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Sandec: Department of Water and Sanitation in Developing Countries

Greywater Management

in Low and Middle-Income Countries

Review of different treatment systems
for households or neighbourhoods

Sandec Report No. 14/06

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Cover photos:
Front: Horizontal-flow planted filter treating greywater in Mexico (photo: Sarar Transformacion)
Back: Horizontal-flow planted filter (constructed wetland) treating greywater in Costa Rica (photo: Sandec)

Foreword

The issue of greywater management – including wastewater from bath, laundry and kitchen but excluding toilet wastewater – is steadily gaining importance, especially in low and middle-income countries (LMIC) where inadequate wastewater management has a detrimental impact on public health and the environment. In recent years, inadequate greywater management has not only been linked to environmental degradation and serious health risks, but has also been increasingly identified as a valuable resource rather than a waste. Appropriate reuse of greywater not only reduces agricultural use of drinking water and water costs, but also increases food security and improves public health.

This report compiles international experience in greywater management on household and neighbourhood level in low and middle-income countries. In urban areas of LMIC, greywater is commonly discharged untreated into drainage channels, on open fields or into natural aquatic systems. The rural and peri-urban areas mainly use untreated greywater for agricultural purposes, thereby leading to environmental degradation and exposing the population to health risks. Though greywater is generally less polluted than domestic or industrial wastewater, it may still contain high levels of pathogenic microorganisms, suspended solids and substances such as oil, fat, soaps, detergents, and other household chemicals.

The report is not a plea for stand-alone greywater management systems for all situations and at all costs but aims at providing a comprehensive description of the main components for successful greywater management. Recommendations are formulated for control measures at the source, design of primary and secondary treatment systems as well as safe reuse and disposal of treated greywater. Though information on greywater management experience in LMIC is scarce, several cases of implemented and engineered greywater management systems could be identified. The documented systems, which vary significantly in terms of complexity, performance and costs, range from simple systems for single-house applications (e.g. local infiltration or garden irrigation) to rather complex treatment trains for neighbourhoods (e.g. series of vertical and horizontal-flow planted soil filters). Treated greywater is not always reused. In regions with water scarcity and poor water supply services, emphasis is placed on agricultural reuse of treated greywater, whereas in regions with abundant water, greywater reuse is of minor importance and locally infiltrated or discharged into nearby water streams.

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Special thanks go to the resource persons who shared their field experience and supported the authors in documenting the case studies. Many of them have spent time and effort in reviewing the draft case study reports, contributing with additional documentation, thereby helping to further complement and update the information contained herein.

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We hope that this report will provide a valuable tool for interested development agencies, NGOs and CBOs working in environmental sanitation in low and middle-income countries.

Dübendorf, September 2006

Antoine Morel

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Content

Glossary

Aerobic digestion	Breakdown of organic matter into simpler compounds by microorganisms in the presence of oxygen. *See also anaerobic digestion*.
Alkalinity	Capacity of water to neutralise acids; a property imparted by carbonates, bicarbonates, hydroxides, and occasionally borates, silicates and phosphates. Alkalinity stabilises water at pH levels around 7 (neutral). However, high water acidity decreases alkalinity and may cause harmful conditions for aquatic life. Alkalinity is expressed in ppm or mg of calcium carbonate per litre (mg/L $CaCO_3$).
Anaerobic digestion	Digestion of organic matter by anaerobic (absence of free oxygen) microbial action, resulting in the production of methane gas.
BOD_5	Biological oxygen demand. A measure of the amount of oxygen used by bacteria to degrade organic matter in a wastewater sample over a 5-day period at 20 ºC (expressed in mg/l).
Cesspit	A covered hole or pit to receive drainage or sewage, as from a house.
cfu	Colony forming unit. Measure indicating the number of microorganisms capable of multiplying in a sample.
Coliforms	Coliforms are often used as a food and water quality indicator. Coliform bacteria are defined as rod-shaped, Gram-negative organisms, which ferment lactose and produce acids and aldehydes. These organisms are normally found in the aquatic environment and on vegetation. The coliforms include Escherichia, Klebsiella, Eterobacter, Citrobacter and may include Serratia and Edwardsiella.
COD	Chemical oxygen demand (indicated in mg/l). Quantitative measure of the amount of oxygen required for chemical oxidation of carbonaceous (organic) material in a sample by a strong chemical oxidant.
COD/BOD_5	Ratio indicating the level of biodegradability of a sample. A low ratio COD/BOD_5 (less than 2.0 or 2.5) indicates a high biodegradability.
Colloids	Very small, suspended particles (less than 12 µm and more than 0.001 µm), which may be removed by coagulation, biochemical action or membrane filtration.
Denitrification	Chemical reduction of nitrate and nitrite to gaseous forms by certain species of bacteria in anoxic conditions.
Disinfection	Destruction of disease-causing organisms, the so-called pathogens (e.g. bacteria, viruses) by chemical agents (e.g. chlorine, bromine, iodine, ozone, lime) or physical agents (e.g. heat, UV radiation).
DO	Measure of the amount of oxygen dissolved in water, expressed as: (i) mg/l – which is the absolute amount of oxygen dissolved in the water mass, or (ii) as percentage of oxygen-saturated water (% sat).
d_{50}	Median grain size of sand or gravel.
EC	Electrical conductivity (expressed in µS/cm). Indicates salinity in soil and water.

E. coli	*Escherichia coli* is a faecal coliform bacterium of almost exclusively faecal origin. If it is found in water or food, it indicates faecal contamination and poses a public health risk since other faecal pathogens such as viruses or parasites may also be present.
Eutrophication	Excess nutrient concentration in an aquatic ecosystem leading to: (i) increased productivity of autotrophic green plants and to the blocking out of sunlight, (ii) elevated temperatures within the aquatic system, (iii) depletion of oxygen, (iv) increased algae growth, and (v) reduction in fauna and flora variety.
FC	Faecal coliforms. Common, harmless forms of bacteria present in human intestines and found in faeces and wastewater. Faecal coliform bacteria counts are used as an indicator of the presence of pathogenic microorganisms.
Filtration	A process whereby suspended and colloidal matter is removed from water and wastewater by passage through a granular medium.
Flotation	A process by which suspended matter is lifted to the surface of a liquid to facilitate its removal.
Helminth	Worm or worm-like animal, especially parasitic worms of the human digestive system, such as roundworm (e.g. Ascaris) or hookworm.
Heavy metal	Inorganic species of large atomic weight, usually chromium (Cr^{3+}), lead (Pb^{2+}), mercury (Hg^{2+}), zinc (Zn^{2+}), cadmium (Cd^{2+}), and barium (Ba^{2+}).
HLR	Hydraulic loading rate. The amount of water applied to a given treatment process, typically expressed as volume per unit time or volume per unit time per unit surface area ($m^3/m^2/d = m/d$).
HRT	Hydraulic retention time. The average length of time that a soluble compound remains in a system (such as a tank or filter). Its influence is determined by the volume of the system and flow rate of the soluble compound ($m^3/(m^3/d) = d$).
Macrophytes	Large aquatic plants visible to the naked eye. Their roots and differentiated tissues may be emergent (cattails, bulrushes, reeds, wild rice), submergent (water milfoil, bladderwort) or floating (duckweed, lily pads).
Indicator	A chemical or biological parameter used to indicate the possible presence of other contaminants. The presence of faecal coliform in an aquatic system indicates a contamination by faecal matter.
LAS	Linear alkylbenzenesulfonate (LAS) is the most widespread anionic surfactant used in domestic and commercial detergent formulations, primarily in laundry detergents and cleaning products. LAS, derived from petroleum bi-products, is quite rapidly degraded aerobically, but only very slowly or not at all under anaerobic conditions.
MBAS	Methylene blue active substances. Indicate the presence of detergents (anionic surfactants) in a sample (in mg/l). When methylene blue dye reacts with synthetic anionic detergent compounds, the solution of this substance will turn blue. In wastewater, LAS amounts to about 75% of the MBAS.
Microorganisms	Neither plant nor animal, but small, simple unicellular or multicellular organisms such as protozoa, algae, fungi, viruses, and bacteria.

Mulch	In agriculture and gardening, mulch is a protective soil cover primarily used to modify the effects of climatic conditions, to block the loss of moisture and to prevent the growth of weeds. A variety of materials, such as organic residues (e.g. grass clippings, leaves, hay, straw, sawdust, wood chips) and compost, are the most common, however, gravel, stones or plastic mulch are also applied.
Nitrification	Aerobic process in which bacteria transform ammonia and organic nitrogen in wastewater into oxidised nitrogen (usually nitrate), yielding energy for decomposing organisms. Nitrification is a process of nitrogen compound oxidation (i.e. loss of electrons from the nitrogen atom to the oxygen atoms): 1. $NH_3 + O_2 \rightarrow NO_2^-$ (nitrite) $+ 3H^+ + 2e^-$ 2. $NO_2^- + H_2O \rightarrow NO_3^-$ (nitrate) $+ 2H^+ + 2e^-$
Nutrient	Essential chemical elements and compounds (mainly nitrogen, phosphorus, potassium) needed for plant and animal growth. Excessive amounts of nutrients in water can cause eutrophication (degradation of water quality and growth of excessive algae). Some nutrients can be toxic at high concentrations.
O&G	Oil and grease (often indicated in mg/l). In wastewater, a water insoluble group of substances (including fats, waxes, free fatty acids, calcium and magnesium soaps, mineral oils, and certain other non-fatty materials) that can be removed by natural flotation skimming.
OLR	Organic loading rate. Amount of organic material, typically measured as BOD, applied to a given treatment process. Expressed as weight per unit time and per unit surface area (g BOD/m^2/d) or per unit volume (g BOD/m^3/d).
Pathogen	Infectious biological agent (bacteria, protozoa, fungi, parasites, viruses) causing disease or illness to its host.
pH	A logarithmic scale determining whether a solution is acid, neutral or basic, and derived from the number of hydrogen ions present. The pH scale commonly in use ranges from 0 to 14, where 7 indicates a neutral solution, less than 7 an acidic one and more than 7 a basic solution.
POP	Persistent organic pollutants. Chemical substances persisting in the environment, bioaccumulating in the food chain and posing adverse effects on human health, animals and the environment. This group of priority pollutants comprise pesticides (such as DDT), pharmaceuticals, hormones, industrial chemicals (such as polychlorinated biphenyls, PCBs) and unintentional by-products of industrial processes (such as dioxins and furans).
PO_4-P	Phosphate, the naturally occurring form of the element phosphorus.
ppm	Parts per million-unit. One ppm is one unit weight of solute per million unit weight of solution. In water analysis, 1 ppm is equivalent to 1 mg/l.
Predation	Killing and/or consumption of living organisms by other living organisms.
Protozoa	Single-celled, eukaryotic microorganisms without cell walls measuring no more than 5–1000 µm in size (like amoeba). Some protozoa can cause disease in humans. Protozoa form cysts whose specialised cells like eggs are extremely resistant to chlorine. Protozoa cannot be effectively killed by chlorine and must be removed by filtration.

Q	Flow (expressed in volume units per time units, e.g. m^3/s or m^3/d).
Reverse osmosis	A membrane process in which solutions of two different concentrations are separated by a semi-permeable membrane. An applied pressure gradient greater than the osmotic pressure ensures flow from the more concentrated to the less concentrated solution.
SAR	Sodium absorption ratio. Measure of the relative proportion of sodium ions (Na^+) in a water sample to those of calcium (Ca^{++}) and magnesium (Mg^{++}). SAR is used as indicator of the effect of sodium in water, on soil and crops (sodium can be highly toxic for plants at high concentration).
Screening	Use of screens to remove coarse solids from water.
Sedimentation	Settling by gravity of solid particles in a liquid system. Also called settling.
Sewer	An underground pipe or open channel in a sewage system for carrying water or sewage to a treatment system (ideally) before disposal.
Surfactants	Organic compounds with a hydrophilic (attracted by water) head and a hydrophobic (repelled by water) end. Surfactants reduce the surface tension of water by adsorbing at the air-water interface. They also reduce the interfacial tension between oil and water by adsorbing at the liquid-liquid interface. Surfactants are the main components of cleaning products.
TDS	Total dissolved solids. The sum of all dissolved colloidal and suspended solids (volatile and non-volatile) in a liquid. Any particle passing a 1.2-µm filter is defined as dissolved.
TKN	Total Kjedahl nitrogen (mg/l). The sum of organic nitrogen and ammonia. High measurements of TKN typically result from sewage and manure discharges to aquatic systems.
TN	Total nitrogen (mg/l). TN = TKN (ammonia + organic nitrogen) + NO_2^- + NO_3^-.
TP	Total phosphorus (mg/l). Total phosphorus includes the amount of phosphorus in dissolved (reactive) and particle form. Phosphorous is a nutrient essential to the growth of organisms, and is commonly the limiting factor in the primary productivity of surface water. Wastewater is a typical source of phosphorus possibly contributing to the eutrophication of surface waters.
TS	Total solids. Weight of all the solids in a liquid, including dissolved, suspended and filterable solids per unit volume of water. TS is usually determined by evaporation.
TSS	Total suspended solids. Amount of insoluble solids floating and suspended in wastewater. They are determined by filtration or centrifugation followed by drying and expressed in mg/l.
Turbidity	Measure of the amount of material suspended in water and indicated as NTU (nephelometric turbidity units). An increase in water turbidity decreases the amount of light that penetrates the water column. High levels of turbidity are harmful to the aquatic life.
Virus	A non-cellular infectious agent that replicates within cells of living hosts. Viruses consist of nucleic acid (DNA or RNA) wrapped in a thin coat of protein; some animal viruses are also surrounded by membrane. Inside the infected cell, the virus uses the synthetic capability of the host to produce progeny virus.

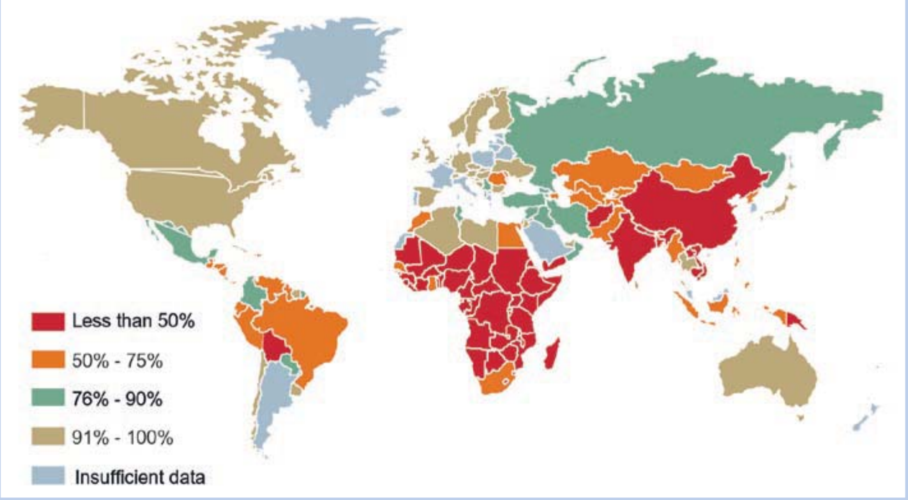
1. Rationale for this Report

Why is a publication on this topic necessary?

Sanitation, usually defined as “the means of collecting and disposing of excreta and community liquid waste in a hygienic way so as not to endanger the health of individuals and the community as a whole” (WHO, 1987), is given high priority in matters relating to public health protection and pollution prevention.

The approach of centralised, water-based sewer systems was applied to attain considerable public health improvement in urban areas of industrialised countries. This approach was generally perceived as the right approach to adopt also in developing countries. However, the cost of such a sewer-based system with its required piped water supply prevented its application in most poor communities of low and middle-income countries. On-site sanitation remained the only appropriate alternative to providing a hygienically safe environment to poor communities. Since safe disposal of human excreta was rightly perceived as one of the most important public health protection measures, many development projects focused on the area-wide implementation of latrines, which achieved mitigated success. Despite the efforts undertaken so far, 2.6 billion people still lack access to improved sanitation facilities (see Figure 1-1).

Figure 1-1: Population using improved sanitation in 2002 (United Nations, 2005)



Water scarcity, poor water quality and water-related disasters are the three main concerns related to current and future water resources (UNESCO, 2003). Improving water quality and mitigating water scarcity are closely linked to greywater management. Reuse of treated greywater, generated by bath, laundry and kitchen, and amounting to two thirds of the total domestic wastewater produced, could save the limited sources of freshwater. Even if reuse of greywater is not considered a priority (for reasons of abundance of freshwater resources or cultural barriers), appropriate greywater treatment prior to its discharge could significantly reduce water pollution. Greywater contributes to half of the total organic load and up to two thirds of the phosphorous load in domestic wastewater. Treating greywater before its discharge into aquatic systems will, therefore, significantly contribute to protecting the environment and improving public health and living conditions of communities relying on these freshwater sources, be it for

Table 1-1: Percentage of income spent on food by low-income residents in selected cities (Akinbamijo et al., 2002)

City	*Income spent on food*
Bangkok, Thailand	60%
La Floride, Chile	50%
Nairobi, Kenia	40–50%
Dar es Salaam, Tanzania	85%
Kinshasa, Congo	60%
Bamako, Mali	30–60%
Urban USA	9–15%

drinking, domestic, recreation or irrigation purposes.

The economic value of greywater from households and small communities is often underestimated. In terms of nutrients, greywater may largely replace commercial fertilisers. For many low-income households, food is the main total daily cost factor (see Table 1-1). Greywater-irrigated gardens and crop trees develop favourably if certain irrigation rules are followed. Use of treated greywater for irrigation thus contributes to a more balanced food diet and relieves the household budget. The section on *Reuse in irrigation* provides a more detailed account on greywater reuse.

Projects aiming to increase the sanitation coverage in low and middle-income countries typically give low priority to proper management of greywater. It is often assumed that by implementing latrines the issue of inadequate sanitation is extensively mitigated. Greywater is then still discharged without adequate treatment into the environment, be it through open drains, sewer systems or in an uncontrolled way.

Several reasons are assumed to be responsible for not considering greywater reuse in household sanitation projects:

- **Lack of awareness:** Policy-makers, planners, engineers, municipal officers, or even house owners may be unaware of the potential as well as the economic and environmental value of adequate greywater management.
- **Information centred on high-income countries:** Lack of awareness is aggravated by a lack of adequate and easily available documentation providing practical information. Although publications on greywater management are available, they are strongly focused on applications in high-income countries, which, in most cases, cannot be transferred to low and middle-income countries.
- **Lack of documented success stories in low and middle-income countries:** There is only little documented knowledge and experience on greywater management in low and middle-income countries. Some examples of low-cost greywater treatment systems for households or neighbourhoods have spread by word of mouth. These cases are, however, not documented in a way as to allow them to be replicated or adapted to other sites.
- **Lack of hands-on guidance:** Existing articles on greywater management concepts and treatment systems for a low-income country context are primarily written for a scientific community. Such articles are neither readily accessible nor easily understood by non-scientists. This situation discourages potentially motivated and interested non-scientific communities or institutions.

What is the purpose of this publication?

This publication is not a plea to implement greywater management systems unconditionally and at all costs but aims at providing a comprehensive description of the issues related to greywater and its appropriate management. It solely illustrates the availability of sound and sustainable greywater management systems for households and neighbourhoods. In some specific contexts (such as in highly populated urban areas), management of greywater jointly with other domestic wastewater sources may be economically more appropriate, e.g. use of simplified sewer networks and treatment of the collected wastewater in a large treatment facility, such as in stabilisation ponds or constructed wetlands.

Chapter 2 presents an overview of the common greywater management or non-management practices and problems. Chapter 3 describes the characteristics of greywater and factors influencing these characteristics. Both greywater composition and volume vary greatly according to climatic region, cultural habits or social status. Chapter 4 aims at providing an overview of potential greywater management options to inform and support interested persons in their choice of the most appropriate approach for their specific situation. Management and treatment components are described in a system perspective, presenting suitable source control measures in the household, technical solutions for primary and secondary treatment as well as disposal and reuse options for treated greywater, such as discharge into aquatic systems, groundwater recharge or reuse in irrigation.

Chapter 5 illustrates innovative greywater management systems based on different case studies worldwide. The case study documentation includes information on design, costs as well as operation and maintenance requirements. However, this chapter not only presents success stories, but also highlights problems leading to system failures, and suggests measures to prevent operational problems. Reference to relevant literature and contact persons/institutions is provided whenever possible.

The planning of greywater management strategies must be seen as one component of a comprehensive environmental sanitation planning framework, comprising aspects such as water supply, stormwater drainage, excreta, greywater and solid waste management as well as hygiene education. The Household-Centred Environmental Sanitation Approach (HCES) is a suitable tool allowing participatory planning of environmental sanitation projects, as it places the household and its neighbourhood at the core of the planning process. The approach, based on effective household demand, emphasises resource conservation and reuse to reduce waste disposal. The approach is presented in Chapter 6.

Who are the targeted readers of this publication?

Main focus of this publication is placed on describing and illustrating a wide range of greywater management options to facilitate informed decision-making when confronted with the task of developing a sanitation concept. This document is not a design manual for greywater management systems, although design principles and construction plans of treatment chains are provided whenever possible.

The report mainly aims at sensitising and encouraging national, regional and municipal water and environmental sanitation authorities and agencies to integrate greywater management into their development policies and programmes. NGOs and CBOs working in the field of environmental sanitation are invited to include greywater management into their neighbourhood upgrading projects. This report will hopefully support them in their efforts and provide assistance to house owners during pre-selection of greywater management schemes adapted to their specific requirements and prior to soliciting expert advice.

2. Definition and Common Practices

Greywater sources and their properties

Apart from toilet wastewater, the term greywater is used when designating all the wastewater produced in a household. Sullage, grey wastewater and light wastewater are terms also used. Greywater is wastewater from baths, showers, hand basins, washing machines and dishwashers, laundries and kitchen sinks (e.g. Dixon et al., 1999; Eriksson et al., 2002; Ledin et al., 2001; Otterpohl et al., 1997; Ottoson and Stenstrom, 2003). Although some authors exclude wastewater originating from kitchen sinks given its high content of oil and food particles (Al-Jayyousi, 2003; Christova Boal et al., 1996; Little, 2002; Wilderer, 2004), this document also classifies it as greywater, but clearly indicates that greywater from kitchen sinks requires special attention.

Since greywater is a reflection of household activities, its main characteristics strongly depend on factors such as cultural habits, living standard, household demography, type of household chemicals used etc. (see Chapter 3). Nonetheless, specific greywater sources have specific characteristics as summarised below:

Kitchen	Kitchen greywater contains food residues, high amounts of oil and fat, including dishwashing detergents. In addition, it occasionally contains drain cleaners and bleach. Kitchen greywater is high in nutrients and suspended solids. Dishwasher greywater may be very alkaline (due to builders), show high suspended solids and salt concentrations.
Bathroom	Bathroom greywater is regarded as the least contaminated greywater source within a household. It contains soaps, shampoos, toothpaste, and other body care products. Bathroom greywater also contains shaving waste, skin, hair, body-fats, lint, and traces of urine and faeces. Greywater originating from shower and bath may thus be contaminated with pathogenic microorganisms.
Laundry	Laundry greywater contains high concentrations of chemicals from soap powders (such as sodium, phosphorous, surfactants, nitrogen) as well as bleaches, suspended solids and possibly oils, paints, solvents, and non-biodegradable fibres from clothing. Laundry greywater can contain high amounts of pathogens when nappies are washed.

Practices and risks related to greywater management worldwide

Compared to other aspects of environmental sanitation, such as toilet wastewater or solid waste, greywater traditionally receives the least attention. In urban and peri-urban areas of low and middle-income countries, greywater is most often discharged untreated into stormwater drains or sewers, provided they exist, from where it mainly flows into aquatic systems. This leads to oxygen depletion, increased turbidity, eutrophication as well as microbial and chemical contamination of the aquatic

Photo 2-1: Greywater discharge in Hanoi (photo: Sandec)

systems. In Hanoi for example, greywater is discharged untreated directly into street drains (see Photo 2-1) that flow into rivers. Rivers in the city of Hanoi can in fact be compared to open sewers.

Where drainage and sewer systems are missing, greywater is often discharged onto streets or open ground, thereby leading to negative impacts on public health, local economy and living conditions as exemplified by Djenné, Mali. Implementation of a water supply network in the 1990s, which lacked a strategic concept and project for the safe disposal of greywater, has led to a serious deterioration of the streets (see Photo 2-2). Outbreaks of water-borne diseases were reported (due to mosquito breeding in stagnant water) and complaints by the citizens about odour nuisance and aesthetic deterioration. Even transport costs of goods as well as transport period increased significantly as a result of deteriorating street conditions.

Risks related to inadequate greywater reuse

Reuse of greywater for irrigating home gardens or agricultural land is widespread, especially in regions with water scarcity or high water prices such as the Middle East, parts of Africa and Latin America. Greywater is thus perceived and recognised as a valuable resource, but potential drawbacks of such practices are often not taken into account. Untreated greywater, although less contaminated than other wastewater sources, does contain pathogens, salts, solid particles, fat, oil, and chemicals. If reuse practices are inappropriate, these substances may potentially have a negative effect on human health, soil and groundwater quality.

Photo 2-2: Djenné, Mali – The uncontrolled discharge of greywater has led to a deterioration of the streets, disease outbreaks, odour problems, and increased transport costs (left photo). The introduction of simple greywater infiltration systems as seen in the right photo on the wall, significantly improved the living conditions (photos: left, Alderlieste M.C., right, Langeveld J.G.)

Pathogen ingestion through consumption of raw vegetables, inadequately irrigated with untreated greywater, is an important disease transmission route. The risk can be reduced by improving irrigation techniques (see *Irrigation systems*) and through awareness raising and sensitisation campaigns of farmers and house owners. By respecting a few rules of thumb, this risk of groundwater contamination can be minimised (see *Groundwater pollution risk*). Inadequate reuse of greywater can also have detrimental effects on soil. Suspended solids, colloids and excessive discharge of surfactants can clog soil pores and change the hydro-chemical characteristics of soils. Use of saline and sodium-rich greywater for irrigation over a long period can cause complete and irreversible salinisation and deterioration of the topsoil, especially in arid regions with high evaporation rates (discussed in *Reuse in irrigation*). Irrigation with greywater must thus be adapted to local conditions, taking into account climate, soil characteristics, water demand of plants, and greywater characteristics. Irrigation with untreated greywater is not recommended.

Japan, North America and Australia rank globally highest in decentralised greywater management. In areas with low population densities, such as throughout North America and Australia, greywater reuse is common practice due to water scarcity and lack of centralised treatment facilities.

Economic value of greywater

Greywater should be regarded as a valuable resource and not as a waste. Despite the described inadequate greywater management risks, greywater has, nevertheless, a great potential to reduce the water stress currently faced by regions in the world. Greywater reuse is an effective measure for saving water on the domestic level. Where water is scarce and expensive, greywater reuse may lead to considerable economic benefits. In Amman, Jordan, an extensive survey of urban farmers revealed that 40% use greywater to irrigate their gardens (DOS, 2001). Households treating and reusing greywater locally may reach an average annual benefit of USD 376, accounted for by increased product yields, as well as reduced water and fertiliser costs (Faruqui et al., 2001). In Cyprus, a study on greywater reuse indicates a 36% reduction in water bills when household greywater is reused (Redwood, 2004). In Israel, the return on investment of a household greywater management scheme (comprising a recycled vertical-flow constructed wetland and a garden irrigation system) is approximately three years and regarded as economically attractive (Gross et al., 2006a).

3. Greywater Characteristics

How much greywater is produced?

The generated amount of greywater greatly varies as a function of the dynamics of the household. It is influenced by factors such as existing water supply service and infrastructure, number of household members, age distribution, lifestyle characteristics, typical water usage patterns etc. Water consumption in low-income areas with water scarcity and rudimentary forms of water supply (e.g. community taps or wells) can be as low as 20–30 litres per person and day. Greywater volumes are even lower in regions where rivers or lakes are used for personal hygiene and for washing clothes and kitchen utensils. A household member in a richer area with piped water may, however, generate several hundred litres per day (see Table 3-1). Literature data indicates a typical greywater amount of 90–120 l/p/d with piped water in houses without water shortage. This figure drops significantly in areas where water scarcity and lower levels of water supply prevail.

Table 3-1: Domestic greywater volumes in selected countries

	Vietnam [1] *l/p/d*	*Mali* [2] *l/p/d*	*South-Africa* [3] *l/p/d*	*Jordan* [4] *l/p/d*	*Israel* [5] *l/p/d*	*Nepal* [6] *l/p/d*	*Switzerland* [7] *l/p/d*	*Australia* [8] *l/p/d*	*Malaysia* [9] *l/p/d*
Total	80–110	30	20	50	98	72	110	113	225
Kitchen	15–20	–	–	–	30	–	28	17	–
Shower, bath	30–60	–	–	–	55	–	52	62	–
Laundry	15–30	–	–	–	13	–	30	34	–
Water source	In-house taps	Single tap	Community tap/well	In-house taps	In-house taps	In-house taps	In-house taps	In-house taps	In-house taps

Note: These figures do not reflect national averages but relate to specific cases with specific settings. Type of water supply and living standards appear to be more decisive than the location.

1: Busser (2006); 2: Alderlieste and Langeveld (2005); 3: Adendorff and Stimie (2005); 4: Faruqui and Al-Jayyousi (2002); 5: Friedler (2004); 6: Shrestha (1999); 7: Helvetas (2005); 8: www.greenhouse.gov.au; 9: Martin (2005).

Siegrist et al. (1976) estimated that 65% of all wastewater generated in a household is greywater. In households with dry latrines, the greywater fraction of the total wastewater production may even reach 100%. The bathroom contributes up to 60% of the total greywater produced; kitchen greywater represents generally the smallest fraction. Greywater characteristics are closely related to the volumes produced. Where little water is used, high strength greywater exhibits similar characteristics as conventional domestic wastewater. In places where water consumption is high, the volume of greywater is greater but more diluted.

