Whitepaper on

GREYWATER TREATMENT & REUSE

सत्यमेव जयते
Goverment Of India

JAL JEEVAN MISSION LEH
Union Territory of Ladakh
Government of India

NOVEMBER 2020

Published by:
Bremen Overseas Research and Development Association, South Asia (BORDA-SA)
November 2020

PREFACE & ACKNOWLEDGEMENT

Greywater treatment and reuse is gaining attention as a solution to reduce the dependence on freshwater for non-potable uses. However, there is limited knowledge and experience on greywater treatment systems and its reuse potential in India. This document provides an overview to engage in the discourse of greywater treatment and reuse in increasing water use efficiency as well as preserving water ecosystems.

This document has been primarily developed by **Er. Saman Khalil**, BORDA WesCA and adapted to the Indian context by **Gayathri Lalu**, BORDA SA. The designs of the greywater treatment systems were generously contributed by **Rajesh Pai**. **Susmita Sinha** gave valuable inputs for finalisation of the document.

Ladakh Ecological Development Group (**LEDeG**) provided all the implementation support on the installation of two pilot household greywater treatment systems in Leh. **Shri A K Sahu**, Commissioner/ Secretary, Administration of the Union Territory of Ladakh actualized this collaborative effort. **Dr Zahida Bhano**'s, (Director, Urban Development Department, UT of Ladakh), continuous support and encouragement was valuable in completion of this document.

Design by: Studio Inspira, Mumbai, India
Printed in Bangalore, India

Printed on FSC-certified, recyclable, chlorine-free, wood-free paper

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01 INTRODUCTION

1.1 OBJECTIVE

The objective is to provide an overview of the need for greywater treatment and reuse for effective water resource management. Greywater accounts for a significant percentage of the volume of wastewater with lesser pollution loads. Hence requires relatively less treatment and has great reuse potential.

1.2. SCOPE

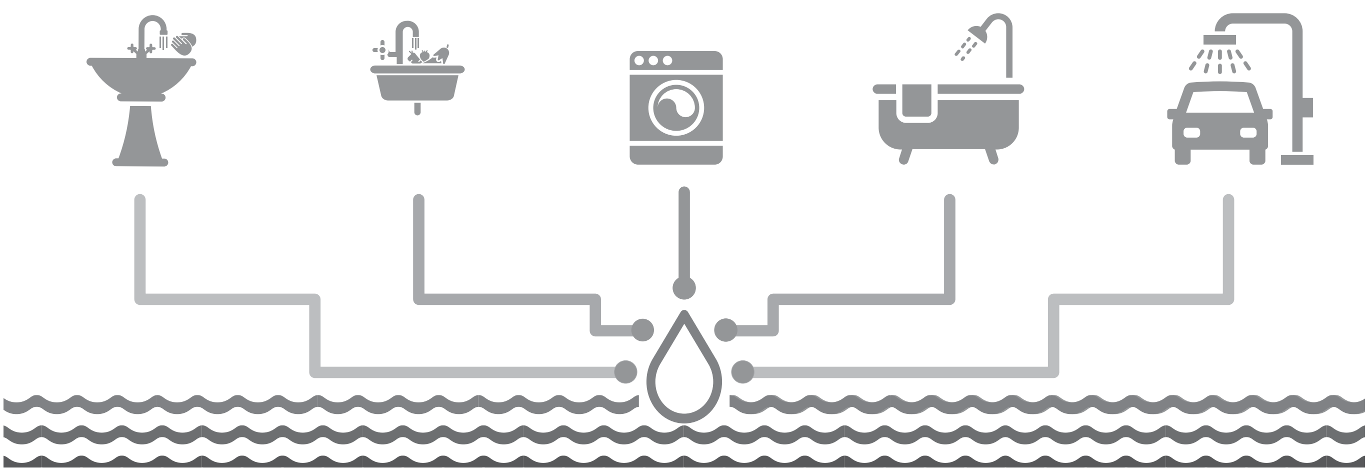
This document focuses on the treatment and reuse of greywater for domestic purposes to achieve the following:

- protection of groundwater;
- protection of surface water;
- protection of land and vegetation;
- reducing public health risk.

1.3. WHAT IS GREYWATER?

Greywater is the total volume of wastewater generated from a household other than blackwater. This includes wastewater generated from kitchen sink, wash basin, laundry, car wash and bath but not from toilets. It may contain traces of excreta (e.g., from washing diapers or bathing) and, therefore, also pathogens.

FIGURE 1: DIFFERENT STREAMS OF GREYWATER



1.4. WHY REUSE GREYWATER?

Wastewater is generated when fresh water is used for various purposes. To reuse this wastewater, the contaminants introduced into fresh water by the various uses need to be removed or minimized. Treating wastewater is an expensive and complex process. The best way to recover clean water after usage would therefore be to minimize the contamination levels. The most suitable way to maximize the recovery process, is to keep the contamination levels minimal, to separate wastewater streams and treat it as close to the point of usage as possible (in-situ). This has multiple benefits – simpler systems to treat the water, no cost for conveyance and reuse option at source.

The Swachch Bharat Mission (Grameen)-II Guidelines 2020 has included greywater management as one of its components. It emphasizes the need for treating greywater at source for a household or at community level. It has mandated the gram panchayats to make available provisions for greywater treatment through convergence with various national schemes.

At the urban level, various pollution control guidelines as well as the National Urban Sanitation Policy recommends grey water reuse and recycling. Various urban apartments in India have implemented dual plumbing system to reuse treated greywater for flushing and other non-potable uses in addition to reuse for gardening purposes.

Considering the water stress situation in India, it is pertinent to develop and implemenet solutions that ensure reliable water resources for everyone whilst protecting the natural environment. Exploring ways to reduce demand for fresh water supply is essential to ensure a sustainable future for water resources. One of these options is reusing greywater by installing greywater treatment systems to substitute fresh water use for purposes where drinking water quality is not required (Technical Guide for Greywater Recycling, 2014).

1.5. QUANTIFICATION OF GREYWATER

The quantity of greywater depends on geographical location, lifestyle, climatic conditions, type of infrastructure, culture and habits, among others. As a consequence there are huge disparities in the quantity of greywater generated.

For instance, the amount of greywater produced in a household can vary greatly ranging from as low as 15 L per person per day for poor areas to several hundred liters per person per day in affluent areas.(Oteng-Peprah, Michael et al., 2018).

Another example is depending on the type of toilet, greywater accounts for up to 75% of the wastewater volume produced by households with flush toilets, and this can increase to about 90% if dry toilets are used (Oteng-Peprah, Michael et al., 2018).

Bathroom greywater (bath, wash basin, and shower) contributes about 40% of the total usable greywater volume (Technical Guide for Greywater Recycling, 2014). The quality of bathroom greywater depends on the behavior of the people using the appliances and it can be contaminated with hair, soaps, shampoos, hair dyes, toothpaste, lint, nutrients, body fats, oils and cleaning products. It also contains some fecal matter (and the associated pathogens) from body washing.

Laundry greywater contributes about 20% of the total usable greywater volume (Technical Guide for Greywater Recycling, 2014). Used water from the laundry varies in quality from wash water to rinse water to second rinse water. Laundry greywater can contain fecal matter with the associated pathogens, lint, oils, greases, chemicals, soaps, nutrients and other compounds derived from soiled clothes or cleaning products.

