dr.ir. G. Zeeman

Centralised or decentralised sanitation chains?

Grietje Zeeman
Wageningen University

Nieuwe Uitdagingen

1. Introduction

Household waste water was until recently almost exclusively considered as a hygienic risky, polluting stream, which should be removed and treated as far as possible from the production site. The application of central, water-based, transport and treatment systems was a logical consequence.

The same stream may however be regarded as a source of raw materials, such as energy, fertilizer and water, which can be used locally. With a growing demand for renewable energy and decreasing availability of raw materials such as phosphate (Driver, 1999) and (depending on the location) of water, domestic (waste)water is increasingly recognized as a source of raw materials.

For an efficient recovery of resources often alternative collection (toilet), transport and treatment systems are needed. Separation at source and prevention of dilution of concentrated flows are leading when selecting such systems. The answer to the question, 'centralised or decentralised sanitation' is on one side inspired by the optimal scale of the collection and transport system, on the other side by, location-dependent, usage of the sanitation products. Wortmann (2008) introduces the term 'New Utilities', which are based on a local balance between supply and demand, with maximum use of local sustainable resources. 'New Utilities' take a position, in between central (macro) and individual (micro) systems (Figure 1). On this decentralised (meso) level, local resources utilization is encouraged and supply and demand can be aligned.

As an example of such a 'New Utility the DeSaR, Decentralised Sanitation and Reuse project in Sneek (Zeeman et al., 2008) is mentioned, in which black water of a community of 32 houses provides energy and nutrients to be reused. In the 'Zonneterp' concept (Figure, 2, Mels, et al, 2006), DeSaR is combined with green houses, together achieving a large extent of autarky (Wortmann, 2008).

Central in the 'Zonneterp' concept, is a greenhouse in which solar heat is harvested and used in the neighbourhood. At the other hand fertilizers present in domestic waste streams are recovered and used for cultivation of plants in the greenhouse. The concept results in maximum recovery and reuse of local resources.

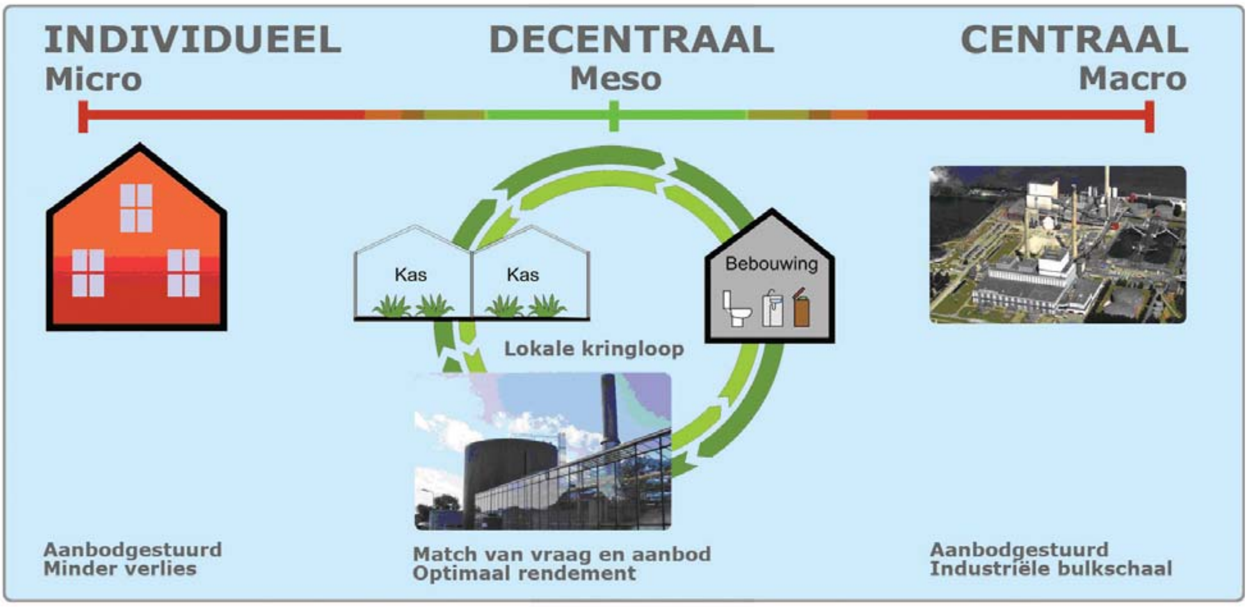

Figure 1 - The scale of 'New Utilities' taking a position in between central (macro) and individual (micro) systems (Wortmann (2008).