Greywater composition

The composition of greywater mainly depends on quality and type of available water supply and household activities. Cooking habits as well as amount and type of soap and detergent used significantly determine the level of contamination. Greywater may contain soaps, food particles, grease, oil, lint, hair, pathogens, and traces of other chemicals (Crites and Tchobanoglous, 1998). Greywater also contains high levels of detergents. These contain surfactants (surface active agents), builders, bleaches, enzymes, preservatives, solvents, fillers etc. (Ledin et al., 2001). A number of studies have been conducted to characterise domestic greywater (e.g. Del Porto and Steinfeld, 2000; Eriksson et al., 2003; Eriksson et al., 2002; Ledin et al., 2001; Siegrist et al., 1976), however, these studies all focus on European and North American countries. Only limited information is available on typical characteristics of greywater in low and middle-income countries. The following section aims at illustrating selected physical, chemical and microbiological parameters of domestic greywater, which are believed to be relevant for the design of appropriate management strategies, with focus on low and middle-income countries.

Table 3-2: Domestic greywater characteristics in selected countries

	Costa Rica [1]	***Palestine*** [2]	***Israel*** [3]	***Israel*** [4]	***Nepal*** [5]	***Malaysia*** [6]	***Jordan*** [7]
Q (l/p/d)	107	≈ 50	≈ 100	≈ 100	72	≈ 225	≈ 30
pH	–	6.7–8.35	6.5–8.2	6.3–7.0	–	–	6.7– >8.35
EC (µS/cm)	≈ 400	1585	1040–2721	1000–1300	–	–	475–1135
SAR	–	2.3–5.7	–	–	–	–	1.0–6.8
COD (mg/l)	–	1270	822	702–984	411	212	–
BOD (mg/l)	167	590	477	280–688	200	129	275–2287
COD/BOD	–	2.15	1.72	1.80	2.06	1.64	–
TSS (mg/l)	–	1396	330	85–285	98	76	316
TN (mg/l)	–	–	–	25–45	–	37	–
NH_4-N (mg/l)	–	3.8	1.6	0.1–0.5	13.3	13	–
TP (mg/l)	–	–	–	17–27	–	2.4	–
PO_4-P (mg/l)	16	4.4	126	–	3.1	–	–
Na^+ (mg/l)	–	87–248	199	–	–	–	–
MBAS (mg/l)	–	–	37	4.7–15.6	–	–	45–170
Boron (mg/l)	–	–	–	1.4–1.7	–	–	–
Faecal coli (cfu/100ml)	$1.5–4.6 \times 10^8$	3.1×10^4	2.5×10^6	5×10^5	–	–	1.0×10^7
O&G (mg/l)	–	–	193	–	–	190	7–230

Note: These figures do not reflect national averages but relate to specific cases with specific settings. Type of water supply and living standards appear to be more decisive than the location.

1: Dallas et al. (2004); 2: Burnat and Mahmoud (2005); 3: Friedler (2004); 4: Gross et al. (2006a); 5: Shrestha et al. (2001); 6: Martin (2005); 7: Al-Jayyousi (2003), Faruqui and Al-Jayyousi (2002); Bino (2004).

Physical characteristics of greywater

Temperature

Greywater temperature is often higher than that of the water supply and varies within a range of 18–30 °C. These rather high temperatures are attributed to the use of warm water for personal hygiene and discharge of cooking water. These temperatures are not critical for biological treatment processes (aerobic and anaerobic digestion occurs within a range of 15–50 °C, with an optimal range of 25–35 °C) (Crites and Tchobanoglous, 1998). On the other hand, higher temperatures can cause increased bacterial growth and decreased $CaCO_3$ solubility, causing precipitation in storage tanks or piping systems.

Suspended solids

Food, oil and soil particles from kitchen sinks, or hair and fibres from laundry can lead to high solids content in greywater. These particles and colloids cause turbidity in the water and may even result in physical clogging of pipes, pumps and filters used in treatment processes. Especially non-biodegradable fibres from clothing (polyester, nylon, polyethylene), powdered detergents and soaps, as well as colloids are the main reasons for physical clogging. Suspended solids concentrations in greywater range from 50–300 mg/l, but can be as high as 1,500 mg/l in isolated cases (Del Porto and Steinfeld, 1999). The highest concentrations of suspended solids are typically found in kitchen and laundry greywater. Suspended solids concentrations strongly depend on the amount of water used. Observations in Nepal, Malaysia, Israel, Vietnam, and the United States revealed average suspended solids loads of 10–30 g/p/d (see Table 3-3), contributing to 25–35% of the total daily suspended solids load in domestic wastewater, including toilet wastewater (Ledin et al., 2001).

Chemical characteristics of greywater

The chemical parameters of relevance are hydrochemical parameters such as pH, alkalinity, electrical conductivity, sodium adsorption ratio (SAR), biological and chemical oxygen demand (BOD, COD), nutrient content (nitrogen, phosphorous), and problematic substances such as heavy metals, disinfectants, bleach, surfactants or organic pollutants in detergents.

pH and alkalinity

The pH indicates whether a liquid is acidic or basic. For easier treatment and to avoid negative impacts on soil and plants when reused, greywater should show a pH in the range of 6.5–8.4 (FAO, 1985; USEPA, 2004). The pH value of greywater, which strongly depends on the pH value of the water supply, usually lies within this optimal range. However, Christova Boal et al. (1996) observed 9.3–10 pH values in laundry greywater, partly as a result of the sodium hydroxide-based soaps and bleach used. Greywater with high pH values alone are not problematic when applied as irrigation water, but the combination of high pH and high alkalinity, a measure of the water's ability to neutralise acidity, is of particular concern. Greywater alkalinity (indicated as $CaCO_3$ concentrations) is usually within a range of 20–340 mg/l (Ledin et al., 2001), with highest levels observed in laundry and kitchen greywater.

Salinity and Sodium Adsorption Ratio (SAR)

Greywater contains also salts, indicated as electrical conductivity (EC, in µS/cm or dS/m). EC measures salinity of all the ions dissolved in greywater, including negatively charged ions (e.g. Cl^-, NO_3^-) and positively charged ions (e.g. Ca^{++}, Na^+). The most common salt is sodium chloride – the conventional table salt. Other important sources of salts are sodium-based soaps, nitrates and phosphates present in detergents and washing powders. The electrical conductivity (EC) of greywater is typically in the range of 300–1,500 µS/cm, but can be as high as 2,700 µS/cm, as observed in Palestine (Burnat and Mahmoud, 2005). Salinity of greywater is normally not problematic, but can become a hazard when greywater is reused for irrigation. High EC of irrigation water can considerably reduce yield potential. This problem can be overcome by choosing more salt-tolerant plants. Further information on salt in greywater and its effects on greywater reuse are given in Grattan (2002) and the section on *Reuse in irrigation*.

Aside from the effects on the immediate crop, there is a long-term impact of salt loading of the soil. Use of saline greywater for irrigation over a longer period may lead to increased salinisation of the topsoil. Such problems can occur especially when clay and loamy soils with low percolation rates are irrigated with saline greywater and in arid regions with high evaporation rates. Permissible EC limits of greywater are strongly dependent on soil characteristics; however, the suggested limits differ in the literature reviewed. According to Grattan (2002), EC below 1,300 µS/cm should normally not cause problems, whereas irrigation with more saline greywater (EC exceeding 1,300 µS/cm) requires special precautions (use of salt-tolerant plants, well-functioning drainage etc.). Bauder et al. (2004) suggest conductivity limits for irrigation water of 3,000 µS/cm, with optimal conductivity below 750 µS/cm.

While EC determines all soluble salts in greywater, the sodium hazard is defined separately due to its specific detrimental effects on the soil's physical properties in the event of greywater infiltration or reuse in irrigation. The sodium hazard is indicated as sodium adsorption ratio (SAR), which quantifies the proportion of sodium (Na^+) to calcium (Ca^{++}) and magnesium (Mg^{++}). SAR values of greywater are within a typical range of 2–10, depending mainly on the laundry powder used by the household (Gross et al., 2005; Bino, 2004). Sodium salts are utilised as filler in laundry detergents. In laundry wastewater, sodium concentrations can be as high as 530 mg/l (Friedler, 2004), with SAR exceeding 100 for some powder detergents (Patterson, 2001). Sodium is of special concern when applied to loamy soils poor in calcite or calcium/magnesium. High SAR may result in the degradation of well-structured soils (dispersion of soil clay minerals), thus limiting aeration and water permeability. The sodium hazard can best be avoided by using low sodium products, such as liquid laundry detergents (see section *Source control*). While European and North American countries recommend irrigation water with SAR < 15 for sensitive plants (FAO, 1985), Patterson (1997) observed hydraulic conductivity problems in Australian soils irrigated with a SAR > 3 wastewater.

Biological and chemical oxygen demand (BOD, COD)

The biological and chemical oxygen demand (BOD, COD) are parameters to measure the organic pollution in water. COD describes the amount of oxygen required to oxidise all organic matter found in greywater. BOD describes biological oxidation through bacteria within a certain time span (normally 5 days (BOD_5)). The main groups of organic substances found in wastewater comprise proteins (mainly from food), carbohydrates (such as sugar or cellulose), fats and oils as well as different synthetic organic molecules such as surfactants that are not easily biodegradable. Discharging greywater with high BOD and COD concentrations into surface water results in oxygen depletion, which is then no longer available for aquatic life.

The BOD loads observed in greywater in different countries amount to 20–50 g/p/d (Friedler, 2004; Mara, 2003). BOD and COD concentrations in greywater strongly depend on the amount of water and products used in the household (especially detergents, soaps, oils and fats). Where water consumption is relatively low, BOD and COD concentrations are high. Dallas et al. (2004) observed average BOD_5 of 167 mg/l in mixed greywater in Costa Rica with a 107 l/p/d water consumption. In Palestine, where the greywater flow from comparable sources (bath, kitchen, laundry) attains only 40 l/p/d, average BOD was as high as 590 mg/l and exceeded 2,000 mg/l in isolated cases (Burnat and Mahmoud, 2005).

The COD/BOD ratio is a good indicator of greywater biodegradability. A COD/BOD ratio below 2–2.5 indicates easily degradable wastewater. While greywater is generally considered easily biodegradable with BOD accounting for up to 90% of the ultimate oxygen demand (Del Porto and Steinfeld, 2000), different studies indicate low greywater biodegradability with COD/BOD ratios of 2.9–3.6 (Al-Jayyousi, 2003; Jefferson et al., 2004). This is attributed to the fact that biodegradability of greywater depends primarily on the type of synthetic surfactants used in detergents and on the amount of oil and fat present. While Western countries have banned and replaced non-biodegradable and, thus, troublesome surfactants by biodegradable detergents (e.g. ABS replaced by LAS) (Tchobanoglous, 1991), such resistant products may still be used (e.g. in powdered laundry detergents) in low and middle-income countries. Greywater data collected in low and middle-income countries indicate COD/BOD ratios within a range of 1.6–2.9, with maximum rates in laundry and kitchen wastewater (see Table 3-2).

Nutrients (nitrogen, phosphorous)

Greywater normally contains low levels of nutrients compared to toilet wastewater. Nonetheless, nutrients such as nitrogen and phosphorous are important parameters given their fertilising value for plants, their relevance for natural treatment processes and their potential negative impact on the aquatic environment. Especially the high phosphorous contents sometimes observed in greywater can lead to problems such as algae growth in receiving water.

Levels of nitrogen in greywater are relatively low (urine being the main nitrogen contributor to domestic wastewater). Kitchen wastewater is the main source of nitrogen in domestic greywater, the lowest nitrogen levels are generally observed in bathroom and laundry greywater. Nitrogen in greywater originates from ammonia and ammonia-containing cleansing products as well as from proteins in meats, vegetables, protein-containing shampoos, and other household products (Del Porto and Steinfeld, 2000). In some special cases, even the water supply can be an important source of ammonium nitrogen. This was observed in Hanoi (Vietnam) where NH_4-N concentrations as high as 25 mg/l were measured, originating from mineralisation of peat, an abundant organic material in Hanoi's groundwater aquifers (Hong Anh et al., 2003). Typical values of nitrogen in mixed household greywater are found within a range of 5–50 mg/l (see Table 3-2), with extreme values of 76 mg/l, as observed by Siegrist et al. (1976) in kitchen greywater.

Greywater's nitrogen deficit

Ratios of BOD-to-nitrogen (optimal ratio: 15–30) and nitrogen-to-phosphorous (optimal ratio: 5–10) in greywater are not ideal for optimal bacterial growth and microbial breakdown in biological treatment processes (Sasse, 1998). Low nitrogen limits microbial processes, thus hindering degradation of organic matter in biological treatment processes. When untreated greywater is applied to soils (e.g. in infiltration trenches or for irrigation purposes), undigested organic matter, such as fats, oils, soaps, detergents etc, may accumulate and clog the soil or infiltration beds (Del Porto and Steinfeld, 2000). This risk must be taken into account when implementing natural greywater treatment and disposal/reuse systems. Frequent monitoring and adjustments (e.g. addition of nitrogen from alternative sources such as urine) are a precondition for a satisfactory long-term performance of such systems.

In countries where phosphorous-containing detergents have not been banned, dishwashing and laundry detergents are the main sources of phosphorous in greywater. Average phosphorous concentrations are typically found within a range of 4–14 mg/l in regions where non-phosphorous detergents are used (Eriksson et al., 2002). However, they can be as high as 45–280 mg/l in households where phosphorous detergents are utilised, as observed in Thailand (Schouw et al., 2002) or Israel (Friedler, 2004).

Microbial characteristics of greywater

Greywater may pose a health risk given its contamination with pathogens. Information on the presence of pathogenic microorganisms in greywater in low and middle-income countries is scarce. However, pathogens, such as viruses, bacteria, protozoa, and intestinal parasites, are assumed to be present in partly high concentrations. These pathogens originate from excreta of infected persons. They can end up in greywater through hand washing after toilet use, washing of babies and children after defecation, diaper changes or diaper washing. Some pathogens may also enter the greywater system through washing of vegetables and raw meat, however, pathogens of faecal origin pose the main health risks (Ledin et al., 2001).

Faecal contamination of greywater, traditionally expressed by faecal indicators such as faecal coliforms, strongly depends on the age distribution of the household members. High contamination must be expected where babies and young children are present. Average concentrations are reported to be around 10^3–10^6 cfu/100 ml (see Table 3-2). However, contamination can be as high as 10^7–10^8 cfu/100 ml in laundry or shower greywater, as observed in Costa Rica or Jordan (Al-Jayyousi, 2003; Dallas et al., 2004). Since greywater may contain high loads of easily degradable organic compounds, re-growth of enteric bacteria, such as the faecal indicators, are favoured in greywater systems (Ottoson and Stenstrom, 2003; WHO, 2005). Hence, bacterial indicator numbers may lead to an overestimation of faecal loads and thus risk.

Oil and grease (O&G)

Greywater may contain significant amounts of fat such as oil and grease (O&G) originating mainly from kitchen sinks and dishwashers (e.g. cooking grease, vegetable oil, food grease etc.). Important O&G concentrations can also be observed in bathroom and laundry greywater, with O&G concentrations ranging between 37 and 78 mg/l and 8–35 mg/l, respectively (Christova Boal et al., 1996). The O&G content of kitchen greywater strongly depends on the cooking and disposal habits of the household. No data was found on O&G concentrations specific to kitchen greywater, but values as high as 230 mg/l were observed in Jordan for mixed greywater (Al-Jayyousi, 2003), while Crites and Tchobanglous (1998) observed O&G concentrations ranging between 1,000 and 2,000 mg/l in restaurant wastewater. As soon as greywater cools down, grease and fat congeal and can cause mats on the surface of settling tanks, on the interior of pipes and other surfaces. This may cause a shutdown of treatment and disposal units such as infiltration trenches or irrigation fields. It is therefore important that O&G concentrations are maintained at acceptable levels (< 30 mg/l, (Crites and Tchobanoglous, 1998)) to avoid problems with downstream treatment and disposal systems.

Surfactants and other household chemicals

Surfactants are the main components of household cleaning products. Surfactants, also called surface-active agents, are organic chemicals altering the properties of water. They consist of a hydrophilic head and a hydrophobic tail. By lowering the surface tension of water, they allow the cleaning solution to wet a surface (e.g. clothes, dishes etc) more rapidly. They also emulsify oily stains and keep them dispersed and suspended so that they do not settle back on the surface. The most common surfactants used in household cleansing chemicals are LAS (linear alkylbenzene sulfonate), AES (alcohol ether sulphate) and AE (alcohol ethoxylate). While in most Western countries non-biodegradable surfactants have been banned in the 1960s, these environmentally problematic organic chemicals are still used in many developing countries, e.g. Pakistan (Siddiq, 2005) and Jordan (Bino, 2004). Laundry and automatic dishwashing detergents are the main sources of surfactants in greywater; other sources include personal cleansing products and household cleaners. The amount of surfactants present in greywater is strongly dependent on type and amount of detergent used. Studies conducted by Friedler (2004); Gross et al. (2005); Shafran et al. (2005) revealed surfactant concentrations in greywater ranging between 1 and 60 mg/l, and averaging 17–40 mg/l. The highest concentrations were observed in laundry, shower and kitchen sink greywater. A per capita production of mixed surfactants of 3.5–10 g MBAS/p/d seems realistic (Feijtel et al., 1999; Friedler, 2004; Garland et al., 2004).

There are many conflicting literature studies on the fate and impact of surfactants in the natural environment. While most studies indicate full biodegradation of common surfactants in aerobic environments, such as in aerobic treatment systems and unsaturated soil (Garland et al., 2000; Garland et al., 2004; Hatfield Venhuis and Mehrva, 2004; Jensen, 1999; Scott and Jones, 2000), other studies indicate a potential accumulation of surfactants in greywater-irrigated soil, leading to a

Table 3-3: Low, typical (bold) and high BOD, TSS, TP, and TN concentrations as a function of greywater production; typical daily loads in greywater

Daily greywater production	**≈ 200 l**	**≈ 100 l**	**≈ 30–50 l**	**Loads**
BOD (mg/l)	50...**150**...600	100...**250**...500	300...**700**...1500	20–50 g/p/d
TSS (mg/l)	50...**100**...500	50...**150**...500	150...**500**...1500	10–30 g/p/d
TP[a] (mg/l)	1...**10**...50	1...**15**...100	5...**30**...200	0.2–6.0 g/p/d
TN (mg/l)	1...**5**...30	1...**10**...50	1...**20**...80	0.8–3.1 g/p/d
Observed in	USA[1], Malaysia[12]	Vietnam[2], Sweden[3], Canada[4], Israel[5], Nepal[6], Costa Rica[7], Thailand[8]	Jordan[9], Palestine[10], Mali[11]	

[a] *The level of phosphorous in greywater strongly depends on the presence or absence of phosphorous in laundry and dishwasher detergents. High values must be expected where phosphorous-based products are used in the household.*

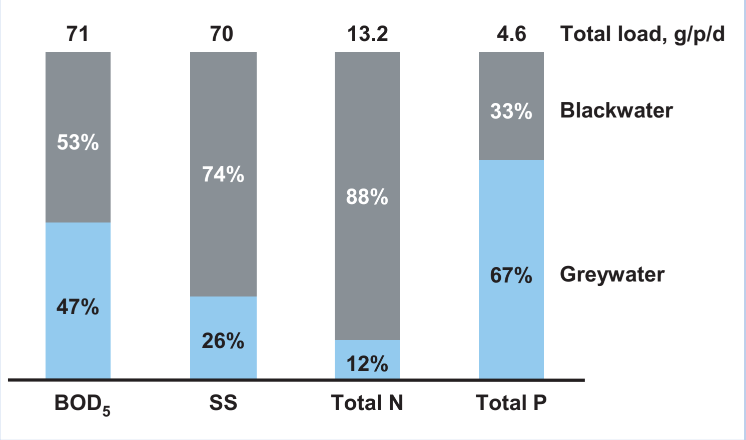
1: Del Porto and Steinfeld (2000); 2: Busser (2006); 3: Gunther (2000); 4: Oasis Design (1994); 5: Friedler (2004); 6: Shrestha et al. (2001); 7: Dallas and Ho (2005); 8: Schouw et al. (2002); 9: Al-Jayyousi (2003); 10: Burnat and Mahmoud (2005); 11: Alderlieste and Langeveld (2005); 12: (Martin, 2005).

reduction in capillary rise and build-up of hydrophobic soils (Doi et al., 2002; Gross et al., 2005).

During greywater irrigation, toxicity problems may occur if boron ions (similarly to sodium ions) are taken up by plants and accumulate to concentrations high enough to cause crop damage or reduced yield. Detergents are the main sources of boron in greywater. Although boron is an essential micronutrient for plants, excessive amounts are toxic. Gross et al. (2005) observed boron concentrations reaching 3 mg/l in laundry greywater. The recommended maximum value for irrigation water amounts to 1.0 mg/l for sensitive crops such as lemon, onion or bean (FAO, 1985).

Bleach, disinfectants and solvents are further substances of concern in greywater. Inhibition of the biological process by bleach begins at concentrations as low as 1.4 ml/l, with quite a substantial inhibition occurring at 3 ml/l. By using environmentally-friendly household chemicals and refraining from pouring hazardous substances (paint, solvents etc.) into the sink, the levels of toxic substances in greywater can be maintained low (Ridderstolpe, 2004). Since many environmentally-friendly detergents are available on the market, the problems with greywater treatment, reuse and disposal systems can be minimised (see section *Source control*).

Figure 3-1: Average pollution loads in greywater compared to total loads in domestic wastewater, as described by Lindstrom (2000)



Even though greywater is less polluted than toilet wastewater, it is an undeniable fact that due to the large volumes of greywater produced, its contribution to the total pollution load in domestic wastewater is considerable. According to different studies, grey-water makes up on average more than half of the BOD load, up to two thirds of the total phosphorous load (where phosphate-containing detergents are used) and one fourth of the total suspended solids load (see Figure 3-1). This clearly reveals the importance of including greywater in sanitation programmes. Focussing only on blackwater will not meet the objective of providing adequate sanitation and reducing public health risks and environmental degradation.

4. Low-Cost Management and Treatment Options

Requirements of greywater management systems in low and middle-income countries

The choice of a greywater management strategy is highly dependent on the end use of the effluent produced (Mara, 2003). Greywater management strategies should therefore be adapted to a specified purpose, such as generating an effluent suitable for agricultural reuse or whose quality allows its safe discharge into inland or coastal waters. The very basic objective of greywater management is to protect public health and the environment in a socio-culturally and economically sustainable manner. Furthermore, greywater should whenever possible be considered as a valuable resource. Management systems should also account for the willingness and ability of users to operate their own system (user-friendliness) and comply with relevant legislation and regulations. The basic objectives of a household or neighbourhood greywater management system can be summarised as follows:

- **Protection of public health:** A greywater management system should create an effective physical barrier between contaminated greywater and user, as well as avoid odour emissions and stagnant water leading to breeding sites for mosquitoes.
- **Protection of the environment:** A greywater management system should prevent eutrophication and pollution of sensitive aquatic systems (surface water, groundwater, drinking water reservoirs) as well as terrestrial systems (irrigated soil).
- **Ensuring soil fertility:** If greywater is reused in irrigation, groundwater recharge or landscaping, appropriate management should minimise short or long-term impacts on soil (soil degradation, clogging, salinisation).
- **Socio-culturally and economically acceptable:** Greywater management systems have to be adapted to the socio-cultural and economic settings of the household or neighbourhood. If waste reuse is culturally not anchored for example, greywater management systems aiming at vegetable garden irrigation are likely to fail.
- **Simple and user-friendly:** Household or neighbourhood greywater management systems should be manageable by the user, technically simple and robust and possibly not rely on external fuel, power supply or chemicals.
- **Compliance with national and international regulations and standards:** Qualitative and quantitative effluent standards have to maintain or even enhance the quality of receiving waters, to ensure soil fertility and protect public health. If greywater is appropriately treated, these standards will in general be easily met. Further information on discharge and reuse standards is provided in the section *Standards and regulations*.

Typical greywater management schemes

Since there is no standard solution for greywater management at household or neighbourhood level, a wide range of management systems have been successfully implemented worldwide. Households or neighbourhoods (supported by local experts) have to select the system that best meets their needs. This chapter provides an overview of potential management options to assist interested persons in making an informed choice.

One management option often discussed in literature is to separate, manage and treat each specific greywater stream according to its specific characteristics. It is argued that since the different greywater sources are not comparable, they cannot be managed in the same way. Kitchen greywater is sometimes not regarded as greywater (Al-Jayyousi, 2003; Bino, 2004; Friedler, 2004) and often excluded from certain greywater treatment systems given its high oil and grease content, which may clog a sand filter or infiltration bed. However, separate handling of different greywater streams will lead to complex systems that cannot be managed by house owners. A potential option is the discharge of kitchen greywater into the sewer system. However, such a system is missing in most rural and peri-urban areas of low and middle-income countries. Furthermore, this could lead to management systems tackling only selected greywater streams, while other streams are disregarded, thereby leading to their uncontrolled discharge into the environment and eliminating the overall benefits of the management system. Therefore, a more pragmatic approach is to include all greywater streams into the management system and subsequently develop preventive measures to avoid certain difficulties, rather than to exclude one type of greywater from the system.

A greywater management system should always comprise source control measures to avoid use and discharge of problematic substances, such as oil and grease, large particles or chemicals. Once the greywater is collected, it can undergo a certain level of treatment depending on its final destination. Greywater treatment reduces pollution loads to an acceptable level and thereby also negative impacts on humans as well as aquatic and terrestrial environments. The different treatment steps remove organic pollutants (expressed in COD and BOD) and reduce the levels of suspended solids, pathogenic organisms and other problematic substances.

Treatment steps of greywater on household level may include simple primary and secondary treatment. Tertiary treatment, which aims at removing specific pollutants such as toxic or non-biodegradable compounds, is mostly an energy and technology-intensive process not considered adequate for household application, especially in low and middle-income areas.

Source control

Implementation of an environmentally and economically sustainable greywater management strategy will be easier if control measures at the source (i.e. in the household) are practised. Source control is by far the most effective way to reduce pollution loads and avoid operational problems in treatment systems, to lower management costs and guarantee long-term satisfactory performance of the treatment systems.

Active participation of all household members is required when applying the following source control measures:

- minimise water usage
- optimise usage of common cleansing products
- avoid discharge of problematic substances such as oil, fat, bleach, solvents
- substitute hazardous products by environmentally-friendly ones

Minimising water usage can be attained by combining technical and economic measures. The number of manufacturers of water-saving infrastructure and equipment is increasing globally (e.g. washing machines or dishwashers with reduced water consumption or improved tap systems). Indoor water use can be reduced significantly and combined with economic incentives such as charging a fee per amount of water consumed (Ridderstolpe, 2004). The potential for reducing water consumption is highest in regions with high water consumption such as South-East Asia, Europe or North America. In arid regions where water is scarce and water consumption lowest, a further reduction of in-house water consumption is generally not feasible.

Costs and vulnerability of a treatment system are directly linked with the pollution load in greywater. Design of treatment systems is based on the physical and chemical characteristics of the inflowing greywater. These pollution loads can be controlled and reduced by source control at household level. The level of contamination can be lowered significantly if use of domestic cleansing products (shampoos, shower oils, soaps, detergents etc) is reduced. Choice of cleansing products and amounts used therefore strongly influence the impact of greywater on the treatment system and the environment.

Most hard soaps and common washing powders contain sodium salts that produce a saline greywater and lead to hypertension in plants and salinisation of soils (see section *Reuse in irrigation*). When greywater is reused for irrigation, sodium-containing products should be substituted by potassium-based soaps and detergents, since potassium has a fertiliser potential and facilitates water uptake by the plants (Del Porto and Steinfeld, 2000). Most liquid soaps are poor in sodium and contain potassium. Patterson R.A. (1997) estimated that by simply changing laundry products, a reduction of up to 38% of the current sodium concentrations in Australian domestic wastewater can be achieved at no cost to the consumer and without any negative impacts on household operation.

Disinfectants, such as chlorine bleach, are very efficient in killing pathogens; however, they have detrimental effects on natural treatment systems and soil organisms. Cleaners and laundry soaps containing bleaches, softeners, whitening products, non-biodegradable surfactants or heavy metals such as boron, must be avoided. Greywater management should therefore provide information on environmentally-friendly household chemicals. Unfortunately, the labelling of household cleaning products is often incomplete and especially widespread in most low and middle-income countries. Different studies were conducted to test common detergents for sodium, boron, phosphate, alkalinity, and other parameters (Prillwitz and Farwell, 1995; Zimoch et al., 2000). However, these studies investigated only products marketed in Europe, Australia or North America. Some countries give special eco-labels to environmentally-friendly cleansing products. Thailand has for example created the Green Label (www.tei.or.th/greenlabel), an environmental certification awarded to specific products known for their minimal detrimental impact on the environment compared to other products serving the same purpose. The Global Eco-labelling Network (GEN, www.gen.gr.jp) provides an overview of eco-labels in different regions of the world.

The solids content of greywater discharged into a treatment or disposal system can be reduced considerably and simply in-house. Kitchen sinks, showers, pipes, washing machines, and other appliances must always be equipped with appropriate screens (Photo 4-1), filters or water traps (Ridderstolpe, 2004).

Photo 4-1: Kitchen sink screen to prevent solids from entering the treatment system (photo: Sandec)

Since fat and oil can be detrimental to treatment systems, they should be retained at the point of origin. Cooking oil and grease should not be thrown into the sink. In households where oil and grease are used in large quantities for food preparation, special grease traps should be installed to protect subsequent treatment steps. If efficient source control measures cannot be implemented for oil and grease in kitchen greywater, the greywater source should not enter the treatment system but rather be disposed of together with toilet wastewater (this may be difficult in situations where dry toilet systems are used).

