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Association for Rainwater
Harvesting and Water Utilisation

Greywater Recycling and Reuse

What is greywater?

Greywater is all wastewater that is discharged from a house, excluding blackwater (toilet water). This includes water from showers, bathtubs, sinks, kitchen, dishwashers, laundry tubs, and washing machines (Figure 1). It commonly contains soap, shampoo, toothpaste, food scraps, cooking oils, detergents and hair. Greywater makes up the largest proportion of the total wastewater flow from households in terms of volume. Typically, 50-80% of the household wastewater is greywater. If a composting toilet is also used, then 100% of the household wastewater is greywater.

Not all greywater is equally "grey". Kitchen sink water laden with food solids and laundry water that has been used to wash diapers are more heavily contaminated than greywater from showers and bathroom sinks. Therefore, different greywater flows may require different treatment methods that would render the water suitable for reuse.

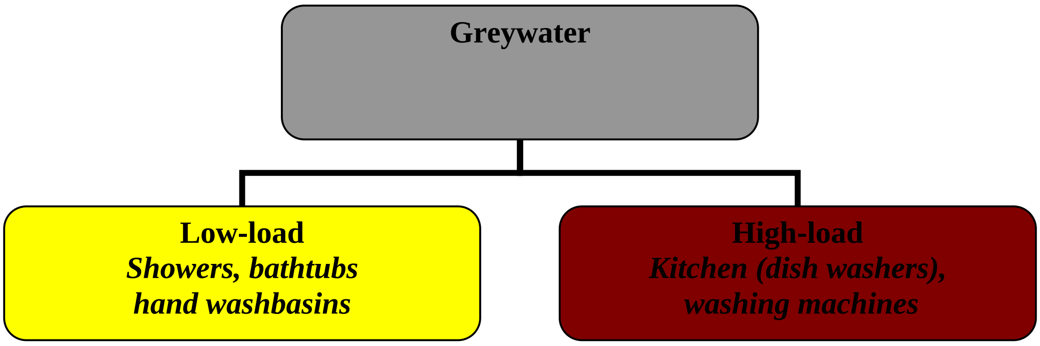

Fig. 1: Major greywater sources

Greywater composition and characteristics

Greywater is a reflection of the household activities and its characteristics are strongly dependent on living standards, social and cultural habits, number of household members and the use of household chemicals. Greywater from bathtubs, showers and hand washbasins is considered as the least polluted greywater source. The average greywater contribution to the total organic load (BOD_5) amounts to about 40 – 50%. Greywater also contributes to one fourth of the total suspended solids and up to two thirds of the total phosphorous load. Dishwashing and laundry detergents are the main sources of phosphorous in greywater. In countries where phosphorous-free detergents are used, these loads are minimal. Kitchen greywater is the main source of nitrogen in domestic greywater, while the lowest levels are generally observed in bathroom and laundry greywater.

Table 1 summarises the chemical and microbiological composition of greywater from different sources in German households.

Table 1: Composition of greywater from different sources in German households based on measurements of 10 to 100 for each parameter compared to the average concentration of domestic blackwater (Adapted from Nolde, 1995, and Bullermann et al., 2001).

	Greywater from bathtubs, showers and hand basins	Greywater from bathtubs, showers, hand basins and washing machine (including baby diaper)	Greywater from bathtubs, showers, hand basins, washing machines and kitchen	Domestic wastewater (blackwater)
BOD_5 (mg/l)	85 – 200 Ø 111	125 - 250	250 – 550 Ø 360	Ø 267
COD (mg/l)	150 – 400 Ø 225	250 - 430	400 - 700 Ø 535	Ø 533
TSS (mg/l)	30 -70 Ø 40	n/a	n/a	Ø 200
P_{total}	0.5 - 4 Ø 1.5	n/a	3 - 8 Ø 5.4	Ø 15
N_{total}	4 - 16 Ø 10	n/a	10 - 17 Ø 13	Ø 67
Total coliforms (MPN/ml)	10^1 – 10^5 Ø 10^5	10^2 - 10^6	10^2 - 10^6	10^4 - 10^7
E. coli (MPN/ml)	10^1 – 10^5 Ø 10^4	10^1 - 10^5	10^2 - 10^6	10^4 - 10^7

In terms of microbial contamination, greywater may still contain pathogens given the likelihood of cross-contamination with excreta. However, this is user-dependent and microbial contamination of the greywater especially with faecal coliforms is generally low, and the risk to contract diseases when greywater is used for irrigation without any prior treatment is very minimal.