In addition to the preservation and recovery of raw materials, removal of micro pollutants, in particular pharmaceutical residues and hormones and pathogens from domestic wastewater becomes increasingly important when considering application of local sanitation concepts. In decentralised, on separation at source-based sanitation concepts, these micro pollutants and pathogens remain in a limited volume, which facilitates the removal. Hospitals and other institutions with an increased concentration of (specific) pharmaceutical residues and pathogens become more and more interested in a resource-oriented approach. This paper addresses a number of sanitation concepts, with varying degree of source separation.

2. Composition of domestic wastewater streams

The distribution of pollutants, especially nitrogen, phosphorus and potassium (N, P, K), among the different waste(water) sub-streams produced in households, demands upon source separation. In source-separation based sanitation concepts wastewater streams are separated according to their degree and type of pollution and reuse potential of resources. Different degrees of separation can be applied. Generally three types of wastewater streams are distinguished: black water, grey water and rain water (Figure 3). Black water is a mixture of feces, urine and flush water. A large fraction of the main components of domestic wastewater, viz. organics, nutrients
(nitrogen, phosphorus, potassium), pathogens, pharmaceuticals residues and hormones are originally present in a very small volume of feces and urine. The concentration of black water can be influenced by choice of a collection system (toilet). Grey water is a voluminous stream characterized by lower concentrations (and even absence) of some components in comparison with black water. It consists of several sub-streams each having its own characteristics (Figure 4).
Some of these sub-streams are lightly polluted –bath and wash water (light grey water, Henze and Ledin 2001); others – especially kitchen wastewater carry a significant pollution load.

Water usage per activity in average Dutch household leading to generation of a specific wastewater stream (NIPO/VEWIN 2002). Similar water consumption and distribution per household activity was measured in other EU countries (EEA 2001). In general drinking water consumption will vary depending on geographic location. To give some examples in US daily indoor consumption of water