Al-Mughalles, Mohammed Hasan et al, 2012 indicates that greywater generated from wash basin and kitchen sink is 5% and 7% of the total wastewater generated respectively.

1.6. CHARACTERISTICS OF GREYWATER

The quality of greywater can be highly variable due to factors such as household occupants, their age, lifestyle, health, water source and products used (such as soaps, shampoos, cleaning products) and other site-specific characteristics.

Greywater is contaminated in three ways:

- contaminated by micro-organisms, many of which may be pathogenic (refer Table 1) which cause diseases such as diarrhea, cramps, nausea, and possibly jaundice;
- physically polluted by particles of dirt, food, lint and sand;
- polluted chemically by dissolved salts such as sodium, nitrogen, phosphates and chloride or organic chemicals such as oils, fats, milk, soap and detergents.

1.6.1. MICROBIOLOGICAL CHARACTERISTICS OF GREYWATER

Greywater streams generally have small traces of microorganisms . For example, small traces of fecal coliform maybe found due to bath water. Also, if there is cross contamination from other wastewater streams or washing of soiled clothes with feces could be other reasons for presence of fecal coliform in greywater.

The Escherichia coli (E. coli) group of bacteria are used as an indicator of microbiological quality. E. coli belongs to the thermotolerant fecal coliforms group. They are a type of microorganism, which typically grow in the intestine of warm-blooded animals (including humans) and shed in their millions in each gram of feces. Occurrence of E. coli in greywater indicates a risk of pathogens being present and hence, the risk of contracting illness or infection through contact with the water.

When untreated greywater is stored, it will turn septic, giving rise to offensive odors and providing suitable conditions for microorganisms to multiply. Thermotolerant coliforms multiply between 10 and 100 times during the first 24 to 48 hours of storage (Technical Guide for Greywater Recycling, 2014). Therefore, untreated greywater must only be stored temporarily, for less than 24 hours.

Table 1 shows the wide range in the concentration of indicator bacteria that may be found in greywater.

TABLE 1: CONCENTRATION RANGES OF INDICATOR BACTERIA REPORTED IN UNTREATED GREYWATER[a]
(Technical Guide for Greywater Recycling. 2014)

	Concentrations (CFU/100mL)			
Source of Greywater	**Total Coliforms**	**Thermotolerant Coliforms**	**Escherichia coli**	**Fecal enterococci**
Hand wash basins	$2.4x10^2$ – >$2.4x10^6$	n.a.[b]	0 – $2.4x10^6$	0 – $2x10^4$
Bath/showers and hand basins	$2.5x10^2$ –$1.8x10^8$	0 – $5.0x10^3$	10 – 10^5	10 – 10^5
Laundry, kitchen sinks	$7x10^5$	$7.3 x10^2$	n.a.	n.a.
Greywater[c]	10^2 – 10^6	10^2 – 10^6	10 – 10^5	n.a.

[a] From Gardner (2003), Koivunen et al. (2003), Lazarova et al. (2003), Ottoson and Stenstrom (2003), Birks et al. (2004), FBR (2005) and NRMMC-EPHC (2006).

[b] n.a. = not available.

[c] Wastewater from all domestic sources, excluding the toilet and kitchen sink.

1.6.2. 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 (Morel and Diener, 2006).

SUSPENDED SOLIDS

Food, oil and soil particles from kitchen sinks, or hair and fibers 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 fibers 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) (Morel and Diener, 2006).

1.6.3. CHEMICAL CHARACTERISTICS OF GREYWATER

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 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 neutralize acidity, is of 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. (Morel and Diener, 2006)

SALINITY AND SODIUM ADSORPTION RATIO (SAR)

Greywater also contains salts, presented 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 – 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 for example (Burnat and Mahmoud, 2005). Salinity of greywater is normally not problematic but can become a risk 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 (Morel and Diener, 2006) (*see part 3.1.1 Crop Assessment*).

BIOLOGICAL AND CHEMICAL OXYGEN DEMAND (BOD, COD)

The biological and chemical oxygen demand (BOD, COD) are parameters used to measure organic pollution in water. COD describes the amount of oxygen required to oxidize all organic matter found in greywater. BOD describes amount of oxygen consumed by bacteria and other microorganisms to decompose organic matter under aerobic conditions at a specified temperature within a certain time span (normally 5 days (BOD_5)). The main groups of organic substances found in greywater are; 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. Table 2 gives typical physical and chemical parameters measured in raw greywater.

TABLE 2: TYPICAL PHYSICAL AND CHEMICAL PARAMETERS MEASURED IN RAW GREYWATER (Jeppesen and Solley, 1994)

Parameter	Unit	Raw Greywater (range)
Suspended Solids	mg/L	10-100
Turbidity	NTU	20-100
BOD_5	mg/L	50-150
Ammonia	mg/L	1-10
Total Phosphorous	mg/L	0.5-5
Sulphate	mg/L	10-50
pH		6.5-8.5
Total Hardness as $CaCO_3$	mg/L	30-150
Conductivity	µs/cm	150-500
TOC	mg/L	50-100

NUTRIENTS

Greywater contains low levels of nutrients (nitrogen, phosphorous, potassium) compared to blackwater. Nitrogen content is relatively low, however phospohours content may vary depending on detergents used for dishwashing and laundry. 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).(Morel and Diener, 2006)

OIL AND GREASE

Greywater contain significant amount of fat such as oil and grease, mainly from kitchen sinks and dishwasher. The oil and grease content depends on cooking and disposal habits.

HEAVY METALS AND EMERGING CONTAMINANTS

Small traces of heavy metals (Cd, Pb, Cr, Ni, Zn, Cu) and emerging contaminants (nonylphenol (NP), nonylphenol mono-ethoxylate (NP1EO), nonylphenol di-ethoxylate (NP2EO), triclosan (TCS) bisphenol-A (BPA) are also present in GW due to use of laundry detergents and personal care products (eg: shampoo, cosmetics) (Noutsopoulos, C et al., 2018).

1.7. THE RISKS OF USING TREATED GREYWATER

1.7.1. PUBLIC HEALTH CONSIDERATIONS

Greywater is capable of transmitting disease through contact, inhalation of greywater spray and contact with broken skin or indirect contact via contaminated items such as toys, garden equipment, grass or soil (i.e. by possible transmission of pathogens through surface contamination by greywater).

The more 'barriers' there are between the untreated greywater and the public, the lower the risk of exposure to pathogens and contaminants. For example, combining a tertiary treatment process with reliable disinfection, well maintained pipes, application controls and restrictions will reduce risks to public health by improving treated greywater quality and lowering exposure to greywater.