Why greywater recycling?

The main purpose of greywater recycling is to substitute the precious drinking water in applications which do not require drinking water quality. Non-potable reuse applications include industrial, irrigation, toilet flushing and laundry washing dependent on the technologies utilised in the treatment process. With greywater recycling, it is possible to reduce the amounts of fresh water consumption as well as wastewater production, in addition to reducing the water bills. If greywater is regarded as an additional water source, an increased supply for irrigation water can be ensured which will in turn lead to an increase in agricultural productivity.

Unlike rainwater harvesting, greywater recycling is not dependent on season or variability of rainfall and as such is a continuous and a reliable water resource. This results in smaller storage facilities than those needed for rainwater harvesting. Greywater has a relatively low nutrient and pathogenic content and therefore, it can be easily treated to a high-quality water using simple technologies such as sand/gravel filters and constructed wetlands (planted soil filters). Moreover, if space is not available, other systems such as sequencing batch (SBR) or membrane reactors (MBR) can be installed in the cellar.

How is greywater reused?

Greywater from baths, showers, washbasins and washing machines has to be collected separately from blackwater, treated and eventually disinfected for reuse as a non-potable water source.

Reusing greywater can be as cheap and easy (but labour intensive) as bucketing water outside, or as complex and costly (but convenient to use) as installing automatic greywater diversion, treatment, distribution and/or irrigation systems.

Garden irrigation is most commonly applied, whereby greywater can be bucketed or diverted to the garden for immediate use. Advanced systems are also available that collect, filter and treat greywater for indoor use such as toilet flushing or laundry washing.

Laundry washing accounts for 10-30% of the average household water use. Greywater from laundry is easy to capture and, with the right choice of laundry products, the treated greywater can be reused for garden watering or irrigation.

Figure 2 summarises the major possible applications for treated greywater.

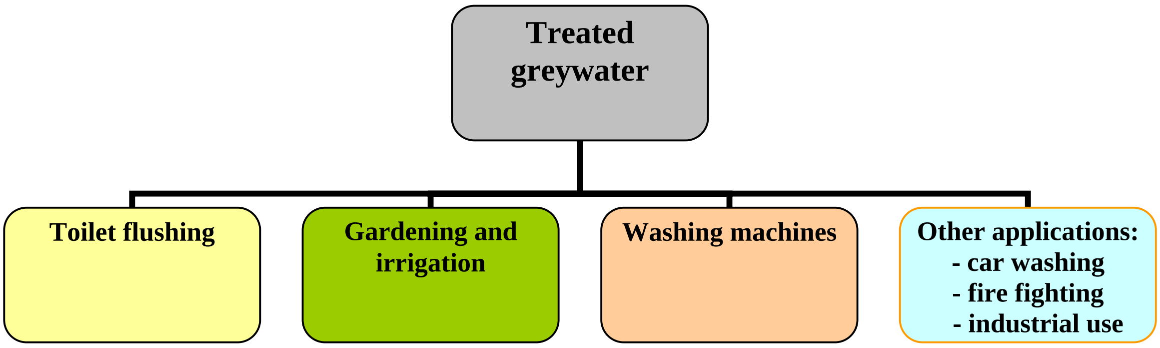

Fig. 2: Major greywater reuse applications.

Several factors may influence the choice of greywater reuse application including:

• *Budget*: costs for greywater treatment range from simple, relatively inexpensive diverters to complex treatment, storage and irrigation systems which are more costly. In some states, such as in Hamburg, Germany, rebates are offered on greywater recycling systems which are built in households and industry.
• *Existing plumbing*: the availability of pipes that carry greywater inside the house will affect the reuse options.
• *Existing garden area*: some systems incorporate surge tanks, which may require space in the garden, and the installation of irrigation systems may disturb existing plants or soil. Garden design and the choice of plants will also determine the watering needs.
• *Elevation of garden beds compared with greywater sources*: this will partly determine whether or not the force of gravity alone is enough to push the greywater through the system to where it is needed. Some sloping blocks are well suited for gravity-fed greywater diversion systems, while systems that recycle greywater for toilet flushing or flat blocks with raised garden beds may require a pump.