Primary treatment

Large amounts of oil and grease, grit (large food waste particles, fishbone, sand, gravel etc.) and suspended solids may lead to collection, treatment and disposal problems. The aim of primary treatment is the removal of coarse solids, settleable suspended solids, oil and grease, and part of the organic matter. Some organic nitrogen and phosphorous as well as heavy metals associated with those solids are also removed, however, colloidal and dissolved particles remain in the system.

Primary treatment is thus characterised by physical pollutant removal mechanisms (screening, sedimentation, flotation, and filtration).

Coarse filtration

Coarse filtration is a primary treatment option to prevent solid matter (e.g. hair, lint, skin, food particles) from entering subsequent treatment steps or disposal/irrigation sites. In this filtration process, particles of a certain size are retained by screens or filter media and only smaller particles are filtered out.

The wide range of filtration systems differs in filter material and size. The simplest form of coarse filtration is achieved by placing screens on hand basins or shower drains, stocking or sock filters on the inlet of a pump sump, mosquito nets on the inlet of a grease trap and sedimentation tank, as observed for example in Bangkok (see Photo 4-2). More complex filter systems of activated charcoal or ceramic are available on the market. Several authors provide a good survey of filter systems, their application range, strengths and weaknesses (e.g. Christova Boal et al., 1996; Del Porto and Steinfeld, 2000; Little, 2002).

Photo 4-2: Mosquito nets used as coarse filter in a combined sedimentation/filtration system for greywater treatment in Bangkok's channel communities. The light blue basin can be removed and easily cleaned (photo: Sandec)

Drain screens should always be installed in kitchen sinks, shower and hand basins. They prevent food residues, hair and other large particles from being flushed to subsequent treatment units and thus significantly reduce the risk of clogging in drainage pipes, filters and soil. Screens can easily be cleaned after use, and the trapped particles must be disposed of on the rubbish dump and not in the drain. Drain screens must be anticorrosive and easily removable for cleaning; users may otherwise simply remove them and thus jeopardise subsequent treatment steps, as experienced in Mali (see case study *Koulikoro, Mali*).

Simple coarse filters can significantly reduce the solids load to subsequent treatment steps, but will not remove sufficient pollution load to be suitable as main treatment process. Large mesh sizes (>0.16 mm) will not remove all relevant particles, while small mesh sizes (<0.03 mm) will quickly clog. Non-biodegradable fibres, mainly found in laundry greywater, are of main concern since they are often too small to be filtered out by conventional filters (Del Porto and Steinfeld, 2000). These fibres can clog pipes, irrigation systems and infiltration trenches. Filters can be operated in series, with large mesh sizes at the front and small mesh sizes at the end, however, this will enhance system complexity.

Coarse filters need to be cleaned regularly. Christova Boal et al. (1996) describe weekly cleaning frequencies, with potential health risks for the person cleaning the filters. Alternatively to permanent filters, disposable filter materials can also be used. Satisfactory results were observed with nylon socks or geotextile filter socks (Christova Boal et al., 1996).

Gravel and sand filters, used as primary treatment unit, tend to create problems. Numerous examples worldwide reveal that treatment efficiency quickly drops if the filters are not well-maintained (see case study *Koulikoro, Mali*). Non-biodegradable particles, heavy loads of oil and grease as well as other large particles easily clog sand and gravel filters, whereas microfibres from laundry will not be retained and thus affect subsequent treatment steps. The filter material needs to be washed or replaced periodically. This operation is expensive and unpleasant, hygienically unsafe and difficult in the case of filter washing. Households in Koulikoro, Mali, whose coarse gravel and sand filter did not work properly, simply removed the filter material without replacing it. This led to clogging and operational deterioration of the irrigation field (Werner C., 2006, personal communication). Use of a sand filter as primary treatment unit is therefore not recommended, however, its suitability as secondary treatment step (e.g. after a sedimentation tank or a coarse filter) is clearly recognised (see section *Vertical-flow filter*). As an alternative to inert filter material, such as sand and gravel, many experts suggest the use of biodegradable material such as wood, leaves or straw, which can be removed and replaced rather than backwashed. Systems using mulch as filter substrate are also discussed (see section *Irrigation systems*).

Flotation – Grease trap

Flotation is a physical process by which light components, such as grease, oil and fat, accumulate on the surface of the water. The grease trap is a simple method applied in small-scale greywater treatment systems. Grease traps are typically used as primary treatment units in greywater infiltration systems (see case studies *Djenné, Mali*) or greywater irrigation systems (see case study *Koulikoro, Mali*) and a low-cost alternative to sedimentation or septic tanks (see below). They are often applied as a preliminary treatment step for specific greywater sources with high oil and grease content (e.g. kitchen greywater, restaurant greywater) prior to a secondary treatment step. Stand-alone grease traps for combined greywater are also frequently applied for domestic greywater.

Table 4-1: Grease Trap

Working principle	Removal of oil and grease through flotation, removal of grit through sedimentation.
Design criteria	HRT = 15–30 min; V_{min} = 200–300 l; 1–2 vertical baffles; l:w = 1.3–2.0.
Removal efficiency	BOD ≤ 20%; TSS ≤ 20%; TN ≤ 10%; TP ≤ 10%; O&G ~ 70%; LAS ~ 20%.
Typical application	Primary treatment step for (kitchen) greywater before treatment in a septic tank or a mulch system or prior to reuse in garden irrigation.
Strengths	Cheaper than septic tank; efficient O&G removal if well-designed and maintained.
Weaknesses	Low TSS and BOD removal efficiency; requires frequent maintenance; odour nuisance if not sealed; unpleasant cleaning.
Examples	Case studies: *Djenné, Mali; Koulikoro, Mali; Costa Rica; Jordan*.
References	Tchobanoglous (1991), INWRDAM (2003), von Sperling and Chernicharo (2005).

Grease traps must be designed to satisfy two basic criteria for effective separation of grease and grit, i.e. time/temperature and turbulence.

Time/temperature: The grease trap must provide sufficient retention time for emulsified grease and oil to sufficiently cool down, separate and float to the surface of the trap.

Turbulence: Turbulence must be minimised so as to avoid suspension of grease and solids and their flow into the next treatment step.

Photo 4-3: Grease trap ahead of horizontal-flow planted filter installed in Tepozlán, Mexico (photo: Sandec)

Since grease traps are often undersized, as experienced in Peru and Mali, the entering greywater will not be able to cool down sufficiently, thus reducing the trapping of fat and grease. Furthermore, small traps require more frequent maintenance. In Djenné, Mali, frequent clogging of the grease and grit trap has been reported for lack of maintenance, thus jeopardising the long-term performance of the infiltration trench (see case study *Djenné, Mali*). Maintenance staff of a hotel in Sri Lanka did not perform the required monthly cleaning of the kitchen grease trap, as clearly observed by the strong foul odour emitted from the accumulated scum and grease in the trap. This resulted in large amounts of oil and grease escaping to the planted filter and further contributing to system failure (Harindra Corea, 2001).

Literature indicates a minimum hydraulic retention time of 15 to over 30 minutes (Crites and Tchobanoglous, 1998). Given the very high variability of the greywater flows in a household, with flow peaks as high as 10–15 litres per minute (e.g. dishwashing with running water), a minimum tank volume of 300 litres is recommended in the event of high water consumption (100 l/p/d or more). Where water consumption is lower, the size of grease traps can be reduced accordingly.

Traps are best constructed of concrete or bricks with an airtight cover to avoid odour nuisance (see Photo 4-3). Alternatively, recycled and locally available materials such as plastic barrels can also be used (see Photo 4-4). Prefabricated grease traps

Figure 4-1: Possible grease trap layouts for households with (left) and without (right) piped disposal system (scale: approximately 1:20). In the example on the right, oil and grease-containing greywater is poured with buckets onto the strainer (which retains coarse particles such as food residues) before entering the double baffled trap. This system can be used as e.g. primary treatment unit prior to direct reuse in a tower garden (see case study *South Africa*)

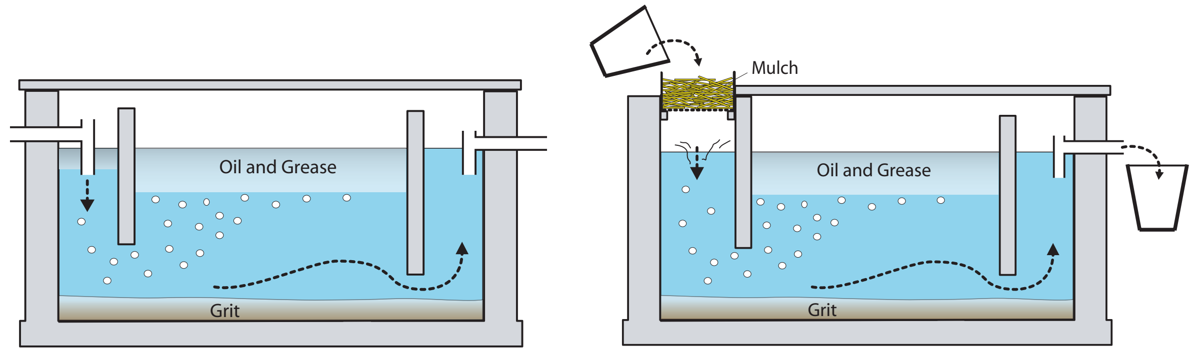


Photo 4-4: Left: Grease and grit trap used as primary treatment unit in a greywater infiltration system in Djenné, Mali. Given its small size, the trap often clogs, thus jeopardising the subsequent infiltration system (photo: Alderlieste M.)
Centre: Grease trap implemented in a household greywater irrigation system in Peru. The trap is undersized, vertical baffles are missing, resulting in clogging of the subsequent planted filter (photo: García O.)
Right: Buried, recycled 160-litre plastic barrel used as grease trap and grit chamber ahead of an unplanted horizontal-flow gravel filter in Jordan (photo: Kassay J., IDRC)

are available on the market, however, they are often more expensive than self-made traps. They have not always been effective given the low detention time provided by such units (Tchobanoglous, 1991). Traps must be installed and connected so as to be readily and easily accessible for inspection, cleaning and removal of grease and other material. Accumulated grease is best disposed of together with solid waste. Maintenance of grease traps is usually required at least on a monthly basis. Guidance on how to design, operate and maintain grease traps is given by e.g. Crites and Tchobanoglous (1998), Sasse (1998) or Tchobanoglous (1991).

Sedimentation in tanks (septic/sedimentation tanks)

The septic tank is the most common, small-scale treatment system worldwide. To cite two examples, over 17 million housing units in the United States depend on septic tanks, and more than 100 million people are served by septic tank systems in Brazil (Harindra Corea, 2001). Septic tanks consist of either one (also known as settling or sedimentation tank) or two compartments. Most experts tend to agree that a two-compartment tank will remove more solids than a single compartment tank (Loudon et al., 2005). Figure 4-2 depicts a schematic cross-section of a typical

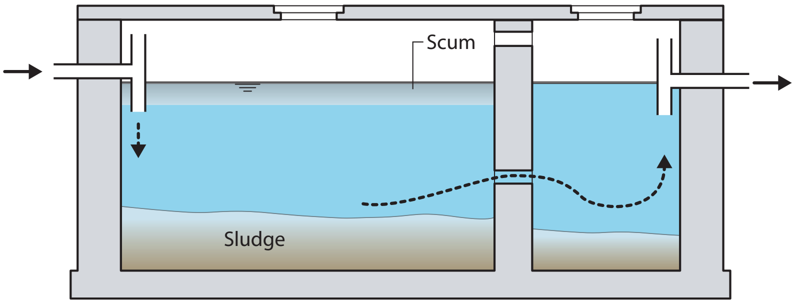
Table 4-2: Basic design criteria for septic/sedimentation tanks

Construction material	Reinforced concrete, bricks, pre-fabricated fibreglass or plastic tanks. The tank structure must be airtight.
Hydraulic retention time	≥ 24 hours at maximum sludge depth and scum accumulation.
Required sludge and scum volume	Sludge accumulation rate multiplied by desludging frequency.
Sludge accumulation rate	70–100 l/p/y.
Desludging frequency	Every 2–5 years.

double-compartment septic tank. In a double-compartment septic tank, the first compartment typically comprises ⅔ of the entire tank volume.

Most countries provide national standards for domestic septic tank design and size.

Figure 4-2: Schematic cross-section of a two-compartment septic tank (scale: approximately 1:30)



Septic tanks are designed for gravity separation, combined sedimentation and flotation of settleable solids, oil and grease. Substances denser than water settle at the bottom of the tank, while fats, oil and grease float to form a scum layer. The organic matter retained at the bottom of the tank undergoes anaerobic decomposition and is converted into more stable compounds and gases such as carbon dioxide, methane and hydrogen sulphide. Given the anaerobic processes in such tanks, odour emissions will occur. To avoid odour nuisance and uncontrolled release of inflammable gas, septic tanks must be sealed. Biochemical reactions occur mainly in the accumulated sludge and far less in the liquid phase between scum and sludge layer. Dissolved and unsettleable solids leave the tank more or less untreated. Even though the settled solids undergo continuous anaerobic digestion, there is always a net accumulation of sludge in the tank. This gradual build up of scum and sludge layer will progressively reduce the effective volumetric capacity of the tank. To ensure continuous effective operation, the accumulated material must therefore be emptied periodically. This should take place when sludge and scum accumulation exceeds 30 percent of the tank's liquid volume.

Septic tanks will generally have to be desludged every two to five years, otherwise they produce very poor effluents with high suspended solids content, which can be detrimental to subsequent treatment steps (e.g. clogging of subsurface irrigation networks and soil porosity). Desludging of septic tanks should not be conducted manually, as accumulated sludge is rich in pathogens. In most cities of low and middle-income countries, septic tank desludging services are provided by government or private enterprises.

Not only the sludge but also the effluent of septic tanks still contains pathogens and high levels of dissolved solids. Therefore, septic tank effluent requires further treatment or special attention prior to its reuse in irrigation.

Septic tanks are frequently used in greywater treatment systems in low and middle-income countries. Predominantly they find application as primary treatment units upstream to an anaerobic filter (see case study *Jordan*), ahead of a planted sand filter (see case study *Nepal*) or infiltration beds (Anda et al., 2001). Serious problems have seldom been observed where septic or sedimentation tanks are used as primary treatment unit. Some minor problems were reported in Sri Lanka, where kitchen wastewater from a hotel restaurant has led to high scum accumulation rates in the septic tank. The problem was easily solved by using a grease trap for kitchen greywater prior to its discharge into the septic tank (see case study *Sri Lanka*). Serious problems can be expected in cases where septic tanks are not regularly desludged. It is therefore of key importance to develop monitoring and maintenance plans and ensure regular service. Kerri and Brady (1997) provide comprehensive guidance for septic tank operation and maintenance.

Further information on septic tank design, operation and maintenance is available from Crites and Tchobanoglous (1998), Harindra Corea (2001), Kerri and Brady (1997), Sasse (1998) or Franceys et al. (1992).

Innovative septic tank design

In recent years, improved septic tank designs have been developed to enhance removal efficiency of unsettleable and dissolved solids; a major drawback of conventional septic tanks. The basic principle of such systems is to increase contact between the entering wastewater and the active biomass in the accumulated sludge. This can be achieved by inserting vertical baffles into the septic tank to force the wastewater to flow under and over them as it passes from the inlet to the outlet. Wastewater flowing from bottom to top passes through the settled sludge and enables contact between liquid and biomass.

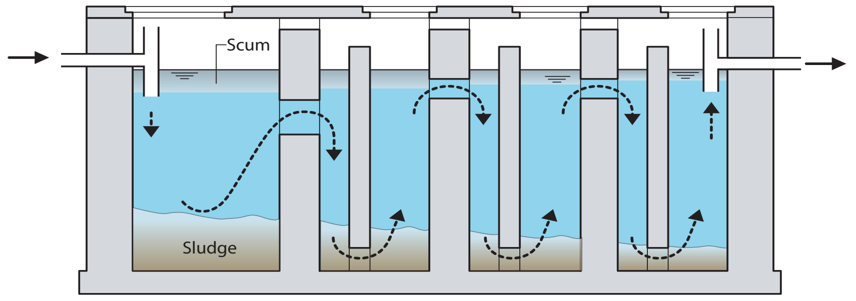
The improved septic tank system, also known as up-flow anaerobic baffled reactor (ABR) or baffled septic tank, is relatively new. So far, it has mainly been applied in domestic wastewater and blackwater treatment (toilet wastewater). Examples of its application come from Vietnam, Thailand and Malaysia (Koottatep et al., 2006; Martin, 2005; Viet Anh et al., 2005). First positive experiences with an ABR as primary

Table 4-3: Anaerobic baffled reactor (ABR)

Working principle	Vertical baffles in the tank force wastewater to flow under and over them as it passes from the inlet to the outlet, thus guaranteeing intense contact between wastewater and resident sludge. Sedimentation of settleable solids, flotation of grease, anaerobic degradation of suspended and dissolved solids.
Design criteria	HRT = 48 h; v_{max} = 1.4–2 m/h; 1 sedimentation chamber, 2–3 up-flow chambers.
Removal efficiency	BOD ≤ 80%; TSS ≤ 80%; TN ≤ 20%; O&G ~ 70%; LAS ~ 25%.
Typical application	Alternative to a conventional septic tank. So far, mainly used to treat toilet wastewater. First positive experience with greywater primary treatment gained in Malaysia.
Strengths	High treatment performance; high resilience to hydraulic and organic shock loadings; long biomass retention times; low sludge yields; ability to partially separate between the various phases of anaerobic catabolism.
Weaknesses	Long-term greywater treatment experience is still missing; construction and maintenance are more complex than septic tanks; clear design guidelines are not available yet; its costs are higher than a conventional septic tank.
Examples	Case study: *Malaysia*.
References	Dama et al. (2002); Sasse (1998); Koottatep et al. (2006).

treatment of greywater were gained in Malaysia, where a three baffled reactor is operated as grease trap and sedimentation tank ahead of a trickling filter and horizontal-flow sand filter (see case study *Malaysia*).

Figure 4-3: Schematic cross-section of an up-flow anaerobic baffled reactor (ABR) (scale: approximately 1:50)



A maximum up-flow velocity of wastewater of v_{max} = 1.4–2 m/h must be maintained to avoid washout of the accumulated sludge. The ABR usually comprises one sedimentation tank and 2–3 up-flow chambers; however, other configurations with up to five up-flow chambers have also been reported (Sasse, 1998).

Primary treatment in ponds

Pond systems have been successfully used as preliminary treatment units in low and middle-income countries, though mainly for large-scale applications, as described for example in India (Mara, 1997; Mara and Pearson, 1998). Pond systems are not recommended as primary treatment unit for household greywater. Pond systems look unpleasant, emit odours and offer a perfect environment for mosquitoes if not well-operated and maintained (Ridderstolpe, 2004). The new WHO (2005) guidelines for safe use of excreta and greywater do not promote pond systems if appropriate mosquito control measures are not guaranteed. Septic or sedimentation tanks are recommended as primary treatment unit.

Secondary treatment

The main objective of secondary treatment is the removal of organic matter and reduction of pathogen and nutrient loads. After primary treatment, the organic matter present in greywater takes the form of (von Sperling and Chernicharo, 2005):

- Dissolved organic matter that cannot be removed only by physical processes such as in primary treatment.
- Suspended organic matter although largely removed in well-functioning primary treatment units, possibly contains solids that settle more slowly and thus remain in the liquid fraction.

The biological process component, where organic matter is removed by microorganisms through biochemical reactions, is of key importance in secondary treatment (von Sperling and Chernicharo, 2005). Microbial decomposition of organic matter can take place under anaerobic and aerobic conditions:

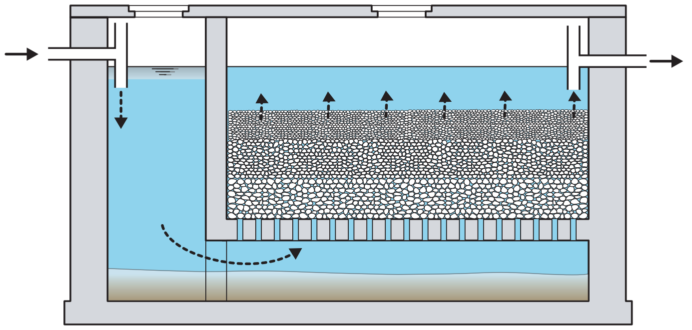
Aerobic degradation	Degradation of organic matter by aerobic microorganisms in the presence of oxygen and resulting in the production of carbon dioxide, water and other mineral products. Generally a faster process than anaerobic decomposition.Typical process in systems such as trickling filters, planted sand filters and mulch systems.
Anaerobic degradation	Degradation of organic matter by anaerobic microorganisms in oxygen-depleted environments and resulting in the production of carbon dioxide, methane or hydrogen sulphide. Generally a slower process than aerobic decomposition. Some surfactants such as LAS are not biodegradable in anaerobic conditions. Typical process in systems such as anaerobic filters, anaerobic baffled reactors (ABR) and septic tanks.

Most aerobic and anaerobic systems used for secondary treatment of greywater are based on the principle of attached biofilms. In these systems, biological degradation of suspended and dissolved organic matter occurs as greywater passes a filter media that serves as surface for bacterial growth. The bacteria attached to the filter media decompose the suspended and dissolved organic matter in greywater. Planted and unplanted sand and gravel filters are typical treatment systems taking advantage of aerobic attached biofilm processes. On the other hand, the anaerobic filter is the most common attached biofilm system operating under anaerobic conditions.

Anaerobic filtration

Anaerobic filters are widely used as secondary treatment step in household greywater treatment systems. They have been successfully used when placed after a grease trap or septic tank (see case studies *Palestine*, *Jordan* or *Sri Lanka*). In Sri Lanka, several hotels and residences successfully operate greywater treatment systems based on anaerobic filters (Harindra Corea, 2001). Since 2001, the Inter-Islamic Network on Water Resources Development (INWRDAM) has been pioneering the use of low-cost greywater treatment kits based on up-flow anaerobic filters in Jordan (see Photo 4-5). Given the exclusively positive reactions of the users and high cost/benefit ratio, INWRDAM installed in 2002 several hundred anaerobic filters as greywater treatment units in low-income households across Jordan. The project was financed by the Jordanian Ministry of Planning and International Cooperation (MOPIC).

Figure 4-4: Schematic cross-section of an anaerobic filter (scale: approximately 1:30)



The anaerobic filter is an attached biofilm system (fixed-film reactor) that aims at removing non-settleable and dissolved solids. It comprises a watertight tank containing several layers of submerged media, which provide surface area for bacteria to settle. As the wastewater flows through the filter – usually from bottom to top (up-flow) – it comes into contact with the biomass on the filter and is subjected to anaerobic degradation (see Figure 4-4). Primary

Table 4-4: Anaerobic filter

Working principle	Dissolved and unsettleable solids are removed through close contact with anaerobic bacteria attached to the filter media under exclusion of oxygen (= anaerobic condition).
Design criteria	HRT_{min}= 0.7–1.5 d; HLR ≤ 2.8 m/d; filter depth ≥ 1 m; filter material: gravel, rocks, cinder, plastic with a specific surface of 90–300 m^2/m^3 and 12–55 mm grain size; 2–3 layers; sealed and ventilated.
Removal efficiency	BOD = 50–80%; TSS = 50–80%; TN ≤ 15%; TC ≤ 1–2 log.
Typical application	As secondary treatment step after primary treatment in a septic tank. Effluent can be treated further in planted filters, infiltrated in percolation beds or reused as irrigation water (mulch system, drip irrigation).
Strengths	High treatment performance (TSS, TDS); high resilience to hydraulic and organic shock loadings; long biomass retention time; low sludge yield; stabilised sludge.
Weaknesses	Long-term experience with greywater treatment is still lacking; limited removal of nutrients, pathogens and surfactants.
Examples	Case studies *Jordan, Palestine, Sri Lanka.*
References	Chernicharo and Rosangela (1998); Harindra Corea (2001); Henze and Harremoes (1983); Kobayashi et al. (1983); Sasse (1998); von Sperling and Chernicharo (2005); Young (1991).

treatment in a septic tank is usually required to eliminate solids of larger sizes before greywater is allowed to pass through the anaerobic filter.

Young's (1991) study of 30 full-scale anaerobic filters in the USA, Canada and Europe concludes that the hydraulic retention time is the single most important design parameter influencing filter performance. Typical hydraulic retention times of 0.5–1.5 days are reported by Harindra Corea (2001); Sasse (1998) or US EPA (2004b). Based on his extensive experience with anaerobic filters for hotels and residences in Sri Lanka, Harindra Corea (2001) suggests a maximum surface loading rate of 2.8 m/d (or 2.8 $m^3/m^2/d$) and a minimum hydraulic retention time of 0.7–1.5 days.

As observed in Sri Lanka, treatment performance of the anaerobic filter as regards suspended solids and BOD removal can be as high as 85–90% and is typically within a 50–80% range. Nitrogen removal is, however, limited and normally does not exceed 15% in terms of total nitrogen (TN).

Good filter material provides a specific surface area of 90–300 m^2 per m^3 of filled reactor volume (Sasse, 1998). Gravel, rocks, cinder or specially formed plastic pieces are used as filter material. Filters with two to three filter layers and a minimum depth of 0.8–1.2 m are recommended by von Sperling and Chernicharo (2005). With up-flow systems, filter material size decreases from bottom to top. Typical filter material sizes range from 12 to 55 mm. Finally, the water level should cover the filter media by at least 0.3 m to guarantee an even flow regime through the filter.


Photo 4-5: Four-barrel up-flow anaerobic filter implemented in Jordan. Two tanks of 220-litre capacity each filled with gravel media acting as anaerobic filters are inserted between a sedimentation and a final storage tank (photo: Redwood M., IDRC)

Anaerobic filters produce inflammable gases (methane) and foul odours that need to be controlled and evacuated. The filters may be constructed above ground, but most often they are below the ground surface to provide insulation and protection against severe climates. Access to inlet and outlet should be provided to allow for cleaning and servicing. Cleaning is required when the bacterial film on the filter media becomes too thick. The filter mass is removed and cleaned outside the reactor. More frequently the filter is not removed but cleaned by backwashing.

Vertical and horizontal filters

In vertical-flow filter systems, water is applied intermittently and evenly on the filter surface to ensure oxygen supply into the filter medium. To improve the treatment performance of vertical filters, they may be planted with macrophytes. The root zone of the plants is a favourable habitat for bacterial growth as it enhances microbial degradation.

The horizontal-flow filter differs from the vertical filter as parts of the filter are permanently soaked and operated aerobically, anoxically (no free oxygen present but nitrates) and anaerobically.

Planted filters (horizontal or vertical-flow) are becoming increasingly popular worldwide for secondary treatment of domestic wastewater, including greywater. They first appeared as wastewater treatment technology in Western Europe in the 1960s and are now successfully used for all kinds of liquid waste, ranging from surface water runoff to heavily loaded faecal sludge. Planted filters are currently also used successfully for wastewater and greywater treatment in low and middle-income countries, including tropical Asia (Koottatep and Polprasert, 1997; Martin, 2005), Africa (Kaseva, 2004), Nepal (Shrestha et al., 2001), and Latin America (Dallas and Ho, 2005).

Planted filters are often referred to as sub-surface-flow constructed wetlands, reed beds, root zone method, gravel bed hydroponic filters, vegetated submerged beds or artificial wetlands.

The following three chapters describe in detail the Vertical-Flow Filter (VFF), the Horizontal-Flow Planted Filter (HFPF) and the Vertical-Flow Planted Filter (VFPF).

Vertical-flow filter (percolation bed, unplanted)

Vertical-flow filters (VFF) are frequently and successfully applied as secondary treatment of domestic greywater throughout the world, even in regions with cold winters such as Canada, Germany, Switzerland, Norway or Sweden. VFF are also referred to as subsurface biofilters, percolation beds, infiltration beds or intermittent sand filters.

The basic structure consists of a watertight box filled with filter material (see Figure 4-5). Greywater is applied to the top of the VFF, percolates through an unsaturated zone of porous material and is then collected in a drainage system. The water is applied intermittently and evenly on the filter surface by a pressure distribution device such as an electric pump or mechanical siphon. By charging the entire surface of the filter, oxygen is supplied to the filter media.

Table 4-5: Vertical-flow filter (percolation bed)

Working principle	Pretreated greywater is applied intermittently to the surface of a filter media, percolates through an unsaturated filter zone where physical, biological and chemical processes treat the water. The treated greywater is collected in a drainage network or infiltrates the underlying soil.
Design criteria	HLR = 5–10 cm/d; OLR 20–25 g BOD/m^2/d; filter depth = 0.8–1.2 m; filter material: sand, pea gravel, crushed glass; area: 0.4–0.6 m^2/p.
Removal efficiency	BOD = 80–90%; TSS = 65–85%; TN = 30–40%; FC ≤ 1–2 log; MBAS ~ 90%.
Typical application	As secondary treatment step after primary treatment in a septic tank or grease trap. The effluent is reused in irrigation, infiltrates the soil or is discharged into surface water.
Strengths	Efficient removal of suspended and dissolved organic matter, nutrients, pathogens, and surfactants; no odour problems as wastewater is not above ground level.
Weaknesses	Well functioning pressure distribution with pumps or siphons required for even distribution on filter bed; uneven distribution causes zone clogging and plug flows with reduced treatment performance; high quality filter material is not always available and can be expensive; expertise is required for design, construction and operation monitoring.
Examples	Europe, USA, Australia, Peru, case studies *Palestine, Sri Lanka*.
References	Gustafson et al. (2002); Ridderstolpe (2004); Sasse (1998).