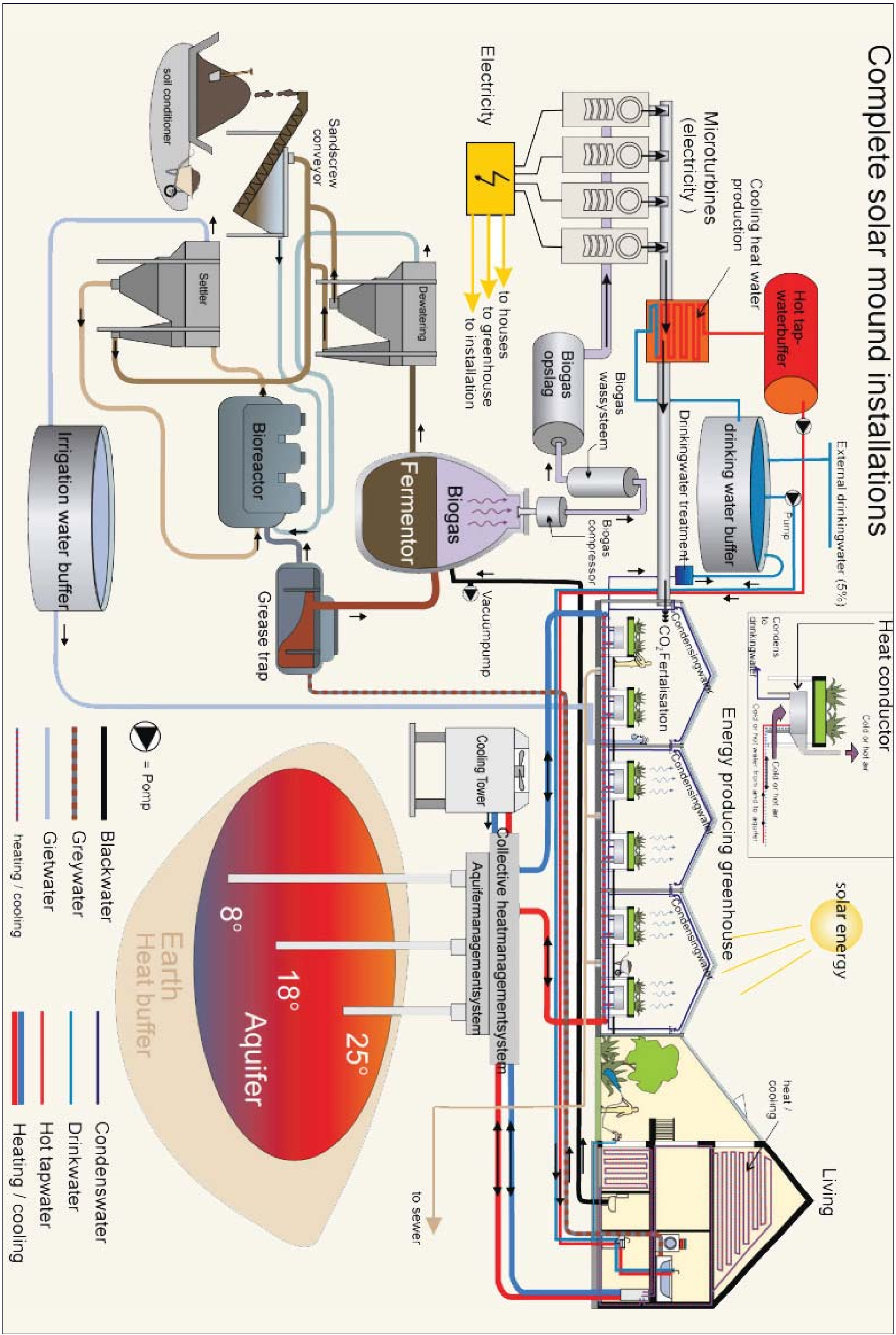

Figure 2 - Technical lay-out of Zonneterp (Greenhouse Village) (Mels, et al, 2006).

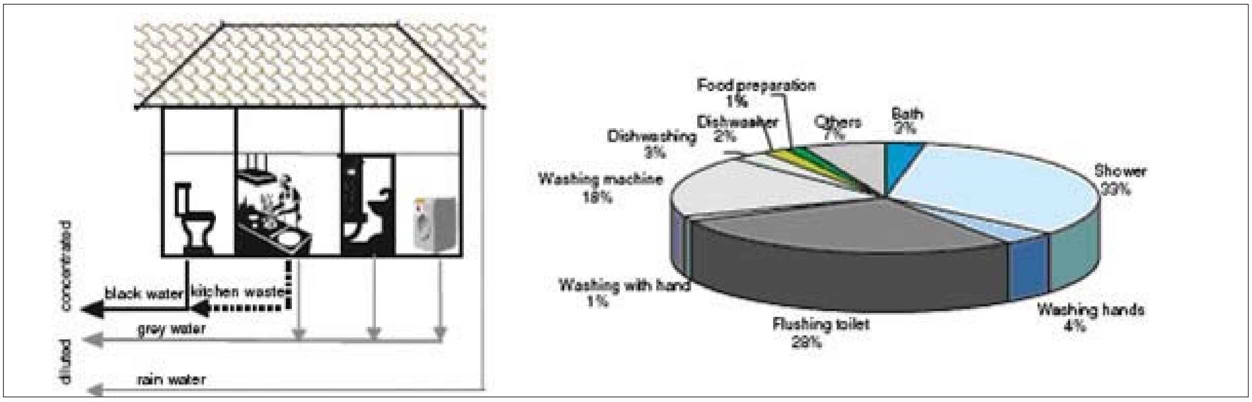

Figure 3 - General types of wastewater streams from household (Kujawa-Roeleveld & Zeeman, 2006).

is around 280 L capita)1 day)1 (AWWA 2005), in Europe around 140 (EEA 2001) and in sub-Saharan Africa 52 L capita)1 day)1 (IFPRI 2002).

Most of the nutrients present in domestic wastewater originate from feces and urine.
By diverting black water plus kitchen waste from grey water, 80–95% of the nutrients from households can be recovered (Figure 4). In a healthy adult, the amounts of nutrients are in equilibrium within the body. All the nutrients consumed are excreted; normally via the urine or via the feces (Guyton 1992). The nutrient content in urine and feces will vary depending on the food intake, e.g. on protein intake (Drangert 2000; Jönsson et al. 2000).

