



Appropriate De-central Wastewater Technologies for Low Income Regions

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ABSTRACT

For low income, rural and semi-urban region sanitation systems based on sewerage and centralised wastewater treatment plants are not appropriate due to the high costs for construction and maintenance. In addition, valuable nutrients are diluted and wasted to the environment resulting in unwanted pollution. Particularly in developing countries many farmers do not have access to mineral fertilisers with the negative effect of low income and consequently migration to cities. Therefore, alternative approaches are tested and improved based on the separation of toilet waste from other parts of wastewater. Dry sanitation, vermi-composting in compost chambers and anaerobic digestion of toilet and kitchen waste have turned out to be very promising approaches. Finally the treatment of the remaining greywater, which is the wastewater from kitchens and bathrooms, in constructed wetlands is discussed in this paper.

INTRODUCTION

The fundamental idea of integrated water concepts is based on the principle of separating the different flows of domestic wastewater according to their characteristics. The yearly consumption of water per person (not including water for food production) is about 50 m³, while only 0.5 m³ of urine and faeces are produced. Human excreta contain the main part of nutrients and hazardous substances. If the urine and faeces are collected separately, an appropriate treatment and the reuse of nutrients and soil

conditioners are possible. In rural and semi-urban areas with a direct link to agriculture an on-site treatment is also an economic option, because the construction of a costly sewerage system can be prevented. For this purpose some options are discussed. To find a decision about the most appropriate sanitation system, cultural, social and economic conditions have to be taken into consideration. The awareness of hygiene and sanitation has to be strengthened by train the participating people in school and by public campaigns (TV, newspapers, roadside billboards).

DRY SANITATION

The most obvious way is to separate greywater from toilet waste. The treatment of greywater is described beneath. If the water use for toilet purpose is minimised, the amount of waste to treat is also minimised. To reach this the dry sanitation is a good option. Two types of dry sanitation facilities are developed: compost toilets and desiccation toilets. Composting toilets need a strong participation of users, because the composting process requires a narrow range of moisture and an oxygen supply due to addition of biowaste and/or structural material. Additionally a high strength leakage has to be treated. Therefore, desiccation toilets have a greater potential, when operated properly. To avoid moisture, diversion of urine and where required a separate washing place (wet anal cleaning) are favourable.

Facilities for urine diversion are known for long time (see **Figure 1**), but these traditional methods are lacking user acceptance, comfort and hygiene. To divert urine from males, waterless urinals were developed and often used especially for public toilets (see **Figure 2**).

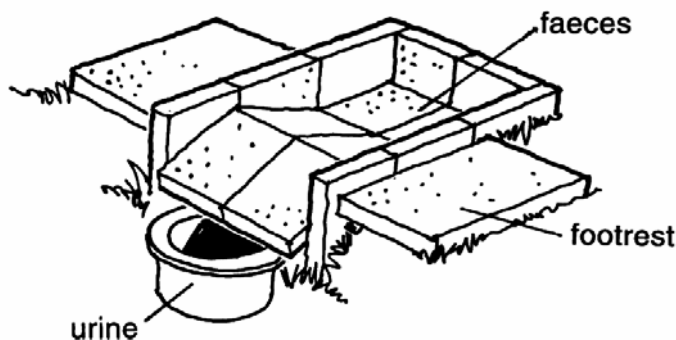


Figure 1. Urine diverting toilet from Vietnam (Esrey et al. 1998)



Figure 2. Waterless Urinal.

The main risk with handling human excreta is provoked by the faeces due to pathogenic germs. One important duty of sanitation is to make the faecal material safe for the toilet users, operators and finally for reuse in agriculture. The principle of reaching this is to get and keep the faecal material dry. Hence dry toilets were constructed

- above soil (to prevent water contact due to flooding, rainfall etc.),
- with two chambers (one chamber is used while the faecal material in the second chamber can dry completely before removed by an operator) and
- with urine diversion (urine is rich in nutrients and can be used directly for fertilising fields (after storage)).

In **figure 3** a urine diverting dry toilet with seat is shown and in **figure 4** a corresponding squatting toilet. On the right side in both photographs the hole for the second chamber is covered. To enhance the drying process and to avoid unpleasant odour, dry material as sawdust, ash or compost can added. In China even lime is used for this purpose.



