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DECENTRALISED GREYWATER SOLUTIONS FOR ARID & SEMI-ARID REGIONS

IN THE CONTEXT OF COOPERATIVE DEVELOPMENT

Master's Thesis
Natural Resources Management and Ecological Engineering

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Abbreviations & Acronyms

BOD	Biochemical Oxygen Demand
CBO	Community Based Organization
COD	Chemical Oxygen Demand
DPSIR	Driving forces–Pressures–State–Impacts–Responses
EC	Electrical Conductivity
Ecosan	Ecological Sanitation
EU	European Union
FAO	Food and Agricultural Organization
Fcfa	Communauté Financière Africaine Francs
GW	Greywater
GWP	Global Water Partnership
IDRC	International Development Research Centre
INWRDAM	Inter-Islamic Network on Water Resources Development & Management
IWMI	International Water Management Institute
IWRM	Integrated Water Resources Management
LEISA	Low-External-Input and Sustainable Agriculture
MBAS	Methylene Blue Active Substances
MDG	Millennium Development Goals
NGO	Non-Governmental Organization
PPP	Permaculture Pilot Project
PTD	Participatory (or People-centred) Technology Development
ROSA	Resource-Oriented Sanitation concepts for peri-urban areas in Africa
SAR	Sodium Adsorption Ratio
TSS	Total Suspended Solids
UN	United Nations
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNICEF	United Nations Children's Fund
WHO	World Health Organization

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Zusammenfassung

Mehr als 1,1 Milliarden Menschen haben keinen Zugriff auf sauberes Trinkwasser in der Welt, und 2,6 Milliarden Menschen haben unausreichende Abwasserentsorgung. Das Ziel internationaler Bemühungen ist es im Rahmen der 'Millennium Development Goals' diese Zahlen bis zum Jahr 2015 zu halbieren. Als Teil dieser Bemühungen entwickelt das ROSA Projekt (Resource Oriented Sanitation for peri-urban areas of Africa) nachhaltige Abwassersysteme in den ostafrikanischen Städten Arba Minch in Äthiopien, Kitgum in Uganda, Nakuru in Kenia und Arusha in Tansania.

Für die Entwicklung arider und semi-arider Gebiete ist die Verfügbarkeit von Wasser absolut notwendig. Zentrale Abwasserkanalisationssysteme sind generell ungeeignet für Entwickelungsländer mit Wassermangel, da sie unwirtschaftlich und nicht umweltfreundlich sind. Um mit weniger Wasser auszukommen müssen neue Wege erkundet werden, einschließlich Abwasserrückgewinnung und Wasserwiederverwendung. Grauwasser ist ein bei der Wäsche erzeugtes Haushaltsabwasser, das als eine nützliche Wasserquelle für nicht-trinkbare Wiederverwendung betrachtet werden kann, wie zum Beispiel für die eingeschränkte Bewässerung von Kulturpflanzen. Primäre und sekundäre Behandlungen von Grauwasser werden für die Wiederverwendung empfohlen, sowie für die Entsorgung von unbehandelten Haushaltsabwässern. Umweltbelastungen und Gesundheitsprobleme der Bevölkerung können bei der Entsorgung von unbehandelten Haushaltsabwässern auftreten.

Diese Masterarbeit vermittelt Ergebnisse von Haushaltsgrauwassernutzungen in randstädtischen Siedlungen von Entwickelungsländern mit Wassermangel. Detaillierte Ergenbisse von Grauwasser Projekten aus Ländern mit vergleichlichen Vorraussetzungen wie die der ROSA Städte werden vorgestellt, zum Beispiel von innovativen und erfolgreichen Grauwassernutzungen in Südafrika, Mali, und Jordanien. Erfahrungen von Grauwasserwiederverwendung, Grauwasserentsorgung, sowie Ergebnisbewertung, und Erfahrungen aus der Projektentwicklung werden dargestellt. Beobachtungen von einer Studienfahrt, sowie Ergebnisse einer Umfrage und von anderen Studien bieten eine vorläufige Einschätzung über den gegenwärtigen Haushaltswasserverbrauch und über Grauwasser-Nutzungsmethoden innerhalb der ROSA Städte an. Der begriffliche Rahmen von DPSIR (Driver-Pressure-State-Impact-Response) wird benutzt um Zusammenhänge und Komponenten des Hauswasserwiedergebrauches im Hinblick auf Grauwasser zu strukturieren. Mittels dieses Rahmens wird ein Systemverständnis vermittelt und praktische Interventionen als Teil einer integrierten Wassermanagement-Strategie identifiziert.