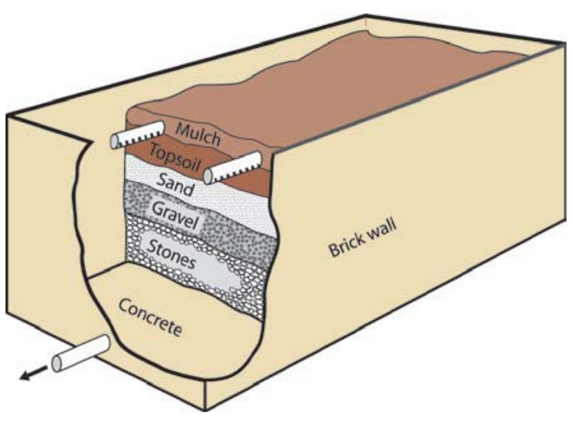
Greywater undergoes physical, chemical and biological treatment in a VFF. Suspended solids are removed by mechanical filtering and sedimentation, and degradation occurs by microorganisms that colonise the filter bed. Since organic matter and nutrients in the greywater allow microorganisms to grow and reproduce, the organic matter is mineralised and nutrients are partly removed. Chemical adsorption of pollutants onto the media surface also plays a role in removal of some chemical constituents (e.g. phosphorus, surfactants).

Although different materials, such as pea gravel, peat or crushed glass, can be applied as filter media in VFF, sand is the most widespread material used. A combination of different filter material (e.g. gravel, sand and mulch) has also been observed (see case studies *Palestine* and *Koulikoro, Mali*).

A VFF exhibits typical filter depths of 80–120 cm (Sasse, 1998; US EPA, 2004b) and can be constructed either with or without coverage. Coverage consisting of 15–20 cm top-soil and vegetation can provide efficient insulation during cold winter periods; however, filter bed maintenance becomes more complicated when covered.

If greywater reuse is not an option and where soil conditions are favourable, VFF can be operated without impermeable liner and drainage network. After flowing through the filter material, treated greywater will in this case infiltrate directly into the soil below. Infiltration issues are discussed in the section *Subsurface infiltration*.

Figure 4-5: Multi-layer percolation bed (adapted from Oasis Design)



Clogging of the filter bed is the main risk in VFF. Greywater pretreatment before use in a VFF is thus crucial to allow removal of large particles, oil and fat and thus to avoid filter operational problems. In most observed cases, septic tanks are used as primary treatment unit (e.g. case studies *Palestine* and *Malaysia*). Literature references indicate that to avoid premature clogging, the organic and hydraulic loading rates in a VFF should not exceed 20–25 g BOD/m^2/d and 5–10 cm/d, respectively (Ridderstolpe, 2004; Sasse, 1998).

Uniform distribution of greywater onto the filter surface is essential and can be achieved either through a dense network of perforated pipes or a sprinkler system. Most applications observed in low and middle-income countries use a network of pipes as flooding technique (e.g. case study *Sri Lanka*). Distribution by sprinklers is an efficient technique but prone to malfunction due to clogging of the sprayer nozzles. First experiences with sprinkler distribution in a VFF in low and middle-income countries were gained in Malaysia, where effluent of an anaerobic baffled reactor was sprayed onto a VFF prior to a horizontal-flow sand filter (see case study *Malaysia*).

A properly operated VFF can produce high-quality effluent with less than 10 mg/l BOD (90–95% removal) and less than 10 mg/l TSS (90–95%). Nitrogen removal in VFF is rather limited (30–40%). However, the current operational VFF concepts recirculate the nitrified effluent from the VFF back through the anaerobic primary treatment of the system (e.g. septic tank or ABR) where denitrification occurs. The recirculating VFF system is very efficient at removing nitrogen (up to 95%), however, the complexity of the system makes it inappropriate for application on household level in low and middle-income countries.

Horizontal-flow planted filters (constructed wetlands)

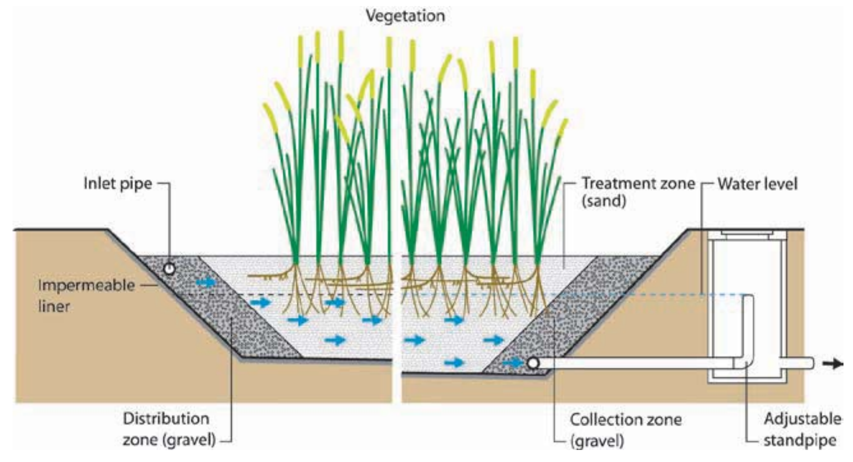
Horizontal-flow planted filters (HFPF) consist of a bed lined with impermeable material (typically solid clay packing, concrete or plastic foils) and filled with sand or gravel (see Figure 4-6). Alternative filling material such as PET is investigated to reduce costs of the HFPF (Dallas and Ho, 2005). A 5–10-cm soil layer is often applied on top of the filter substrate to facilitate growth of emergent plants.

Photo 4-6: Horizontal-flow planted filter treating greywater of one household in Tepozlán, Mexico (photo: Sandec)

The greywater entering the filter bed through an inlet zone devoid of vegetation flows horizontally through the bed. The water line lies below the filter surface and is controlled by a simple swivelling elbow device located at the outlet typically 10–15 cm below the filter surface (see Photo 4-8).

While the top surface of the filter is kept horizontal to prevent erosion, the bottom slopes preferably 0.5–1% from inlet to outlet. The grain size of the filter media should allow continuous flow of the greywater without clogging, however, it should not be

Figure 4-6: Schematic cross-section of a horizontal-flow planted filter (constructed wetland)



too large to hinder efficient treatment. In case of gravel, a round, uniform grain size of 20–30 mm is considered optimal (US EPA, 2004b). A coarser grain size in the inlet and outlet zone (40–80 mm) guarantees an even distribution of greywater input. The properties of the top layer to be considered include pH, electrical conductivity (EC), texture, and organic matter of the soil. The pH of the soil affects availability and retention of nutrients and heavy metals. Soil pH should range between 6.5 and 8.5. EC of a soil affects the efficiency with which plants and microbes process the waste material flowing into a planted filter. Soils with less than 4 dS/m EC are best for growth media. Soils with a high clay content enhance phosphorous retention, however, their low nutrient content may limit growth and development (Davis, 1995). The optimal length to width ratio of horizontal filters is not defined. However, experience has shown that too narrow HFPF tend to clog due to an overcharge at the inlet zone (see Photo 4-7).

The treatment level is determined by the hydraulic retention time (HRT) in the filter. HRT are typically within a range of 3–7 days, with hydraulic loading

Table 4-6: Horizontal-flow planted filter (horizontal-flow constructed wetland)

Working principle	Pretreated greywater flows continuously and horizontally through a planted filter media. Plants provide appropriate environments for microbial attachment, growth and transfer of oxygen to the root zone. Organic matter and suspended solids are removed by filtration and microbial degradation in aerobic, anoxic and anaerobic conditions.
Design criteria	HRT = 3–7 d; HLR= 5–8 cm/d; OLR = 6–10 g BOD/m^2/d; filter depth = 0.6 m; filter material: coarse sand, pea gravel, crushed glass, PET; area: 1–3 m^2/p.
Removal efficiency	BOD = 80–90%; TSS = 80–95%; TN = 15–40%; TP = 30–45%; FC ≤ 2–3 log; LAS > 90%.
Typical application	As secondary treatment step after primary treatment in a septic tank. The effluent can be reused for irrigation, infiltration into the soil or discharge into surface water.
Strengths	Efficient removal of suspended and dissolved organic matter; no wastewater above ground level and, thus, no odour, mosquitoes and contact to users; can be cheap to construct where filter material is available locally; pleasant landscaping and use of harvested plant biomass possible.
Weaknesses	High permanent space required, as well as extensive construction knowledge and experience; high quality filter material not always available and often expensive; risk of clogging if greywater is not well pretreated.
Examples	Europe, USA, Australia, Peru, case studies *Malaysia, Jordan, Sri Lanka.*
References	Crites and Tchobanoglous (1998); Dallas and Ho (2005); IAWQ (2000); Kadlec and Knight (1996); Ridderstolpe (2004); Sasse (1998).

rates (HLR) and organic loading rates (OLR) of 5–8 cm/d and 6–10 g BOD/m^2/d, respectively. Depending on greywater production rates and due to high HRT, a HFPF requires 1–3 m^2 of land per person.

Photo 4-7: Clogging of the inlet zone of an unplanted horizontal-flow filter, indicating an overload of the inlet zone, possibly caused by the high L:W ratio, Sri Lanka (photo: Harindra Corea, E.J.)

Treatment of greywater occurs by a complex mixture of processes, some aerobic (presence of oxygen), some anaerobic (absence of oxygen) and some anoxic (use of nitrate). Filtration, adsorption and biochemical degradation are the most important treatment mechanisms.

Horizontal-flow planted filters are very efficient in removing organic matter and suspended solids. BOD removal rates range between 65% and 90%, with average BOD effluent concentrations below 30–70 mg/l. Typical effluent TSS levels are below 10–40 mg/l and correspond to 70–95% removal rates. Pathogen removal amounting to 99% or more (2–3 log) total coliforms has been reported by Crites and Tchobanoglous (1998).

Nutrient removal in HFPF is a complex and variable process. While it is recognised that plants themselves only remove a small amount of nutrients, they provide the necessary sites and conditions for a large number of bacteria and other organisms with a more efficient nutrient removal capacity. 15–40% nitrogen and 30–50% phosphorous removal is considered typical in HFPF (Harindra Corea, 2001; IAWQ, 2000), but nitrogen removal rates as high as 70% have also been reported (Crites and Tchobanoglous, 1998). Removal of surfactants in HFPF is not well-documented. Surfactant removal rates of 46% in terms of MBAS were observed in a HFPF treating laundry greywater in Israel (Gross et al., 2006b). Since this treatment unit showed also low treatment performances in terms of BOD, TSS and faecal coliforms, it must be assumed that a well-designed and operated HFPF can achieve removal rates as high as 80%, similarly to a HFPF treating domestic wastewater (Conte et al., 2001).

Photo 4-8: Left: Subsurface horizontal-flow filter (crushed limestone) fed by pretreated greywater from a neighbourhood of 45 persons in Kuching, Sarawak, Malaysia. The vegetation has an ornamental function only. The filter surface amounts to 2.8 m^2 per person equivalent (photo: Martin C.)
Centre: HFPF with a simple swivelling elbow device (below, right) at the outlet for water level control in the filter, Sri Lanka (photo: Harindra Corea, E.J.)
Right: HFPF (crushed rock) fed by pretreated greywater of four households (18 persons) in Monteverde, Costa Rica, with 1.7 m^2/p specific surface. *Coix lacryma-jobi,* a locally available wetland plant, is used as emergent vegetation (photo: Sandec)

Tropical and subtropical climates hold the greatest potential for the use of HFPF. Cold climates tend to show problems with both icing and thawing. In hot and arid climates, planted filters may even become zero-discharge systems, with evapotranspiration rates exceeding inflow rates. Evapotranspiration rates as high as 5 cm/d have been observed in a HFPF during the summer months in southern USA (Kadlec and Knight, 1996), an almost equivalent rate to the recommended HLR of 5–8 cm/d. In Lima, Peru, for example, emergent vegetation (papyrus) suffered water stress due to insufficient inflow. Water stress of plants in a HFPF is an important issue to be considered especially in household systems during periods without inflow (e.g. during holidays).

HFPF is more demanding in terms of operation and maintenance than anaerobic systems such as septic tanks or anaerobic filters; however, HFPF remain simple and inexpensive. Main focus is placed on maintenance of the vegetation and monitoring of the water level. During the initial vegetation period, the filter must be kept clean and free from other plants. The system is considered to have an average lifespan of 20 years.

HFPF are frequently applied in situations where treated greywater is planed to be reused in irrigation or where water quality requirements for direct discharge into surface water have to be met. Greywater treatment systems based on horizontal-flow filters in low and middle-income countries are reported in Malaysia, Costa Rica, Jordan, Sri Lanka, and Mexico (see Photos 4-6, 4-8 and respective case studies) and for treatment of laundry greywater in the Philippines (Parco et al., 2005).

Role of filter plants, selection criteria

Plants provide an appropriate environment for microbial growth in the filter media and help transfer the oxygen to the root zone. Plants also stimulate soil activity by root excretions, assimilate pollutants into their tissue and reduce the volume of effluent by transpiration. *Phragmites australis* (common reed) is the most common plant used for planted filters treating domestic wastewater (Shrestha et al., 2001). According to Dallas (2002), they reveal thriving difficulties in greywater-only systems due to nitrogen deficits in greywater. Other plants, such as *Typha* spp. (cattails), *Scirpus* spp. (bulrushes) or *Glyceria maxima* (sweet manna grass), are also used (Kadlec and Knight, 1996).

The selected plant species should show a high standing crop throughout the year. Plants should be tolerant to pollutant concentrations and adverse climatic conditions, resistant to pests and disease, simple in management (harvesting), and have a high pollutant adsorption capacity. Plants must be locally available and not endanger local ecosystems due to uncontrolled spreading.

Vertical-flow planted filters (constructed wetlands)

Vertical-flow planted filters (VFPF) work similarly to the vertical-flow unplanted filter system (VFF) presented earlier. The main purpose of plant presence in VFPF systems is to help maintain the hydraulic conductivity of the bed. VFPF are shallow excavations or above-ground constructions with an impermeable liner, either synthetic or clay (see Figure 4-8). VFPF beds are fed intermittently and batchwise 3–4 times a day by a pump or mechanical siphon flooding the surface. Wastewater percolates

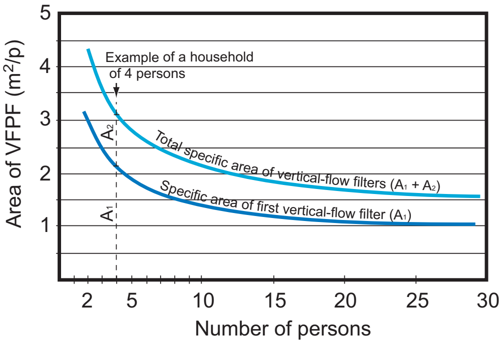
Table 4-7: Vertical-flow planted filter (vertical-flow constructed wetland)

Working principle	Pretreated greywater is applied intermittently to a planted filter surface, percolates through the unsaturated filter media where physical, biological and chemical processes purify the water. The treated greywater is collected in a drainage network.
Design criteria	HLR = 10–20 cm/d; OLR = 10–20 g BOD/m^2/d; filter depth = 0.8–1.2 m; filter material: sand, pea gravel, crushed glass or bricks; area: 0.5–3 m^2/p.
Removal efficiency	BOD = 75–95%; TSS = 65–85%; TN < 60%; TP < 35%; FC ≤ 2–3 log; MBAS ≤ 90%; TB ≤ 50%.
Typical application	As secondary and tertiary treatment step after primary treatment in septic tanks. Effluent can be reused for irrigation or is discharged into surface water.
Strengths	Efficient removal of suspended and dissolved organic matter, nutrients and pathogens; no wastewater above ground level and therefore no odour nuisance; plants have a landscaping and ornamental purpose.
Weaknesses	Even distribution on filter bed requires a well-functioning pressure distribution with pump or siphon; uneven distribution causes clogging zones and plug flows with reduced treatment performance; high quality filter material not always available and expensive; expertise required for design, construction and monitoring.
Examples	Europe, USA, Australia, Israel, case studies *Nepal, Sri Lanka.*
References	Harindra Corea (2001); IAWQ (2000); Kadlec and Knight (1996); Sasse (1998); Shrestha (1999); (Gross et al., 2006a).

down through the unsaturated bed, undergoes filtration, comes into contact with the dense microbial populations on the surface of the filter media and roots and is finally collected by a drainage network at the base. This kind of VFPF loading enhances oxygen transfer and thus nitrification (Shrestha, 1999). The different types of media used as substrate range from soil to crushed glass, but gravel and coarse sand are most widely used (CWA, 2005; Harindra Corea, 2001; Shrestha et al., 2001).

The design of a VFPF is dependent on hydraulic and organic loads. Harindra Corea (2001) observed that the influent concentration is a key parameter for clogging besides the organic load in several VFPF implemented in Sri Lanka. Clogging problems of the filter did not occur with influent BOD concentrations below 110 mg/l, however, serious clogging was experienced with influent concentrations exceeding 300 mg BOD/l. This clearly reveals the importance of an efficient primary treatment unit (e.g. septic tank) ahead of a vertical-flow planted filter. While hydraulic loading rates as high as 80 cm/d have been reported in domestic wastewater treatment (Cooper, 2005), most applications for greywater treatment are operated at HLR < 20 cm/d. Given the nitrogen deficit typical for greywater, too high loading rates may lead to clogging

Figure 4-7: Sizing of two-stage VFPF according to Cooper (1999)

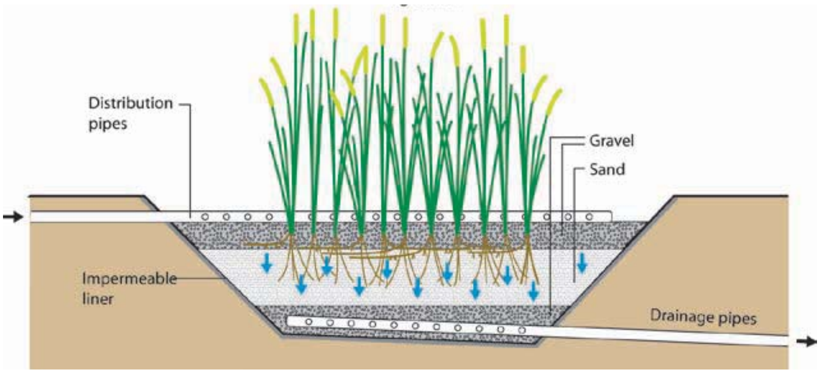


$A_1 = 3.6 \times P^{0.35} + 0.6\,P$
$A_2 = 0.5 \times A1$

A_1 and A_2 = area of first and second flow bed in m^2
P = number of persons
(population equivalent)

problems, also called carbon clogging (Del Porto and Steinfeld, 2000), due to the accumulation of difficult-to-metabolise carbon-containing fat, oil, grease, cellulose, soaps, detergents etc.

Figure 4-8: Schematic cross-section of a vertical-flow planted filter (VFPF, constructed wetland)



VFPF have a typical depth of 0.8–1.2 m (Sasse, 1998). For small systems (i.e. single households) receiving septic tank effluents, Cooper (1999) proposes the use of two vertical-flow beds in series. A sizing example for the two-stage VFPF is given in Figure 4-7.

Based on this design guideline, the total specific area for treating septic tank effluent decreases from 3 m^2/p for a 4-person household to 1.5 m^2/p for a neighbourhood of 25 persons. Experiences worldwide reveal specific filter surfaces of 0.5–2 m^2/p. The greywater treatment systems in Nepal and Sri Lanka for example (see case studies *Nepal* and *Sri Lanka*) exhibit three times smaller surface areas than the ones indicated in the aforementioned formula.

Removal efficiencies in terms of BOD, COD and pathogens of VFPF are generally higher than comparable horizontal-flow planted filters. However, removal of suspended solids is somewhat lower than in horizontal-flow filters (Cooper et al., 1999). Average removal efficiencies are typically within a range of 75–95% and 65–85% in terms of BOD and TSS, respectively. Pathogen removal in terms of total coliforms are typically within a range of 2–3 log and can be as high as 5 log as seen in Nepal (Shrestha, 1999). Harindra Corea (2001) observed significant reductions in treatment performance of VFPF at low pH values of inflowing greywater. He suggests including a 0.3-m layer of crushed limestone as buffer zone when treating kitchen greywater.

Vertical-flow planted filters reveal higher rates of nitrification (transformation of ammonia to nitrate) than horizontal-flow filters on account of the greater oxygen supply into the filter. Almost complete nitrification is commonly reported with ammonia removal efficiency exceeding 90% (Cooper, 1999; Shrestha, 1999). On the other hand, since VFPF do not provide much denitrification, rather low total nitrogen removal rates are achieved.

Phosphorous removal in a VFPF is dependent on the phosphorous sorption capacity of the filter media. Phosphorous is mainly retained by precipitation with Ca, Al and Fe. However, the materials typically used as a substrate (pea gravel, coarse sand) usually do not contain high concentrations of these elements and therefore removal of phosphorous is generally low and decreases with time. Typical phosphorous removal rates in vertical-flow filters (planted and unplanted) do not exceed 35% (von Sperling and Chernicharo, 2005). Removal efficiency may

Photo 4-9: Left: VFPF treating kitchen and laundry greywater in a hotel in Sri Lanka, after pretreatment in a grease trap and septic tank (photo: Harindra Corea E.J.)
Centre and right: VFPF implemented in a household in Kathmandu metropolis, Nepal, during construction and in operation. The constructed wetland has a surface of 6 m^2 and treats 500 l/d of mixed greywater after pretreatment in a sedimentation tank. The filter is planted with *Phragmites karka* and *Canna* spp. (photo: Shrestha R.R.)

be enhanced by using materials with higher concentrations of Ca, Al or Fe (e.g. limestone gravel, spoil from mining, sand with higher Fe content, crushed bricks). TP removal rates exceeding 70% were observed in a VFPF treating greywater in Israel (Gross et al., 2006a).

Vertical-flow planted filters can basically be applied where other filter types are also appropriate. Given their reliance on a well-functioning pressure distribution, they are more adapted to locations where natural gradients can be used, thus enabling to load the filter by gravity. Since flat areas require the use of pumps, they are thus dependent on a reliable power supply and frequent maintenance.

Pond systems for secondary treatment

Most systems described in the literature and applied worldwide for secondary treatment of domestic greywater are based on the principle of attached biofilm. Other less popular systems are in use but not well-documented yet. Especially pond systems look promising, however, documentation is rather scarce on household and neighbourhood-scale pond systems for greywater treatment.

Pond systems for full wastewater treatment (from primary to tertiary treatment) have been successfully implemented in Europe, South-Asia and Africa; though not on a household or neighbourhood scale. These full treatment systems comprise a series of artificial ponds, each with the following very specific function: A first deep sedimentation pond for primary treatment of raw wastewater (functioning like an open septic tank) is followed by two to three shallow aerobic and facultative oxidation ponds for predominantly aerobic degradation of suspended and dissolved solids (secondary treatment). Polishing ponds finally aim at retaining suspended stabilised solids, bacteria mass and pathogens (Sasse, 1998).

As explained earlier, ponds are not recommended as primary treatment of greywater for households or neighbourhoods due to mosquito breeding and bad odour. Ponds may be considered for larger scale applications (e.g. for treating greywater from a condominium) where sufficient space is available and where operation and maintenance of the system can be performed by skilled staff. Mara (2003) provides good guidance on how to design, operate and maintain pond systems for treatment of domestic wastewater in low and middle-income countries.

Currently, polishing ponds are mainly used in household or neighbourhood greywater management systems after a chain of treatment comprising primary and secondary treatment steps (typically septic tank followed by a horizontal-flow planted filter, e.g. case study *Costa Rica*). Polishing ponds can be located quite close to residential areas provided they are well-designed and implemented.

Wetpark – combining horizontal-flow filter and pond system (Gunther, 2006)

A pond system for household greywater treatment was implemented in Skåne, Sweden. The system consists of a series of ponds with an impermeable bottom and permeable shore zones, porous enough for water to pass through. The shore zone between two ponds acts similarly to a horizontal-flow filter. The water flows through the first, second and third shore zone until it is taken out from the reception well with a small wind pump and continually pumped back to the inlet tank. The water is thus recycled several times through the system, thereby increasing the system's capacity for nutrient uptake. Purified water is reused for domestic (non-potable) purposes.

Photo 4-10: Wetpark in Skåne (photo: Holon Ecosystem Consultant)

High-tech treatment systems

Compact, commercially available in-house greywater treatment systems are increasingly applied. The systems sold comprise rotating biological contactors and membrane filtration such as microfiltration, ultrafiltration, nanofiltration, and reverse osmosis. These systems are technically complex, expensive (compared to low-tech systems) and require skilled labour to install and maintain. Given the limited experience with such systems, they cannot be recommended yet for application in low and middle-income countries. An overview of compact greywater treatment systems available on the German market is presented by the German Association Fachvereinigung Betriebs- und Regenwassernutzung (see www.fbr.de/publikation/marktuebersicht_gw.pdf). Activated sludge systems, widely applied for municipal wastewater treatment in Western countries, have hardly been used for greywater treatment. WHO (2005) assumes that their activated sludge treatment efficiency is likely to be low on account of the low nutrient content in greywater.

Greywater discharge and reuse

The last step in a greywater management system is the safe discharge or reuse of the treated greywater, which can be (Ridderstolpe, 2004):

- Discharged into surface water (river, lake, pond, sea).
- Infiltrated into soil, with possible groundwater recharge.
- Reused in agricultural production (irrigation).

The option selected is strongly dependent on the local situation. Although many claim that wastewater, and thus greywater should be regarded as a resource to be reused in agriculture, this option may not always be the most suitable. Reuse is probably not the best option in certain socio-cultural contexts where wastewater is considered dirty and unacceptable or where abundance of freshwater does not provide sufficient incentive to invest in greywater irrigation infrastructure. In peri-urban areas, agricultural land may not always be available, and thus alternative recipients such as surface water, may be more appropriate. Disposal of treated greywater, be it through groundwater recharge or discharge into surface water, can be viewed as a very indirect and long-term reuse option as it re-enters the hydrological cycle (Tchobanoglous, 1991).

Whatever the fate of treated greywater, it will significantly influence type and level of treatment necessary as well as the precautionary measures required. The following sections discuss suitable management schemes, expected benefits and potential risks of each type of reuse or discharge option.

Relevant standards and regulations determining greywater management

Up until recently, greywater reuse and disposal applications have not received a great deal of consideration by regulatory authorities. Few countries have developed greywater-specific regulations, such as some North American States (Arizona, New Mexico, California, New Jersey), Australia (Queensland, New South Wales) or China (Beijing, Tianjin). Most countries have no greywater-specific regulations but more general standards for residential wastewater management. Regulations relevant to wastewater management for households and neighbourhoods are often found in different laws and regulations, such as in building codes, municipal wastewater regulations, health acts etc. However, all have three basic objectives: To ensure public health, protect the environment and, in case of reuse, ensure long-term soil fertility. Therefore, national regulations are often related to different types of reuse or discharge options. The Israeli effluent quality standards for example distinguish between “Discharge to Rivers” and “Unrestricted Irrigation”. Both these standards differ significantly from each other (Ministry of the Environment, 2003). Nutrient-rich water is highly appreciated for irrigation but leads to eutrophication and oxygen depletion of surface waters. Water used for irrigation may thus contain nearly 15 times higher ammonia-nitrogen values than if discharged into rivers. On the other hand, water used for irrigation must not contain more than 10 cfu/100 ml faecal coliforms to minimise the food crop contamination risk (see Table 4-9), while the "Discharge to River" standards allow up to 200 cfu/100 ml.

The surface water pollution problem caused by untreated wastewater discharge has been globally recognised and prioritised, leading to the establishment of quality standards for wastewater discharge into surface waters. The most widely applied effluent standard is the so-called "20/30 standard" (i.e. $BOD_5 \leq 20$ mg/l and SS ≤ 30 mg/l) developed in the United Kingdom and later adapted and adopted by most other countries in the world, often ignoring the reason behind it (Mara, 2003). Whether these standards are meaningful or not may, however, be seriously questioned. Most national discharge standards set maximum concentrations rather than pollution loads. In regions where little water is used given constant water scarcity (notably Middle East and Sub-Saharan Africa), contaminant concentrations may be high and discharge standards will hardly be met. The interested reader is invited to study (Mara, 2003) and critically review the sense and nonsense of existing effluent standards, especially in low and middle-income countries.

WHO's wastewater reuse guidelines (Mara and Cairncross, 1989) set stringent water quality standards for irrigation. However, many developing countries cannot apply these standards for lack of financial and human resources. New guidelines currently developed by WHO (WHO, 2005) are based on the Stockholm Framework and suggest that countries should adapt guidelines to their own social, technical, economic, and environmental contexts, thus giving more flexibility to policy-makers. The framework involves the assessment of health risks (using the Quantitative Microbial Risk Assessment Methodology, QMRA) prior to setting health-based targets and developing guideline values. The basic approach of the guidelines is to apply various combinations of risk management options for meeting the site-specific and health-based targets, such as excreta and greywater treatment performance, as well as other technical, practical and behavioural measures. Non-technical risk management options could include e.g. hygiene education, handling methods, control of human exposure, crop restrictions, mosquito breeding control measures, irrigation methods etc.

