



GREYWATER REUSE: CONCEPTS, BENEFITS, RISKS AND TREATMENT TECHNOLOGIES

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ABSTRACT

Greywater reuse concepts argued in technical literature as well as the benefits and risks of greywater reuse are discussed in this paper. Some greywater treatment technologies are presented. However, it is not attempted to describe reuse systems in detail.

KEYWORDS: Ecological sanitation, greywater, reclamation, reuse.

INTRODUCTION

Greywater is that part of domestic wastewater which is not passing toilets, i.e. it is originating from bath tubs, showers, hand-wash basins, washing machines, automatic dishwashers, kitchen sinks and eventually from floor drains. Some Australian greywater experts have a slightly different definition: They attribute kitchen wastewater to black water, as its organic loading may be quite high.

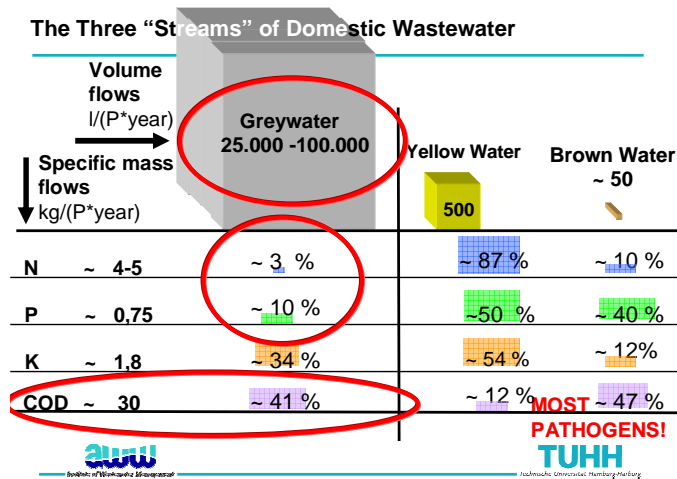


Figure 1. Specific volume flows of the three partial streams of domestic wastewater as well as their percentage distribution to domestic wastewater nutrient and COD specific mass flows (from German data); adapted from Otterpohl (2001)

Greywater represents the largest part of domestic wastewater as can be seen from fig. 1. At the same time it contains only about 3 % of the nitrogen and 10 % of the phosphorus contained in the entire domestic wastewater. Contrasting to municipal effluents - which are also subject of research work about wastewater reuse - it is safely segregated from industrial wastewaters occasionally containing high loads of hazardous



substances. This makes it a highly suitable "nonconventional" water source. It should be noted that data in fig. 1 can vary according to personal behavior like e.g. frequency of showering and laundry. The specific volume flow of "brown water" (faeces) in fig. 1 does not contain toilet flush water.

GREYWATER CHARACTERISTICS

The main constituents of greywater are salts (including such salts causing alkalinity like hydrogen carbonates) and organic substances. In the eco-settlement Luebeck-Flintenbreite where a constructed wetlands for treatment of separately collected greywater is operated, during a two-years period BOD₅ concentrations between about 50 and 370 mg/l have been measured in the raw greywater, while COD concentrations were between 90 and 700 mg/l. These concentrations are highly varying. For Swedish greywater samples, Palmquist and Hanaeus (2005) report BOD₇ ranges of 350 to 500 mg/l and COD ranges of 495 to 682 mg/l. In hot climates, evaporation may lead to enhanced organics concentrations. Although different greywater sources are mentioned to exhibit different organic strengths, for bathroom greywater BOD concentrations are given ranging from 26 to 300 mg/l and COD concentrations of 77 to 633 mg/l (Eriksson et al. 2003). So, they show a similar variation as the entire greywater sampled at Luebeck-Flintenbreite. From a literature survey, Jefferson et al. (2004) give a BOD range from 33 to 300 mg/l which would characterise a medium strength influent municipal sewage.

Among the organics contained in greywater, Eriksson et al. (2003) identified 191 particular trace organics – mainly long-chain aliphatic carboxylic acids – in the µg/l range. They also found organic compounds of concern like e.g. *tert.*-butylhydroxyanisol (BHA), an endocrine disrupting chemical (EDC). Palmquist and Hanaeus (2005) detected a couple of phthalic acid esters (some of them also being EDCs), polycyclic aromatic hydrocarbons and brominated flame retardants in the µg/l range.