Stichwörter: Entwicklungszusammenarbeit, dezentralisierte Grauwasserbehandlung, DPSIR, integrierte Wassermanagement-Strategie, ressource-orientierte Abwasserentsorgung, Wassermangel

Abstract

More than 1.1 billion people worldwide currently lack access to safe drinking water and 2.6 billion people do not have access to basic sanitation. Reducing these numbers by half by 2015 is the focus of international efforts as part of the Millennium Development Goals. In this context, the ROSA (Resource-Oriented Sanitation concepts for peri-urban areas in Africa) project aims to develop sustainable sanitation systems in the East African cities of Arba Minch, Ethiopia; Kitgum, Uganda; Nakuru, Kenya; and Arusha, Tanzania.

In most arid and semi-arid regions, water is a limiting factor for development. It is generally accepted that centralized water-borne sewerage is an inappropriate solution in water scarce developing countries as it is neither economically feasible nor environmentally sensible. Learning to cope with less water has commanded new approaches to water resources management, including wastewater recovery and reuse. Greywater, generated from household washing activities, is regarded as a viable water source for non-potable applications, such as restricted irrigation of crops. Precautionary measures, including source control and primary and secondary treatment are recommended prior to reuse. Effective greywater management options are also required in cases where supply-driven water management has neglected to take care of the resulting domestic wastewater in non-sewered areas. In these cases, open disposal of greywater is common and reportedly causes environmental and health problems among the population.

This thesis explores systems of household greywater management in the context of peri-urban settlements in water scarce developing countries. Presented is information, gathered primarily from literature, detailing greywater projects of similar context to that of the ROSA cities. Case studies of innovative and successful greywater management systems from South Africa, Mali, and Jordan are provided with emphasis on greywater reuse and disposal techniques, assessment results, and experiences of the project development process. Furthermore, field observations, results from a semi-structured questionnaire, and review of baseline study reports offer a preliminary assessment of current domestic water consumption and greywater management practices within the ROSA cities. The DPSIR (Driver-Pressure-State-Impact-Response) conceptual framework is used to structure the interrelated components of domestic water use with the focus on greywater; supporting an understanding of the system and identifying practical intervention strategies as part of an integrated management approach.

Keywords: cooperative development, decentralised greywater treatment, DPSIR, integrated household-centred management approach, resource-oriented sanitation, water scarcity

1 Introduction & Background

The United Nations report that more than 1.1 billion people worldwide currently lack access to safe drinking water and 2.6 billion people do not have access to basic sanitation. Reducing these numbers by half, by the year 2015, is currently the focus of international efforts as part of the Millennium Development Goals (MDGs) (WHO/UNICEF, 2005).

The drive to supply communities with access to safe drinking water through water services has often failed to effectively deal with the resulting increase in wastewater. Open disposal of greywater often contributes to negative impacts on human and environmental health, especially in densely populated non-sewered settlements (ALDERLIESTE and LANGEVELD, 2005; CARDEN *et al*., 2007a). Centralized water-borne sewerage is considered an inappropriate solution in water scarce developing countries as it is neither economically feasible nor environmentally sensible (NARAIN, 2002; UJANG and HENZE, 2006). Therefore, onsite sanitation systems are promoted as the most appropriate alternative for managing human excreta in a safe and hygienic manner. This approach however, requires separate strategies for the management of domestically produced greywater.

1.1 Water Scarcity

The theme of the 2007 World Water Day (March 22, 2007) was "Coping with Water Scarcity". Water scarcity, driven primarily by increasing demand and decreasing availability, is a problem which affects a large proportion of the world population. Arid and semi-arid regions, characterized by low precipitation and high evaporation rates, suffer from physical water scarcity whereas many developing countries experience economic water scarcity (Figure 1). Sub-Saharan Africa, for example, has the least access to improved fresh water supplies (UN-WATER, 2007).