Figure 3. Urine diverting dry toilet from Ukraine



Figure 4. Urine diverting squatting dry toilet from Ukraine

Construction details are shown in **figure 5**, and a photograph in **figure 6** displays an example for a toilet in a public primary school in Romania. This kind of toilet consists of a toilet room with a seat riser or slab for urine diversion. For each toilet there are two easily accessible faeces chambers with a sealed floor made from concrete. The vaults are designed such that one vault is in use for at least 1 year, then allowed to rest for another year while the other chamber is used. Ventilation pipes are installed from the faeces-chambers to above the roof to supply the vault with oxygen and avoid odour and flies.

The urine from the urine diverting toilets and the waterless urinals is collected in one or two urine tanks. The two tanks, similar to the faeces chambers, are necessary for the resting time in which many pathogens are killed or at least reduced. The urine from

private households can be collected in small canisters and used directly in the garden to fertilise the plants. Only during winter the plants cannot take up the nutrients, therefore the urine should be stored until spring. The urine-pipe is conducted to the bottom of the tank to avoid ammonia stripping and thus bad odour and nitrogen-losses when fresh urine is fed into the tank.

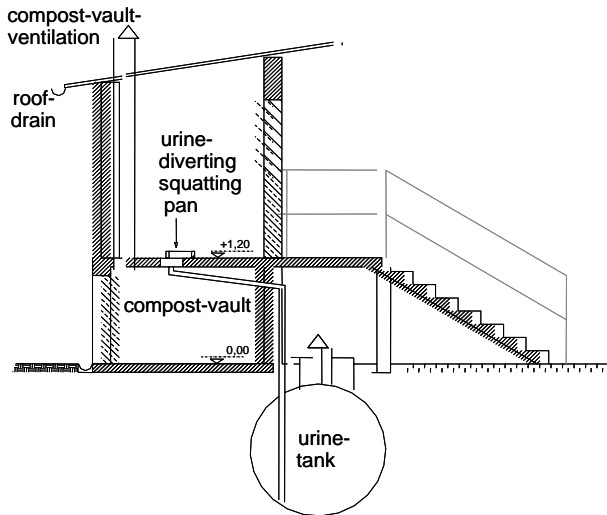


Figure 5. Urine diverting dry toilet cross section



Figure 6. Photograph of a urine diverting dry school toilet

The investigation in Romania has indicated that the stored urine is nutrient rich and very poor in pathogens. A double chamber urine storage tank is shown in **figure 7**. Test with plants has also shown the fertilising impact that is comparable with mineral fertilisers (Simons & Clemens 2003). The stored urine was applied to fields and gardens where tomatoes, corn, and aubergines will be grown using 1 l Urine/ m² (equals 50 kg N/ ha) undiluted four weeks before the planting season began (see **figure 8**). The urine should be used very carefully, e.g. not on edible plants that are consumed raw until more information about the health-risks are available (Vinnerås, 2003).





Figure 7. Double chamber urine tank

Figure 8. Urine application in agriculture

COMPOSTING CHAMBER AND VERMI COMPOSTING

For many people the access to water flushing toilets is a desirable ambition. This is not to neglect, because the participation of the toilet users is obligatory for the success of a sanitation concept. In any case the separation of toilet waste from wastewater is required to avoid the pollution of surrounding water bodies and/or the groundwater. The diversion of urine is also helpful to extract fertiliser from toilet waste. Therefore urine diverting flushing toilets can be used (see **figure 9**).

Compared to other flows of domestic wastewater, faeces represent a very small quantity and are very rich in organic material as well as nutrients like phosphorus and potassium which are very valuable to the soil. But before applying this material to the soil, it has to be treated to assure sanitisation as well as transforming the nutrients into forms which are readily available to the plants.

Composting chamber systems consist usually of an underground monolithic concrete tank having two filter beds at its bottom or two filter bags (pore size of 1 - 2 mm and made from non-biodegradable material) that are hung side by side and used alternately in intervals of 6-12 months (see **figure 10** and **figure 11**). The influent is discharged into one of the two filter beds or bags, respectively retaining solid materials while draining the liquid. The principal role of the filter medium (filter bed or bag) is to achieve an efficient 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 fresh solid material on its surface.