Greywater collection

The installation of greywater treatment systems should comply with the national technical regulations for drinking water installations, drainage and wastewater treatment. A strict separation of the drinking water and greywater pipes and clear labelling of the taps and devices is mandatory for all types of reuse.

Approaches to greywater treatment and reuse

The various systems of greywater reuse fall into two categories: diversion systems and treatment systems.

(1) Diversions systems: direct greywater from the laundry or bathroom to the garden for immediate use in restricted irrigation, without making changes to its quality. The water is not stored for more than a few hours, if at all.

(2) Treatment systems: improve the quality of the greywater by filtering, treating and disinfecting it. Treated greywater can be stored for longer periods without the risk of it going septic and causing odour nuisances. Its higher quality and ability to be stored means that it can be used for more purposes, including garden watering and irrigation, toilet flushing and laundry washing.

Centralised and decentralised systems

Greywater recycling can be achieved in centralised or decentralised systems. With decentralised systems, greywater collected from one or more apartments is treated inside the house while centralised systems collect and treat the greywater from several apartments or houses in a treatment plant outside the house.

An advantage of decentralised systems is the short distances involved for which only collection and distribution pipes are needed inside the house. On the other hand, because of their smaller size compared to centralised systems, decentralised greywater treatment systems will usually exhibit higher investment and maintenance costs while centralised systems usually will have a larger space requirement.

Greywater reuse concepts and treatment technologies

Greywater treatment approaches range from simple, low-cost devices that route greywater directly to applications such as toilet flushing and garden irrigation, to highly complex and costly advanced treatment processes incorporating sedimentation tanks, bioreactors, filters, pumps and disinfections units.
There are several ways to treat greywater to yield a hygienically safe water for reuse. The most commonly used greywater is that originating from baths, showers and hand washbasin which is usually less polluted than greywater from kitchens and washing machines. Separate greywater plumbing is a prerequisite for all systems.

The choice of technology for greywater recycling is dependent on several factors:
- Planned site
- Available space
- User needs
- Investment and maintenance costs

An efficient and functional treatment scheme for greywater recycling comprises:
- A primary treatment /buffering tank
- A secondary biological treatment
- UV-disinfection
- Storage tank
- Booster pump

Figure 3 presents the different state-of-the-art technologies for greywater recycling in Germany (Nolde, 2005).