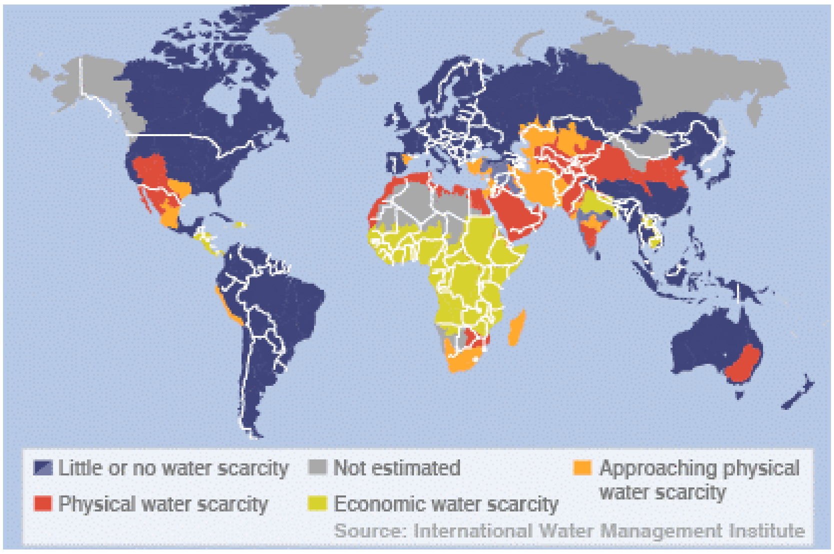

Figure 1: Where water is scarce (BBC, 2007; IWMI, 2006)

Water availability is a commonly used indicator of water scarcity. A population is considered to be under water stress when water availability is less then 1,700 $m^3/c/y$. Below 1,000 $m^3/c/y$ water scarcity is predicted to lead to problems with food production, economic development, and human health and well-being. Below 500 $m^3/c/y$ water availability is a main constraint to life (BOBERG, 2005).

WOLFE and BROOKS (2003) propose that water scarcity may be characterized on three levels:

1. Physical (first order) scarcity implies a limit in absolute water quantity available.
2. Economic (second order) scarcity identifies water as a valuable resource because of its limited availability compared to demand.
3. Social (third order) scarcity is defined as the limited capacity to provide service or cope with physical and/or economic scarcity.

A better understanding of the types of water scarcity can help to identify adaptive management options, with the range of response options increasing with the order of scarcity (WOLFE and BROOKS, 2003).

1.2 Adopting an Integrated Approach

The complexity of issues surrounding the lack of access to safe drinking water (a component of water scarcity) and sanitation call for more integrated approaches to support development efforts. Rapid population growth, increasing urbanization, and climate change, among other factors, place further demands on limited fresh water resources and the management responses required to effectively cope with the dynamic situation (UNESCO, 2006). Addressing the interrelated social, economic and environmental issues of water management has prompted the introduction of more interdisciplinary approaches including: Integrated Water Resources Management (IWRM) (RADIF, 1999), adaptive ecosystem assessment and management (LIGHT, 2001; PAHL-WOSTL, 2007), ecological engineering (THOMAS and ZEISEL, 1997), and participatory involvement (MOSERT, 2006; GIUPPONI *et al*., 2006) to name a few. PAHL-WOSTL (2007) offers a comparison between the current water management regime and an integrated adaptive one.

An integrated approach focused on locally developing sanitation services is that of Household-Centred Environmental Sanitation (HCES), which "responds directly to the needs and demands of the user and attempts to avoid the problems resulting from either 'top-down' or 'bottom-up' approaches" (SCHERTENLEIB *et al*., 2003). HCES is similar in design to the Participatory (or People-centered) Technology Development (PTD) approach promoted as part of Low-External-Input and Sustainable Agriculture (LEISA) practices at farm level (REIJNTJES *et al*., 1992; van VELDHUIZEN *et al*., 1997). HCES contributes to the larger concept of ecological sanitation.

1.2.1 Ecological Sanitation

Ecological sanitation (ecosan) concepts address the collective challenges of sustaining water resources and finding appropriate sanitation options to improve conditions for human and environmental health. The ecosan concept incorporates system's thinking to close water, nutrient, and material cycles on a local scale (Figure 2). Numerous technologies are employed; adapted to local conditions, with a preference for modular decentralised partial-flow systems for more appropriate, cost-efficient solutions (GTZ, 2007). Source separation of wastewater streams (stormwater, urine, faeces, and greywater) is a component of ecosan and is gaining recognition as a more efficient treatment method. Reuse applications such as the reuse of greywater, is starting to be employed to manage the distinctive wastewater characteristics of the different streams.