Figure 9. Urine diverting flush toilet (Foto: Otterpohl)

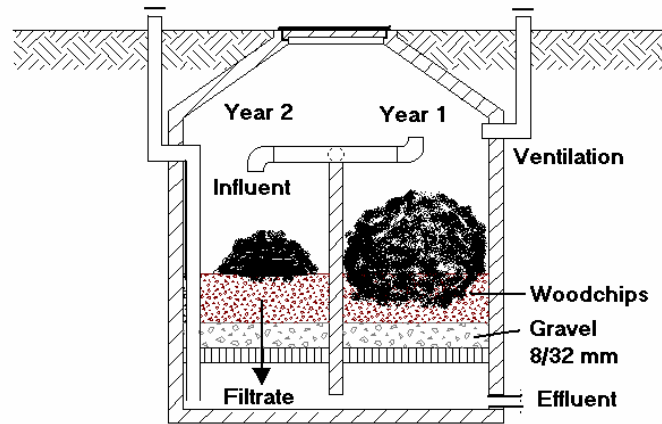


Figure 10. Schematic view of a composting chamber system

The filtrate that is collected at the bottom of the composting chamber needs further treatment. The solid materials, which are retained in the filter medium, are biodegradable and during the silent phase (the filled one is left in a silent phase for degradation) decomposition takes place. Because of the degradation, the volume of the material in the filter bag or bed, respectively will be reduced. The degradation is quite slow due to the high water content of the faecal material. If structural material for the improvement of oxygen penetration is not added in a sufficient amount, the admixture of earth worm for vermin composting is a good option to improve the process.



Figure 11. Photograph of a composting chamber system



Figure 12. Photograph of vermi-composting faecal material from a composting chamber after 15 weeks using earth worms

Vermicomposting can be used to treat human excreta (Shalabi et al. 2006) as well as sludge from wastewater treatment plants (Bajsa *et al.* 2004). The concept of

vermicomposting started from the knowledge that certain species of earthworms grow and consume organic residues very rapidly, converting them into earth-like, soil building substance that forms a beneficial growing environment for plant roots (Aranda *et al.* 1999). The action of the earthworms in this process is both, mechanical and biochemical. The mechanical processes include: substrate aeration, mixing as well as grinding. These mechanical unit processes realised in a technical way usually represent the largest cost associated with a traditional microbial composting process. Vermicomposting, therefore saves all these unit operations (Ndegwa *et al.* 2000). The biochemical process is affected by microbial decomposition of the substrate in the intestines of the earthworms. Good degradation was achieved under following conditions:

- Water content: 70-85%.
- C/N ratio: 20-25.
- Temperature: 20-28°C.
- pH: 6.5-7.5.

ANAEROBIC TREATMENT

In rural areas particularly in Asia and in some African countries anaerobic treatment of toilet waste and additionally manure and kitchen waste is commonly applied for waste treatment. Different types of biogas digesters exist, such as floating-drum plants or fixed-dome plants. Where good masonry work is available to ensure that no biogas is lost due to cracks in the brickwork, fixed-dome digesters can be recommended since no moving parts or parts susceptible to rusting are needed. These fixed-dome plants consist of a digester which is completely constructed in the ground and a gasholder that is placed at the top of the digester (see **figure 13** and **figure 14**). The gas pressure which increases with the volume of stored gas displaces the liquid slurry into the compensation tank. **Figure 15** shows a photograph of a digester in Vietnam and **figure 16** the use of biogas for cooking and lighting.

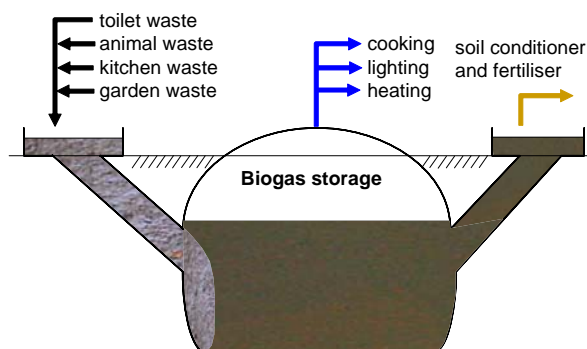


Figure 13. Scheme of a digester for



Figure 14. Photograph of the building phase

anaerobic (toilet)waste treatment

of a digester (www.borda.de)

Organic matter is converted into biogas (about 40-70% CH₄), which can then be used to replace non-renewable or non-sustainable energy sources such as firewood. Appliances for cooking and lighting and even engines can easily be modified for the use of biogas. With a properly working digester and a sufficient retention time of about 15 to 30 days, organic matter in the wastewater is degraded, whereas plant nutrients (N, P, K) remain in the slurry. Pathogens are reduced to some extent, although only little information about treatment performance and effluent quality is available to date. The slurry can be used as a soil conditioner and fertilizer on agricultural fields. Storage and transport of slurry might be a drawback of the system, however. The slurry can be either used as liquid fertilizer or separated into a solid and liquid part with further composting of the solid fraction. Slurry application to fields is easiest in cases where the digesters are located close to agricultural land.