3. *Sanitation concepts*

Several authors stress the importance of development of sanitation concepts based on separation at source, to enable possibilities of recovery and reuse of water and resources. The collection, transport and treatment methods for feces and urine (black water) are strongly interrelated and finally determine the possibilities of recovery and reuse of resources like energy, nutrients, compost and energy. Alternatives to be discussed when choosing/ developing a sanitation concept, are the degree of separation, viz. black and grey water or brown (only feces), yellow (urine) and grey water, the maximum allowable dilution, especially of feces and urine, full or partial decentralization and house-on-site or community-on-site treatment. A lower degree of

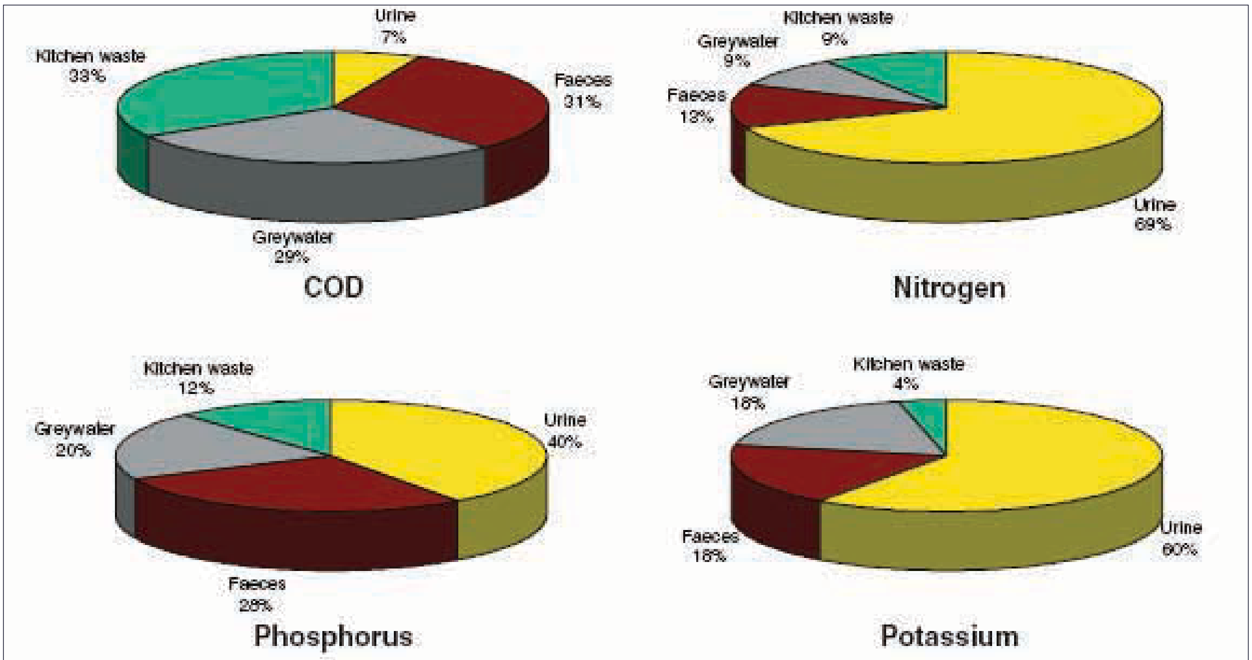

Figure 4 - Distribution of organic matter (COD) and nutrients (N,P,K) over major groups of domestic (waste)water streams (Kujawa-Roeleveld & Zeeman, 2006).