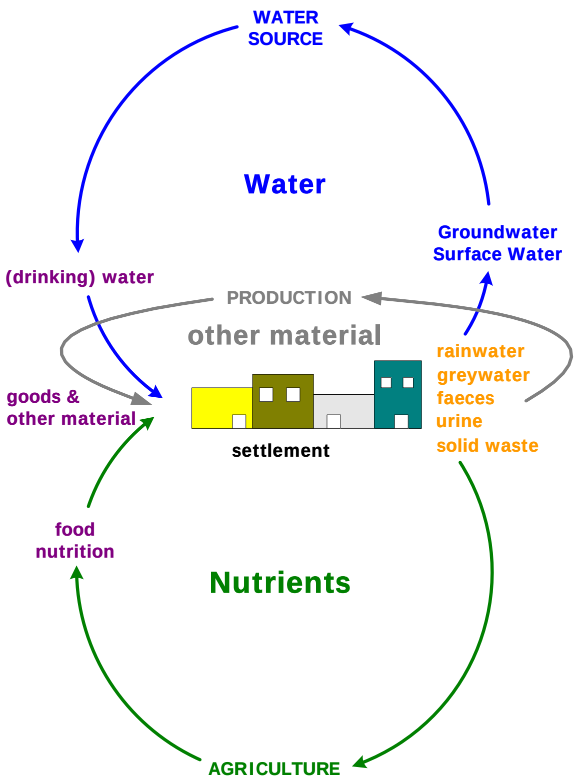

Figure 2: Ecosan concept (LANGERGRABER and MUELLEGER, 2005)

1.3 Greywater

Greywater is defined as the wastewater coming from the kitchen, bath/shower, laundry and hand-washing basin produced in households, offices, schools, etc. It specifically excludes wastewater originating from the toilet, as this water may be mixed with excreta (RIDDERSTOLPE, 2004; ERIKSSON *et al*., 2002).

Greywater recovery and reuse enhances water productivity. Depending on the quality and quantity, greywater can be reused for toilet flushing, irrigation, landscaping, and groundwater recharge. In arid and semi-arid regions domestic greywater treatment and reuse offers an attractive option as it supports the conservation of fresh water as well as reduces the level of pollutants in the environment (AL-BEIRUTI, 2006).

1.3.1 Quality & Quantity

The volume and composition of greywater varies by source and lifestyle of the water-user. Typically, urban dwellers consume more water, thus producing more wastewater, than people in rural areas (CALVERT *et al*., 2004). The volume of greywater accounts for approximately 75% of the domestic wastewater generated (ERIKSSON *et al*., 2002).

The quality of greywater is also affected by the choice of soap and detergent and other cleaning products, method of washing (manual or machine), and incidence of washing diapers (AL-BEIRUTI, 2006). Kitchen greywater is considered to be the most polluted, as a result of food residues and oils and fats from cooking. Bathroom greywater is considered the least contaminated greywater source (MOREL and DIENER, 2006). Tables of typical greywater quality concentrations are provided in the Appendix. In water scarce regions greywater is more concentrated due to lack of water, with a large variability in composition (AL-JAYYOUSI, 2003).

1.3.2 Treatment Methods

The design and operation of greywater treatment systems depend on several factors including: climate, community size, density of development, existing drainage systems, pollution load, and community demands (RIDDERSTOLPE, 2004; METCALF & EDDY, 1991). Greywater management options are also influenced by the water resources available, water use habits, and the capacity to effectively manage the system.

Greywater treatment steps typically follow a sequence of:

1. Source control;
2. Primary treatment involving the removal of fats, oils, greases and suspended solids;
3. Secondary treatment involving the biological breakdown of organic contaminants and reduction in pathogen and nutrient concentrations; and
4. Tertiary treatment by means of effluent polishing and disinfection.

However, not all treatment steps are always completed.