In order to reduce the risk to public health and to ensure that greywater recycling systems do not cause any public health nuisance, the following requirements should be applied:

- Treated greywater shall be used strictly for non-potable purposes and shall be limited to toilet flushing, general washing, and irrigation
- Treated greywater shall meet the internationally accepted treated greywater quality requirements as mentioned in Table 3 for purpose of reuse. The minimum sampling and monitoring regime for the treated greywater quality shall be in accordance with Table 3
- There shall be no inter-connection or cross-connection between a pipe or fitting for conveying, storing or containing potable water and a pipe or fitting for conveying, storing or containing non-potable water including greywater
- Equipment, devices, pipes and fittings for the conveyance, treatment, storage and use of greywater shall be labelled
- Standard quality equipment, devices, pipes, fittings and materials with which the greywater comes into contact with to avoid any adverse impact on the environment and public health
- The greywater recycling system shall be operated and maintained in such a way, that it does not cause any public health nuisance such as excessive noise, odour problems, mosquito breeding or any other form risks or inconveniences to the public
- To avoid mosquito the greywater collection tanks must be covered

TABLE 3: THE PERMITTED LIMIT FOR GREYWATER REUSE ACCORDING TO THE PURPOSE OF REUSE (WHO, 2004)

Test	Permitted Limit		
	Irrigation of ornamental fruit trees and fodder crops	Irrigation of vegetables likely to be eaten uncooked	Toilet flushing
BOD_5 (mg/L)	≤ 240	≤ 20	≤ 10
Sample number	Sample/month	Two samples/month	Sample/week
TSS (mg/L)	≤ 140	≤ 20	≤ 10
Sample number	Sample/month	Two samples/month	Sample/week
Thermotolerant coliforms (cfu/100 mL)	≤ 1000	≤ 200	≤ 10
Sample number	Two samples/month	Sample/two weeks	Sample/week

1.7.2. ENVIRONMENTAL CONSIDERATIONS

Greywater is microbiologically and chemically contaminated with human excretions from bathing and laundry. Microbial and chemical contamination of greywater poses a potential risk to human health, a risk that is likely to be increased if microbial contamination is increased. It is important to recognize that greywater does have the potential to transmit disease.

To minimise negative impacts on the environment from greywater recycling, the following requirements should be applied:

- Greywater shall be adequately treated and disinfected to meet the required water quality before it is re-used for toilet flushing, general washing. Disinfection is an essential treatment component of greywater recycling system to ensure that treated greywater is fit for use. Among the disinfection options available for greywater are chlorination containing chemicals; ozonation, and UV radiation.

  Chemical disinfection to inactivate pathogens is an important treatment barrier. Chemicals used include chlorine, chloramine, chlorine dioxide and ozone. Treatment effectiveness is a function of dose, contact time, temperature and sometimes pH. The concept of disinfectant concentration and contact time is integral to the understanding of disinfection kinetics and the practical application of the CT concept (which is defined as the product of the residual disinfectant concentration [C in mg/l] and the contact time [T in minutes] (USEPA, 1999). Table 4 outlines CT values for inactivation of viruses.

TABLE 4: TYPICAL REQUIRED CT VALUES FOR 99.99% INACTIVATION OF VIRUSES (USEPA, 1999)

Organism	**Dosage** (mg.min/l)
Chlorine	31
Chloramine	20
Chlorine dioxide	30
Ozone	30
Note: Value based on temperature 10 °C, pH range 6 to 9	

UV disinfection system uses UV lamps that emit ultraviolet light of a spectrum wavelength ranging between 200nm to 310nm, with maximum effectiveness around 265 nm, which can attack the genetic code of the microorganism and rearranges the DNA /RNA, eliminating the microorganism's ability to function and reproduce. If a microorganism can no longer reproduce, it cannot replicate, therefore it cannot infect other organisms with which it has contact (Jagger, 1967). Table 5 shows that UV is an effective disinfectant for bacteria and viruses.

TABLE 5: TYPICAL UV DOSAGES REQUIRED FOR 99.99% INACTIVATION OF SELECTED MICROBES (Malley (2000) and USEPA (2003))

Organism	**Dosage** (mW-sec/cm^2)
BACTERIA:	
Bacillus subtilis spores	31.00
Escherichia coli	20.00
S. faecalis	30.00
Salmonella typhi	30.00
Vibrio cholera	0.65
VIRUSES:	
MS-2	100.00
Coxsackie AZ	30.00
Hepatitis A	16.00
Poliovirus	30.00
Rotavirus — Wa	50.00
Rotavirus SA11	40.00
Adenovirus	186.00

- Chemical waste such as paints, automotive oils and greases, pesticides and pharmaceuticals waste, etc. and any other trade waste or industrial liquid waste shall not be discharged into the greywater recycling system.
- Treated greywater shall not be permitted to run off onto neighboring properties or driveways, car parks or any hard surfaces where it can run into the street and into storm water drains and eventually into surface waters. Also, the greywater or the treated greywater shall not be discharged into open drains or rivers leading to the sea or reservoirs. They shall be discharged into public sewer or recycled for other uses. This is important to avoid cross contamination and growth of microorganisms due to stagnation.
- The use of greywater can accelerate the process of soil salinization due to higher salt content, especially in arid and semi-arid regions where accumulated salts are not flushed regularly from soil profile by rainfall. Practices to limit salinization include soil washing and appropriate drainage. (WHO, 2014)
- Greywater should not be directly discharged into the soil as it can contaminate groundwater if the water table is high or depending on the soil conditions and percolation rates.

02 GREYWATER TREATMENT SYSTEMS

This chapter primarily focuses on on-site nature-based technology options for household level and community level. Depending on the characteristics of greywater and purpose of reuse, a greywater treatment system from the options below can be selected (Refer Table 6). The systems described below can be customized to suit the local conditions.

The Greywater Management in Rural India, a Ministry of Drinking Water and Sanitation publication recommends more technologies applicable at the household, community and village level.

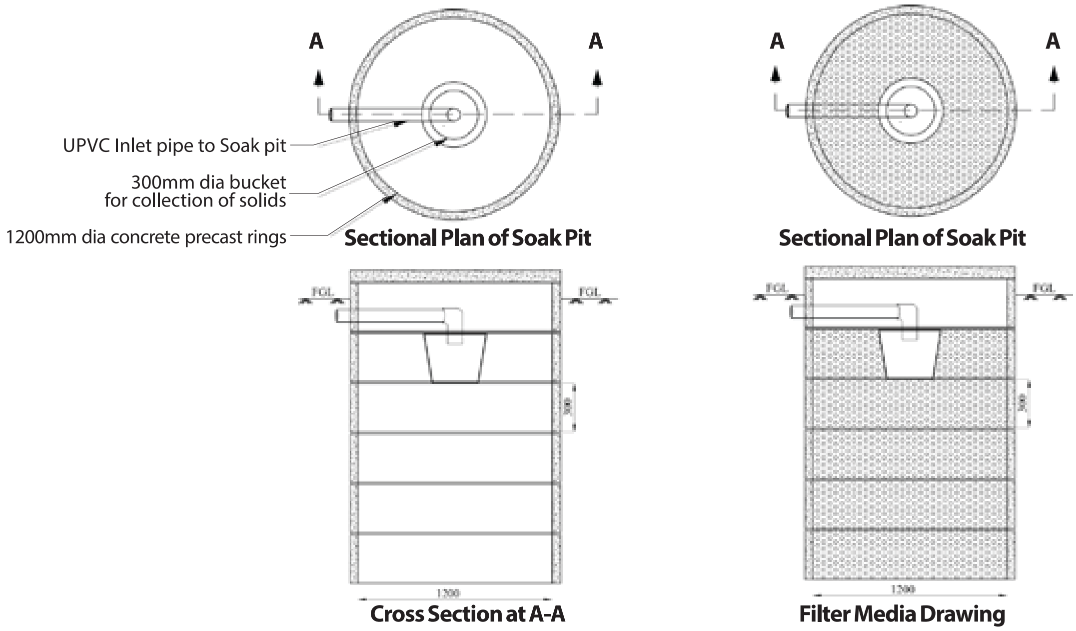
TABLE 6: OPTIONS FOR ON-SITE GREYWATER TREATMENT SYSTEMS