Salts lead to electric conductivities of bathroom greywaters of 220 to 820 µS/cm (Eriksson et al. 2006). The conductivity of greywater does not only depend on introduction of salts into the greywater, but also on conductivity of tap water (Eriksson et al. 2006). One type of salts in greywater are phosphates originating from detergents and automatic dishwasher agents. Total phosphorus concentrations in Swedish greywater samples have been found to vary from 4.6 to 11 mg/l (Palmquist and Hanaeus 2005).

Individuals' behaviors (water consumption, use of personal care products and household chemicals) have a large influence on chemical greywater composition.

According to reasonable BOD concentrations, microorganisms easily grow in untreated greywater. Faecal coliform concentrations determined by Nolde (2000) in different greywater sources varied between 0.1/ml and 10⁶/ml, total coliforms between 10/ml and 10⁶/ml. Ottosson and Stenstroem (2003) have executed quantitative microbial risk assessments with greywater. They recommend that "guidelines for greywater recirculation and reuse should *not* be based on thermotolerant coliforms as a hygienic parameter, because of the large input of non-faecal coliforms and/or growth of coliforms". The same authors suggested that the risk from viruses contained in greywater is the most prominent in a greywater reuse system without disinfection because of the high excretion figures, environmental persistence and low infectious doses of viruses. Treatment of greywater (settling tank, activated sludge, and constructed wetlands) only led to a 0.2 to 0.3 log reduction of somatic coliphages used as index organisms for rotavirus, while subsequent treatment of the pretreated greywater in a pond led to a 1.2 log reduction of viruses (Ottosson and Stenstroem 2003).

GREYWATER REUSE CONCEPTS AND TREATMENT TECHNOLOGIES

Reuse purposes for greywater mentioned in literature and internet publications are: Garden irrigation, toilet flushing, animal husbandry, industrial use, golf course or cemetery irrigation, groundwater recharge, hand washing, potable water uses, vehicle washing, helicopter washing, firefighting, laundry, bathing/showering, crop irrigation, ornamental lakes and streams, industrial construction, dust control, street washing/snow melting. Of course, different reuse purposes require different quality standards and thus different treatment extents: from relatively simple to relatively complex. Standards related to particular reuse purposes are subject of different jurisdictions in different countries and are not presented in this paper.

Figure 2 contains four different treatment/reuse options. For all scenarios, separate greywater plumbing is a prerequisite. A practice doing without any treatment is groundwater recharge via the so-called "soil aquifer treatment" (SAT). The soil (and eventually also the aquifer) passage is the treatment itself. This practice is not recommended to be executed without expertise, because it can lead to severe contamination of groundwater. Soil properties and level of water table are important parameters to be considered. Using untreated greywater for irrigation is more or less an SAT, as the greywater may seep to aquifers – especially when groundwater tables are shallow – with the consequence of contamination. As untreated greywater smells after a short period, irrigation with untreated greywater does not allow for storage.

A more advanced reclamation technology is collecting the greywater in a septic tank (which is actually anaerobic treatment without harvesting the generated biogas) with subsequent aerobic treatment leading to stabilisation of the greywater. By this, the BOD is removed, growth of microorganisms is reduced, and no odor problems occur making the treated greywater suitable for storage over longer periods. The area of application of biologically treated greywater is thus wider. However, regulations concerning quality parameters – especially hygiene parameters – for different reuse purposes have to be obeyed. While some experts mention toilet flushing as a reuse application of biologically treated greywater, others say that for this purpose, the treated greywater has additionally to be disinfected. An alternative to the septic tank is anaerobic treatment in more technical reactors (like the upflow anaerobic sludge blanket, UASB, reactor; see Elmitwalli and Otterpohl 2007) which exploit the chemical energy of the greywater organics as biogas.