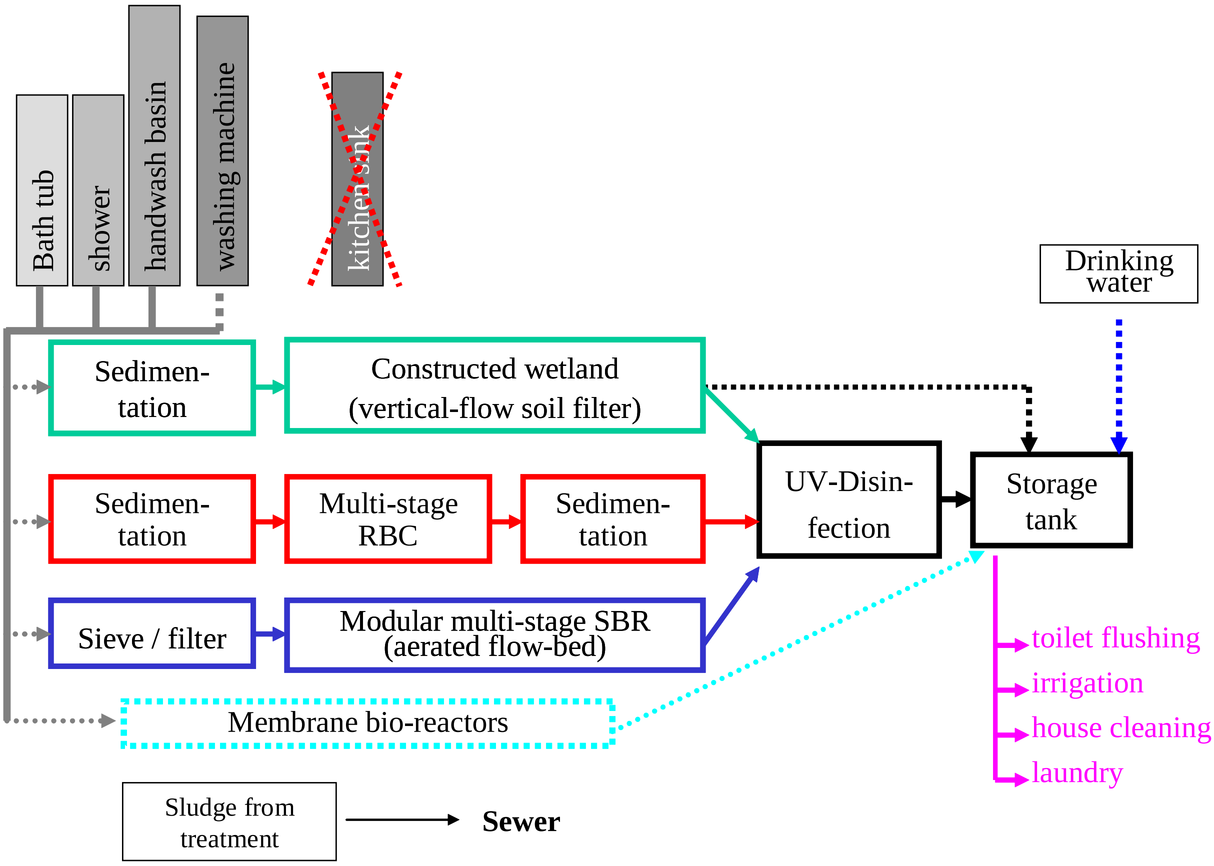

Fig. 3: Proved greywater recycling technologies in Germany (Nolde, 2005).

The most efficient systems for the treatment of greywater are biological systems in combination with physical treatment processes. These have proved to reduce the BOD of the greywater to below 10 mg/ thus producing a better effluent quality than systems which merely apply physical processes. Biological systems have been successfully employed in the past 20 years for the treatment of greywater. Several examples exist in Germany that have been built in one-family households, hotels or multi-storey residential buildings.

1. Constructed wetlands:
Constructed wetlands have been used successfully in the past for the treatment of wastewaters. Physical, chemical, and biological processes combine in wetlands to remove contaminants from wastewater. Greywater treatment is achieved by soil filtration in reed-bed systems which reduces the organic load of the greywater considerably, in addition to decreasing the concentrations of faecal bacteria. If properly designed, these systems would produce a clear and odourless effluent, which can be stored for several days without the need for disinfection. One

disadvantage is the high evaporation rate from the reed beds, especially in warm climates and the high space requirement. Compared to conventional treatment methods, constructed wetlands tend to be simple, inexpensive and environmentally friendly. They also provide food and habitat for wildlife and create pleasant landscapes.

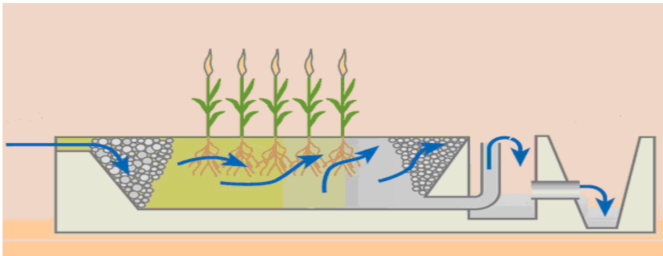

Fig. 4: A constructed wetland.

2. Rotating biological contactors (RBC):
Multi-stage, rotating biological contactors have been also used for wastewater treatment following primary treatment. Multi-stage RBCs have been successfully employed for greywater treatment. These are usually preceded by a primary sedimentation stage with a final clarification stage for biomass removal. UV disinfection of the treated greywater yields a high-quality water for non-potable uses. RBC systems can be placed in the cellar as they have a low space requirement.