The new WHO guidelines for greywater reuse are described in Table 4-8 (WHO, 2005). According to WHO (2005), compliance with these standards is feasible in large treatment systems. In small-scale systems, where frequent microbiological analyses are not possible, linking treatment performance to guideline values becomes extremely difficult. In small-scale systems, WHO suggests more general performance criteria for treatment and handling of excreta and grey-water. Primary treatment is recommended in all cases to prevent clogging of subsequent treatment steps. If effluents are discharged into lakes or rivers, secondary treatment

Table 4-8: Tentative WHO quality standards for greywater reuse (WHO, 2005)

	Helminth eggs No./l	***E. coli*** cfu/100 ml
Greywater reuse in restricted irrigation	1	10^5 (extended to 10^6 when exposure is limited or regrowth is likely)
Irrigation of crops eaten raw	1	10^3

Table 4-9: Effluent standards in selected countries for different types of reuse options

Country		**Costa Rica [1]**	**India [2]**		**Israel [3]**		**Jordan [4]**	**Sri Lanka [5]**	**Switzerland [6]**	**Thailand [7]**	**USA [8]**
Type of discharge/reuse (explanation see below)		Type 1 Type 2	Type 1	Type 3	Type 1	Type 3	Type 2 Type 4	Type 1	Type 1	Type 3	Type 2 Type 5
pH		5.0–9.0	5.5–9.0	5.5–9.0	7.0–8.5	6.5–8.5	6.0–9.0	6.0–8.5	–	6.5–8.5	6.0–9.0
EC	µS/cm	–	–	–	–	1,400	–	–	–	2,000	–
Turbidity	NTU	–	–	–	–	–	10	–	–	–	2
TSS	mg/l	–	100	200	10	10	50	50	–	30	–
O&G	mg/l	30	10	10	1	–	8	10	–	5	–
COD	mg/l	–	250	–	70	100	100	250	–	–	–
BOD_5	mg/l	40	30	100	10	10	30	30	20	20	10
NH_4-N	mg/l	–	50	50	1.5	20	–	50	2	–	–
TN	mg/l	–	–	–	10	20	45	–	–	–	–
TP	mg/l	–	–	–	0.2	5	30	–	0.8	–	–
Faecal coliforms	cfu/100 ml	1,000	–	–	200	10	–	–	–	–	0
E. coli	cfu/100 ml	–	–	–	–	–	100	–	–	–	–

Type 1: Discharge into surface water

Type 2: Landscape irrigation

Type 3: Unrestricted irrigation

Type 4: Irrigation of vegetables consumed cooked

Type 5: Irrigation of vegetables consumed raw

1: MdS (1997); 2: Central Pollution Control Board (1993); 3: Ministry of the Environment (2003); 4: Government of Jordan (2003); 5: CEA (1990); 6: Bundesamt für Umwelt (1998); 7: Pollution Control Department PCD (2000); 8: US EPA (2004a).

is recommended, and compliance with the aforementioned standards if effluent is reused in irrigation or groundwater recharge. Finally, sophisticated tertiary treatment with disinfection is suggested for in-house effluent reuse. The new WHO guidelines for safe use of excreta and greywater will be published in 2006.

Discharge into surface water

Discharge into surface water is the most common way of returning greywater to the natural environment, especially in urban and peri-urban areas. In most low and middle-income countries, however, greywater is discharged untreated, thus causing serious contamination of the receiving water and posing a risk to the population downstream using this polluted water for recreational or irrigation purposes. Severe oxygen depletion, high loads of pathogens and eutrophication are but a few of the main pollution effects caused by the discharge of untreated greywater into surface water. Proper greywater treatment prior to discharge into surface waters maintains the ecological value of receiving waters and also enhances resilience of the ecosystem.

Subsurface infiltration

In percolation or infiltration systems, water is infiltrated in a controlled manner into the soil. Conventional infiltration systems consist of perforated pipes surrounded by media such as gravel, chipped tires or other porous material enhancing even greywater distribution and ensuring the best possible greywater contact with the surrounding soil. Furthermore, pipes and surrounding media provide storage capacity during peak flows.

Feasibility and functionality of infiltration systems are dependent on the existing soil structure. Sandy or loamy soils with a strong granular, blocky or prismatic structure are best suited (Crites and Tchobanoglous, 1998). On loams, only 20 l/d/m^2 of pretreated greywater may be applied, while on fine sand, application rates may amount up to 50 l/d/m^2. Neither coarse sand nor gravel or clays are suitable soils for greywater infiltration systems. On soils of coarse grain size and high

Greywater storage and reuse for toilet flushing

Storage of greywater is difficult as it begins to smell strongly when turning anaerobic. In-house storage of greywater should therefore be avoided whenever possible (Marshall, 1996). Where temporary storage of greywater is unavoidable (e.g. in pump sumps or distribution boxes), the tanks must be constructed so as to be inaccessible to mosquitoes, provide ventilation, be child-safe, and easily accessible for maintenance.

Greywater reuse for toilet flushing is basically possible but involves some difficulties. Greywater has to be adequately treated to prevent build up of undesirable by-products in the cistern or operating components. It is important to avoid biological degradation of water in the cistern. Fat, soap and hair usually produce bad-smelling compounds when degrading; a rather unsuitable situation, particularly indoors. In a private residence in Kathmandu, Nepal, treated greywater is successfully used for toilet flushing (see case study *Nepal*). Neither odour emissions nor algae growth in the cistern have been observed so far (Shrestha R.R., 2006, personal communication).

Table 4-10: Subsurface infiltration	
Working principle	Infiltration into soil by infiltration trenches or beds; treatment by filtration, adsorption and biochemical reactions within the soil.
Design criteria	Loading rate dependent on soil texture; unsaturated zone of 0.6–1.2 m required; application rates: 20–50 l/d/m^2.
Removal efficiency	BOD = 70–80%; TN = 30–60%; TP = 60–90%; faecal coliforms ≤ 4 log.
Typical application	Disposal unit with polishing effect before groundwater recharge.
Strengths	Simple and inexpensive disposal, groundwater recharge; few operation and maintenance requirements.
Weaknesses	Can only be applied on suitable soils; requires sufficient depth of unsaturated soil above groundwater table, well-functioning pretreatment required to avoid premature clogging.
Examples	Case studies *Djenné, Mali, Sri Lanka.*
References	US EPA (1992); Crites and Tchobanoglous (1998).

permeability, greywater infiltrates too rapidly, thus reducing contact time with the soil and microbial degradation processes. With clays of low permeability, water will not infiltrate easily, will collect near the surface and eventually form puddles around the infiltration trench.

Although Figure 4-11 refers to infiltration of pretreated domestic wastewater, application rates specific to greywater are not documented, however, the figures given are assumed to be very similar. The following internet site provides information on how to conduct a percolation test: www.health.gov.bc.ca.

Table 4-11: Recommended (pretreated domestic) wastewater application rates for trenches and lower bed areas, adapted from Crites and Tchobanoglous (1998)

	Percolation rate	***Application rate***
Soil texture	min/cm	l/m^2/d
Gravel, coarse sand	< 0.4	Not suitable
Coarse to medium sand	0.4–2	50
Fine sand, loamy sand	2–6	30
Sand loam, loam	6–12	25
Loam, porous silt loam	12–25	20
Silty clay loam, clay loam	25–50	8
Clays, colloidal clays	> 50	Not suitable

To function correctly, the greywater should percolate through an unsaturated soil layer. In such unsaturated flow, greywater percolates hydroscopically through the finer pores while the larger pores are left open and aerated (Ridderstolpe, 2004). The soil colour is a good suitability indicator. Bright, uniform colours indicate well-drained and well-aerated soils. Dull, grey or mottled soils reveal continuous or seasonal saturation and unsuitable soils (Crites and Tchobanoglous, 1998). The geometry of the infiltration zone may vary. Long, narrow infiltration trenches are most widely used, although infiltration beds or deep infiltration pits can also be applied for local greywater infiltration (US EPA, 1992).

Subsurface infiltration systems are most common in unsewered areas of the USA. In Djenné, Mali, infiltration trenches were introduced successfully to dispose of household greywater (see case study *Djenné, Mali*).

Groundwater recharge

Greywater infiltration to underlying groundwater aquifers occurs both intentionally (percolation beds or infiltration trenches) or unintentionally (excess agricultural irrigation). Recharging groundwater with wastewater is often the most significant but generally rather uncontrolled manner of local wastewater “reuse”. Although infiltrating greywater improves in quality and is stored as water resource for future use, a potential groundwater pollution risk remains. Potential groundwater pollutants from greywater infiltration include pathogenic microorganisms, nutrients and organic pollutants. The level of risk is determined by groundwater hydrology, soil structure and greywater characteristics, and is relevant mainly where groundwater is used as drinking water source. For non-potable applications, such as irrigation, the potential for hazardous exposure is much lower (Aertgeerts and Angelakis, 2003). If recharged groundwater is used as drinking water, its contamination by pathogens is of main concern. Effects of detergents and household cleansing products in recharged groundwater have not been determined yet (Aertgeerts and Angelakis, 2003), however, the health risk related to consumption is assumed to be low.

A high risk of microbial groundwater contamination by infiltrating greywater is only an issue where the groundwater table is high or where the soil strata do not serve as an effective barrier for microorganisms. This can be the case in porous, deeply weathered soil or in fissured or karst rocks. Here, contaminated liquids may reach the groundwater table within a short time and then travel long distances within the groundwater before pathogen die-off. In saturated conditions, bacteria and viruses can travel a distance equivalent to a groundwater travel time of 10–15 days.

In unsaturated and unconsolidated soils with strong granular, blocky or prismatic structure, the risk of groundwater contamination is almost negligible. To minimise groundwater pollution risk and exposure of humans to potentially polluted groundwater, the following precautionary measures are recommended:

- 2–3 m of unsaturated and unconsolidated, well-structured soil effectively protects the aquifer from contamination (Cave and Kolsky, 1999; Lewis et al., 1982). A one-meter unsaturated zone is sufficient if greywater is treated prior to infiltration (which is always recommended) (Crites and Tchobanoglous, 1998; Ridderstolpe, 2004).
- When infiltrating into porous or fissured strata, a 50-cm sand cover (sand of 2-mm effective grain size) is likely to reduce pathogen loads in the saturated zone (Cave and Kolsky, 1999; Lewis et al., 1982).
- Where groundwater levels are very high and soil saturation reaches the topsoil, safety distances to water extraction wells have to be kept. These distances depend on the local geohydrological conditions and should correspond to the estimated travel distance covered by groundwater in 10–15 days (Cave and Kolsky, 1999; Lewis et al., 1982).

Reuse in irrigation

When considering irrigation with treated greywater, its microbial and biochemical properties should be evaluated and compared with reuse standards. Focus should be placed on the irrigated crop, soil properties, irrigation system used, and crop consumption practice. If the effluent meets these standards, the next step is to evaluate the treated greywater in terms of chemical criteria such as dissolved salts, relative sodium content (SAR) and specific toxic ions. In households with high water consumption (> 100 l/p/d) and applied source control measures, the effluent of greywater treatment systems will most probably not cause any toxic effects on the crop or pose increased health risks. Caution is recommended in households with low water consumption or with greywater potentially contaminated by pathogens. High pathogen loads may be attributed to an acute illness of one or several household members, or use of critical chemicals such as solvents and disinfectants. Use of problematic chemicals, such as solvents or disinfectants combined with low amounts of greywater generated, may lead to the accumulation of some chemicals in the soil and crop tissues, with significant negative effects on agricultural productivity and environmental sustainability (Shafran et al., 2005).

Compared with domestic wastewater, greywater will generally contain a reduced number of pathogenic viruses, bacteria, protozoa or helminth eggs. However, as indicated in Chapter 3, washing of babies and their soiled clothing and diapers may substantially raise the pathogen load in greywater. Irrespective of pathogen load or treatment system used, it should be noted that some pathogenic life forms may pass the treatment unaffected and cause a potential health risk if greywater is used for irrigation. Although treatment plant removal rates of 99% or even 99.9% may appear impressive, survival rates nevertheless amount to 1% or 0.1%. This degree of pathogen survival may be significant if the generated greywater is highly contaminated by an acute illness of one or several household members. In low and middle-income countries, where greywater may exhibit high pathogen concentrations, survival of more than one percent is generally considered inadequate.

Not only the presence of pathogens but also their survival time in the water, soil and on irrigated crops are important. Feachem et al. (1983) summarised pathogen behaviour in warm climates (20–30 °C) as shown in Table 4-12. Due to degradation processes caused by sunlight and/or desiccation, pathogen survival time on crops is much shorter than in water or soil.

During primary treatment in grease and grit traps and septic tanks, helminth eggs, protozoal cysts and viruses (attached to settable solids) tend to settle and accumulate in the sludge. However, helminth eggs may survive for several months in this sludge and therefore still pose a health risk when the sludge is removed.

The greywater disposal option selected influences the existence of breeding sites for mosquitoes, important vectors of diseases such as malaria or Bancroftian filariasis (Elephantiasis). Treated or untreated greywater discharged into backyards may form puddles where mosquito larvae can develop in the absence of natural enemies. Even if greywater is led into open stormwater drains, mosquito problems may occur. Drains, built for occasional stormwater events are often used for sewage

Table 4-12: Survival time of selected excreted pathogens in different media at 20–30 °C (Feachem et al., 1983)

Pathogen	***Survival time, days***		
	in fresh water and sewage	in soil	on crops
Viruses			
Enteroviruses	<120 but usually <50	<100 but usually <20	<60 but usually <15
Bacteria			
Faecal coliforms	<60 but usually <30	<70 but usually <20	<30 but usually <15
Salmonella spp.	<60 but usually <30	<70 but usually <20	<30 but usually <15
Protozoa			
Entamoeba histolytica cysts	<30 but usually <15	<20 but usually <10	<10 but usually <2
Helminths			
Ascaris lumbricoides eggs	Several months	Several months	<60 but usually <30

and greywater discharge. They tend to clog and form stagnant puddles, thus creating mosquito breeding grounds. Especially in urban areas, where reuse or local infiltration of treated greywater is often difficult, frequent efforts are necessary to maintain unclogged drains.

As regards the use of irrigation water, one of the main concerns relates to the decrease in crop yield and land degradation resulting from excess salt present in water and soils. High salt concentrations (measured as electrical conductivity, EC, in dS/m or µS/cm) in the irrigation water lead to water stress and decreased crop yield. To assess the suitability of irrigation water in terms of salinity management, other factors must be considered besides water quality. These include salt tolerance of the cultivated crop and characteristics of the irrigated soil.

Figure 4-9: Relative salt tolerance of agricultural crops (Maas, 1984)

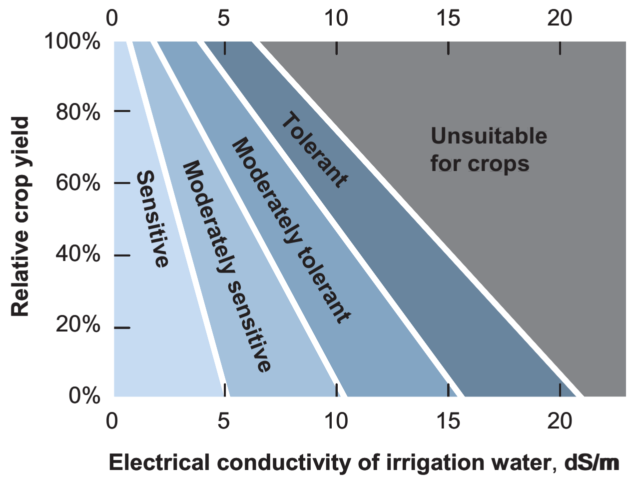


Figure 4-9 exhibits the relative reduction in crop yield for crops of different salt tolerance levels as a function of the electrical conductivity of irrigation water. Examples of crops and their sensitivity to salt are given in Table 4-13. Greywater irrigation with a typical 300–1,500 uS/cm (0.3–1.5 dS/m) EC, should not lead to yield loss if moderately sensitive crops are cultivated. Sprinkler irrigation with more saline greywater within this range may cause leaf burn on salt-sensitive crops, especially at higher temperatures in the daytime when evaporation is high.

An important issue related to greywater irrigation is its sodicity. In plants, excess sodium leads to a perceived drought effect and plants will show burn edge effects and eventually die (Patterson, 1997). High concentrations of sodium in irrigation water

Table 4-13: Relative salt tolerance of selected agricultural crops (Maas, 1984)

Sensitive		**Moderately tolerant**	
Bean	*Phaseolus vulgaris*	Cowpea	*Vigna unguiculata*
Okra	*Abelmoschus esculentus*	Wheat	*Triticum aestivum*
Onion	*Allium cepa*	Fig	*Ficus carica*
Avocado	*Persea americana*	Olive	*Olea europaea*
Lemon	*Citrus limon*	Papaya	*Carica papaya*
Mango	*Mangifera indica*	Pineapple	*Ananas comosus*
Moderately sensitive		**Tolerant**	
Maize	*Zea mays*	Barley	*Hordeum vulgare*
Rice, paddy	*Oryza sativa*	Sugarbeet	*Beta vulgaris*
Cabbage	*Brassica oleracea capitata*	Asparagus	*Asparagus officinalis*
Eggplant	*Solanum melongena esc.*	Date palm	*Phoenix dactylifera*
Spinach	*Spinacia oleracea*		
Tomato	*Lycopersicon lycopersicum*		

can lead to the degradation of well-structured soils (dispersion of clay particles), reducing soil porosity and aeration, and increasing the risk of poor water movement through the soil. Depending on soil characteristics, greywater with a SAR as low as 3-4 can already lead to degradation of soil structure (Patterson, 1997, Gross et al., 2005).

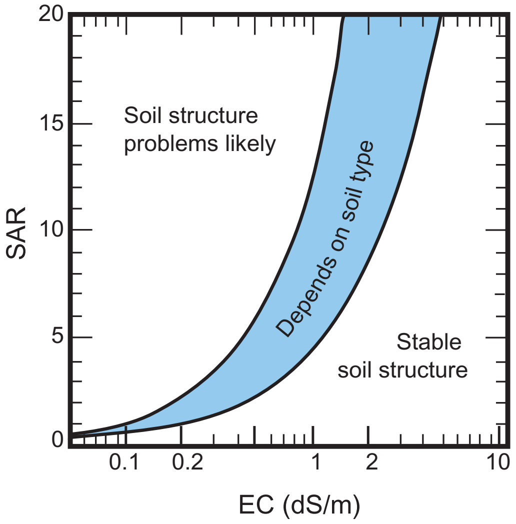
Sodium salts are soluble and cannot be removed under typical wastewater treatment conditions. The best and by far cheapest strategy to avoid excessive sodium loads on soils is the selection of low sodium laundry detergents (see Chapter *Source control*).

Figure 4-10 can be used to evaluate irrigation water quality in relation to its potential impact on soil structure as a function of EC and SAR values. In the event of uncertainty regarding the potential effects of greywater irrigation on soil structure stability, soil samples can be submitted for analysis to an accredited laboratory.

Other problems related to greywater irrigation may be caused by chloride and boron toxicity. Although essential to plants in very low concentrations, boron and chloride can cause toxicity to sensitive crops at high concentrations. Leaf burn at the leaf tip is a typical toxicity symptom for high chloride concentrations. Similar to sodium, high chloride concentrations cause more problems when applied with sprinklers. Plant injuries must be expected with chloride concentrations as low as 140 mg/l (Bauder et al., 2004). Boron toxicity is likely to occur on sensitive crops at concentrations lower than 1 mg/l. Gross et al. (2005) observed boron accumulation in greywater-irrigated soils in Israel. After three years of irrigation, boron concentrations in the soil reached 2.5 mg/kg. The risk of chloride and boron toxicity can best be minimised by utilising cleaning agents poor in boron and chloride.

The fate of surfactants in irrigated soils in not yet fully understood and requires further research. Most studies conclude that biodegradable surfactants are unlikely to accumulate in soil and biota (e.g. Doi et al., 2002; Jensen, 1999). One study conducted in Israel indicates that long-term irrigation of arid loess soil with greywater may result in the accumulation of LAS (linear alkylbenzene sulfonate) and AE (alcohol ethoxylate), two of the most frequently used surfactants in household detergents. The study concludes that soils irrigated with greywater may turn hydrophobic due to a reduction in capillary rise (Gross et al., 2005; Shafran et al., 2005). According to Barber (2002), the fate of surfactants and other organic contaminants in the subsurface depends on geochemical and nutrient conditions, with low dissolved oxygen and low nutrient conditions favouring long-term persistence.

Figure 4-10: Irrigation water quality in relation to SAR and EC to predict soil structure stability (deHayr, 2006)



Irrigation systems

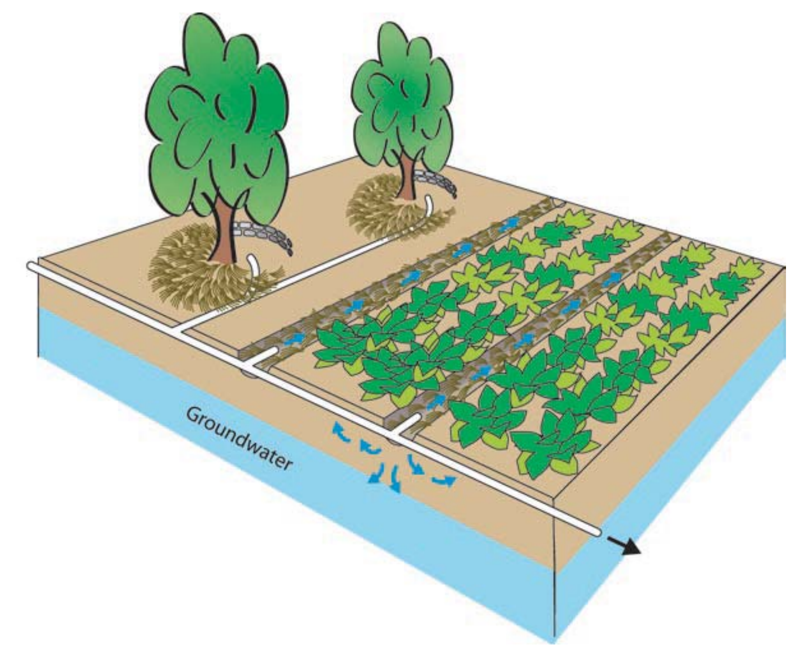
Although solar radiation destroys pathogens on crops within a few days, irrigation systems should try to avoid contact of greywater with the edible part of the crop. Sprinkler installations enhancing direct contact of greywater with above-ground plant parts are therefore not recommended.

Drip irrigation systems have shown to be highly effective if well-designed and maintained. Simple hoses release the water directly at the point of need. The pathogen contamination risk of plants by irrigation water is therefore markedly reduced. Drip irrigation systems normally need a dosing pump and, consequently, also a reliable power supply. Mofoke et al. (2004) also successfully tested an alternative, gravity-driven drip irrigation system (see Photo 4-11). This system was constructed exclusively from cheap and locally available materials, incorporating a modified form of the medical infusion set as emitter. Maintenance has to be ensured, as the emitters tend to clog frequently. Polak et al. (1997) tested another low-cost drip irrigation system whose movable dripper line can irrigate ten plant rows and thus reduce investment costs by 90 percent. Farmers reported that this low-cost drip irrigation system cut labour requirements by half and doubled the area irrigated with the same amount of water. Use of greywater in drip irrigation requires an appropriate primary treatment to remove oil, grease and suspended solids and thus prevent clogging of the dripper holes.

Figure 4-11: Gravity-driven drip irrigation (photo: Mofoke, A.)

The mulch trench system is a simple and promising irrigation system especially for greywater reuse. A trench filled with straw, leaves, rice, spelt, wood or other mulch material is laid around a

Figure 4-11: Schematic layout of a greywater garden irrigated by a mulch trench system



tree or in rows to form irrigation trenches within the irrigated garden. Treated greywater is poured directly into the trench, whereby the mulch acts as a sponge, retaining water and nutrients close to the soil and reducing the impact of sun, wind and evaporation. Reduced evaporation and increased storage prevent shallow roots from drying out, minimise water requirements and promote healthy plant growth. In such trenches, pathogens are not in contact with above-ground plant parts and are further inactivated by microorganisms present in the mulch. To prevent clogging and odour emissions, greywater should be treated in a grease and grit trap prior to irrigation in mulch trenches. In such a trench system, greywater is normally applied by gravity, however, a pressurised system using siphons or pumps is also applicable. The trenches have to be replaced upon degradation of the organic material of the mulch. Figure 4-11 illustrates a greywater-irrigated mulch trench system.

In Texas, USA, a simple irrigation system using a 20-litre plastic bucket, cement and radial pipes (Ø 2.5 cm) distribute pretreated (by a grease and grit trap) kitchen greywater to mulch chambers irrigating nearby trees (papaya and banana) (see Photo 4-12). The wood chips used as mulch decompose over time and have to be replaced annually by several centimetres of new mulch material. The distribution hub has to be cleaned every four months. The Texan example has been in operation since the early 1990s and shows no signs of excess salinity (Omick, 2005).

Photo 4-12: Greywater infiltration and irrigation system in Casa Juliana, Texas. Kitchen greywater is distributed via a hub to six small infiltration chambers irrigating papayas and bananas. The chambers are filled with mulch (photo: www.omick.net)

5. Examples of Greywater Management Systems

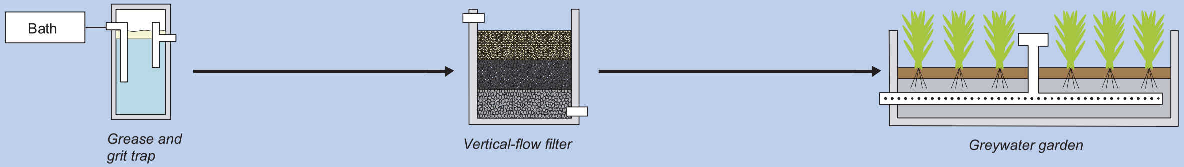
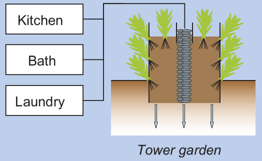
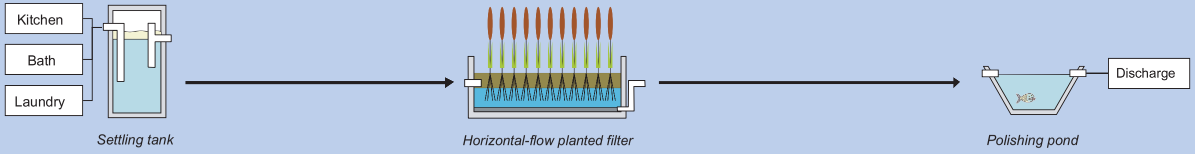
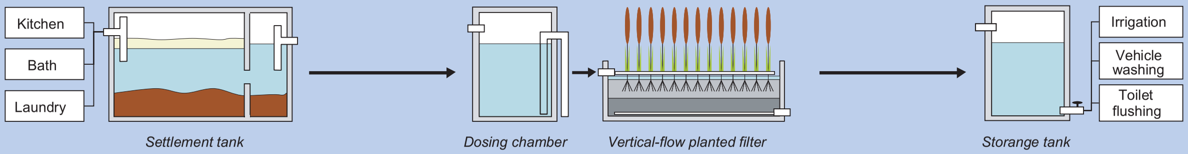
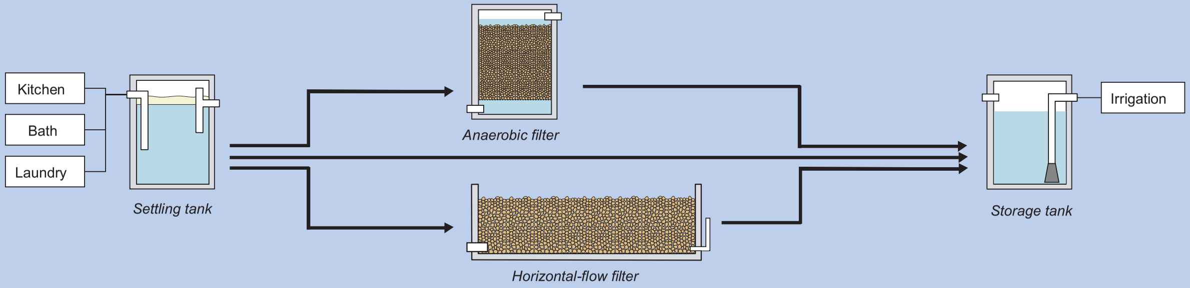
Case studies of greywater management systems

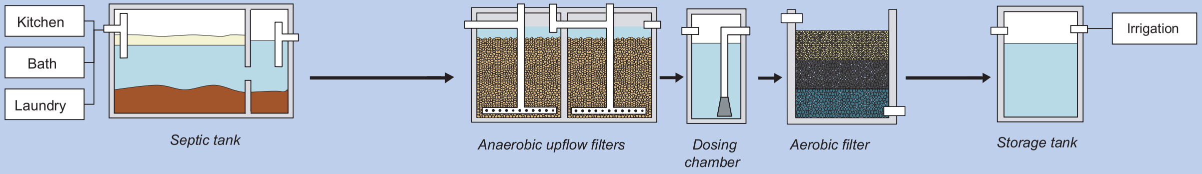
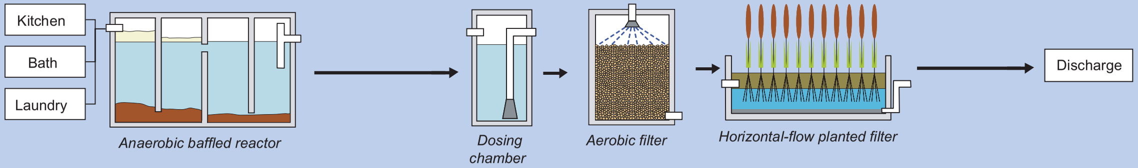
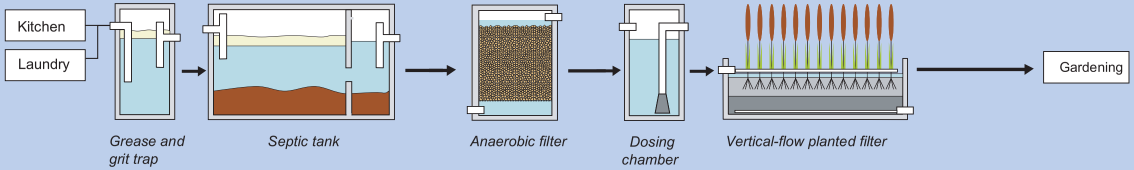
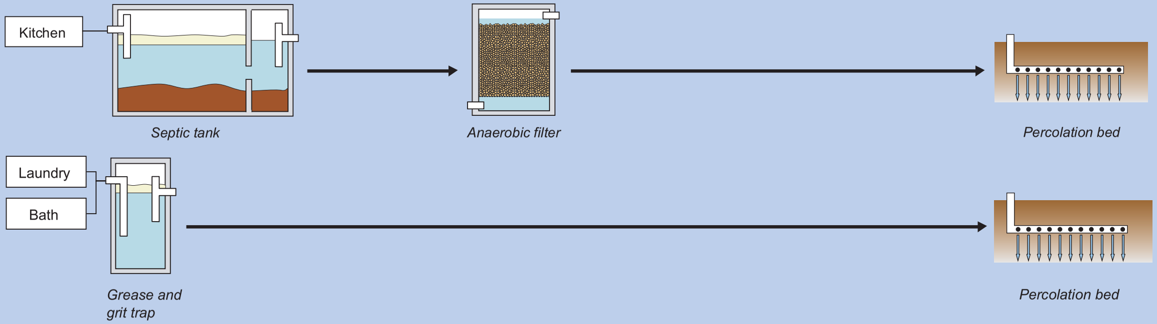
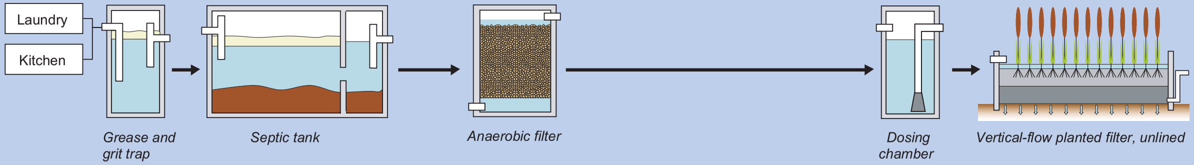
This section provides an overview of greywater management systems implemented in different low and middle-income countries. The few identified cases, summarised in Table 5-1, show a wide range of systems, from simple infiltration trenches to sophisticated systems based on anaerobic/aerobic filter combinations.