Concepts

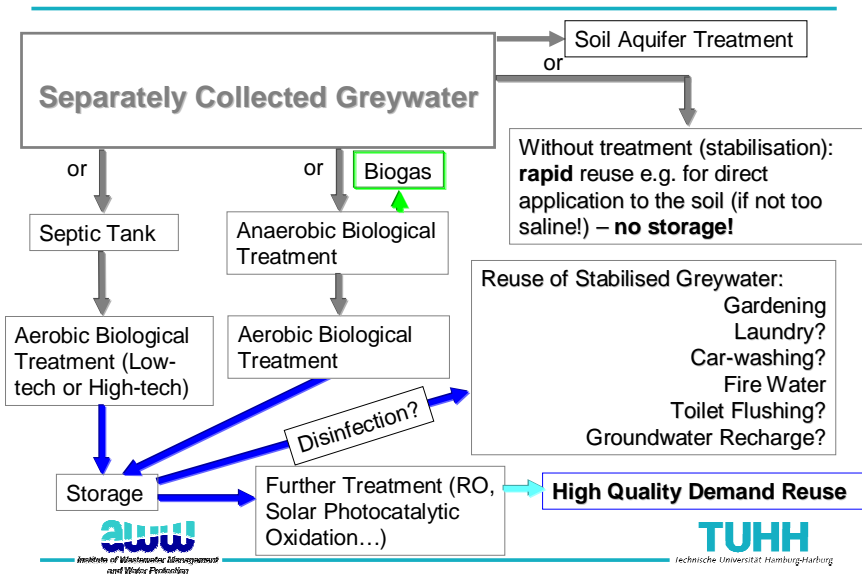


Figure 2. Possible concepts for greywater reuse without and with treatment

Anyway, biologically treated greywater is a resource which can be finished with another treatment stage, including disinfection (chlorination, UV irradiation). It is conceivable that reverse osmosis leads to potable water quality (additionally, disinfection is required). Biologically treated greywater may be a more suitable source for desalination than seawater, which is more saline. On a low-tech scale in remote areas with sufficient solar radiation, biologically treated greywater can be distilled in so-called solar stills. Also photocatalytic oxidation can be powered by the sun and has the potential to remove organic contaminants (Gulyas et al. 2007a) and at the same time to disinfect the water. However, this process does not affect the salt concentration and does thus not lead to drinking water quality.

Recently, a couple of aerobic biological treatment technologies have been investigated and some of them have also been implemented for greywater reclamation: rotating biological contactors (Nolde 2005), membrane bioreactors (MBR; Lesjean and Gnirss 2006), sequencing batch reactors (Lamine et al. 2007), and constructed wetlands (Gross et al. 2006, Li et al. 2003). It should be noted that aerobic greywater treatment systems with



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forced aeration (like the MBR) use considerable quantities of electricity. Other aspects to be carefully considered for the selection of the treatment technology are investment costs and expenses for maintenance.

One simple treatment train is not contained in fig. 2, as it is not recommendable: a separation process (e.g. fast sand filtration or flocculation/settlement) with subsequent chlorination. The chlorination of a wastewater with high organic load will inevitably lead to the formation of the carcinogenic chloroform and other halogenated organics. Contrasting to fast sand filtration, slow sand filtration is a biological process and will lead to BOD removal.

BENEFITS/RISKS OF GREYWATER REUSE

The clear benefit of greywater recycling is saving of water. Besides reducing water bills for individuals, there is also a broader community benefit in reducing demands on public water supply. This is especially a good option in case of water shortage caused by either low rainfall or excessive demand e.g. when big cities are competing with surrounding farmers for scarce water sources. Reducing public water demand has also environmental benefits as tapped water for the public is usually chlorinated. Hence, also the release of the ozone-depleting gas chlorine is decreased with greywater reuse (unless more chlorine is utilised for disinfection of reclaimed greywater). If greywater is an additional water source leading to increased supply of irrigation water, this can stimulate an increase in agricultural and forestal production. More trees and plants have benefits: They absorb carbon dioxide helping to mitigate global warming; in a country like Australia where skin cancer poses a large threat, trees provide shade and protection from the sun; trees increase evaporation and thus condensation of the evaporated moisture as clouds and finally lead to a greater chance of precipitation; leaves from the trees create soil organic matter; roots of trees increase permeability retaining water from storms and preventing runoff thus reducing soil erosion and increasing ground water recharge; plants generally enhance the aesthetic value of an area.