Treatment Systems	Direct Disposal	Direct Reuse & Excess disposal by Soaking	Primary Treatment for Reuse & Excess disposal by Soaking	Secondary Treatment for Reuse & Excess disposal by Soaking	Advanced Secondary Treatment for Reuse
Greywater streams					
Wash Basin	✓	✓	✓	✓	✓
Bath	✓	✓	✓	✓	✓
Kitchen Sink			✓	✓	✓
Laundry			✓	✓	✓
Planning Unit					
Household-Level	✓	✓	✓	✓	
Community Level				✓	✓

2.1. DIRECT DISPOSAL

This system can be used where the greywater is from wash basin and bath and is not mixed with any other wastewater stream. This is a simple soaking system - a soak pit with a bucket for collection of solids. The greywater collects in the bucket and over flows into the filter media. The greywater percolates through the filter media filters into the sub-soil. This system is suitable at a household level.

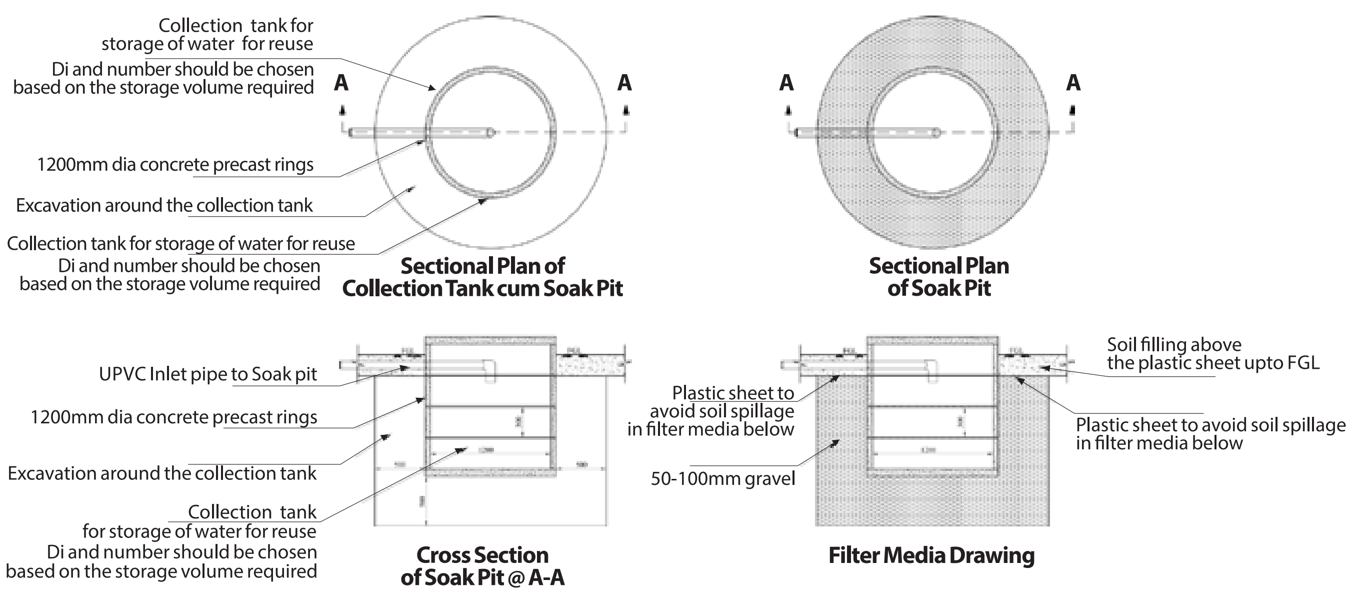
FIGURE 2: DIRECT DISPOSAL SYSTEM (Source: BORDA South Asia)



2.2 DIRECT REUSE & EXCESS DISPOSAL BY SOAKING

This system can be used where the greywater is from wash basin and bath and is not mixed with any other wastewater stream. The greywater collected can be directly used for watering floriculture. This is a simple soaking system. The greywater collects in the collection tank and overflows into the surrounding filter media. This excess greywater will soak away into the filter media into the soil.

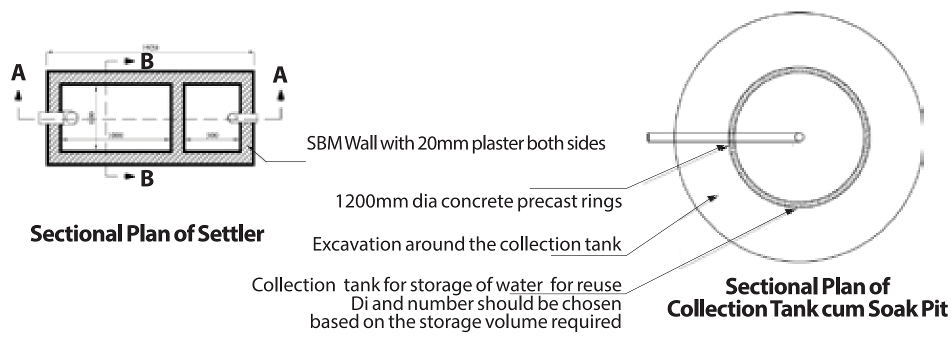
FIGURE 3: DIRECT REUSE & EXCESS DISPOSAL BY SOAKING (Source: BORDA South Asia)



2.3. PRIMARY TREATMENT FOR REUSE & EXCESS DISPOSAL BY SOAKING

This system can be used for greywater streams from kitchen sink, bath, laundry and wash basin. This system constitutes a settler and a soak pit. An oil and grease trap can be added in order to avoid clogging or formation of scum. A settler is a two-chamber tank which allows the formation of sludge that undergoes anaerobic digestion and the primary treated liquid flows into a soak pit. Soak pits mentioned in section 2.2.1 or 2.2.2 maybe used as per the requirement. This can be used for a household or a cluster of households. Depending on the quality of the treated greywater, it can be reused as prescribed by national or international standards. This system has been piloted with support of LEDeG in two households in Leh.