The case study documentation comprises, whenever possible, a technical description of the systems used, their operation and maintenance requirements, dissemination activities conducted, performance indications, and economic considerations. Where operational problems occurred, reasons for failure are discussed.

It is surprising that the main reasons for system failure are caused by a lack of maintenance and understanding of the operational principles of the treatment chain. During project implementation, it is therefore of utmost importance to focus not only on technical equipment and infrastructure but also to include information and training of the different key stakeholders. The key stakeholders are most often women who are generally in charge of water-related issues within the community. Stakeholder involvement has to be ensured before laying the first stone or digging the first hole. Cultural habits, national and regional regulations and policies as well as existing sanitation infrastructure and services must be integrated into the solution finding process to lead to successful and sustainable implementation.

Table 5-1: Overview of greywater systems presented in Chapter 5

Location	Greywater management system	Capacity	Performance	Costs
	Primary treatment — *Secondary treatment* — *Disposal/reuse*			
Djenné, Mali		Variable	n/a	n/a
Koulikoro, Mali		n/a	n/a	n/a
Gauteng, South Africa		20 l/d	n/a	n/a
Monteverde, Costa Rica		755 l/d	BOD$_5$: 99% NH$_4$-N: 95% PO$_4$-P: 84%	USD 83/p
Kathmandu, Nepal		500 l/d	BOD$_5$: 98% TSS: 97% NH$_4$-N: 96% PO$_4$-P: 33%	USD 61/p
Ein Al Beida, Jordan		n/a	BOD$_5$: 70–89% TSS: 51–85%	USD 40-60/p

Location	Greywater management system Primary treatment / Secondary treatment / Disposal/reuse	Capacity	Performance	Costs
Bilien, Palestine		550 l/d	BOD_5: 78–95% TSS: 93–96% NO_3-N: 39–74% PO_4-P: 39–74%	USD 250/p
Kuching, Malaysia		6,800 l/d	BOD_5: 99% TSS: 96% Total P: 88%	USD 250/p
Kandy, Sri Lanka		7,400 l/d	n/a	USD 70/p
Kandy Lake, Sri Lanka		n/a	n/a	USD 35/p
Hikkaduwa, Sri Lanka		3,000 l/d	n/a	USD 220/p

Djenné, Mali

Project Framework

Type of project

Project for the restoration and renovation of the city of Djenné

Supervision

Mission Culturelle, Djenné
National Museum of Ethnology, Leiden, The Netherlands

Funding

Dutch government

Project period

Jan. 2000–Jan. 2003

Project scale

100 single households
(2004: 600 households)

Contact address

National Museum of Ethnology
P.O. Box 212
NL-2300 AE Leiden
The Netherlands
E-mail: info@rmv.nl

Direction nationale de l’hydraulique
E-mail: dnh@afribone.net.ml
Web: www.dnh-mali.org

M.C. Alderlieste
UNICEF Zimbabwe
6 Fairbridge Av., Harare
E-mail: malderlieste@UNICEF.org

References

Alderlieste, M. C., and Langeveld, J. G. (2005). Wastewater planning in Djenné, Mali. A pilot project for the local infiltration of domestic wastewater. Water Science and Technology 51, 57-64

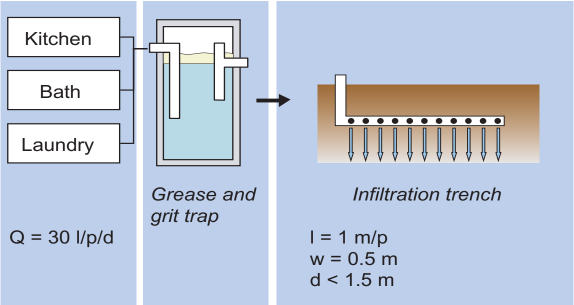
Faggianelli, D. (2005). Respect du patrimoine et modernité: un pari gagné. In “La lettre du pS-Eau”, Vol. 48, pp. 6-10

Local infiltration of domestic greywater

Project background and rationale

The city of Djenné with its approx. 20,000 inhabitants is situated in the inner delta of the Niger River (Sub-Saharan climate). The city, famous for its adobe buildings, is considered one of the most architecturally interesting cities of West Africa. Since 1988, UNESCO lists Djenné as a World Heritage Site. In the early 1990s, foreign development organisations built a drinking water supply system in the city of Djenné. Washing and bathing activities were thus shifted from the river shore to the household. No facilities were provided for greywater disposal. Despite the very low water consumption of 30 litres per person and day, a considerable daily greywater volume was discharged directly onto the streets. This type of disposal not only had a detrimental effect on public health, but also led to impassable roads and suspended street cleaning operations altogether. In 2000, a study was conducted to evaluate possible options to mitigate the greywater problem (Alderlieste and Langeveld, 2005). Local greywater infiltration was piloted in 2002. Within the project framework, one hundred infiltration systems were built throughout the city using local material and labour. By 2004, already 600 households were connected to a greywater infiltration system.

Greywater management system



Greywater from kitchen, bath and laundry flows through a PVC pipe (Ø 110 mm, covered with local pottery so as to blend in with the adobe buildings) into a grease and grit trap (Figure 5-1). The trap, located at the bottom of the outer wall of the house, is easily accessible for maintenance. The pretreated greywater leaves the grease and grit trap through a small bore pipe (Ø 40 mm) entering the infiltration trench.

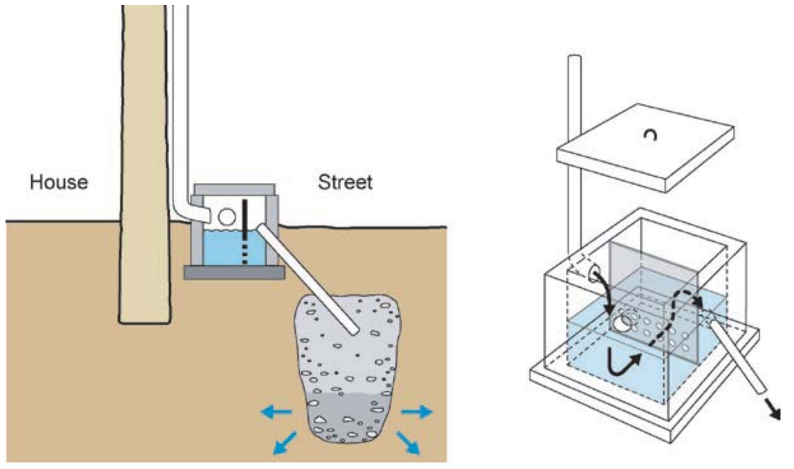
The infiltration trench is 0.5 m wide and not more than 1.5 m deep to allow safe working conditions for the craftsmen. The length of the infiltration trench is calculated by the following equation:

$$L = \frac{n \times Q}{2 \times d \times I}$$

where

L : length of trench [m]
n : number of users
Q : flow per capita and day [l/d]
d : depth [m]
I : infiltration rate [$l/m^2/d$]

Figure 5-1: Grease and grit trap and infiltration trench, Djenné, Mali (Alderlieste and Langeveld, 2005)



Hydraulic conductivity measurements indicate a maximum infiltration rate of 150 $l/m^2/d$. Assuming a peak water consumption of 50 l/p/d, a trench depth of one meter and a maximum application rate of 50 $l/m^2/d$, the trench length amounts to one meter per family member.

The infiltration trench is filled with gravel of an estimated 25 mm d_{50} and covered by at least 0.5 m of soil.

Performance

One year after completion of the pilot project, the streets with adjacent infiltration systems were dry and clean (see Photo 5-1). Transport costs of goods decreased significantly due to improved road conditions. Transport of 100 kg of grain currently costs Fcfa 75–100 compared to Fcfa 250 before project implementation. Water samples taken from 10 wells did not reveal any groundwater contamination caused by the greywater disposal system (Faggianelli, 2005).

Operation and maintenance

Clogging of the grease and grit trap was frequently reported. Such system failures were caused by a lack of maintenance of the trap and clogging of the subsurface outlet pipe by plastic bags. Meetings with the local community, especially the women, were consequently held to raise awareness and to train them in infiltration system maintenance. Furthermore, design of the grease and grit trap was modified to prevent floating material from clogging the outlet.

Photo 5-1: Street in Djenné before implementation of infiltration trenches (left) and one year after implementation (right) (photos: above, Alderlieste M.C.; below, Langeveld J.G.)

Table 5-2: Detailed investment costs per infiltration system, Djenné, Mali

	Costs	
	Fcfa	USD
Material and construction	52,600	94
Construction supervision	15,300	27
Maintenance	3,100	5.5
Training	12,000	21
Total costs	83,000	147.5

Fcfa 1,000 = USD 1.78 (January 2006)

Costs

Construction or maintenance costs are not reported in the publication by Alderlieste and Langeveld (2005), but total costs of USD 150 per infiltration unit were established by a subsequent project supervised by pS-Eau and supported by the German Development Bank (KfW) (see Table 5-2) (Faggianelli, 2005). The financial contribution of the households amounted to USD 50.

Practical experience and lessons learned

Success of the project strongly depends on local community involvement. The basic principle and impact of the infiltration system were demonstrated at two strategic locations: at the house of a person of rank and of the mayor. Based on the visible success of these two reference locations, acceptance and willingness of the community to cooperate increased significantly. Organisation of instruction meetings with woman groups before, during and after construction of the infiltration system with special focus on maintenance of the grease and grit trap also contributed to successful implementation of the system. Much effort was put into training local craftsmen who were organised in teams of one mason and two labourers. After intensive training, the first team further disseminated its knowledge to other teams. Upon project evaluation in January 2003, the various teams trained could set up an infiltration system in two days. In September 2004, over 600 houses were equipped with infiltration facilities whose number is further increasing.

This case study is a good example for successful implementation of a simple but effective greywater treatment system. Involvement of local technical expertise and intensive training of users proved to be an important tool for implementing a sustainable solution. Future potential clogging of the infiltration trench should continue to be investigated with increasing water consumption and greywater production.

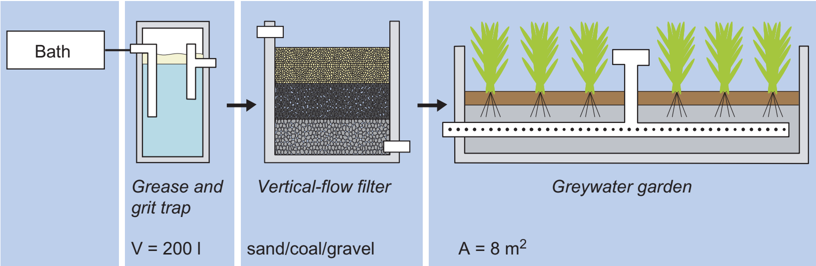
Koulikoro, Mali

Greywater garden

Project background and rationale

Koulikoro with its 26,000 inhabitants is the capital of Mali's second largest administrative area. The town spreads across a sandy river valley up to an adjacent rocky plateau. The average household numbers 10–25 persons, all residing in a spacious compound (300–400 m^2) and sharing a single sanitation facility. Most households use traditional pit latrines including a shower area. Urine and shower water usually flow over the latrine floor either into a "puisard" (collection and infiltration pit for wastewater) outside the compound and into the open stormwater drains or directly onto the street. Infiltration of wastewater is difficult given the high groundwater table in the river valley area and the rocky subsurface in the other neighbourhoods. Within the framework of a pilot project headed by the German Technical Cooperation (GTZ) and aiming at establishing appropriate, sustainable, low-tech and low-cost sanitation systems, a treatment system was implemented for bathroom greywater using planted filters for combined vegetable production.

Greywater management system



A wire mesh covering the outlet of the shower prevents large particles from being washed into the 200-litre open grease and grit trap. The collected greywater from the grease and grit trap is then conveyed into a vertical-flow filter (0.36 m^2) with an upper layer of sand (30 cm), a middle layer of charcoal (30 cm) and a bottom layer of gravel (20 cm). The thereby filtered water then enters a subsurface irrigated bed (8 m^2) planted with fruits and vegetables (see Figure 5-2 and Photo 5-2). The greywater fed through perforated pipes into this garden is equipped with two aeration pipes. For hygienic reasons, only crops with above-ground edible parts are planted. The garden is fenced off to prevent damage by domestic animals.

Project Framework

Type of project
Urban upgrading project

Planning institution
OtterWasser GmbH, Lübeck
Executing Institution
German Technical Cooperation, BOATA GmbH, Mali

Project period
Start of construction: April 2000
Start of operation: July–Dec. 2001

Project scale
11 decentralised treatment units, each for ca. 10–25 inhabitants

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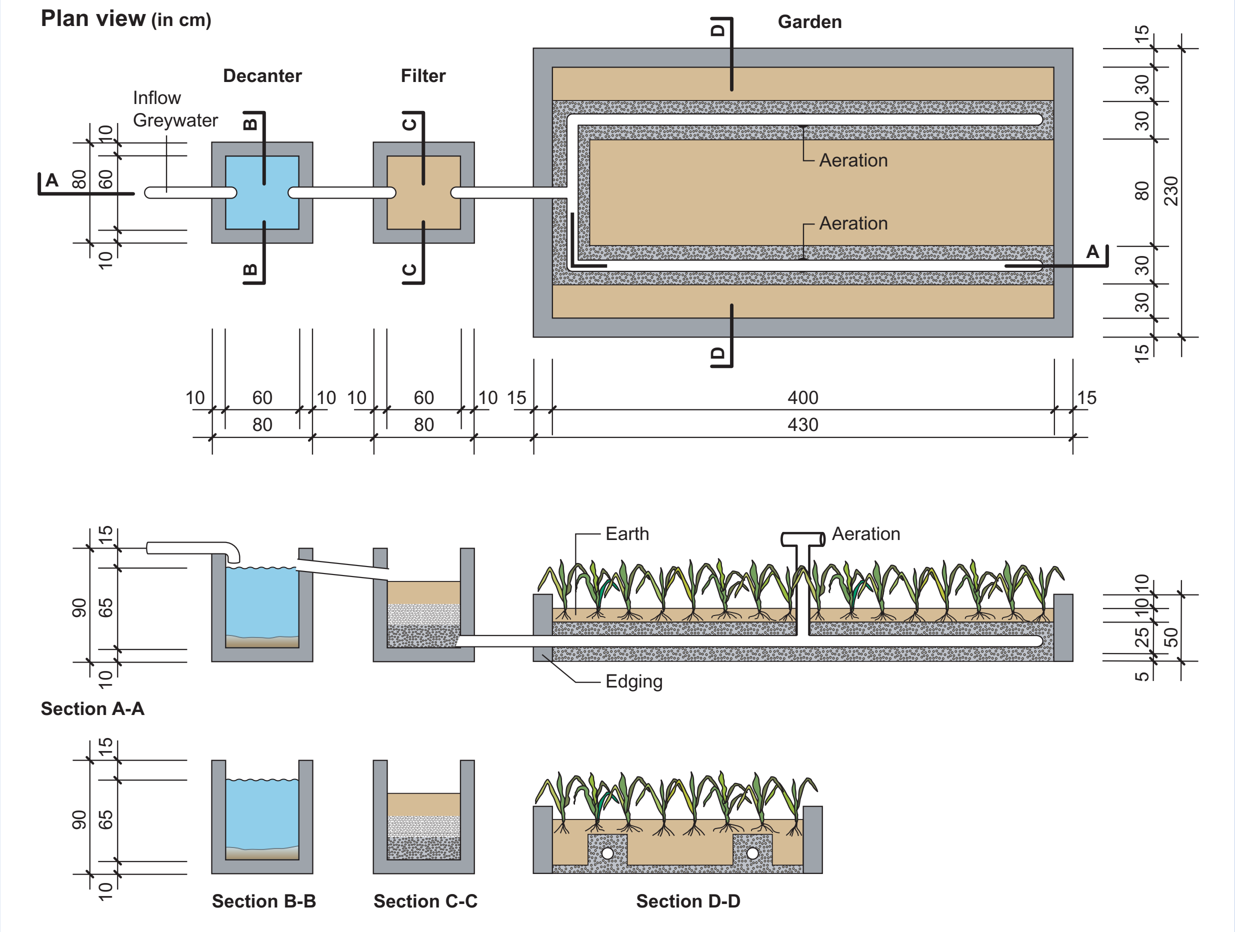
References

Werner, C., Klingel, F., Bracken, P., Schlick, J., Freese, T., and Rong, W. 2001. "Kurzbericht ecosan Projekt - Koulikoro, Mali." Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ), Eschborn, Germany

Figure 5-2: Plan view and cross-sections of the greywater garden implemented in Koulikoro, Mali; Source: OtterWasser



Performance

The garden initially provided access to vegetables, a fact highly appreciated by all families. Within a short time however the system failed for lack of maintenance. As the wire mesh started to rust, it was removed and caused the solids load on the filter to increase and the filter material to clog. Users subsequently removed the filter material to water at least the garden, however, the untreated greywater eventually clogged the perforated irrigation pipes and surrounding substrate.

Photo 5-2: Planted greywater garden and aeration pipe (photo: GTZ)

Operation and maintenance

Frequent maintenance of all components seems the key factor in achieving appropriate system operation. Since daily cleaning of the wire mesh is necessary, it has to be easily accessible and removable. The grease and grit trap has to be emptied periodically to avoid washout of coarse solids, oil and fat into the vertical filter. If the filter material shows signs of clogging (surface covered with sludge, remaining water on the surface), the different layers need to be removed and either cleaned or replaced.

Maintenance and repair of the fence around the garden is also an important aspect to ensure proper functioning of the greywater garden. Uncontrolled access of animals to the garden can lead to plant degeneration.

Costs

Construction or maintenance costs are not reported.

Practical experience and lessons learned

Despite an extensive exchange of information and communication among all stakeholders, long-term commitment of the users was rather limited. Lack of awareness for regular maintenance finally led to failure of the system. Similar projects should in future be structurally less complex to facilitate maintenance and ensure adequate operation over longer periods. The filter material currently used (inert sand and gravel) could for example be substituted for wood chips or other natural substrates, which are replaceable after degradation (see section *Irrigation systems*).

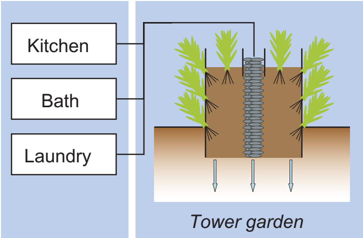
Gauteng Province, South Africa

Greywater tower garden

Project background and rationale

For a number of reasons, many rural South African villages hardly practice gardening. Despite available land, finding and transporting water is generally the main barrier. Water collected at the nearest standpipe and carried home will not be used for irrigation. Adendorff and Stimie (2005) describe a user-friendly, low-cost and low-tech greywater reuse system, where gardening does not have to rely on rainfall and where nutrients are derived from greywater originating from washing clothes, kitchen utensils etc.

Greywater management system



The external structure of the greywater garden consists of poles (iron bars or fence posts) and shading material (see Photo 5-3 and Figure 5-3) surrounding soil and a central stone-packed drain. The purpose of the stones is to spread the water flow throughout the column. Greywater is poured daily with buckets on top of the central stone core. The water trickles through the stone core and is more or less evenly distributed within the soil column. Leafy vegetables (such as spinach) are planted into slits of the shading material surrounding the soil column. The slits are offset to one another thus giving more space for root development. Tomatoes or onions may be planted on top of the column. The most appropriate filling material mix for the tower should be composed of three parts soil, two parts animal manure and one part wood ash.

Photo 5-3: Tower garden during growing (left) and before harvesting (right) (photos: Rural Integrated Engineering)

Project Framework

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References

Adendorff, J., and Stimie, C. 2005. Food from used water - making the previously impossible happen. In "The Water Wheel", Vol. 3, pp. 26-29. South African Water Research Commission (WRC)

Smith, M. 2005. Tower garden ideal where water is limited, AgriNews - Newsletter of the South African Department of Agriculture, Pretoria, pp. 12

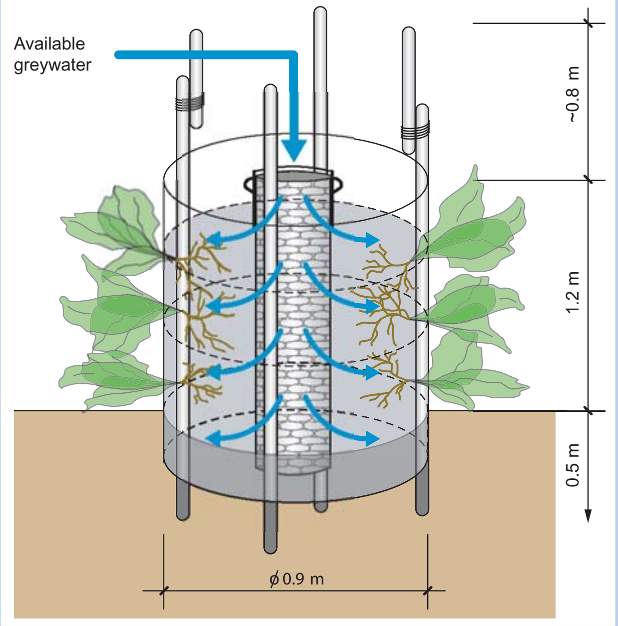
Performance

Information on treatment efficiency of the garden tower is not available. However, the vegetables planted grew well and thrived even in severe heat not tolerated by conventionally planted crops in gardens. Several possible reasons are attributed to this benefit: Lower soil temperatures caused by air circulation in the core and cooling by evapotranspiration or higher elevation of the plants away from the hot ground.

Operation and maintenance

Two to three buckets of greywater have to be applied daily to prevent the soil from drying out. A puddle forming around the bottom of the tower indicates excess water. Tower gardens are best located in the courtyard so as to minimise transport distance of greywater.

Figure 5-3: Schematic view of a tower garden



Costs

Construction or maintenance costs are not reported.

Practical experience and lessons learned

Finding the right type of material to wrap around the sides of the tower is difficult. In Kenya, where identical systems were implemented, nylon gunny bags were used but lasted only about two years. In South Africa, shading material (Photo 5-3) did not last for more than one season, since black plastic sheets deteriorate rapidly when exposed to sunlight. Shade netting proved to be far more durable, however, nylons strings or fishing lines to join up the ends of the shade netting are recommended. The core material should consist of flat stones or building rubble, as round stones allow the applied water to run too quickly down the centre of the tower, thus preventing the soil from being evenly moistened.

One of the main strengths of the system is its minimal labour, monitoring and maintenance requirements. Once familiar with the towers, the users prefer to position them in their courtyards for easy pouring of the greywater into the stone core. Such greywater reuse can thus effectively contribute to increasing food security. However, the risk of plant contamination with pathogens by some splashing water should be avoided. Raw consumption of the harvested vegetables is not recommended. To prevent toxic effects on plants and soil deterioration, household detergents must be selected carefully. To prevent clogging in the stone column and soil, a grease and grit trap for primary treatment should be installed. If free moving domestic animals share the same space, the tower garden should be fenced in.

Monteverde, Costa Rica

Horizontal-flow planted filter for domestic greywater treatment of four households

Project Framework

Type of project
Private initiative funded project

Supervision and implementation
Monteverde Institute

Funding
Ford Motors Co Environment Award

Project period
March 2001–August 2002

Project scale
Four single households (total 18 persons)

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References

Dallas, S., Scheffe, B., Ho, G., 2004. Reedbeds for greywater treatment – case study in Santa Elena-Monteverde, Costa Rica, Central America. Ecological Engineering 23, 55-61

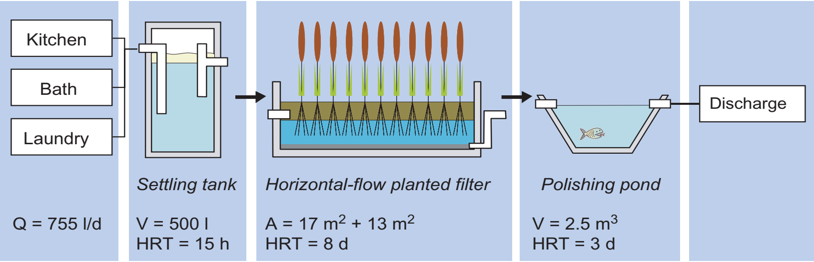
Dallas, S. and Ho, G., 2005. Subsurface flow reedbeds using alternative media for the treatment of domestic greywater in Monteverde, Costa Rica, Central America. Water Science and Technology, 52(10): 119-128

Dallas, S., 2004. Up in the clouds. Murdoch University, Environmental Technology Centre

Project background and rationale

Monteverde, situated in the northwest of Costa Rica at approx. 1,200 meters altitude, has a tropical climate. Attractive eco-tourism in Monteverde has led to significant unregulated growth during the last two decades. Typically for rural Latin America, separation of wastewater at the source is common, and Monteverde is no exception. Blackwater is treated in septic tanks while greywater is mostly discharged directly onto streets and into streams. Given this unacceptable situation, a local resident, inspired by a demonstration greywater reedbed project, offered the necessary land for implementation of a suitable greywater treatment system provided additional funding was raised.

Greywater management system

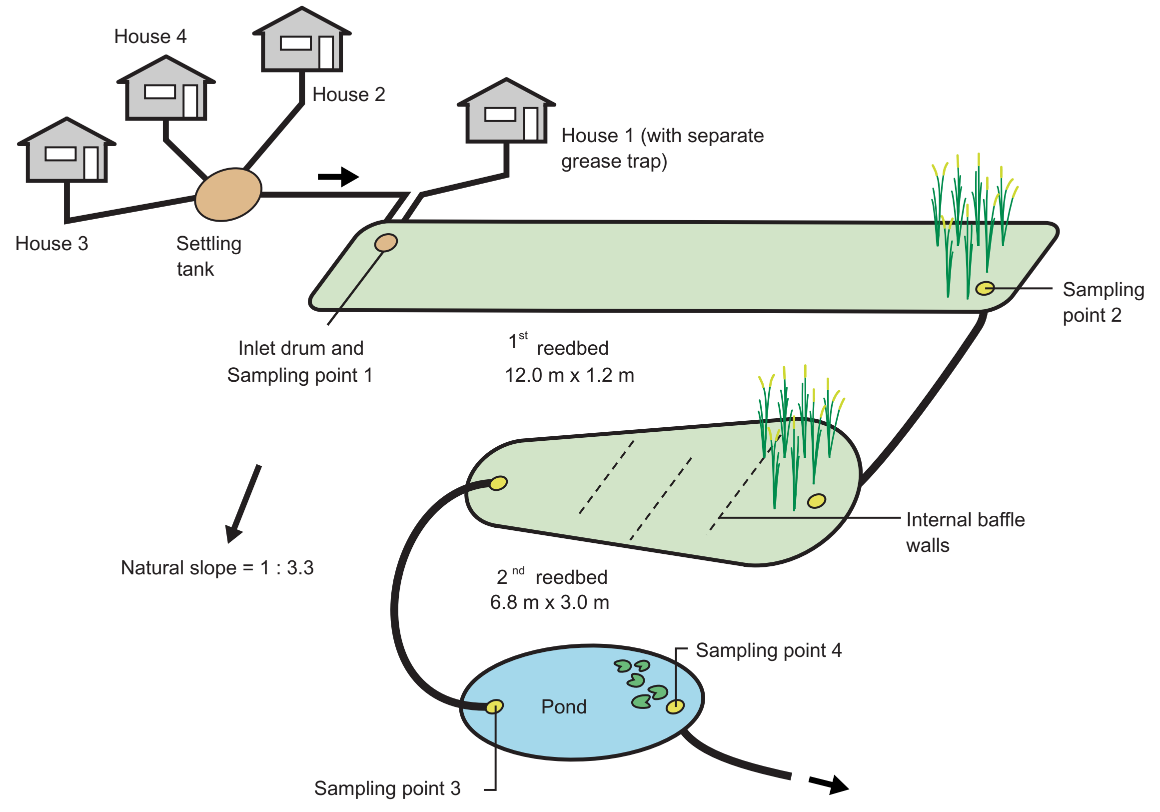


The greywater system was designed to receive water from four households with an average of 4.5 persons per household and an average water consumption of 139 l/p/d. To assess daily greywater generation, a 75/25 greywater/blackwater ratio was used. This resulted in a fairly conservative figure of 2,500 l greywater per day. In system design capacity, 25% were added as reserve to this figure. Although only three homes have currently been connected to the system at any one time, measurements reveal that the greywater volume amounts to only about 750 l/d.