Figure 15. Photograph of digester in operation in Vietnam



Figure 16. The use of biogas for cooking and lighting

According to Kossmann et al. (1999) costs for a biogas plant including all necessary installations amount to about 50-75 US\$ per m³ capacity, of which about 30-45% are costs for the digester. However, the investment costs can be reduced if the construction can be made locally. There is no need of expensive devices and operation and maintenance can be usually done by the users. Since the size of the digester directly depends on the volume of substrate, wastewater should not be diluted too much in order to keep construction costs small. This can be achieved, for example, by using low-flush toilets.

In order to make the construction of a biogas digester economical, it should be considered to combine several households to one digester and/or to combine the



treatment of human excreta with the treatment of animal manure and biowaste. Biogas technology is particularly promising in areas with stable livestock husbandry and where there is a high demand for alternative energy sources and fertiliser.

GREYWATER TREATMENT WITH CONSTRUCTED WETLANDS

The requirements for the treatment of greywater are lower than for the treatment of municipal wastewater, because a nutrient removal is not essential. Therefore, only COD removal is required. For de-central treatment many options can be taken into consideration:

- Small scale wastewater treatment plant (activated sludge process with membrane separation of biomass, biofilter, trickling filter, rotating disc contactor
- Constructed wetlands
- Pond systems

In this paper the treatment with constructed wetlands is discussed, as they are an appropriate technology for small communities in rural and suburban areas. Many rural projects with activated sludge plants failed because these were not properly operated, since often no skilled staff is available or the energy costs are no longer affordable. Pond systems have a large area requirement and their effect on vector reproduction is not yet clear. Constructed wetlands are principally using the same natural degradation processes and nutrient uptake but they are acting as extensive systems. There is wide acceptance and interest because of the following advantages (SWAMP 2002):

- Simple in construction, operation and maintenance
- Low operation and maintenance costs (low energy demand)
- High ability to tolerate fluctuations in flow
- High process stability
- Aesthetic appearance

This system can be divided into two types: the free-water surface type (FWS) in which the water level is over the surface, and the subsurface type (SF), in which the water level is maintained below the surface. The latter one can be further categorized into two types based on the pattern of flow, one with horizontal subsurface (HSF) and one with vertical subsurface flow (VSF) (Crites, et. al., 2000). The SF type is also called “reed bed” and has advantages in lower water evaporation and better vector control. The VSF system, illustrated in more detail in [fig. 17](#) and [fig. 18](#), needs a well designed and constructed system to distribute the water equally over the whole area. The construction is therefore more expensive than for the horizontal flow systems. For VSF, **filtration** is also an important removal mechanism. The bed medium must be carefully chosen according to the wastewater constitution.

The water level is always at the bottom. Its best performance can be achieved by **intermittent feeding** when aerobic and anoxic phases alternate. Due to the higher effort in designing and constructing the VF properly, the performance of these systems in term of COD and nitrification is much higher than the performance of other constructed wetland systems.

Figure 19 and **figure 20** show the construction phase of a constructed wetland. Above a foil-sealing the drainage tubes for the treated water are located. These tubes are protected by a gravel 2/8 layer of 20 cm. The filter bed consists of sand (0/4) of 80 cm and the distribution tubes are covered with gravel 8/16 to ensure an equal distribution of the inflow and to avoid ponding. The required surface for the constructed wetland is about 1 m²/PE for greywater treatment. The storage tank for the intermittent feeding should be designed for 30 mm per feed and 3 feeds per day.