“Source control is by far the most effective way to reduce pollutant loads and avoid operational problems in treatment systems, to lower management costs and guarantee long-term satisfactory performance of the treatment systems” (MOREL and DIENER, 2006).

Source control involves user participation in reducing the pollutant load and volume of greywater to be treated. This includes the choice of soaps, detergents, and other household cleaning products, which is more feasible than trying to remove the pollutants later. In cases where greywater is used or considered for irrigation, liquid soaps containing potassium should be used instead of hard soaps. Larger particles, fibres, hair and grease should be removed at source to prevent clogging of the pipe system. Screens, filters and water traps can be fitted at the outlet from kitchen sinks, showers, bathtubs, washing machines and other appliances (RIDDERSTOLPE, 2004). Regardless of the source of the greywater, the filters require frequent cleaning. To limit contact and health risks, a disposable filter is a possible option (CHRISTOVA-BOAL *et al*., 1996).

In primary treatment, suspended solids are removed mechanically by gravity, screens, seals or filters. Septic tanks with multiple compartments or baffles are an efficient and reliable technique to separate solids from water. Floating particles and coagulated grease collect in a scum at the top of the tank. Sedimented particles are collected as sludge at the bottom.

Numerous secondary treatment technologies have been developed for rural and urban settings. These systems are typically based on the principle of attached biofilm, where biological degradation of suspended solids and dissolved organic matter occurs as greywater passes through a filter media that offers the surface area for bacterial growth (MOREL and DIENER, 2006). Aerobic and anaerobic biofilm systems are possible. Figure 3 identifies various aerobic biofilm systems which range from extensive land applications (e.g. irrigation) to technically intensive biofilter reactors.

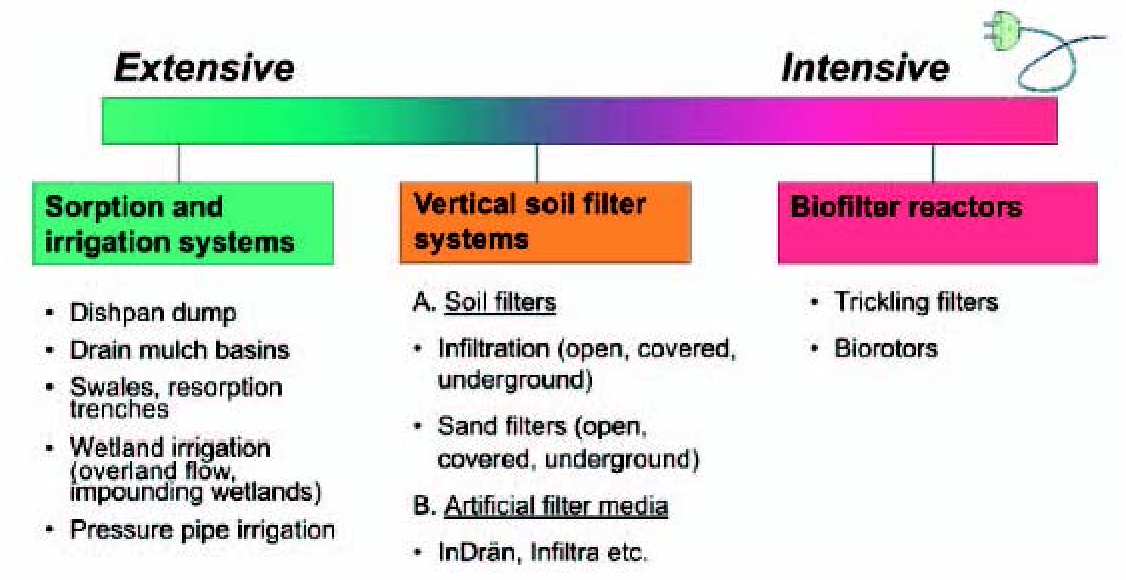

Figure 3: Numerous aerobic biofilm greywater treatment options (RIDDLESTOLPE, 2004)

1.3.3 Operation & Maintenance

The operation and maintenance (O&M) of any onsite greywater treatment system requires both technical knowledge of operation as well as user awareness and involvement. Sustainable O&M systems not only have to be technically and environmentally sound, and economically beneficial, but also socially and culturally sensitive. They should involve all stakeholders, including users and institutions and political decision makers (BRIKKÉ and BREDERO, 2003).