PVC pipes (Ø 50 or Ø 75 mm) convey the greywater from the houses to a 500-l concrete settling tank. A steel mesh inside this settling tank allows easier manual emptying (see Photo 5-4).

The secondary treatment step consists of two horizontal-flow planted filters (HFPF) in series. The first planted filter (reedbed) is rectangular (12 m long, 1.2 m wide (14 m^2) and 0.6 m deep). The second planted filter has an oval shape (6.8 x 3 x 0.6 m; 13 m^2)

Figure 5-4: Layout of the four-household planted filter system for greywater treatment in Monteverde, Costa Rica



(see Figure 5-4). The second reedbed has internal plastic baffle walls which extend the flow path to approx. 12 m length. The locally available crushed rock (20 mm) of 40% porosity in the bed allows for an effective storage volume of 6 m^3, corresponding to a minimum hydraulic retention time (HRT) of 7.9 days (4.5 d in filter one, 3.4 d in filter two). The filters are planted with *Coix lacryma-jobi*, a macrophyte known to occur throughout Costa Rica up to 1,450 meters altitude. After passing through the planted filters, the treated greywater flows into a shallow pond (approx. 2.5 m^3) containing several aquatic plant species and fishes. These fishes help control mosquito breeding (see Figure 5-4). The pond primarily has an ornamental value and serves as demonstration unit only. Its treatment function is marginal.

Photo 5-4: Settling tank (photo: Dallas S.)

Photo 5-5: Build up of 1st reedbed: Excavation (left), inlet drum (centre) and planted filter (right) (photos: Dallas S.)

Performance

System performance was generally satisfactory. Table 5-3 summarises the data measured in November 2001 in both horizontal-flow planted filters.

From a public health perspective, the treated water quality in the final greywater treatment step was equivalent to some of Monteverde's most pristine streams. Fish and frogs have colonised the pond and are assumed to be responsible for the lack of mosquito larvae.

Table 5-3: Efficiency of greywater treatment system, Monteverde, Costa Rica; SP 1-SP 4 refer to sampling points indicated in Figure 5-4

		Inlet drum (SP 1)	*Effluent 1st filter (SP 2)*	*Effluent 2nd filter (SP 3)*	*Effluent polishing pond (SP 4)*	*Effluent standards*
BOD	mg/l	167	8.4	2.0	2.4	≤40[1]
TSS	mg/l	8.4	9.5	10.0	28	30[2]
TDS	mg/l	342	284	213	128	–
Turbidity	NTU	96	7.5	2.0	3.8	–
NH_4-N	mg/l	8.4	1.0	0.1	0.4	–
PO_4-P	mg/l	7.6	5.2	2.3	1.2	–
Total P	mg/l	1.6	3.6	1.5	–	–
Faecal coliform	cfu/100 ml	1.5×10^8	17,000	69	122	≤1,000[1]
Temp.	°C	21	20	20	21	–
pH		6.3	5.9	6.8	7.0	5.0–9.0
DO	mg/l	1.0	1.0	6.9	6.2	–

1: Costa Rican guidelines for wastewater reuse (recreational reuse) (MdS, 1997), 2: Mexican standard for wastewater reuse (Comisión Nacional del Agua, 1997)

Operation and maintenance

Manual desludging of the settling tank has been reported as a necessary maintenance activity. It is carried out annually by the owner's son at a cost of USD 7 and requires about three hours. The removed sludge is buried in the owner's garden. The installed removable and reinforced mesh basket simplifies this task. Having all houses connected to one main settling tank eases maintenance.

Other maintenance tasks include occasional weeding of the planted filters, pruning of overhanging branches, removing of leaves and rubbish from the pond, and thinning of aquatic plants, all of which are relatively straightforward and not very time-consuming tasks.

Costs

Table 5-4: Costs for greywater treatment system, Monteverde, Costa Rica

	Quantity	*Cost/unit* USD	*Total* USD	*Percentage*
Crushed rock (delivered)	15 m^3	25	375	24.8%
Plastic liner (2 HFPF and 1 pond)	480 m^2	0.3	145	9.7%
Pipe, fittings and 500-l settling tank	–	400	400	26.4%
Labour	120	2.5	300	19.8%
Tools, transport and misc.	–	–	292	19.3%
Total direct cost			**1,512**	**100%**
Volunteer labour	~50 hours			
Design and monitoring	~150 hours			

Construction costs amount to USD 1,512 (see Table 5-4), and the filter material costs (crushed rock) represent 25% of the total costs.

Practical experience and lessons learned

Some clogging near the inlet of the first filter was observed after two years of operation. Likely causes: Insufficient bed width given the hydraulic conductivity, insufficient solids/grease removal in the settling tank and clogging of the substrate enhanced by the large amount of sand and silt in the crushed rock used as filter material. Nitrogen deficit typical for greywater may also be one of the causes for clogging.

Liner leakage discovered in the second filter bed highlighted the importance of avoiding joints in the liner as well as the need for a geotextile layer to protect the liner. A more robust liner would, however, lead to a considerable increase in costs.

Dissemination and replication of the concept is largely dictated by installation and maintenance costs as well as opportunity costs caused by further land requirements.

Use of conventional crushed rock influenced construction and operation for the following reasons:

- Responsible for 25% of the total costs.
- Increased salary costs, as handling this heavy material was more labour-intensive.
- Increased clogging risk, as fine sand was also present in the crushed rock material.
- Difficult and expensive repair work (e.g. unclogging inlet section or repairing liner).
- Relatively low porosity and hydraulic conductivity.

Kathmandu, Nepal

Vertical-flow planted filter (constructed wetland) for single households

Project Framework

Type of project
PhD thesis

Supervision
Institute for Water Provision
University of Agricultural Sciences
Vienna, Austria

Project period
Implementation: April 1998
Monitoring period:
April 1998–May 2000

Project scale
Single household (7 persons)

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References

Shrestha, R.R., Haberl, R., Laber, J., 2001. Constructed wetland technology transfer to Nepal. Water Science and Technology 43, 345–350

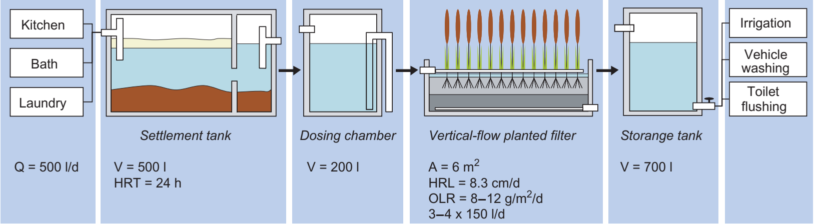
Shrestha, R.R., Haberl, R., Laber, J., Manandhar, R., 2001. Application of constructed wetlands for wastewater treatment in Nepal. Water Science and Technology 44, 381–386

Project background and rationale

In Nepal, many urban rivers have already turned into open sewers due to the discharge of untreated wastewater from households and, in some cases, toxic industrial waste. Appropriate wastewater treatment and reuse are neglected and often considered unaffordable. In the 1970s, four large-scale wastewater treatment plants were constructed around Kathmandu Valley. However, since they are no longer in operation, an increasing number of small-scale and decentralised alternative wastewater treatment systems have been developed and implemented.

The current water demand in the Valley amounts to about 150 million litres per day (MLD) compared to the available 90 MLD. Despite this major deficit, drinking water is used for several non-potable purposes such as toilet flushing, gardening, vehicle cleaning etc. To solve this problem, Mr Shrestha installed within the framework of his PhD thesis a greywater treatment system in his own house to prove the viability of a simple water reuse technology. Based on the positive experience gained, several similar systems for single households, hospitals and larger communities have been implemented in and around Kathmandu.

Greywater management system



A constructed wetland system was built for a 7-person household. The system was designed to treat greywater from bathroom, laundry and kitchen. The greywater is collected in a 500-litre, two-chambered settling tank. A subsequent dosing tank of 200 litres with a mechanical siphon discharges greywater onto a vertical-flow planted filter 3–4 times a day through a perforated pipe (Ø 50 mm) fixed above the surface level of the bed. The filter material of the bed (6 m^2) is composed of a 20-cm layer of gravel (20–40 mm) at the bottom, 10 cm of fine gravel (10 mm) in the middle and 60 cm of coarse sand on the top. The bed

Table 5-5: Infuent and effluent concentrations of the greywater treatment system in Kathmandu, Nepal, April 1998 to May 2000; SD = standard deviation

	Influent range mg/l	*Effluent range* mg/l	*Influent average* mg/l (SD)	*Effluent average* mg/l (SD)
BOD_5	100–400	0–12	200 (93)	5 (4.6)
COD	177–687	7–72	411 (174)	29 (20)
TSS	52–188	1–6	98 (53)	3 (2)
NH_4-N	4–26	0–2	13 (8)	0.5 (0.6)
PO_4-P	1–5	1–4	3 (1)	2 (1)

is planted with *Phragmites karka* and *Canna latifolia* (see Photo 5-6). The treated greywater is then collected in a 700-litre tank before it is used for irrigation, washing vehicles and toilet flushing. An average of 500 litres of greywater is treated daily. Hydraulic retention time (HRT) in the settling tank averages 24 hours and hydraulic loading rate (HLR) of the constructed wetland amounts to 8.3 cm/d. Assuming an average BOD removal rate of 40–50% in the settling tank, the organic loading rate of the constructed wetland totals 8–12 g $BOD_5/m^2/d$.

Performance

The physical and chemical properties of greywater influent and effluent are given in Table 5-5. In the planted filter, NH_4-N is transformed to nitrate (NO_3-N) by nitrification processes. Although ammonia removal efficiency exceeds 90%, total nitrogen removal probably does not exceed 60-70% given the missing denitrification step (such as for example recirculation of the effluent into an anaerobic settling tank).

Operation and maintenance

The system has been in operation since April 1998 and monitored from April 1998 to May 2000. During this time, treatment efficiency was stable. The following maintenance was performed to ensure proper operation of the system:

- Annual sludge removal from the settling tank.
- Regular inspection of dosing chamber to ensure operation of the siphon and intermittently greywater-charged bed.
- Annual plant cutting.
- During monitoring, neither storage tank nor filter bed surface was cleaned.

Photo 5-6: Vertical-flow planted filter shortly after completion (above) and in use (below) (photos: Shrestha R.R.)

Costs

The construction costs of the system, including main treatment unit, settling, dosing and storage tank amounted to USD 430 (i.e. USD 61/p). System costs are strongly dependent on filter material availability. Maintenance costs are reported to be negligible. The 500 litres of drinking water saved every day leads to an annual reduction in household expenditure of USD 40 (water price in Kathmandu: USD 0.23/m^3). Such a reduction in expenditure allows payback of the construction costs within 10 years. Stress and time saving from non-reliance on the municipal water supply are not included in this calculation.

Practical experience and lessons learned

The experience suggests that this system is appropriate for a country like Nepal, whose growing cities have little regard for demographic, municipal and regional planning. After five years of research and development, this technology proved to be useful in Nepal and is now ready for large-scale application. Where urban space for the planted filter is available and where the relatively high construction costs are affordable, the presented treatment chain will undoubtedly contribute to relieving the critical water situation of Kathmandu.

Information on hygienic aspects of the system is not available. Risk of re-contamination of the treated and stored water, as observed in other cases, should be investigated further. Performance of the system strongly depends on the availability of suitable filter material and its correct application during filter bed construction.

Ein Al Beida, Jordan

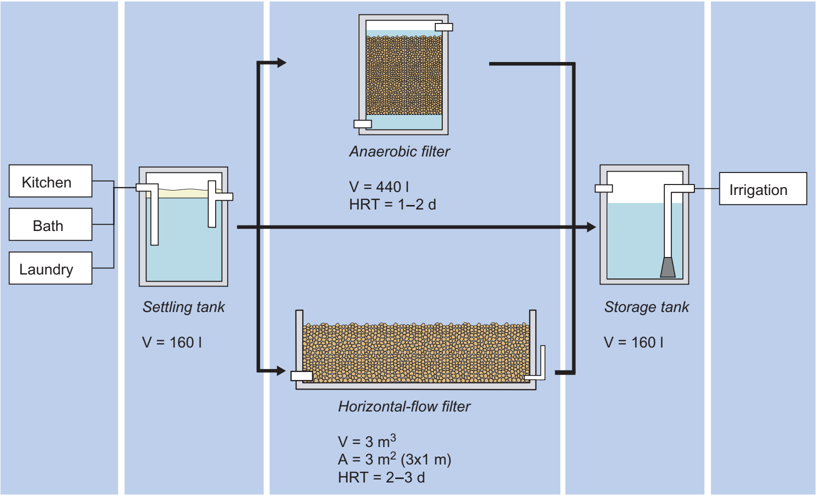
Decentralised greywater reuse for irrigation in peri-urban areas

Project background and rationale

Jordan's annual rainfall quantities vary strongly between 600 mm in the northwest to less than 200 mm in the eastern and southern deserts, which make up 91% of Jordan's total surface area. Water availability is less than 500 m^3 of freshwater per capita and year which represents a severe water stress and primary constraint to life according to Falkenmark (1989).

The International Development Research Centre (IDRC) provided financial assistance to an applied research project on greywater treatment and reuse for home garden irrigation in 25 low-income households in Ein Al Beida village, southern Jordan. The main objective was "to help the peri-urban poor in Jordan preserve precious freshwater, achieve food security and generate income, while helping to protect the environment". The average family size totalled 6.2 persons and domestic water consumption (incl. garden irrigation) averaged 120 l/p/d.

Greywater management system



The following three systems were implemented in Ein Al Beida:

Two-barrel system: A 160-l plastic barrel acts as settling tank where oil, grease and settable solids are retained. The greywater then flows into a second barrel (160 l) acting as storage tank. A small water pump feeds a drip irrigation system as soon as the storage tank is full.

Project Framework

Type of project
Research project

Implementing agency
Inter-Islamic Network on Water Resources Development and Management (INWRDAM)

Funding agency
International Development Research Centre (IDRC)

Project period
2001–2003

Project scale
25 households
(total 155 persons)

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www.idrc.ca

References

Al-Beiruti, S.N., 2005, Decentralized wastewater use for urban agriculture in peri-urban areas: An imminent option for water scarce countries, Inter-Islamic Network on Water Resources Development and Management, pp. 11

Four-barrel system: In addition to the two-barrel system, two further barrels are inserted between settling and storage tank. These two 220-l barrels are filled with gravel (2–3 cm) and act as anaerobic filters. Greywater from the first settling tank enters the second barrel at the bottom, passes through the gravel media and leaves it at the top, from where it enters the third barrel which functions the same way. The hydraulic retention time (HRT) in the two anaerobic filter barrels amounts to 1–2 days.

Photo 5-7: Horizontal-flow filter and storage tank (photo: Ghose R.)

Horizontal flow filter: This system consists of a settling tank, a trench filled with gravel and a storage tank. The trench (3 x 1 x 1 m) is lined with an impermeable polyethylene foil (400–500 µm) and filled with 2–3-cm sized gravel (see Photo 5-7). Pretreated greywater from the settling tank enters the horizontal filter at the bottom and flows through the filter media where mainly anaerobic conditions prevail (HRT: 2–3 d). At the other end of the trench, a perforated 120-l barrel functioning as storage tank (see above) is buried in the filter bed.

Performance

The greywater characteristics analysed by Faruqui and Al-Jayyousi (2002) in Ein Al Beida are given in Table 5-6. Table 5-7 contains the effluent properties of the three different greywater treatment systems. The average values for the horizontal-flow filter are strongly influenced by the first measurements of 467 mg/l (BOD_5) and 398 mg/l (TSS). Further results reveal that due to the established microbial fauna, BOD_5 and TSS values range between 14–32 mg/l and 22–48 mg/l, respectively. The BOD_5 values of the four-barrel system also decreased steadily over time, and the last (and at the same time lowest) value measured amounted to 225 mg/l.

Although no data is available on microbial contamination and removal efficiency, the implementers indicate that regular cleaning of the settling tank improved treatment and coliform removal.

Table 5-6: Greywater properties in Ein Al Beida (Faruqui and Al-Jayyousi, 2002)

Parameter		*Raw greywater*
BOD_5	mg/l	1,500
TSS	mg/l	316
Oil and grease	mg/l	141
Faecal coliforms	cfu/100 ml	10^7

The treated greywater is used for irrigation of olive trees, cactus and fodder crops. Monitoring of the impact of greywater reuse on soil and plants after two years of operation revealed some increase in soil salinity, whose levels do not affect plant yield. Regular irrigation with nutrient-rich greywater improved all plant growth rates, and crops did not reveal any contamination with faecal coliforms.

Table 5-7: Effluent analysis of treated greywater in Ein Al Beida, Jordan

		Two-barrel system		***Four-barrel system***		***Horizontal-flow filter***		***Jordanian standards*[1]**
Sampling period		6/02–12/02		6/02–5/03		7/03–9/03		
		Average	Range	Average	Range	Average	Range	
BOD_5	mg/l	159	12–518	450	225–844	171	14–467	*30*
COD	mg/l	–	–	–	–	204	87–327	*100*
TSS	mg/l	47	2–94	128	76–183	156	22–398	*50*
Oil & grease	mg/l	37	14–96	31	7–44	–	–	8
pH		7.2	6.4–8.3	6.7	4.7–8.2	7.5	7.2–7.7	*6–9*

1: Jordanian standard for treated effluent use (Government of Jordan, 2003).

Operation and maintenance

Specifically trained local technicians carry out operation and maintenance of the greywater treatment units. Leading community women were identified and trained as trainers of other women on subjects such as source pollution control, adequate use of detergents and appropriate dishwashing practices.

The case description of Ein Al Beida does not provide information on required operation and maintenance tasks; however, scum and sludge removal from the settling tank and backwashing of the anaerobic filter will certainly be necessary from time to time.

Table 5-8 contains the costs of the three different greywater treatment systems, including a drip irrigation system for a 2,000-m^2 area.

Table 5-8: Costs of greywater treatment systems in Ein Al Beida, Jordan

	Costs		***Size***
	JOD	USD	
Two-barrel system	163	230	6 persons
Four-barrel system	262	370	6 persons
Horizontal-flow filter	354	500	12 persons

1 JOD = 1.41 USD (January 2006)

According to a cost-benefit study, household income should increase by JOD 10–30 (USD 14–42) per month due to:

- reduced freshwater bill thanks to greywater irrigation
- reduced septic tank emptying costs (blackwater only)
- increased crop yield

The necessary investment can have a payback period of less than three years. The lifespan of the greywater units is assumed to exceed ten years with minimal maintenance costs.

Practical experience and lessons learned

The project had several direct and indirect benefits for the community and the environment. Women in the community benefited most from this project through training workshops, dialogue and learning-by-doing. Further knowledge was acquired on building a productive garden as well as general management skills. The monthly domestic water bills decreased by about 30%, and the reduced septic tank activities also lowered the overall costs. Many families replicated and adopted greywater reuse after neighbours had successfully implemented this system.

Bilien, Palestine

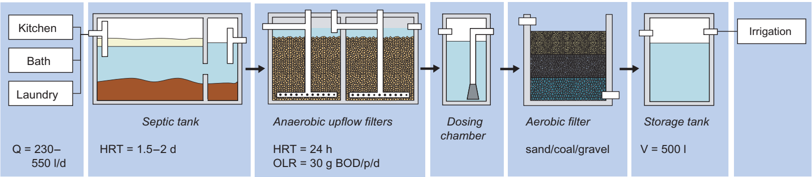
Anaerobic and aerobic filter system for single households

Project background and rationale

Many rural communities of the West Bank, Palestine, do not have access to sufficient water to meet their daily needs. Rural water supply is provided by the Israeli Water Supply Company. The systems are old and water supply is often interrupted for months at a time. Rainwater collected in winter and stored in wells is used up within a few weeks of water supply interruptions. The population therefore relies on tankers or springwater.

All rural communities and the outskirts of the cities use cesspits as on-site sanitation system. Cesspits require wastewater settling (greywater and blackwater), anaerobic sludge digestion and percolation of liquid into the subsurface. However, these prerequisites are not met in the long run. Removed sludge is discharged onto nearby open areas, wadis or transported to the few existing treatment plants. In some cases, untreated greywater is used to irrigate trees in backyards in order to minimise regular desludging of the cesspits in the households. Therefore, the reason for direct reuse of untreated greywater is to reduce desludging frequency. Regular desludging of the cesspits is quite costly (up to USD 50 per month and household). Infiltration of untreated wastewater into the soil and the current practice of uncontrolled sludge disposal have led to the contamination of water resources, especially groundwater. Within the framework of this project, four pilot household gravel filter systems for greywater treatment of single houses in Bilien village are being monitored.

Greywater management system



The greywater treatment system comprises a simple screen, a septic tank, two anaerobic up-flow filters in series, and a vertical-flow aerobic filter. The greywater first flows by gravity through bar screens into a septic tank at a hydraulic retention time (HRT) of 1.5–2 days. The effluent from the septic tank then passes through a T-shaped pipe

Project Framework

Type of project
Urban upgrading project

Implementing agency
Palestinian Wastewater Engineers Group (PWEG)

Project period
2000–2002

Project scale
Four single households
(total 37 persons)

Contact address
Monther Hind
PWEG
Abu Iyad Street 32
P.O. Box 3665
Al Bireh
Palestine
Fax: ++970(0) 2 240 5218
E-mail: monther@palweg.org
www.palweg.org

Jamal Moh'd Burnat
P.O. Box 1810
Ramallah, West Bank
Palestine
E-mail: jamal_pweg@yahoo.com

References

Burnat, J. M. Y., and Mahmoud, N. (2005). “Evaluation of On-Site Gray Wastewater Treatment Plants Performance in Bilien and Biet-Diko Villages/Palestine.” Environment Protection Committee (EPC)

Mahmoud, N., Amarneh, M. N., Al-Sa'ed, R., Zeeman, G., Gijzen, H., and Lettinga, G. (2003). Sewage characterisation as a tool for the application of anaerobic treatment in Palestine. Environmental Pollution 126, 115-122 into a double-chambered up-flow anaerobic gravel filter. The void space of the two chambers amounts to 40% and 50%, respectively. The organic loading rate of the anaerobic filter totals 30 g/p/d BOD with a minimum HRT of one day. The anaerobic filter works at maximum flow during the day and zero flow at night. Effluent from the subsequent dosing chamber is pumped (submersible pump, 0.6 kW) onto an aerobic filter composed of three layers (sand, coal, gravel). Finally, the treated greywater is stored in a 500-litre plastic tank and used for irrigation of non-edible crops.

Performance

Overall analysis of the greywater from 25 families in Biet-Diko and Bilien revealed very high COD and BOD_5 concentrations of 1,270 mg/l and 590 mg/l, respectively. The treated greywater properties of Bilien village are given in Table 5-9. The removal rate for both COD and BOD_5 in these household treatment systems ranges between 75% and 95%.

Table 5-9: Effluent analysis of four on-site treatment systems in Bilien village, Palestine

		Household 1 10 persons	***Household 2*** 6 persons	***Household 3*** 7 persons	***Household 4*** 14 persons	***Effluent standards***
Appearance	–	Clear + bad smell	Clear + no smell	Clear + no smell	Grey + turbid + slight smell	–
pH	–	7.2	7.2	7.3	7.0	*6–9* [1]
EC	µS/cm	2,700	2,200	1,900	2,000	*1,400* [2]
Chloride	mg/l	330	295	268	286	*400* [1]
Sodium	mg/l	248	192	175	191	*230* [1]
TDS	mg/l	1,500	1,200	1,100	1,100	–
COD	mg/l	145	80	85	284	*100* [1]
BOD_5	mg/l	65	27	28	130	*30* [1]
TSS	mg/l	70	54	78	97	*50* [1]
NO_3–N	mg/l	23	16	10	22	*30* [1]
PO_4–P	mg/l	47	13	27	48	*30* [1]

1: Jordanian standard for treated effluent reuse (Government of Jordan, 2003), 2: Israeli effluent quality standard for unrestricted irrigation (Ministry of the Environment, 2003)

Operation and Maintenance

The bar screen is cleaned twice a week. The septic tank is desludged every other year. The author of the study recommends backflushing of the anaerobic filters every three years. The system has been in operation since 2000.

Costs

Construction costs total USD 2,000 for a family of 6–10 persons. Monthly maintenance costs are reported to amount to about USD 3.

Practical experience and lessons learned

The high COD and BOD_5 concentration of the raw greywater is probably attributed to the low water consumption (40 l/p/d) and cooking habits typical for the region. Discarding remaining food and used cooking oil in kitchen sinks is believed to be the main reason for the high greywater pollution loads in the Middle East (Mahmoud et al., 2003). Although greywater is treated prior to reuse, it has a high pollution and impact potential on irrigated soils.

Use of an electric pump in the dosing chamber makes the system vulnerable to pump failure during power cuts. To avoid operation of a pump, topography of the area and use of a mechanically driven dosing chamber (siphon) are recommended. Since the entire system chain seems quite complex, one or several components could be omitted to simplify the treatment system. Monitoring of each treatment component could provide information on its treatment efficiency and necessity.

A similar treatment plant serving five families (total: 45 persons) was implemented in Al-Zaitunah in 2006 (Photo 5-8). System performance will be monitored after a few months of operation and after reaching steady-state treatment conditions.

Photo 5-8: Greywater treatment plant in Al-Zaitunah, Palestine (photo: Sandec)

Kuching, Malaysia

EcoSan greywater demonstration project

Project Framework

Type of project
EcoSan demonstration project

Coordination
Urban Environmental Management System (UEMS)

Implementation
Natural Resources and Environmental Board (NREB) of Sarawak
Danish International Development Assistance (DANIDA)

In operation since
December 2003

Project scale
9 residential terraced houses (average of 5 persons per household)

Contact address
Natural Resources and Environment Board, 18th–20th Floor, Menara Pelita, Petra Jaya
93050 Kuching, Sarawak
Malaysia
Fax: +6082442945
www.nreb.gov.my

References

Chong, B., 2005. Implementation of an urban pilot scale ecological sanitation wastewater treatment system in Kuching Sarawak, Malaysia. Appendix 5, Report No. UEMS_TEC_02_45, Natural Resources and Environment Board Sarawak

Jenssen, P.D., 2005. An urban ecological sanitation pilot study in humid tropical climate. Report No. UEMS_TEC_02_47, Natural Resources and Environmental Board Sarawak

Sarawak Development Institute, 2005. Quick appraisal of views on the eco-sanitation project at Hui Sing Garden, Kuching. Report No. UEMS_TEC_02_51, Urban Environmental Management System (UEMS)

Holte, J.A. and Aas, H., 2005. Effects of frequent dosing in a pre-treatment biofilters under warm climate conditions. Master Thesis, Norwegian University of Life Sciences

Project background and rationale

Kuching, the capital of the Malaysian State of Sarawak, is located on the Island of Borneo in the South China Sea. The city is situated along both sides of Sungai Sarawak (Sarawak River), some 40 km from the river mouth. Large parts of the city are situated on flat terrain of unstable peat swamp and soft clay. The city of Kuching is currently lacking a wastewater treatment plant, and the local subsurface conditions make a conventional centralised wastewater system expensive to implement. Most buildings (residential, institutional, commercial, and industrial) in Kuching are equipped with two separate wastewater outlets, one outlet for blackwater (toilet wastewater) and one or more for greywater (washing, bathing and kitchen), although this is not the required building standard. Blackwater flows into septic tanks, either within the housing plot or at communal level serving commercial buildings or residential complexes.

The septic tanks subsequently discharge their effluents directly into the stormwater drains from where they are conveyed into the nearest aquatic system. Greywater is also discharged into the stormwater network or directly into receiving waters. Some oil and grease traps have been installed at large food outlets at the request of Kuching North City Hall (DBKU) and Kuching City South Council (MBKS). These facilities are, however, generally undersized and often only emptied irregularly.

The demonstration project described herewith is based on source separation of blackwater and greywater from nine residential terraced houses (average of five persons per household) in Hui Sing Garden, Kuching. The treatment facility is located in the adjacent park and operated since December 2003.