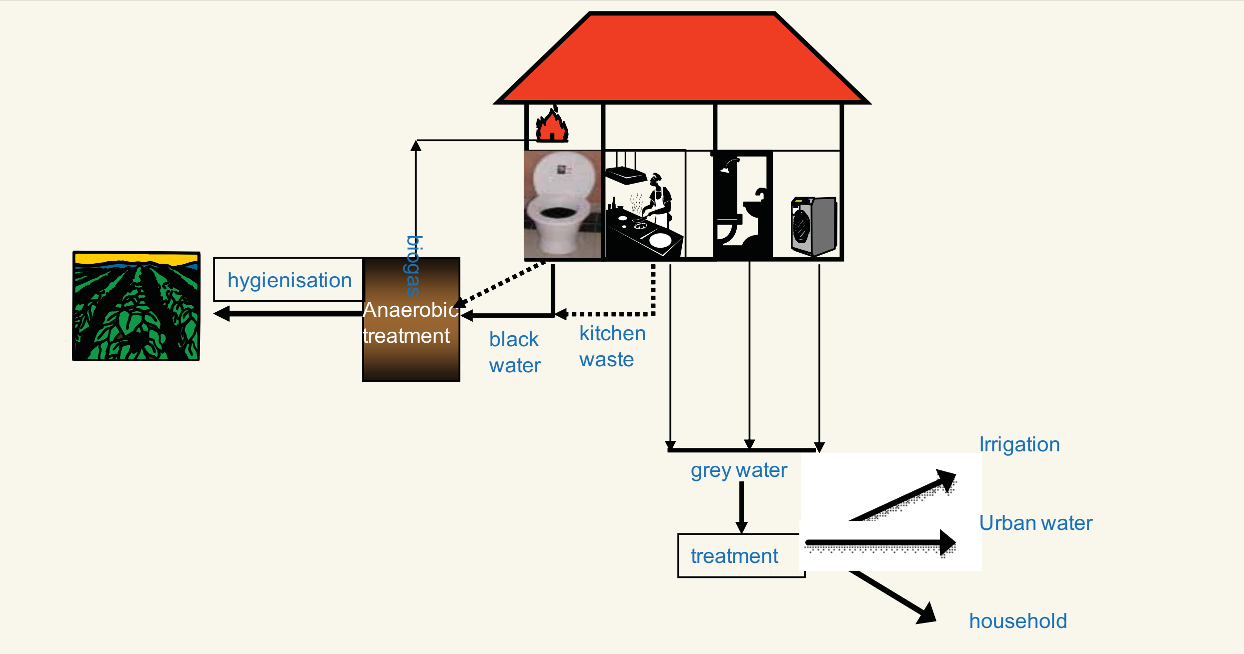

Figure 5 - Decentralized sanitation and reuse concepts with black waste(water) separation from grey water, making use of anaerobic digestion (Zeeman & Kujawa, 2008).

dilution of feces and urine will facilitate the optimal recovery of energy and nutrients and removal of micro-pollutants and pathogens.

Otterpohl (2008) distinguishes 3 main lines in nowadays applied and developing sanitation concepts based on source separation, viz.

- Separation of Black- and Grey- water making use of vacuum black water collection and transport connected to biogas-Systems;
- Dry sanitation / Low Cost solutions
- Urine-Diversion with flush sanitation in combination with existing sewerage.