1.3.4 Guidelines for Reuse

Regulations and guidelines for greywater reuse, where they exist, are primarily concerned with limiting negative health and environmental impacts; and generally established by local authorities. LUDWIG (2000) and LITTLE (2001) offer more information concerning greywater reuse in the USA. The Government of Western Australia (GOWA, 2005) also promotes greywater recycling and offers advice to residents with a code of practice on how to best manage and reuse household greywater.

Many municipalities in developed and developing countries, however, don't distinguish between combined wastewater and greywater; and prohibit its reuse. IWMI and GWP (2006) report that banning irrigation of wastewater has failed in many developing countries and call for more integrated approaches to reduce health risks while maintaining the benefits of wastewater reuse.

In 2006, the World Health Organization (WHO) released an updated edition of guidelines for greywater reuse in agriculture. These guidelines outline acceptable microbial pathogen levels for treated wastewater for use in restricted and non-restricted irrigation (Table 1) (WHO, 2006). Table 2 describes numerous methods, beyond treatment, of reducing pathogen numbers from produce irrigated with wastewater.

Table 1: Guideline values for verification monitoring in large-scale treatment systems of greywater use in agriculture (WHO, 2006)

Greywater use	Helminth eggs (number per litre)	*E.coli* (number per 100ml)
Restricted irrigation[a]	<1/litre	$<10^5$ Relaxed to $<10^6$ when exposure is limited or regrowth is likely
Unrestricted irrigation[b]	<1/litre	$<10^3$ Relaxed to $<10^4$ for high growing leaf crops or drip irrigation

[a] Restricted irrigation refers to crops not directly consumed by humans, such as animal fodder.
[b] Unrestricted irrigation refers to the irrigation of vegetable crops directly eaten by humans, including those eaten raw as well as landscape irrigation.

Table 2: Effectiveness of various health protection measures that can be used to reduce pathogens from produce irrigated with wastewater (IWMI and GWP, 2006)

Protection measure	Pathogen reduction (log units)
Wastewater treatment (to different degrees)	1 - 6
Localized (drip) irrigation (with 'low-growing' crops e.g. lettuce)	2
Localized (drip) irrigation (with 'high-growing' crops e.g. tomatoes)	4
Pathogen die-off on the surface of crops after the last irrigation	0.5 - 2 per day
Washing of produce with clean water	1
Disinfection of produce (using weak disinfectant solution)	2
Disinfection of produce (using vinegar & water, mixed 1:2)	5
Peeling of produce (fruits, root crops)	2
Cooking of produce	6 - 7

Irrigation regimes should be designed to match the water requirements of the plant (and evapotranspiration rate). Too much water will saturate the soil, whereas too little water may lead to soil salinization (RIDDERSTOLPE, 2004). The UN Food and Agricultural Organization (FAO, 2003) identify suitability guidelines of treated wastewater for irrigation, methods of irrigation, health and environmental aspects. MOREL and DIENER (2006) also offer more details about greywater reuse for irrigation.

RIDDERSTOLPE (2004) recommends the following practical advice when greywater is used for irrigation:

1. apply water on the ground or sub-surface rather than sprinkled;
2. choose crops where leaves or stems are not eaten directly by humans, such as fruit trees, berry bushes etc.; and
3. wait at least four weeks between irrigation and harvest when leafy crops for direct consumption are irrigated.

1.3.5 Disposal

Greywater disposal is the last step in greywater management systems, whereby treated effluent is returned to the natural environment (groundwater, surface water). In other words, disposal has no direct reuse after treatment.

Greywater management for disposal adopts many of the handling and treatment components necessary for reuse (presented in the previous section) in order to minimize negative impacts on the receiving environment. Infiltration systems, commonly known as soak pits or vertical soil filters, offer the simplest disposal technique.

In North America, infiltration trenches are commonly applied for stormwater drainage; their primary purpose being the temporary storage and eventual percolation of water into the soil (DAVIS and McCUEN, 2005). Metropolitan Council Data Center and Barr Engineering Co. (MCDC & BE, 2001) offer more details on infiltration trench design and recommended practice.

1.4 Research Justification

Until recently, greywater has largely been neglected in water management and sanitation campaigns in developing countries. MOREL and DIENER (2006) identify several reasons for this, including: a lack of awareness; available information is primarily related to developed countries; a lack of documented success stories in low and middle-income countries; and a lack of practical hands-on guidance.