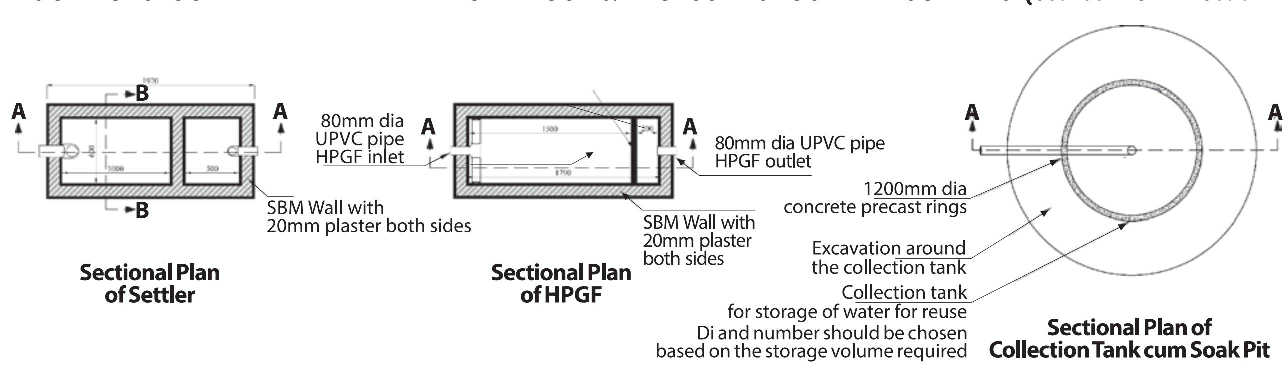
FIGURE 4: PRIMARY TREATMENT FOR REUSE & EXCESS DISPOSAL BY SOAKING (Source: BORDA South Asia)



2.4. SECONDARY TREATMENT FOR REUSE & EXCESS DISPOSAL BY SOAKING

This system can be used for greywater streams from kitchen sink, bath, laundry and wash basin. This system constitutes a settler, a horizontal planted gravel filter (HPGF) and a soak pit. An oil and grease trap can be added in order to avoid clogging or formation of scum. A settler is a two-chamber tank which allows the formation of sludge that undergoes anaerobic digestion. The effluent from the settler flows in to HPGF where aerobic treatment takes place. The treated liquid flows into a soak pit. Soak pits mentioned in section 2.1or 2.2. maybe used as per the requirement.

FIGURE 5: SECONDARY TREATMENT FOR REUSE & EXCESS DISPOSAL BY SOAKING (Source: BORDA South Asia)



2.5. ADVANCED SECONDARY TREATMENT FOR REUSE

Decentralised Wastewater Treatment Systems (DEWATS) are based on the principles of decentralization, simplicity and reuse of the treatment products. Simplicity is achieved through on-site treatment without chemicals or electro-chemical equipment/energy input, and by low maintenance requirements. Necessary maintenance activities can be carried out by service providers or by supervised and trained maintenance personnel on-site. There are three main treatment steps & modules, which are combined and customised according to specific local conditions -

- Primary Treatment: Settler
- Secondary Treatment:
  - Anaerobic Baffled Reactor – ABR,
  - Anaerobic Filter – AF,
  - Horizontal/Vertical Planted Gravel Filter –HPGF/VPGF
- Advanced Secondary (or Tertiary) Treatment Options

Along with local conditions such as site conditions (groundwater table, soil permeability, land availability, slope) other parameters include hydraulic loading and organic loading. DEWATS can be tailored to treat wastewater flows from 1 to 1000 m3 per day and are designed to meet the requirements stipulated by country-specific environmental laws and regulations. Organic loading influences a coordinated follow up of different treatment steps. Refer Table 7 for the organic loading rates for various treatment modules.

TABLE 7: ORGANIC LOADING RATES OF VARIOUS TREATMENT MODULES (Sasse, 1998)

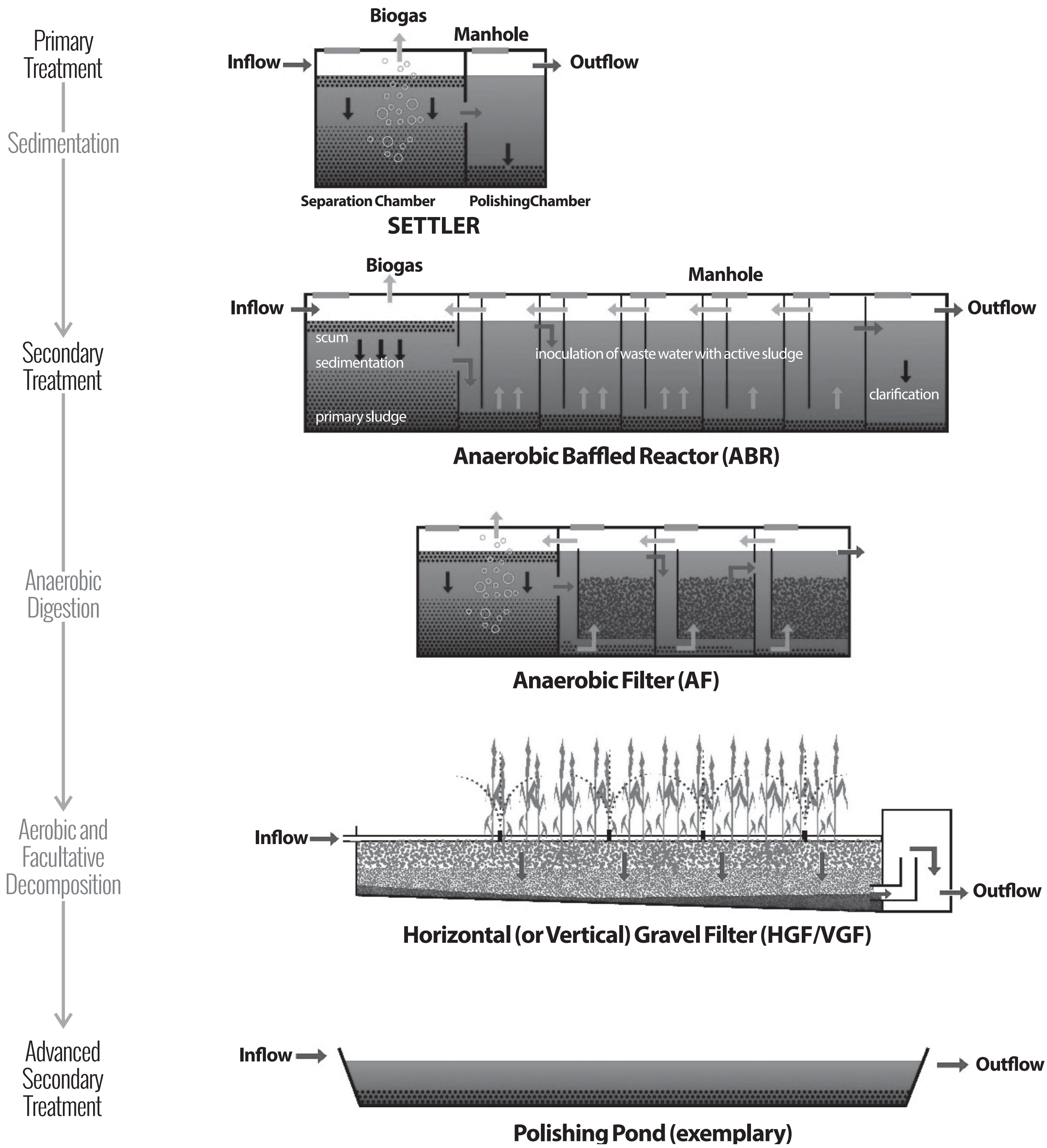
Typical Values	Aerobic Pond	Maturation Pond	Water Hyacinth Pond	Anaerobic Pond	Anaerobic Filter	Baffled Reactor
BOD_5 kg/m^{3}d	0,11	0,01	0,07	0,3 - 1,2	4,00	6,00
BOD_5 removal	85%	70%	85%	70%	85%	85%
Temperature Optimum	20ºC	20ºC	20ºC	30ºC	30ºC	30ºC

SETTLER

A settler, or septic tank, consists of a minimum of two, sometimes three compartments. Most of the sludge is retained in the first chamber, where the settled sludge is stabilised by anaerobic sludge digestion. The second chamber contains only little sludge which allows the water to flow without disturbance from rising gas bubbles. Two treatment principles, namely the mechanical/physical treatment by sedimentation and the biological treatment (sludge digestion) by contact between fresh wastewater and active sludge, are taking place. Optimal sedimentation takes place when the flow is smooth and undisturbed. Biological treatment is optimised by quick and intensive contact between new inflow and old sludge. How the influent enters and flows through the settler decides which treatment principle predominates. The first compartment occupies about two-thirds of the septic-tank volume, allowing for most of the sludge and scum accumulation. The following chamber(s) are provided to calm the turbulent liquid.