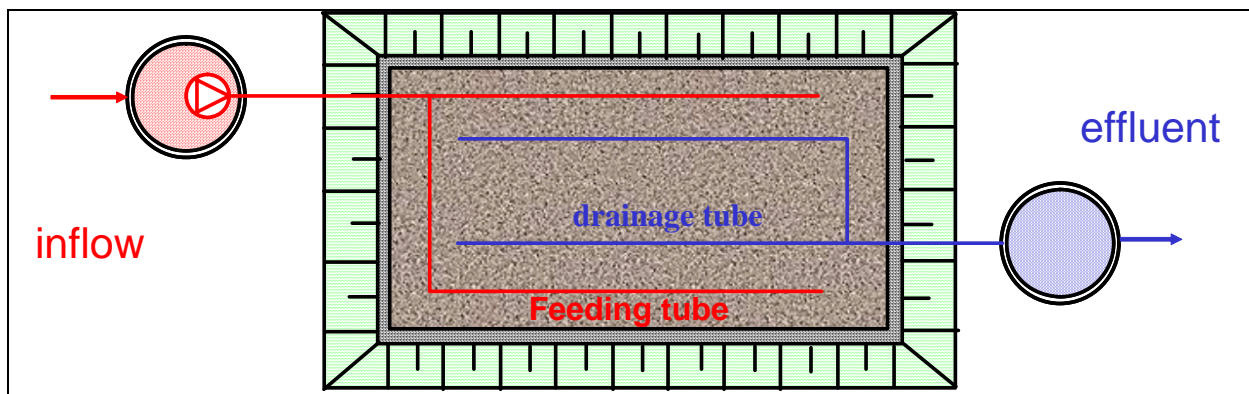


Figure 17. Topview scheme of a vertical flow constructed wetland

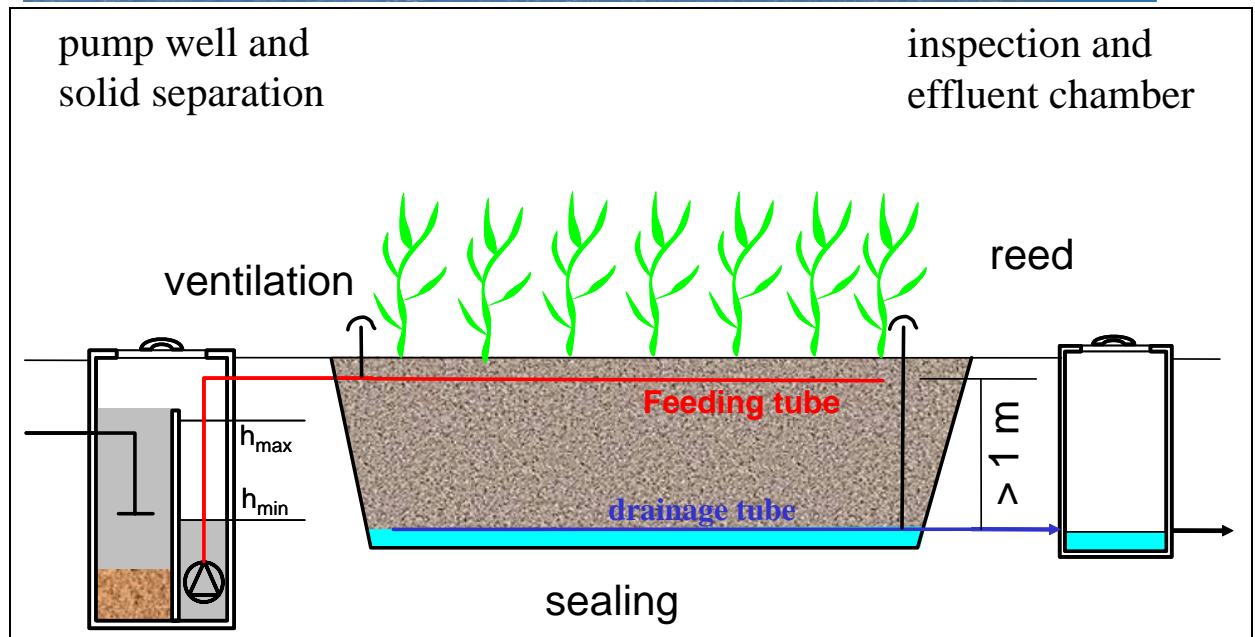


Figure 18. Section scheme of a vertical flow constructed wetland



Figure 19. Sealing and drainage of a constructed wetland



Figure 20. Water distribution system of a constructed wetland



Figure 21. Photograph of a constructed wetland

Table 1. Concentration of influent and effluent of a VSF-constructed wetland (<http://www2.gtz.de>)

component	inflow [g/m ³]	outflow [g/m ³]
COD	502	59
BOD	194	14
N-total	12	2,7
NH ₄ -N	4,5	0,9
P-total *	8	5,7
PO ₄ -P *	7,6	4,8

* relative high P-concentration due to detergents for automatic dishwashers

Figure 21 shows a photograph of a constructed wetland ready for operation planted with reed. The rhizomes of the reeds grow vertically and horizontally, opening up the soil to provide a hydraulic pathway through the media. The most frequently used plant species are *Scirpus* sp. (bulrush), *Typha* sp. (cattail), and *Phragmites communis* (reeds). Without planting anything naturally some local plants will grow with a negative effect on the appearance of the constructed wetland. **Table 1** illustrates the good treatment efficiency of a VF constructed wetland that facilitates the agricultural reuse.

CONCLUSION

Many alternative options for wastewater treatment are developed that can be implemented in rural areas for appropriate prices. These processes allow a save recovery of nutrients from human waste and also a reuse of water for agriculture and horticulture. But all these procedures require perfect maintenance and participation of the users. Additionally the treatment of greywater with natural process requires space.

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