However, the reuse of greywater requires precautionary measures especially with respect to public health. Although statements like "despite all sorts of grievous misuse ..., there has not been a single documented case of grey water transmitted illness in the US" can be found in the internet, microbiological risks by reusing greywater cannot be excluded. Besides the young, also elderly and immunocompromised are more susceptible to disease than the general population. Without doubt, infection risks are higher with untreated greywater than with treated greywater. Therefore, application of sprinklers for irrigation with untreated greywater is a clear "don't": The droplets from the sprinklers can evaporate and leave harmful microorganisms in the air. During periods of wet weather, irrigation with (untreated) greywater should be avoided in order to prevent pathogens from spreading. Special care has to be taken with greywater from the laundry when nappies are washed. Under such circumstances, laundry greywater has to be excluded from irrigation. Untreated greywater should also not be used for irrigation when a household resident has an infectious disease as diarrhoea, infectious hepatitis, intestinal parasites etc. Generally, greywater shall not be applied on food plants which are consumed raw. Although the use of domestic greywater on lawns and gardens is usually considered to have a low risk, the irrigation of lawns may be associated with public health risks because disease causing organisms in greywater are principally transmitted through the ingestion of greywater via contaminated hands, or indirectly through contact with contaminated items such as grass, soil, toys or garden implements. Hand washing following watering gardens or lawns with greywater is a must. It should also be kept in mind that disease causing organisms can also be transmitted by penetration through broken skin. Another way of infectious disease spreading is transmittance by vectors (flies, cockroaches, and rodents such as rats and mice) which have contact to untreated greywater. Even household pets may transmit disease by tracking and carrying disease causing organisms into the home or when petted by children (Australian Capital Territory 2007). Therefore, children and pets should not come into contact with the untreated greywater. In order to stop the possibility of greywater pooling on the surface of irrigated areas where children and pets can play in it or mosquitos can breed, it is best to apply greywater beneath mulch or soil.

Untreated greywater not disinfected should also not be used for toilet flushing as diseases can be transmitted by splashing or other human-contact. As treatment of greywater does not lead to complete elimination of disease transmitting organisms, disinfection is also recommendable for treated greywater prior to its use for flushing toilets. Laundry at different temperatures (30, 60 and 95°C) with biologically treated greywater was reported to present no risk, as garment samples washed and rinsed with recycled greywater as well as garment washed



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under the same conditions with drinking water yielded less than 5 Colony Forming Units after contact with Agar (Nolde 2005).

Reduction of microorganisms by greywater treatment is also a good practice if the reclaimed greywater is used for groundwater recharge. However, as mentioned in the "greywater characteristics" chapter, viruses may present a risk even in treated greywater. Ottosson and Stenstroem (2003) have estimated that the yearly rotavirus infection risk by drinking groundwater recharged with greywater treated in ponds is as high as $10^{-0.2}$ when the retention time in the aquifer is only one month. With a retention time in the aquifer of three months, the risk is reduced to $10^{-6.0}$. In treated greywater, also the die-off of Salmonella (following artificial contamination) from 10^7 /ml to 10/ml during a storage period of less than three weeks is quite efficient (Nolde 2000).

In regions where Malaria occurs, greywater storage and treatment should be done in a way that no mosquito breeding in the greywater is possible. E.g. greywater treatment should be more favourably executed in subsurface flow than in free water surface constructed wetlands or ponds. Subsurface irrigation with greywater is advantageous also as a means against mosquito breeding as it avoids greywater pooling on the surface of irrigated areas (see above).