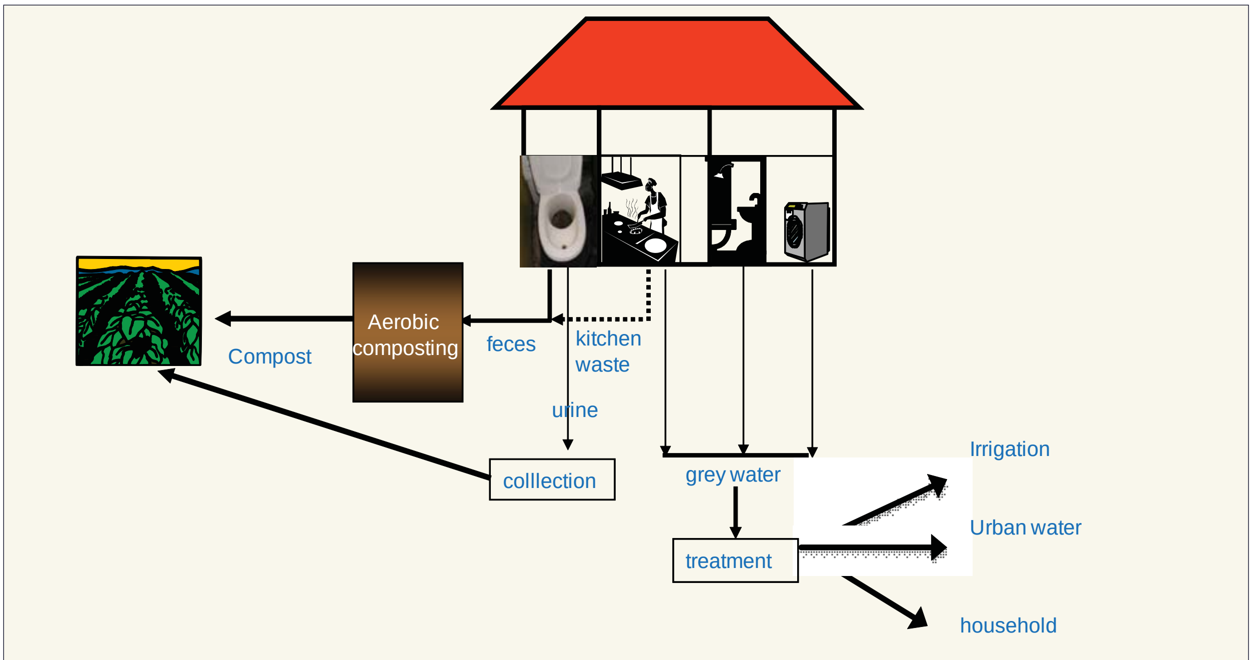

Figure 6 - Decentralized sanitation and reuse concepts with black waste(water) separation from grey water, making use of aerobic composting (Zeeman & Kujawa, 2008).

Figure 7 - Anaerobic treatment of black waste(water) in The Netherlands , 32 houses (Meulman, Landustrie BV).

Figure 8 - Anaerobic treatment of black waste(water) in Tanzania, family.

Figure 9 - Anaerobic treatment of black waste(water) in Tanzania, family.

4. Concepts with separation of black water

Maximal advantage of the reuse potential can be achieved at black water collection with a minimal amount of water. The more the black water is diluted, the more volume there is to be treated, stored, transported and spread on the fields for the same nutritional value. The complexity of the treatment will highly depend on the possibility to directly reuse treated nutrient rich liquid streams and sludge. Decentralization enables reuse of treated streams in for example urban agriculture. For low temperature countries, where application of fertilizers is not allowed in winter, more severe/advanced treatment for recovery of nutrients, or long term storage is demanded. For primary treatment of black water two major techniques can be considered, viz. anaerobic treatment for production of biogas and aerobic composting (composting toilets) (Figure 5 and 6).

While anaerobic treatment of black waste(water) has the major advantage of the production of biogas, which can be used for energy production, composting toilets provide, when well operated, a

Figure 10 - Anaerobic treatment of black waste(water) in Tanzania, family.

stabilized, dry, safe compost for agricultural use. The final choice of the concept will strongly depend on local needs, circumstances and habits. Social and cultural aspects play here an essential role. Vulnerability for a too high water (including urine) content, can be seen as the major disadvantage of composting toilets (Zeeman & Kujawa, 2008). According to Otterpohl (2008) composting toilets are applicable in rural areas but are not really ready for 'the very large scale'. Development of breakthrough technology that works in Hamburg and Addis Ababa is needed (Otterpohl, 2008).

Anaerobic treatment is especially suited for community on-site application as biogas use is favored, though house-on-site application is also applicable (Figure 7 to 10). Transport of concentrated black waste(water) is a point of attention. In Europe vacuum collection and transport is successfully demonstrated at a number of locations (Otterpohl, 1997, Zeeman et al. 2008). In Sneek (the Netherlands; Figure 7) the first treatment system, including nutrient recovery/removal, for black water, collected and transported with vacuum, has been demonstrated for 32 houses (www.themas.stowa.nl).

For developing countries vacuum collection and transport systems might technically become too complex. For highly populated areas, like slumps, central toilet blocks combined with anaerobic treatment systems for energy and nutrient recovery represent a very interesting concept and have been already applied at some locations (Figures 11 to 14).

Figure 11 - The SPARC-style sanitation block in Gatwekera village in Kibera, Nairobi.

Figure 12 - The SPARC-style sanitation block in Gatwekera village in Kibera, Nairobi, managed by the community women (Photograph courtesy of Rob Clarke, Halcrow/Water and Sanitation for the Urban Poor).