FIGURE 6: ADVANCED SECONDARY TREATMENT FOR REUSE

(Bernd Gutterer, Ludwig Sasse, Thilo Panzerbieter and Thorsten Reckerzügel, 2009)



ANAEROBIC BAFFLED REACTOR (ABR)

The baffled reactor consists of a series of chambers in which the wastewater flows from bottom to the top. Suspended and dissolved solids in the pre-settled wastewater undergo anaerobic degradation. The activated sludge settles down at the bottom of each chamber and the influent wastewater is forced to flow through this sludge blanket where anaerobic bacteria make use of the pollutants for their metabolism. Progressive decomposition occurs in the successive chambers which can be maximum 5 chambers. In ABR plants the BOD reduction rate is up to 90% and the pathogen reduction ranges between 40 – 75% (Gutterer et al, 2009). The baffled reactor is resistant to shock load and variable inflow. It operates by gravity and maintenance is reduced to desludging of the chambers at intervals of 1 – 2 years. Sub-soil construction of the module saves space.

ANAEROBIC FILTER (AF)

The anaerobic filter, also known as fixed-bed or fixed-film reactor, includes the treatment of non-settleable and dissolved solids by bringing them into close contact with a surplus of active microbial mass. Active micro-organisms digest the dispersed or dissolved organic matter within a short retention time. Most of the micro-organisms are immobile; they attach themselves to solid particles or, for example, the reactor walls. Filter material, such as gravel, rocks, cinder or specially formed plastic shapes, provide additional surface area for them to settle. By forcing the fresh wastewater to flow through this material, intensive contact with active micro-organisms is established; the larger the surface for microbial growth, the quicker the biofilm formation on the surface of the media.

HORIZONTAL GRAVEL FILTER (HGF)

Horizontal Gravel Filters are suitable for wastewater with a low percentage of suspended solids that have already been removed by pre-treatment. The main removal or treatment mechanisms are biological conversion, physical filtration and chemical adsorption. In case of HGFs, the bottom slope is 1% and the flow direction is mainly horizontal. The horizontal filter is permanently soaked with water and operates partly aerobic, partly anoxic and partly anaerobic. HGF combine physical-filtration processes and the influence of plantation (Planted Horizontal Gravel Filter) on the biological-treatment process and oxygen intake. BOD reduction rate is between 75 – 90% and pathogen removal is over 95% (Gutterer et al, 2009). The operation and maintenance requirements are considered simple.

2.6. OPERATION AND MAINTENANCE REQUIREMENTS (DOs & DON'Ts)

DOs:

- ☑ Minimize human and animal contact with greywater; always wash your hands after contact.
- ☑ Ensure that potable water supply is isolated from the greywater system, with no cross connection of any form.
- ☑ Ensure that greywater tanks and pumps are not located in the same room/enclosure as potable water tanks and pumps.
- ☑ Label pipes, tanks and other fittings storing or conveying greywater to demarcate them from the ones storing or conveying potable water.
- ☑ Label the devices (in which the treated greywater is used) clearly to show that the water used in such devices is not for potable use.
- ☑ Use greywater only for intended non-potable use.
- ☑ Ensure that all water pipes and fittings used for conveying potable water shall also comply with standards and requirements.
- ☑ To avoid mosquitos the greywater or treated greywater storage tanks should be covered
- ☑ Ensure that the greywater if it is not recycled for reuse, be discharged into the public sewer.

DON'TS:

- ☒ Allow hazardous chemicals, such as oils, solvents, pesticides, etc. into your greywater recycling system.
- ☒ Allow diaper wash water or similarly wash water of clothes soiled with infectious bodily fluids into the greywater recycling system.
- ☒ Allow greywater to flow from your property or to enter storm water drain.

03 LAND APPLICATION OF TREATED WATER

This chapter mainly discusses reuse of treated greywater in land application for irrigation. The sections below describes strategies and methods to be consider while using treated greywater as recommended in Greywater Management in Low and Middle Income Countries (EAWAG, 2006) and Wastewater Treatment and Use in Agriculture (FAO, 1992). It is advised to adhere to the acceptable national standards or contextualize to the local conditions to use treated greywater for agriculture.

3.1 SITE ASSESSMENT

With regards to the reuse of treated greywater, 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 treated 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.

3.1.1. CROP ASSESSMENT

These are the easiest plants to irrigate with greywater:

Trees: Fruit trees (or any trees) adapted to the local climate thrive with greywater irrigation.

Bushes and shrubs: Bushes and shrubs suited to the local region are easy to irrigate with greywater.

Vines: Edible vines like passion fruit or kiwi are attractive and produce fruit.

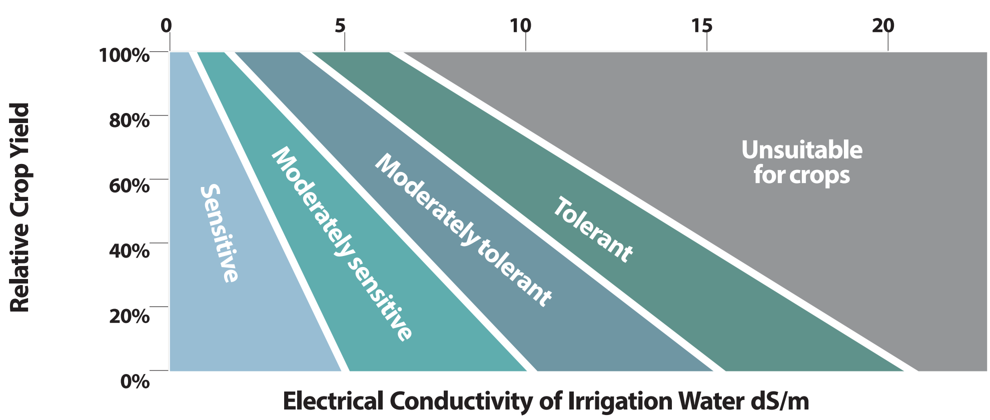
Larger perennials: Perennial vegetables, which produce year after year without needing replanting, are a productive addition to any landscape.

Large annuals: Large annual plants, both edible and nonedible; for example: tomatoes, corn, zinnias. squash. (Remember, one can safely irrigate food crops so long as the edible portion is above the ground and greywater doesn't touch it.)

Smaller plants growing closely together: They can be irrigated in the middle of the planting area, so their roots share the water.

Figure 7 exhibits the relative reduction in crop yield for crops of different salt tolerance levels as a function of the electrical conductivity of irrigation water.