Untreated greywater can cause problems additional to disease transmittance: Because of its reasonable BOD concentrations, it gives rise to offensive odors when it is stored for more than 24 hours. This makes the reuse of untreated greywater limited, because there is no way to cope with the greywater when there is no demand (e.g. due to wet weather) unless the residents are connected to sewers where they can discharge the untreated greywater. Another problem occurring with untreated greywater is when it is used for drip irrigation: Suspended solids contained in the greywater may lead to clogging of the perforations in irrigation tubes as well as of U shaped tubes. Removal of suspended solids e.g. by settling in septic tanks will reduce this problem. However, drip irrigation with settled, but unstabilised greywater has been reported to work only for a few weeks because of clogging of perforations due to microorganism growth.

Besides microorganisms contained in greywater, also its chemical contamination may be of concern. This is the case when greywater is used for irrigation. Common washing powders contain sodium salts as bulking agents (up to 30 %) which generate saline greywater (especially when collected separately from washing machines). As salts are not degraded in the soil, overloading the garden with salt causes degradation of the soil structure and permeability. Eriksson et al. (2006) have found a correlation between willow phytotoxicity of greywaters from different sources and the greywater conductivity which can be looked at as a sum parameter for salts. Some salts – particularly those contained in automatic dishwasher detergents - also represent alkalinity. That is why kitchen greywater is not recommended for irrigation by many experts. Too high alkalinity will especially impair growth of acid-loving plants. Additionally, some detergents and powder cleansers contain boron which is toxic to plants in high concentrations. Therefore, it is recommended to take care for detergent selection when the greywater is used for irrigation (otherwise exclude laundry greywater from irrigation). It is possible to use liquid concentrates (which are generally much lower in salt content) instead of washing powders. Also washing powders which contain potassium salts instead of sodium salts are available. Potassium is a nutrient and thus potassium salts produce better quality greywater than detergents using sodium salts. Rinse water from laundry is suitable for irrigation, of course, but its use and the separation of the detergent-containing greywater makes the reuse scheme additionally complex.

If there is any reason to chlorinate greywater, it should be excluded from irrigation, as chlorine is toxic to plants.

Although greywater is attributed as "poor in nutrients" (compare fig. 1), some detergents contain high amounts of phosphorus. In Germany, phosphorus has been banned from washing powders in order to protect surface waters from eutrophication, but automatic dishwasher detergents funnily may contain up to 20 % of phosphates. This is the reason for phosphorus concentrations of 5 to 7 mg/l in the effluent of the constructed wetlands for greywater treatment in the eco-settlement Luebeck-Flintenbreite (Li et al. 2003). When nutrient-rich greywater is used for irrigation, there can be overloading of the garden with phosphorus. When a site's hydraulic loading is exceeded causing runoff of polluted water into stormwater drains, rivers, or streams it may contribute to surface water eutrophication.

Besides inorganic contaminants, greywater contains trace organics originating from personal care products, household chemicals or foodstuffs (Eriksson et al. 2003, Palmquist and Hanaeus 2005) which can even be detected subsequently to biological treatment of greywater (Gulyas et al. 2007b). Although in treated greywater also chemical endocrine disruptors were found, it is not clear what the environmental and human health impact of these trace concentrations are. Detection of organics in greywater subsequent to biological treatment indicates their recalcitrance toward biodegradation. The probability is high that they (or at least a part of them like e.g. the flame retardant tris-(chloropropyl)-phosphate) will be transferred to aquifers. Other organics which are formed in biological processes – humic materials – cause a yellowish colour of the treated greywater. This might be an aesthetic problem when biologically treated greywater is used for toilet-flushing.



Figure 3. Safety sign for greywater outlet points (Australian Capital Territory 2007)

Finally, when greywater is reused, it has to be assured that plumbing construction is suitable preventing cross-connections with drinking water. The greywater pipes should be permanently colour coded. Greywater outlet points have to be equipped with safety signs (fig. 3) in order to avoid confusion with drinking water. For further advices and safety measures, see e.g. Australian Capital Territory (2007) or New South Wales Government (2007). As separate greywater collection requires dual piping, investment in plumbing might be slightly higher than with conventional sanitation. However, for greywater usually smaller pipe diameters are required than for pipes conducting the entire domestic wastewater.

CONCLUSIONS

Greywater reuse offers without doubts environmental and economic benefits. However, it is accompanied by particular risks and problems which require particular care and solutions in order to ensure a responsible use of greywater.

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