Figure 13 - The SPARC-style sanitation block in Gatwekera village in Kibera, Nairobi.

Figure 14 - The SPARC-style sanitation block in Gatwekera village in Kibera, Nairobi.

Biogas production can be enhanced by addition of kitchen and market wastes. Digested slurry is rich in nutrients, therefore attractive for agricultural purposes, but special attention should be paid at handling and or post-treatment of the slurry, as pathogens are only partially removed during anaerobic treatment.

5. Concepts with separate urine collection

(Kujawa-Roeleveld & Zeeman, 2006)
Since treatment of the whole wastewater stream is not an optimal approach leading to maximization of nutrient recovery and recycling, in some (already existing) cases urine can be separately collected and reused for agricultural purposes. Moreover hospitals and elderly houses become more and more interested in reducing the emissions of hormones and pharmaceuticals via urine separation. Urine separation is often considered in combination with central treatment of the remaining wastewater.

Urine diversion requires a specially constructed toilet where mixing of urine and faeces is avoided (WRS 2001). Simple toilets with urine diversion have been used in parts of China, in Japan and in other parts of the world for centuries (Winblad & Simpson-Hébert 2004). The collected urine can either be used directly in the garden or stored on site for later collection either as liquid fertiliser or further processed to a clean fertilizer (STOWA, 2005). Although urine is originally almost sterile, fecal cross-contamination occurs during its separate collection in the no-mix toilet. The fate of any enteric pathogens present in urine is crucial for the risk assessment for transmission of infectious diseases. A proper storage of urine provides inactivation of pathogenic organisms. The risk for transmission of infectious diseases by reuse is dependent on the storage temperature and the duration of the storage (Höglund 2001). Further inactivation of pathogens is expected in the field and the risk for infection by ingestion of crop will be reduced during the time between fertilization and consumption. The choice of crop will significantly reduce the risk for infections. Urine collected from individual households and used for the household's own consumption involves less risk than large-scale systems and is suitable for fertilising all types of crops if 1 month is allowed between fertilization and consumption (Höglund 2001). Using urine directly as fertilizer implies transport of liquid. This is costly where great distances have to be covered, typically from densely populated urban areas to farmland. In some situations urine would have to compete with animal manure as a potential recycled fertilizer. Modern and highly specialized agriculture is very demanding, making the acceptance and finally reuse of urine difficult or undesired. Production of pure nutrients needs to be developed. Recovery techniques of nutrients from concentrated urine involve struvite formation (Lind et al.2000; Ronteltap et al. 2003), ammonia stripping following absorption, volume reduction by evaporation, partial freezing or reverse osmosis (Maurer et al. 2003a, b) or ion exchange (Nguyen & Tanner 1998). The remaining wastewater mixture, brown water and grey water, contains significantly less nutrients.

6. Conclusions

- Domestic waste (water) should be regarded as a source of raw materials, such as energy, fertilizer and water, which can be used locally.
- Decentralized sanitation enables local resources utilization while supply and demand can be aligned.
- Maximal advantage of the reuse potential of black water can be achieved with collection at a minimal amount of water. The complexity of the treatment will highly depend on the possibility to directly reuse treated nutrient rich liquid streams and sludge.
- Urine separation for recovery and reuse of nutrients can be applied in combination with central treatment of the remaining wastewater.

References

Americal Water Works Association (AWWA, 2005). http://www.awwa.org/Advocacy/pressroom/stats-wp5.cfm *Fact sheets Stats on tap*

Chaggu, E.J. (2004) *Sustainable environmental protec-*

tion using modified pit-latrines (PhD thesis, WUR-ETE)

Drangert J-O (2000) *Reuse - the ultimate sink? Urine-diverting toilets to protect groundwater quality nd fertilise urban agriculture.* In: Chorus I, Ringelband G, Schlag G & Schmoll O (Eds) Water, Sanitation and Health. Proceedings of the International Conference, Bad Elster, Germany, 24–28 November, 1998 (pp. 275–280). IWA Publishing, London, UK

Driver J., Lijmbach D., and Steen I. (1999) *Why recover Phosphorus for Recycling, and How?* Env. Tech, Vol 20, No 7, pp. 651-662.