FIGURE 7: RELATIVE SALT TOLERANCE OF AGRICULTURAL CROPS (Maas, 1984)



Examples of crops and their sensitivity to salt are given in Table 8: Relative salt tolerance of selected agricultural crops (Mass, 1984). Greywater irrigation with a typical 300–1,500 µS/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 (Mass, 1984).

TABLE 8: RELATIVE SALT TOLERANCE OF SELECTED AGRICULTURAL CROPS (Mass, 1984)

SENSITIVE	MODERATELY TOLERANT
Bean Okra Onion Avocado Lemon Mango	Cowpea Wheat Fig Olive Papaya Pineapple
MODERATELY SENSITIVE	**TOLERANT**
Maize Rice Cabbage Eggplant Spinach Tomato	Barley Sugar beet Asparagus Date palm

3.1.2. SOIL ASSESSMENT

An important issue related to greywater irrigation is its sodicity[1] . 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 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 part 3.3 'Friendly' Detergents and Cleaners).

[1] Sodicity is a term given to the amount of sodium.

FIGURE 8: IRRIGATION WATER QUALITY IN RELATION TO SAR AND EC TO PREDICT SOIL STRUCTURE STABILITY (deHayr, 2006)

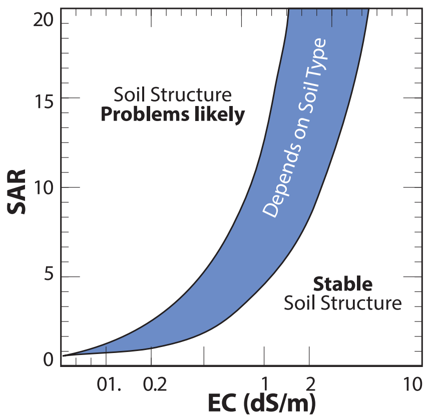


Figure 8 can be used to evaluate irrigation water quality in relation to its potential impact on soil structure as a function of EC and SAR values. Electrical conductivity (EC) is a measure of the total soluble salts in the water reported in deciSiemens per metre (dS/m) or microSiemens per centimetre (µS/cm) and the SAR value is a measure of the relative concentration of sodium to calcium and magnesium. SAR can be calculated from the following equation:

$$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}}$$

Where Na, Ca and Mg are expressed in milliequivalents per litre (meq/L).

3.2 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. It is advisable to use drip irrigation or mulch trench system as described in the following sections.

3.2.1. DRIP IRRIGATION SYSTEMS

FIGURE 9: GRAVITY-DRIVEN DRIP IRRIGATION (Source: Morel and Diener, 2006)

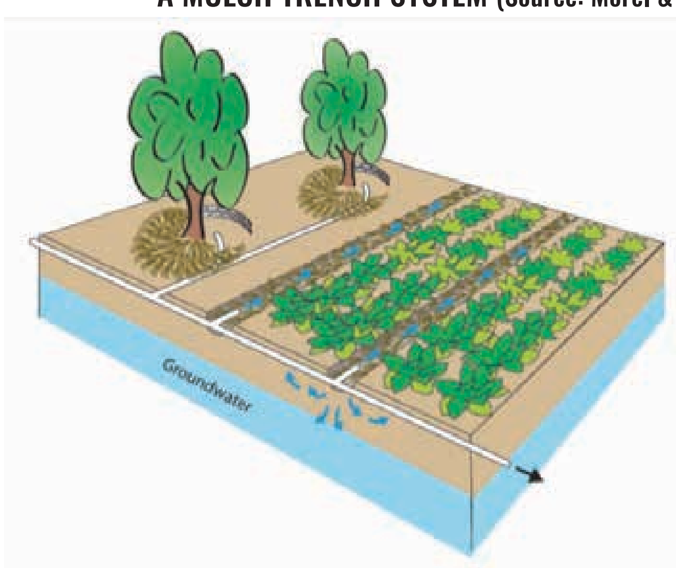
This has shown to be highly effective if well-designed and maintained. Simple hoses release the water directly at the point of need. The pathogen contamination risk of plants by irrigation water is therefore markedly reduced. Drip irrigation systems normally need a dosing pump and, consequently, also a reliable power supply. Mofoke et al. (2004) also successfully tested an alternative, gravity-driven drip irrigation system (see Figure 9). This system was constructed exclusively from cheap and locally available material, 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 the Mofoke et al. low-cost drip irrigation system cut labor 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.

3.2.2 THE MULCH TRENCH SYSTEM

This is a simple and promising irrigation where rice, spelt, wood or other mulch material is laid around a 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 must be replaced upon degradation of the organic material of the mulch. Figure 10 illustrates a greywater-irrigated mulch trench system.

FIGURE 10: SCHEMATIC LAYOUT OF A GREYWATER GARDEN IRRIGATED BY A MULCH TRENCH SYSTEM (Source: Morel & Diener, 2006)



In Texas, USA, a simple irrigation system using a 20-litre plastic bucket, cement and radial pipes (dia. 2.5 cm) distribute pre-treated (by a grease and grit trap) kitchen greywater to mulch chambers irrigating nearby trees (papaya and banana) (see Figure 11). 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.

FIGURE 11: GREYWATER INFILTRATION AND IRRIGATION SYSTEM IN CASA JULIANA, TEXAS (Source: Morel & Diener, 2006)
Kitchen greywater is distributed via a hub to six small infiltration chambers irrigating papayas and bananas. The chambers are filled with mulch.

3.3 'FRIENDLY' DETERGENTS AND CLEANERS

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 cleaning 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 salinization of soils. When greywater is reused for irrigation, sodium-containing products should be substituted by potassium-based soaps and detergents, since potassium has a fertilizer 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.

Disinfections, 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.

3.4 WATER MANAGEMENT

Most treated wastewaters are not very saline, salinity levels usually ranging between 200 and 500 mg/l (ECw = 0.7 to 3.0 dS/m), however, there may be instances where the salinity concentration exceeds the 2000 mg/l level (FAO 1985). In any case, appropriate water management practices will have to be followed to prevent salinization, irrespective of whether the salt content in the wastewater is high or low. It is interesting to note that even the application of a non-saline wastewater, such as one containing 200 to 500 mg/l, when applied at a rate of 20,000 m3 per hectare, a fairly typical irrigation rate, will add between 2 and 5 ton of salt annually to the soil. If this is not flushed out of the root zone by leaching and removed from the soil by effective drainage, salinity problems can build up rapidly. Leaching and drainage are thus two important water management practices to avoid salinization of soils.

3.4.1 LEACHING

Under irrigated agriculture, a certain amount of excess irrigation water is required to percolate through the root zone so as to remove the salts which have accumulated as a result of evapotranspiration from the original irrigation water. This process of displacing the salts from the root zone is called leaching and that portion of the irrigation water which mobilizes the excess of salts is called the leaching fraction, LF.

$$\text{Leaching Fraction (LF)} = \frac{\text{(depth of water leached below the root zone)}}{\text{(depth of water applied at the surface)}}$$

To estimate the leaching requirement, both the salinity of the irrigation water (EC_w) and the crop tolerance to soil salinity (EC_e) must be known. The necessary leaching requirement (LR) can be estimated using the following equation reported by Ayers and Westcot (FAO 1985):

$$LR = \frac{EC_w}{5(EC_e - EC_w)}$$

where:
LR = minimum leaching requirement needed to control salts within the tolerance (EC_e) of the crop with ordinary surface methods of irrigation

EC_w = salinity of the applied irrigation water in dS/m

EC_e = average soil salinity tolerated by the crop as measured on a soil saturation extract.

