perceptions of excreta and greywater use vary so widely in different parts of the world that one cannot assume that any of the local practices that have evolved in relation to such use can be readily transferred elsewhere. Even when projects are technically well planned and all of the relevant health protection measures have been included, they can fail if cultural beliefs and public perceptions have not been adequately accounted for.

3.4.3 Environmental aspects

Excreta are an important source of nutrients for many farmers. The direct use of excreta and greywater on arable land tends to minimize the environmental impact in both the local and global context. Reuse of excreta on arable land secures valuable fertilizers for crop production and limits the negative impact on water bodies. The environmental impact of different sanitation systems can be measured in terms of the conservation and use of natural resources, discharges to water bodies, air emissions and the impacts on soils. In this type of assessment, source separation and household-centred use systems frequently score more favourably than conventional systems.

Application of excreta and greywater to agricultural land will reduce the direct impacts on water bodies. As for any type of fertilizer, however, the nutrients may percolate into the groundwater if applied in excess or flushed into the surface water after excessive rainfall. This impact will always be less than that of the direct use of water bodies as the primary recipient of excreta and greywater. Surface water bodies are affected by agricultural drainage and runoff. Impacts depend on the type of water body (rivers, agricultural channels, lakes or dams) and their use, as well as the hydraulic retention time and the function it performs within the ecosystem.

Phosphorus is an essential element for plant growth, and external phosphorus from mined phosphate is usually supplied in agriculture in order to increase plant productivity. World supplies of accessible mined phosphate are diminishing. Approximately 25% of the mined phosphorus ends up in aquatic environments or is buried in landfills or other sinks. This discharge into aquatic environments is damaging, as it causes eutrophication of water bodies. Urine alone contains more than 50% of the phosphorus excreted by humans. Thus, the diversion and use of urine in agriculture can aid crop production and reduce the costs of and need for advanced wastewater treatment processes to remove phosphorus from the treated effluents.

4 | Summary

In household wastewater, urine contains considerably large amount of nutrients derived from agriculture whereas faeces contain most of the pathogens with a potential of causing diseases. Therefore, source control of faeces from household wastewater prevents these disease-causing pathogens gaining access to water bodies where they survive longer than on land and pose a long-term threat to human health. At the same time, by separating urine large concentration of nutrients can be recovered with low contamination of pathogens which pose little hygienic risk. It is most beneficial when faeces are kept separated at source which avoids dilution. With the development of ecological sanitation it is possible to separate faeces and urine at source. Urine diverting toilets are suitable technologies for source control. The toilet has two bowls, a front one for urine and a rear one for faeces. Urine is piped separately to the collection tank, from where the urine mixture is transported to the storage tank and kept long enough to be sanitised and reused in agriculture. For sanitisation of urine, it is recommended to store it for 6 months at 20 °C and can be reused for all crops. The guidelines released by WHO in 2006 are:
If urine is used on crops that are to be commercially processed e.g. cereal crops, the risk for infection after at least one month of storage through food consumption is negligible. Urine collected from single households is recommended for all type of crops if the crop is intended for the household's own consumption.

Risk can be minimised by introducing other safety barriers beside storage temperature and time. Protection and awareness of risks are important for that. For example, the risk for accidental ingestion can be eliminated, if the people handling the urine will wear gloves and mouth protection. Using suitable fertilising techniques and working the urine into the soil as well as letting some time pass between fertilisation and harvesting will decrease the exposure humans and animals to potential pathogens

The elimination of pathogens in faeces is a more complex issue than in urine. The mostly applied methods for sanitisation of separated faeces are composting and dehydration. Treatment method based on dehydration can reduce pathogens effectively because there is a rapid pathogen destruction at moisture content below 25 %. Composting of a sufficient amount of fresh and easily degradable organic materials can produce heat which raises the temperature of the materials. At the temperature of 55 °C, most of the pathogens are destroyed in some days. Low temperature composting takes long time to kill the pathogens. The rate of reduction of pathogens is significantly dependant on time and temperature. The higher the temperature of the materials, the shorter the time for destroying the pathogens and vice versa. The factors such as high pH, competition for food, antibiotic action and the toxic by-products of decomposing organism play a significant role in eliminating or reducing pathogens.

WHO names two possibilities to sanitize faeces, that is storage and alkaline treatment. The recommendations are different for household municipal levels and larger systems.
In case of household level, the storage time should be more than 1 year above 20°C and up to 2 years temperature 2-20°C. Below 2°C, there is no recommendation. However, the storage time is supposed to be further increased. The alkaline treatment is required to last more than 6 months at pH > 9 and additionally temperature > 35°C as well as moisture < 25%.
For larger systems, WHO gives guideline values for verification monitoring of treatment systems of greywater, excreta and faecal sludge. It is required to meet < 1/g

total solids helminth eggs and < 1000 g/total solids E.coli in treated faeces. For greywater it is < 1/litre helminth eggs and <105 and 103 per 100 ml E.coli for restricted and unrestricted irrigation, respectively.

Guidelines for the use of bio solids in agriculture like the Council of the European Communities Directive No. 86/278/EEC, provide standards for heavy metal concentrations in soil, in sludge and maximum annual quantities of heavy metals that can be introduced into the soil. However in ecological sanitation, heavy metals are not a big concern, since human excreta contain approximately the same amount of heavy metals as food and therefore there is no risk of heavy metal accumulation in soil due to these fertilisers. However, the issue of pharmaceutical residues in excreta has to be addressed.

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