Greywater management system

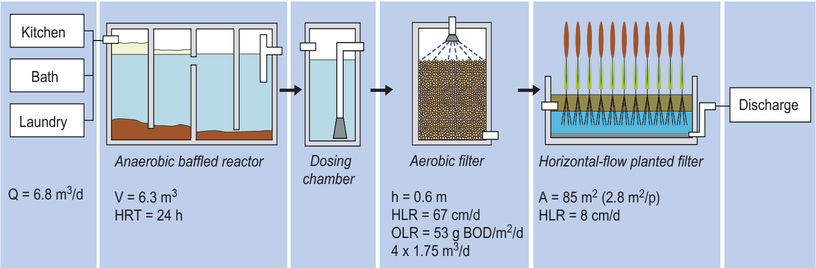
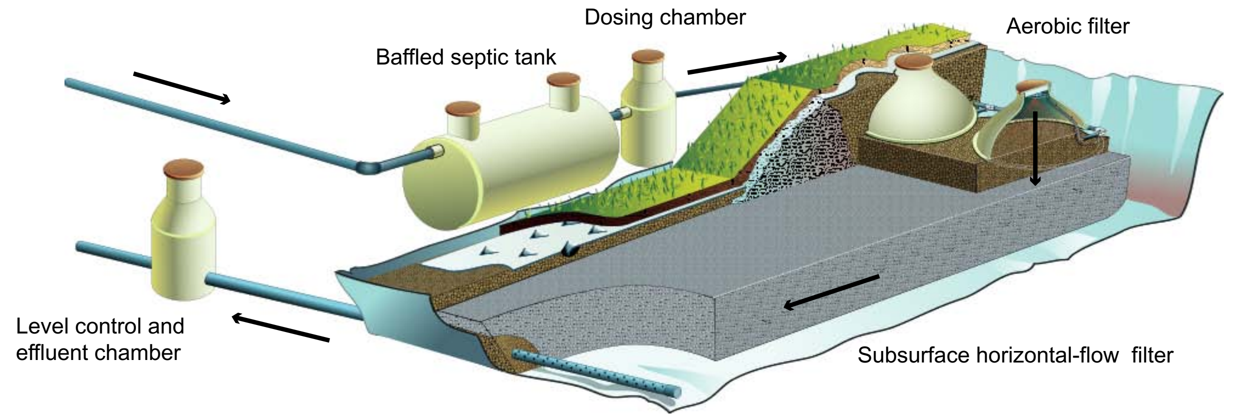


Figure 5-5: Schematic layout of the EcoSan greywater treatment facility in Hui Sing Garden, Kuching (source: Prof. Petter D. Jenssen, Agricultural University of Norway)



The system treats greywater from nine households, including water from laundry, kitchen, bath, washbasin, and other in-house water outlets excluding toilets. Total greywater production amounts to approximately 225 l/p/d, with an average 6.8 m^3/day inflow into the treatment system. The greywater treatment system (see Figure 5-5) comprises a baffled septic tank as primary treatment unit to remove oil, grease and settleable solids, followed by a dosing chamber. The greywater then flows into four vertical down-flow, single-pass aerobic biofilters before reaching a subsurface horizontal-flow planted filter. The treated greywater then exits the system into the stormwater drain through an outlet comprising an integrated tip-bucket flow measurement system.

The baffled septic tank of 6.3 m^3 volume capacity stores greywater for about 24 hours. Baffles divide the trap into four chambers to ensure the highest possible retention time for oil, grease and settleable solids.

Four polyethylene biofilters of 2.63-m^2 surface area received each about 1.75 m^3 of greywater over a period of 24 hours. The regular dose-spraying and interval regime Grundfos pump charges the biofilter surfaces at a 67 cm/day loading rate and 53 g/m^2/d BOD organic loading rate (Holte and Aas, 2005). The greywater percolates through the aerobic filter comprising 600-mm lightweight clay aggregate. Greywater then flows into the subsurface horizontal-flow planted filter (see Photo 5-9).

The subsurface horizontal-flow planted filter consists of a 600 mm bed of crushed limestone. The filter is lined with geotextile benthonite-clay (GCL). A top layer of coconut husk prevents topsoil from settling into the crushed limestone aggregate. The filter requires 2.8 m^2/p of land. The surface of the filter is planted with *Ruellia* sp.

Photo 5-9: Aerobic filters and planted filter under construction (top) and completed (bottom) in Hui Sing Garden, Kuching (photo: NREB, 2003, Martin C., 2005)

Performance

Table 5-10 summarises average properties of the influent and effluent leaving the aerobic filters and the effluent of the system. Mass reduction of various parameters is given in Table 5-11.

Table 5-10: Performance of greywater treatment system in Hui Sing Garden, Kuching

		Influent	*After anaerobic filter*	*Effluent*
BOD_5	mg/l	129	< 2	< 2
COD	mg/l	212	12	11
TSS	mg/l	76	6	3
Total N	mg/l	37	14	9
Ammonia	mg/l	12.6	2.1	0.8
Nitrate	mg/l	2.1	5.4	5.3
Total P	mg/l	2.4	–	0.3
Faecal coliform	(cfu/100 ml)	–	5,600	650
E. coli	(cfu/100 ml)	–	580	390

Table 5-11: Mass reduction, Hui Sing Garden, Kuching

	Influent	*Effluent*	*Removal rate*
	g/p/d	g/p/dl	%
Oil and grease	43.3	0.2	99
BOD_5	36.6	0.5	99
COD	50.0	1.7	97
TSS	10.6	0.3	97
Total N	6.2	0.5	92

Table 5-12: Annual operation and maintenance costs of the greywater treatment system in Hui Sing Garden, Kuching

	Operation and maintenance costs USD/p [1]
Desludging of oil and grease trap	0.66
Maintenance of planted filter	1.06
Maintenance of piping	0.53
Total annual O&M costs	**2.25**

1: Estimate based on Malaysian Ringgit (MYR) and conversion factor MYR 1 = USD 0.27 (July 2006)

Operation and Maintenance

Different operation and maintenance activities are carried out on a regular basis. Desludging of the oil and grease trap (baffled septic tank) takes place every three months. The pump is inspected weekly to assess or avoid damage by particulate matter. Inspection and if necessary cleaning of the spray-nozzles in the vertical biofilter is also conducted regularly to ensure filter efficiency. The annual operation and maintenance costs are given in Table 5-12.

Costs

Table 5-13 contains the capital costs of the described greywater treatment system. If a new housing estate is built, the capital costs will be reduced (approximately USD 230 per person) as piping for separate wastewater types can be installed from the beginning rather than retrofitted. For new and larger housing systems, designed for 500 and 1,000 persons, the total capital costs per person will decrease to USD 165 and USD 127, respectively.

Practical experience and lessons learned

The initial purpose of the Hui Sing Garden EcoSan demonstration project was to prove that the concept chosen is a technically viable approach to decentralised greywater treatment in Sarawak. The second and equally important aspect was to ascertain whether the greywater facility would be accepted in an urban residential setting. The Hui Sing Garden EcoSan demonstration project yielded highly promising treatment results and fulfilled its purpose since its operation in 2003. The project provides valuable data and practical experience on decentralised urban greywater treatment.

Table 5-13: Capital costs of the greywater treatment system based on a 100 p.e. system, Hui Sing Garden, Kuching

	Capital costs for existing housing USD/p[1]
Design work	16.4
Civil work	15.9
Mechanical and electrical equipment	182.5
Mechanical and electrical installation	12.7
Hacking of pavement/walkways	10.6
Turfing	5.3
Relocation of existing facilities	4.0
Total capital costs	**247.3**

1: Estimate based on Malaysian Ringgit (MYR) and conversion factor MYR 1 = USD 0.27 (July 2006)

A social survey of the nine families serviced was conducted in 2004. The residents of Hui Sing Garden strongly support the project, indicating both enthusiasm and interest in its future success. An additional social survey was conducted with 108 daily users of the park containing the greywater facility. Eight park users voiced their concern about the occasional odour emissions from the facility. The other hundred users did not pass any comment or make complaints. Occasional odours are believed to be emitted after clogging of the biofilters given the extremely high levels of oil and grease used in the preparation of traditional Malaysian food.

The capital costs of this greywater treatment system are high and probably not affordable by single households. Nevertheless, this system can be a suitable solution for neighbourhoods, as per capita costs decrease with increasing household connections. Since system performance is extremely high due to the low-strength inflowing greywater, the need for a vertical-flow and a horizontal-flow filter unit should be questioned.

Sri Lanka

Greywater treatment systems for hotel premises

Project Framework

Type of project
PhD thesis

Supervision
University of Leeds
School of Civil Engineering

Project period
Implementation: 1997
Monitoring: 1997–2000

Project scale
Wastewater treatment systems for hotels, houses, schools, and halls of residence, day-time occupancy buildings (28 full-scale systems)

References
Harindra Corea, E.J., 2001. Appropriate Disposal of Sewage in Urban and Suburban Sri Lanka. Doctor of Philosophy Thesis, The University of Leeds, Leeds, UK, 270 pp

Project background and rationale

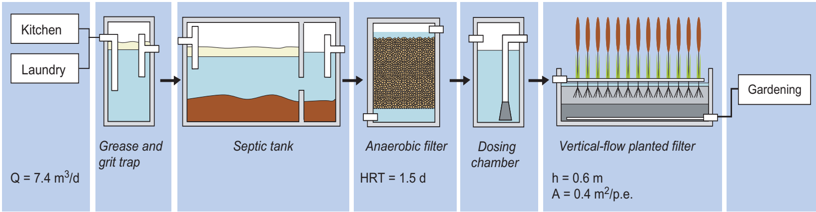
Sri Lanka belongs to the rapidly developing countries. In the last two decades migration from rural to urban areas has increase the pressure on authorities in finding wastewater management solutions. Since 1980, regulations on effluent discharge standards have been established and implemented. Every new building plan has to include an on-site wastewater disposal system approved by the authorities (CEA, 1990). However, the existing regulations or guidelines do not stipulate any system design requirements.

Within the framework of his PhD thesis, Harindra Corea (2001) selected, evaluated and implemented appropriate, cost-effective technologies for on-site wastewater management systems in urban and suburban Sri Lanka. The goal was to develop practical selection and design guidelines.

The thesis presents different treatment technologies with main focus on hotel greywater and blackwater treatment systems. This report describes only three hotel greywater treatment systems. The first greywater treatment plant was constructed for the Swiss Residence Hotel. Based on the experience gained by the Swiss Residence Hotel, further systems were implemented at the hotels Ivy Banks and Coral Sands.

Swiss Residence Hotel

Greywater management system



In a 40-room tourist hotel in Kandy, a treatment system for kitchen and laundry greywater was set up to extend an already existing blackwater treatment system following complaints from neighbouring residents and regulatory authorities (greywater treatment was originally not considered in the sanitation plan). For lack of space, the system had to be installed underground, with setback distances of less than three metres between treatment unit, road and building. The plant (designed for 46 p.e. and a 7.4 m^3/d flow) includes a grease trap, a septic tank and a vertical-flow planted filter (0.4 m^2/p.e., 0.6 m height) fed by an electric pump. The septic tank was designed for an assumed desludging frequency of five years.

Photo 5-10: VFPF for greywater treatment at Swiss Residence Hotel in Kandy (left). The treated effluent is reused for gardening (right) (photo: Harindra Corea E.J.)

During the initial start-up period, the VFPF was fed with the effluent from the anaerobic filter of the existing blackwater treatment system (comprising a septic tank, an anaerobic filter and a percolation bed). This allowed the plants to become acclimatised to the VFPF.

Performance

During start-up, when effluent from the blackwater system was used in the VFPF, the average system load amounted to 19.7 m^3/d, representing almost three times the hydraulic load of the originally designed greywater system. BOD removal of the system averaged 44% at a pH between 6.9 and 7.2.

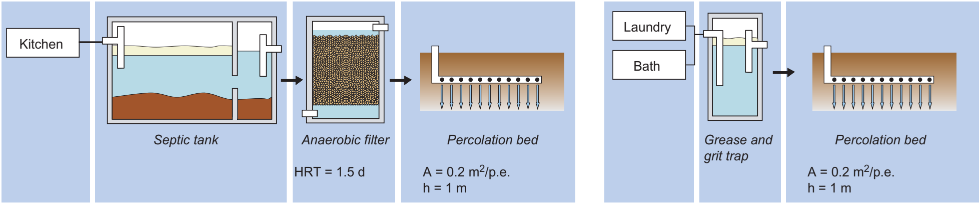
Once the system was fed with kitchen greywater at an average flow rate of 3.9 m^3/d (BOD_5 = 324 mg/l), the pH of the greywater in the VFPF fell significantly to 4.2–5.0 and the BOD removal efficiency dropped to 33%. The septic tank effluent was turbid, milky white and had a strong sour odour. This pH drop below the critical level of 6 is an indicator of toxic substances in the septic tank resulting in an excessive production of organic acids and in a decreased production of methane. Attempts to raise the pH by adding lime to the dosing chamber showed no effect. The VFPF showed signs of clogging after six months of operation, which worsened rapidly when laundry greywater was fed to the system. As a countermeasure, an anaerobic filter was installed after the septic tank, and its effluent jointly treated with blackwater in an additional anaerobic filter and percolation bed.

Operation and maintenance

The grease and grit trap was originally supposed to be cleaned once a month. However, the hotel maintenance staff failed to do so and the accumulated scum and grease in the trap started emitting strong foul odours. Large amounts of oil and grease escaped into the system and further contributed to system failure. Thereupon, a smaller, daily-cleaned grease and grit trap was installed instead. It prevents anaerobic degradation of the trapped oil and grease and is thus cleaned without much opposition by the staff.

Ivy Banks Hotel

Greywater management system



Ivy Banks, a small tourist guesthouse situated on Lake Kandy, set up a greywater treatment system at the request of the Kandy Municipal Council. The system dimensioned for 28 p.e. with an expected daily greywater flow of 4.45 m^3/d, consists of two separate subsystems, the first treating kitchen wastewater and the second other greywater. The effluent of both systems percolates into the subsoil. The first system comprises a septic tank combined with an anaerobic filter unit (HRT 1.5 d, crushed rock as filter media with a nominal diameter of 12 to 50 mm). The effluent then percolates through absorption trenches (0.2 m^2/p.e., 1 m height) into the ground. The second system comprises a grease and grit trap followed by a percolation bed (0.2 m^2/p.e., 1 m height). Setting up two greywater treatment systems is less expensive than excessive plumbing costs for a combined treatment system.

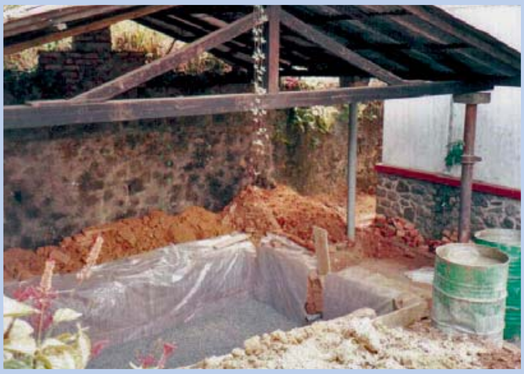


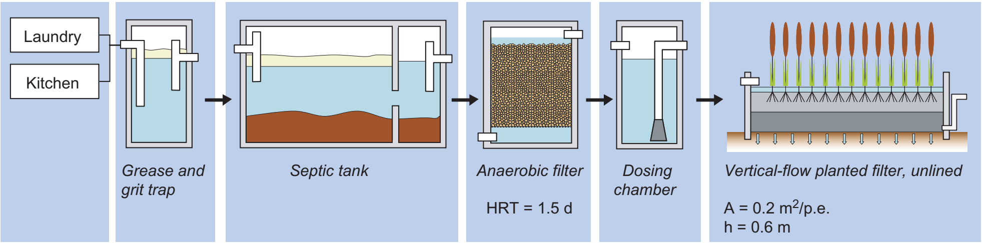
Photo 5-11: Construction of the percolation bed for subsystem 2 (photo: Harindra Corea E.J.)

Operation and maintenance

After four months of operation the treatment system was reported to function well, however, detailed information was not provided. Initially, the second system included only a percolation bed without pretreatment. Due to clogging of the percolation bed, the grease and grit trap was installed at a later stage.

Coral Sands Hotel

Greywater management system



Coral Sands is a beachfront hotel located in Hikkaduwa, on the southwest coast of Sri Lanka. Both blackwater and greywater of the hotel were previously treated in three septic tanks and soakage pits operating satisfactorily. The hotel also required a system to treat the kitchen wastewater.

Wastewater from both the main and staff kitchen is pretreated in two separate grease and grit traps and fed by gravity to a septic tank and anaerobic filter unit. The effluent from the anaerobic filter (HRT 1.5 d) is pumped into a vertical-flow planted filter (0.2 m^2/p.e., 0.6 m height). The VFPF is not lined to allow percolation of the effluent into the ground. The VFPF bed, which also includes a 0.3-m layer of crushed limestone to raise the pH and reduce odour, turned out to be very effective. An overflow is provided to the drain excess effluent in case of a rise in the groundwater table during the rainy season. The system was designed for treatment of 3.0 m^3/d kitchen greywater.

Operation and maintenance

During the four-months monitoring period, the Coral Sands treatment system functioned well, especially when compared to the treatment system of the Swiss Residence Hotel. During hot and sunny periods, such as in the afternoons, some mild malodour was reported. This problem was overcome by shading the bed and increasing the vegetation cover.

Costs of the three hotel systems

Table 5-14 contains the implementation costs of the three greywater treatment systems described.

The cost data for the Swiss Residence Hotel was adapted to reflect the final system layout (system comprising a second aerobic filter and a percolation bed). The Coral Sands system was built under difficult conditions as the septic tank and anaerobic filter unit were designed with heavy-duty covers to withstand heavy tourist buses parked on top. The hotel, located on loose, sandy soil with a high groundwater table, required special boarding to support excavation as well as continuous dewatering during construction, which partly explains the high construction costs.

Table 5-14: Costs of greywater treatment systems in Sri Lanka

	Costs [1] USD	***Costs/p.e.*** USD	***Size***	***Effluent disposal***
Swiss Residence	12,900	69	186 p.e.	Gardening/drainage
Ivy Banks	973	35	28 p.e.	Infiltration
Coral Sands	4,200	220	19 p.e.	Infiltration/drainage

1: Estimate based on Sri Lanka Rupee (LKR) and conversion factor of LKR 1,000 = USD 9.7 (March 2006)

Coral Sands Hotel clearly reveals that it is impossible to provide general cost figures for construction of greywater treatment systems. Every site must be evaluated independently and based on the site-specific conditions.

Practical experience and lessons learned

The example of the Swiss Residence Hotel emphasises the importance of stakeholder involvement. By taking into account the perceptions and feelings of the hotel staff regarding the lack of maintenance, one reason leading to system failure could be identified and corrected.

Based on his manifold experience, Harindra Corea, E. J. suggests the following:

- An annual sludge accumulation rate of 18–20 l/p.e. must be assumed in septic tanks treating greywater.
- Hotel septic tanks should be designed for a larger scum to sludge ratio (0.5 instead of the usual 0.4 value) when allocating storage volumes.
- The nominal HRT in anaerobic filters should range between 0.7 and 1.5 days. Surface loading should be limited to maximum 2.8 m/d.
- Kitchen wastewater from hotels should always be pretreated in grease traps and designed for daily cleaning. Daily-cleaned traps perform better and are more easily maintained than larger grease and grit traps.
- Since percolation beds can be buried, they should be chosen for sites with restricted space.
- The VFPF load should be limited to 60 gBOD/m^2/d. Since VFPF also requires more regular maintenance than percolation beds, costs will be higher. However, the planted filters can be designed in almost any shape to fit the available space and therefore improve the aesthetics of a garden.
- Where kitchen waste is treated separately, a 0.3-m layer of crushed limestone should be included in the filter bed of a VFPF to avoid a low pH level.

6. Conclusions

Finding literature on greywater management systems implemented in low and middle-income countries turned out to be difficult. Information on greywater issues is scarce especially when compared to the abundant literature on latrines and toilets as revealed by the following example: An internet search on Google with the words “toilet developing countries” resulted in more than three million references. Less than 100,000 references were found when searching for “greywater developing countries”. Compared to water supply, excreta and solid waste management including stormwater drainage, greywater has traditionally been given lowest priority in environmental sanitation management systems. In urban and peri-urban areas of low and middle-income countries, greywater discharged untreated onto streets, into drainage channels, rivers or ponds leads to surface water contamination, deterioration of living conditions and increased health hazards. However, greywater is perceived as a valuable resource in rural areas and arid regions where it is often used untreated in irrigation. Without precautionary measures, this practice may lead to contamination of food, salinisation and clogging of soils and potentially also to groundwater pollution.

Greywater characteristics: Low concentrations but high total loads

Greywater quantities and characteristics are highly context-specific and depend on living standards, cooking habits, availability of piped water, household demography etc. Greywater is generally less polluted than other wastewater sources such as toilet wastewater. However, given the high greywater volumes produced in the household (typically within the range of 60–120 l/p/d), its contribution to the total pollution load is significant and cannot be ignored. The average greywater contribution amounts to 40–50% of the total organic load (expressed as BOD_5), one forth of the total suspended solids load and up to two thirds of the total phosphorous load. In contrast to industrial high-income countries where phosphorous-based detergents have been banned, such products are still widely used in many low and middle-income countries. In terms of pathogenic contamination, greywater is much safer than other wastewater sources. Nevertheless, greywater can still contain pathogens given the likelihood of cross-contamination with excreta. An important characteristic of greywater is its nitrogen deficit and potential influence on the performance of biological treatment processes.

Management schemes for households and neighbourhoods

A system perspective is required to develop sound greywater management schemes. Source control is crucial to avoid operational problems in subsequent treatment steps or long-term negative effects on soils. Use of products such as sodium-based soaps (enhancing the risk of soil salinisation and deteriorating soil structure), disinfectants, bleach, and other problematic products must be substituted by environmentally friendly products. Oil and grease from kitchen must be retained by adequate processes.

Appropriate greywater treatment systems range from very simple and low-cost disposal options (e.g. local infiltration) to complex treatment chains for neighbourhoods (e.g. series of vertical and horizontal-flow planted soil filters). Analysis of the case studies reveals that attached biofilm treatment systems such as anaerobic filters as well as planted and unplanted aerobic filters are best suited for secondary greywater treatment. Primary treatment is required to lower the risk of clogging of secondary treatment steps. Septic tank systems and simple sedimentation tanks proved to be efficient and robust. Other systems such as grease and grit traps or simple textile filters are also frequently used. However, these systems require regular maintenance and greater attention by the household, as they are frequently by-passed or removed, thus jeopardising subsequent treatment or management steps. Inappropriate maintenance of primary treatment units was identified as the main cause for system failure.

The required level of treatment strongly depends on “if” and “how” the treated greywater is used. If discharged into streams, greywater should be submitted to primary and secondary treatment, with removal of organic compounds, suspended solids, pathogenic organisms, and nutrients to acceptable levels. Most countries have established effluent discharge standards, which can be easily met when using a combination of primary and secondary treatment (e.g. a septic tank followed by a vertical-flow planted filter).

Reuse of treated greywater in irrigation can significantly contribute to reducing water bills and increasing food security. The in-house reuse of greywater generally requires a disinfection stage and special in-house installations, thus making the system more complex and vulnerable. In-house reuse of greywater in low and middle-income countries is therefore not recommended.

Greywater reuse is especially recommended in areas facing water stress such as the Middle East and Sub-Saharan Africa. In regions with an abundance of freshwater such as in South-East Asia, other options may be more appropriate such as for example groundwater recharge (infiltration) or discharge into surface waters. Reuse-based management systems will only be successful if based on an effective demand and socio-cultural acceptance.

Direct reuse of untreated greywater in irrigation is not recommended. Irrigated greywater should undergo primary treatment as irrigated soil acts as a natural secondary treatment step. Secondary treatment is advisable in cases where large quantities of surfactants are used. Irrigation techniques must be carefully chosen to avoid direct human and crop contact with the hygienically unsafe greywater. Subsurface irrigation techniques are most appropriate, while sprinkler irrigation should be avoided. The mulch trench distribution system is a promising low-cost alternative to conventional piped-based subsurface irrigation techniques, however, long-term experience with this system is still missing.

Most system failures are caused by inappropriate operation and maintenance, sometimes also resulting from a lack of system understanding by the owners. Therefore, simple systems requiring minimal operation and maintenance should be prioritised, and beneficiaries trained on appropriate system management. Their involvement in the planning and implementation process is crucial to raising awareness and improving system understanding (see planning section below).

Greywater management system costs are site-specific as they depend on material costs (e.g. gravel for filter systems). Therefore, the exact total costs for installation of household or neighbourhood-based systems cannot be determined, but implementation costs of small-scale units tend to be lower than centralised systems with large sewerage networks, pump stations and treatment plants (WHO, 2005).

Open questions

The following issues require further investigations:

- Literature on greywater characteristics focuses mainly on Western countries where problematic detergents or phosphorous-containing washing powders have been banned. The limited information on household chemicals and detergents used in low and middle-income countries does not allow to appropriately characterise greywater typical for low and middle-income countries.
- The specific impact on treatment performance caused by the nitrogen deficit in greywater is not well understood. Operational problems such filter bed clogging may be attributed to this deficit. Possibilities to mitigate such problems should be investigated (e.g. increasing nitrogen content by adding urine, a nitrogen-rich additive).
- Since investment costs of the reviewed household-based greywater systems are considerably high, ranging from USD 35–250 per person, ways to reduce them should be given top priority and focus placed on for example the use of alternative filter material such as PET in attached biofilm systems or optimised treatment system design.
- Information on optimal hydraulic loading rates of planted filters is contradictory and recommendations range from 10–80 cm/d. Many current design guidelines are based on data and experiences with domestic wastewater. For greywater-only systems, such guidance may not be applicable.
- Long-term effects of non-biodegradable compounds such as synthetic textile fibres and other hardly degradable pollutants on irrigated soils are not well understood. Furthermore, given the lack of documented and scientifically assessed information, this review did not allow a comprehensive description of the groundwater pollution risks from infiltration of pathogens, phosphorous or persistent pollutants.
- The fate and effect of surfactants on irrigated soils are not fully understood, and literature on this topic is contradictory. The results obtained by Shafran et al. (2005) on the accumulation of surfactants in loess soils, leading to a

decrease in capillary rise and formation of water-repellent soils, require further investigations.

- There is a clear need to develop, validate, disseminate, and facilitate implementation of simple solutions low in engineering work. The mulch trench irrigation system has great potential where reuse is sought. However, long-term experiences are not available yet (or not documented). Research should also centre on the possibility of discharging greywater directly onto compost heaps (co-treatment of greywater and organic solid waste), a suitable approach especially in arid regions with limited greywater quantities and where the composting process requires frequent watering.

How to select the “right” system?

There is no “one-fits-all” technical solution for greywater management. Several household or neighbourhood greywater treatment systems perform well, however, system selection should be adapted to local conditions. Evaluation and decision-making criteria such as discharge quality standards alone are not sufficient for selection of the most appropriate management system. Other criteria, such as social and institutional acceptance, self-help capacities, hygienic risks, public health impacts, reuse opportunities, economic and financial considerations, environmental risks, system energy demand, etc., play an equally important role in the selection and decision-making process.

Since most issues related to greywater management are likely to occur on a household or neighbourhood level, the selection process should be based on a household-centred approach to assist households or neighbourhoods in choosing a system they want and can afford. Experience has shown that the interest of households to invest in environmental sanitation is not necessarily driven by health concerns. According to WHO (2005), the main factors influencing willingness of the households to invest in improved sanitation services are comfort, convenience, prestige, reuse opportunities, and of course costs. To ensure that households or groups of households make an informed choice, a cost analysis of the different management scenarios has to be conducted to allow a comparison of the overall costs (including investment costs, costs related to operation and maintenance of the system, planning and administration costs etc.) and expected system benefits. Should the overall costs of the system of choice exceed the effective and/or perceived benefits by the user (e.g. economic benefit of reusing treated greywater, increased food security, averted health-related costs, improved living conditions, status, etc.), implementation of less expensive measures should be considered.

Integrated planning approach

As greywater management must unconditionally be seen as one part of the whole environmental sanitation package, it should also include solid waste and excreta management, surface water drainage as well as hygiene education aspects. These are all equally important components in an effective environmental sanitation programme. Sanitation projects looking at single components only will never meet their ultimate objective of environmental sanitation, namely “water and sanitation for all within the framework which balances the needs of people with those of the environment to support a healthy life on Earth” (WSSCC and Sandec, 2005). Greywater management planning must thus be integrated into a holistic planning process. A sound basis for such an approach can be found in the Bellagio Principles conceived by the Environmental Sanitation Working Group of the Water Supply and Sanitation Collaborative Council (WSSCC). These call for a departure from past sanitation policies and practices (see box).

The Bellagio Principles

1. Human dignity, quality of life and environmental security at household level should be at the centre of the new approach, which should be responsive and accountable to needs and demands of the local and national setting.
2. In line with good governance principles, decision-making should involve participation of all stakeholders, especially the consumers and service providers.
3. Waste should be considered a resource, and its management should be holistic and form part of integrated water resources, nutrient flows and waste management processes.
4. The domain in which environmental sanitation problems are resolved should be kept at a minimum practicable size (household, community, town, district, catchment, and city) and waste diluted as little as possible.

The Household-Centred Environmental Sanitation Approach (HCES) offers such a planning framework allowing to implement the Bellagio Principles. The HCES planning approach is believed to assist in overcoming the shortcomings of unsustainable planning and resource management practices of conventional approaches. The goal of the HCES approach is to provide stakeholders at every level, but particularly at household and neighbourhood level, with the opportunity to participate in planning, implementation and operation of environmental sanitation services (WSSCC and Sandec, 2005). A provisional guideline for decision-makers on how to implement the HCES planning approach was developed and can be downloaded from WSSCC’s webpage (www.wsscc.org). The new WHO guidelines for safe excreta and greywater reuse contain a comprehensive section on planning needs when establishing excreta and greywater use schemes, including strategies to implement the guidelines (WHO, 2005). Other participatory planning guidelines are provided and may be useful for environmental sanitation projects. Two interesting tools are mentioned here: (a) The Ecosan Source Book (Werner et al., 2003), which gives guidance on how to plan and implement Ecosan projects, with emphasis on awareness building and stakeholder participation in decision-making, and (b) the PHAST approach, designed to promote hygiene behaviours, sanitation improvements and community management of water and sanitation facilities using specifically developed participatory techniques (Wood et al., 1998).

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