Fig. 5: Multi-stage Rotating biological contactor (RBC) for greywater recycling.

3. Sequencing batch reactors (SBR):
The Sequencing Batch Reactor is a variant of the activated sludge process except that it is operated (filled and emptied) discontinuously. There are four stages to treatment: fill, aeration, settling and decanting. It consists of a primary sedimentation tank, an aerated flow-bed reactor in which the bacterial biomass is mainly fixed on foam cubes or other carrier material, and a storage tank. Sequencing batch reactors for greywater treatment are available on the market in the modular design such that, single modules can be added variably dependent on the amounts of generated greywater to be treated.

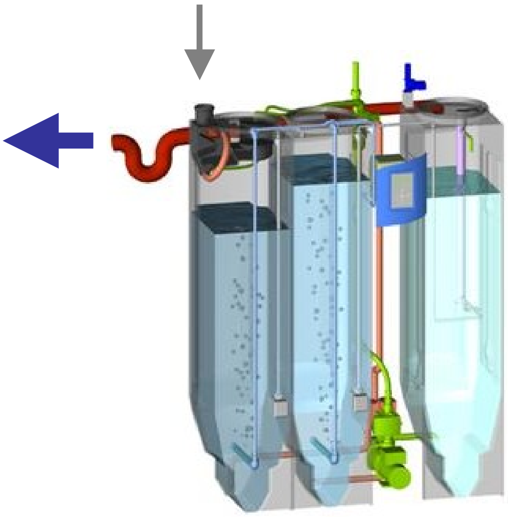

Fig. 6: A schematic diagram of the SBR technology.

4. Membrane Bioreactors (MBR):
The membrane bioreactor is a suspended growth activated sludge system that utilises micro-porous membranes for solid/liquid separation in lieu of secondary clarifiers. The system consists of a pre-treatment settling tank, an aerated settling

tank which also stores the intermittently produced greywater and the aerated activated sludge tank. The generated sludge is held back by the submerged membrane filter module installed in the aeration tank. The purified greywater passes through the membrane under a pressure of 0.1-0.3 bars yielding a bacteria-free effluent. MBRs also require less space than traditional activated sludge systems since less hydraulic residence time (HRT) is needed to achieve a given solids retention time (SRT).

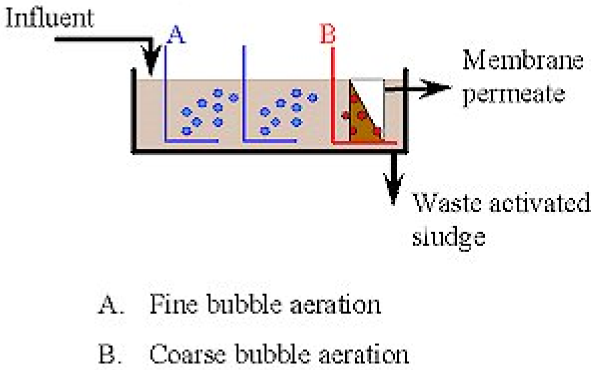

Fig. 7 : A simple schematic diagram of the MBR technology.

Operational requirements

Hygiene requirements: In Germany, treated greywater for use as a non-potable water source should meet the requirements of the EU Guidelines for Bathing Water (76/160/EEC). These include: total coliforms < 10.000 / 100 ml; E. coli: < 1.000 / 100 ml; Pseudomonas aeruginosa: < 100 / 100 ml. Other parameters include: faecal Streptococci: 0 / 0.1 ml; Candida albicans: 0 / 0.1 ml; Staphylococcus aureus 0/1 ml; Legionella sp.: 0 / 10 ml; Salmonella sp.: 0/ 100 ml.

Physical and chemical parameters of significance include BOD_7 < 5 mg/l; O_2 Saturation > 50%; UV-Transmission at 254nm (1 cm) > 60% as a minimum transmission for UV-disinfection. UV disinfection is usually employed as the final treatment stage as a precautionary measure to protect human health

Technical requirements: Treated greywater should not be a source of odour and nuisance to the user and it should be nearly free from colouration and suspended solids.
It should be further guaranteed that no cross-connections exist between the drinking water and service water (treated greywater) networks. A proper and clear designation of the network pipes with different colours and labels protects against unauthorised use.