It is recommended that the EC_e value that can be expected to result in at least a 90% or greater yield be used in the calculation.

3.4.2 DRAINAGE

Drainage is defined as the removal of excess water from the soil so as to permit optimum growth of plants. Removal of excess surface water is termed surface drainage while the removal of excess water from beneath the soil surface is termed sub-surface drainage. It is particularly important in semi-arid and arid areas to prevent secondary salinization. In these areas, the water table will rise with irrigation when the natural internal drainage of the soil is not adequate. When the water table is within a few meters of the soil surface, capillary rise of saline groundwater will transport salts to the soil surface. At the surface, water evaporates, leaving the salts behind. If this process is not arrested, salt accumulation will continue, resulting in salinization of the soil. In such cases, sub-surface drainage can control the rise of the water table and hence prevent salinization.

3.4.3 PRE-PLANTING IRRIGATION

Pre-planting irrigation is practiced in many irrigation schemes for two reasons: (i) to leach salts from the soil surface which may have accumulated during the previous cropping period and to provide a salt-free environment to germinating seeds (it should be noted that for most crops, the seed germination and seedling stages are most sensitive to salinity); and (ii) to provide adequate moisture to germinating seeds and young seedlings.

3.5 LAND AND SOIL MANAGEMENT

Several land and soil management practices can be adopted at the field level to overcome salinity, sodicity, toxicity and health hazards that might be associated with the use of treated wastewater. These practices are explained in the following paragraphs.

3.5.1 LAND GRADING

If the wastewater is saline (conductivities of > 3mS/m, dissolved solids concentration of > 500 mg/l and sodium absorption ratios of >3-9 (WHO, 2006)) , it is very important that the irrigated land is appropriately graded. Salts accumulate in the high spots which have too little water infiltration and leaching, while in the low spots water accumulates, causing waterlogging and soil crusting. Land grading is important to achieve good uniformity of application from surface irrigation methods and acceptable irrigation efficiencies in general. The slope required will vary with the irrigation system, length of run of water flow, soil type, and the design of the field.

3.5.2 DEEP CULTIVATION

In certain areas, the soil is stratified, and such soils are difficult to irrigate. Layers of clay, sand or hardpan in stratified soils frequently impede or prevent free movement of water through and beyond the root zone. This will not only lead to saturation of the root zone but also to accumulation of salts in the root zone. Irrigation efficiency as well as water movement in the soil can be greatly enhanced by sub-soiling and chiseling of the land.

3.6 CROP MANAGEMENT

Several cultural and crop management practices that are valid under saline water use will be valid under wastewater use. These practices are aimed at preventing damage to crops caused by salt accumulation surrounding the plants and in the root zone and adjusting fertilizer and agrochemical applications to suit the quality of the wastewater and the crop.

3.6.1 PLACEMENT OF SEED

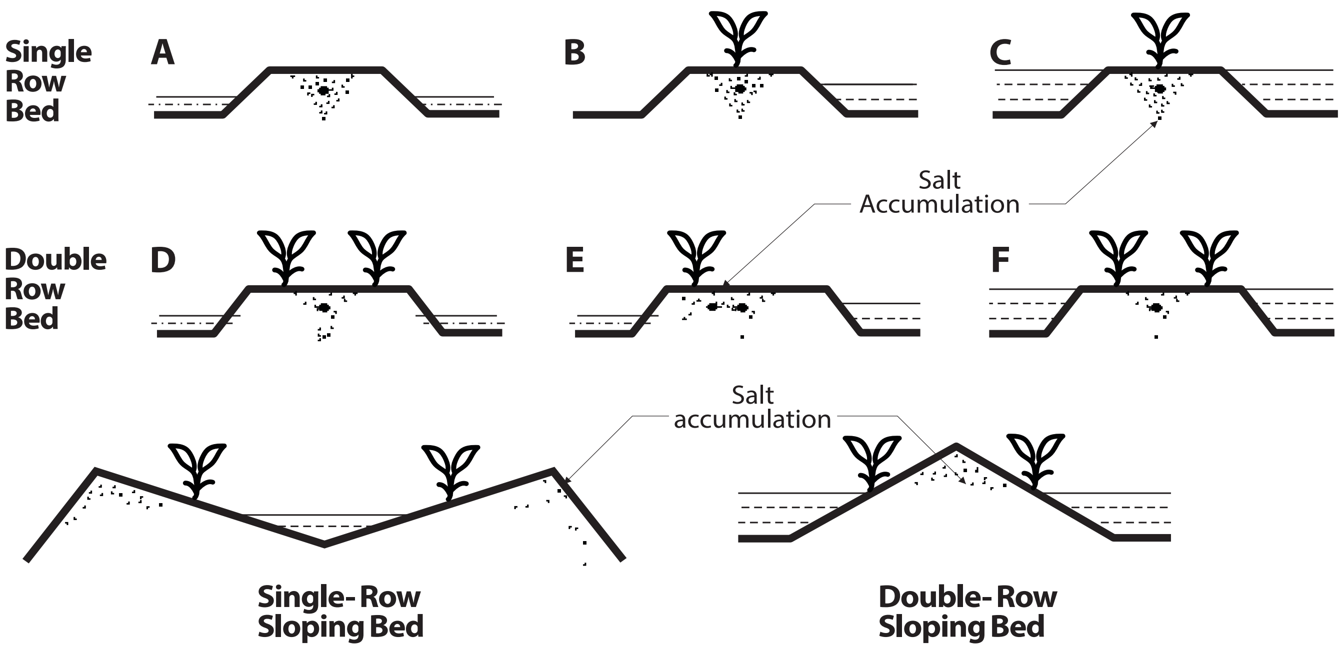
In most crops, seed germination is more seriously affected by soil salinity than other stages of development of a crop. An efficient means of overcoming this problem is to ensure that the soil around the germinating seeds is sufficiently low in salinity. Appropriate planting methods and ridge shapes can significantly decrease damage to germinating seeds. Some specific practices include:

- Planting on the shoulder of the ridge in the case of single row planting or on both shoulders in double row planting,
- Using sloping beds with seeds planted on the sloping side, but above the water line,
- Irrigating alternate rows so that the salts can be moved beyond the single seed row.

Figure 12 presents schematic representations of salt accumulation, planting positions, ridge shapes and watering patterns.

FIGURE 12: SCHEMATIC REPRESENTATIONS OF SALT ACCUMULATION AND PLANTING METHODS

(Bernstein and Fireman 1957)



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BORDA

BORDA Headquarters,
Am Deich 45, D 28199 Bremen, Germany

www.borda.org

BORDA West & Central Asia
Um Uthaina
Mecca Street 5
Amman, Jordan

info@borda-wesca.org
www.borda-wesca.org

BORDA South Asia
Tarana, #7, 1st Floor, Kambipura,
Kengeri, Bangalore – 560060,
Karnataka, India

tsephel@borda-sa.org
www.borda-sa.org

LEDeG

Ladakh Ecological Development Group
(LEDeG)
Karzoo, Leh, Ladakh
194101. J&K, India

mail@ledeg.org
http://www.ledeg.org