European Environmental Agency (EEA, 2001) *Indicator Fact Sheet Signals 2001 – Chapter Households*. YIR01HH07 Household water consumption

Guyton AC (1992) *Human Physiology and Mechanisms of Disease*. W.B.Saunders Company, Philadelphia

Henze M & Ledin A (2001) *Types, characteristics and quantities of classic, combined domestic wastewaters*. In: Lens P, Zeeman G & Lettinga G (Eds) IWA publishing Decentralised Sanitation and Reuse: concepts, systems and implementation.

Höglund C (2001) *Evaluation of microbial health risks associated with the reuse of source-separated human urine*, Doctoral thesis Royal Institute of Technology (KTH), Department of Biotechnology, Applied Microbiology, Swedish Institute for Infectious Disease Control (SMI) Department of Water and Environmental Microbiology.

International Food Policy Research Institute (IFPRI) (2002).

http://www.ifpri.org/media/water_countries.htm#subsaf. *Global Water Outlook to 2025: Averting an Impending Crisis Global Water Outlook to 2025: Averting an Impending Crisis*

Jönsson H, Eriksson H & Vinnera˚ s B (2000) *Collection tanks for human urine – ventilation and ammonia loss.* (Uppsamlingstankar fo¨ r humanurin – gasva¨ xling och ammoniakfo¨ rlust). Department of Agricultural Engineering, Swedish University of Agricultural Sciences, Uppsala, Sweden. Manuscript. (In Swedish, English summary)

Kujawa-Roeleveld, Katarzyna & Grietje Zeeman (2006). *Anaerobic treatment in decentralised and source-separation-based sanitation concepts.* Reviews in Environmental Science and Bio-Technology 5:115–139

Lind BB, Ban Z & Byden S (2000) *Nutrient recovery from human urine by struvite crystallization with ammonia adsorption on zeolite and wollastonite.* Bioresource Technology 73(2): 169–174

Maurer M, Muncke J & Larsen T (2003a) *Techniques for nitrogen recovery and reuse.* In: Lens P et al. (2003) Water and Resource Recovery in Industry. IWA Publishing

Maurer M, Schwegler P & Larsen TA (2003b) *Nutrients in urine: energetic aspects of removal and recovery.* Water Sci. Tech. 48(1): 37–46

Mels, Adriaan, Noor van Andel, Jón Kristinsson, Edgar Wortmann, Peter Oei, Jan de Wilt, Gatze Lettinga en Grietje Zeeman (2006). *Zonneterp - innovatie in energie en water.* Decentrale voorziening in energie, water en andere nutsfuncties. Spil , 229-230, no. 5, 12-18.

Nguyen ML & Tanner CC (1998) *Ammonium removal from wastewaters using natural New Zealand zeolites cations in the synthetic solutions.* New Zeal. J. Agric. Res. 41: 427–446

NIPO/VEVIN (2002) *Milieu en natuur compendium*

http://www.rivm.nl/milieuennatuurcompendium/nl/i-nl-0037–03.html

Otterpohl R, Grottker M & Lange J (1997) *Sustainable water and waste management in urban areas.* Water Sci. Tech. 35(9): 121–133

Otterpohl R (2008). *Pathways for future development in sanitation.* Presentation at International IWA Conference on New Sanitation Concepts and Models of Governance Wageningen, May 19-21, 2008

Ronteltap M, Biebow M, Maurer M & Gujer W (2003). *Thermodynamics of struvite precipitation in source-separated urine* (pp. 463–470). Proceedings of the 2nd IWA/GTZ international symposium on ecological sanitation, Lübeck, Germany

STOWA (2005) *Decentral Sanitation and Re-use: Options for separate treatment of urine*. STOWA report No 2055-11

Winblad U & Simpson-Hébert M (eds) (2004) *Ecological Sanitation, Revised and Enlarged Edition*. Stockholm Environment Institute 2004

Wortmann, E. (2008). *Nieuwe Nuts : duurzame bronnen - lokale business*;. Kruseman (ill.) Rapport / InnovatieNetwerk (nr. 08.2.174) , 153 p

WRS (2001) Water Revival Systems. *Market survey – extremely low flush toilets plus urine diverting toilets and urinals for collection ofblack water and/or urine.* SwedEnviro report 2001:1

Zeeman, Grietje, Katarzyna Kujawa, Titia de Mes, Lucia