Skilled knowledge is needed for the installation and maintenance of more sophisticated geywater treatment systems in order to protect human health. In addition, household products such as soaps, cleaning chemicals and washing powders affect greywater quality and may have a significant effect on the quality of the produced greywater as well as the type of the employed greywater treatment technology.

The fbr- Information Sheet H 201: Greywater Recycling - Planning Fundamentals and Operation Information published by the Association for Rainwater Harvesting and Water Utilisation (fbr) in Darmstadt, Germany gives comprehensive technical information on the planning, operation and maintenance of greywater recycling in the private and public sectors.

Benefits of greywater recycling

- greywater recycling saves water and reduces the amounts of fresh, high-quality drinking water by substituting the water demand not intended for drinking
- on-site greywater treatment reduces the volume of wastewater that must be diverted to more costly sewage and septic treatments
- greywater is a valuable resource for landscaping and plant growth especially in arid climates
- greywater contains one-tenth the nitrogen content of blackwater of which half of it is organic and more easily filtered and removed by biological uptake in plants
- greywater is rich in phosphorous, potassium, and nitrogen, making it a good nutrient or fertilizer source for irrigation
- localized greywater systems decrease freshwater use for transportation and treatment of wastewater
- the use of greywater for irrigation reincorporates nutrients from the waste stream into the land-based food chain, rather than contributing to surface and ground water pollution via sewers and septic systems
- greywater diversion is particularly well-suited for small-scale or decentralized wastewater systems and can be implemented in either a rural or urban setting

Water saving potential

Greywater recycling has the potential to save a third of the domestic mains water usage. If the property is metered, this will reduce the water bill. The resulting financial savings will depend both on the price of water in the area and the amounts of water reused. This in turn will reduce the pressure on the fresh water resources and reduce the quantity of discharged wastewaters.

Environmental benefits

Greywater systems bring significant savings in fresh drinking water in addition to reducing the amounts of generated wastewaters, thus easing the pressure on the environment. In general, low-energy systems should be preferred over high-expenditure systems.

Health aspects

Paramount to the acceptance of greywater reuse is the protection of public health. This is reflected in the emerging government policies and regulatory guidelines which include greywater reuse as part of an overall sustainable water strategy. In practice, the health risk of greywater reuse has proven to be minimal. Nevertheless, greywater may contain pathogenic organisms which may cause disease. Therefore, proper treatment, operation and maintenance of greywater recycling systems is indispensable if any infectious pathways should be intercepted.
Certain precautionary measures should be taken to avoid any health risks from the reuse of greywater:

- Cross-connections between freshwater and greywater plumbing should be excluded. This is guaranteed by using different colours and labels for the drinking water and greywater plumbing systems
- System overload should be avoided. Greywater systems are safest when reusing water that is fairly clean initially. Therefore, less polluted greywater sources such as from showers, bath tubs and hand washbasins should be preferred for treatment and reuse over kitchen or laundry greywater
- Greywater should not be stored but used immediately or within 24 hours
- When used for gardening, greywater should be applied to the subsurface to avoid any contact with the greywater. Greywater should not be applied to fruits and vegetables that are eaten raw. For watering of fruit trees, greywater can be applied under mulch
- When used to water the garden or for irrigation, no sprinklers should be used.

Economic aspects

Greywater reuse should be viewed not only in terms of economic performance but its more significant social and environmental benefits in contributing towards sustainable development and resource use.

For individual domestic greywater systems the most efficient and effective technologies involve simple diversion and in-line surge tanks with coarse filtration with subsurface garden watering and irrigation purposes only. More sophisticated systems that involve storage, fine filtration, biological treatment and UV disinfection and pumping offer greater economic value when used for toilet flushing, laundry washing and garden irrigation applications.

Tertiary treatment systems such as biological processes are most efficient and effective for multi-dwelling applications, where more favourable scales of economy and greywater quality can be achieved by connecting many users to the system.

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