In October 2006 the University of Natural Resources and Applied Life Sciences, Vienna (BOKU) in collaboration with 12 partner organizations launched the start of the ROSA (Resource-Oriented Sanitation concepts for peri-urban areas in Africa) project. The project is funded by the European Union (EU) as a Specific Target Research Project in the EU 6th Framework Programme's Priority 6 "Sustainable development, global change and ecosystems". The project is 3 years in duration (ROSA, 2006).

The partners include: Hamburg University of Technology, Germany; EcoSan Club, Austria; London School of Hygiene and Tropical Medicine, UK; WASTE Advisors on Urban Environment and Development, The Netherlands; University of Dar es Salaam, Tanzania; Makerere University, Uganda; Egerton University, Kenya; Arba Minch University, Ethiopia; Kitgum Town Council, Uganda; Arusha City Council, Tanzania; Municipal Council of Nakuru, Kenya; Arba Minch Water Supply and Sewerage Enterprise, Ethiopia.

Within the cities of Arba Minch, Ethiopia; Nakuru, Kenya; Arusha, Tanzania; and Kitgum, Uganda; the local municipality is partnered with a local university and supported by a European partner.

The scientific and technological objectives of the ROSA project aim to:

1. “promote resource-oriented sanitation concepts as a route to sustainable sanitation and to fulfil the United Nations Millennium Development Goals;
2. implement resource-oriented sanitation concepts in four model cities in East Africa;
3. research the gaps for the implementation of resource-oriented sanitation concepts in peri-urban areas; and
4. develop a generally applicable adaptable framework for the development of strategic sanitation & waste plans” (ROSA, 2006).

The challenge of providing the growing urban populations of Arba Minch, Nakuru, Arusha, and Kitgum, especially the peri-urban poor, with adequate sanitation facilities will not be easy. The reality is these cities, like many in Africa, lack adequate sanitation and waste management systems, suffer from water scarcity and environmental degradation, and have limited finances to implement sustainable solutions. Adopting conventional wastewater management systems, found in industrialized countries, is not considered a sustainable option; thus, not recommended (UJANG and HENZE, 2006). Designing a sustainable sanitation system will involve finding technically manageable, socio-politically appropriate, economically affordable, and environmentally friendly alternatives (UJANG and HENZE, 2006).

There is a need for research investigating site-specific situations and development of treatment systems for the particular waste streams. “This may include gathering information directly in regions where it is to be applied, or regions with similar bioregional characteristics e.g. climate” (HUGHES *et al*., 2006). This thesis attempts to fill this need for information with respect to the greywater waste stream.

IWMI and GWP (2006) argue that an IWRM approach is necessary to look at the whole urban water cycle, at the environmental consequences downstream, as well as the economic benefits of resource recovery. The approach should also recognize that solutions require active stakeholder involvement to reduce the health risks associated with wastewater reuse.

In arid and semi-arid developing countries appropriate greywater management may provide numerous opportunities to mitigate water scarcity, improve food security and public health, limit environmental pollution, and prove economically beneficial. Following the trend towards integrated adaptive water management and cooperative learning in development are seen as necessary for long-term sustainability.

2 Objectives

The overall aim of this thesis is to enhance the understanding of how greywater can be effectively managed on a decentralised scale in water scarce peri-urban regions of developing countries. This work is applied within the context of the ROSA cooperative development project.

The following sub-objectives were pursued:

1. Find information regarding the amount and composition (characteristics) of greywater in water scarce developing countries.
2. Analyse the role of greywater management in water scarce developing countries.
3. Define the components of developing an effective greywater management program, which may include: technical, social, institutional, environmental, and economic factors which support or constrain development.
4. Determine information related to water consumption and greywater production within the cities of Arba Minch, Ethiopia; Kitgum, Uganda; Nakuru, Kenya; and Arusha, Tanzania.

3 Methodology

The research methods used to reach the stated objectives include the following components:

1. Review of current available literature;
2. Personal communication with researchers involved in greywater projects;
3. Participate in a field trip to Nakuru, Kenya and Arusha, Tanzania to better understand the challenges and opportunities for greywater management practices; and
4. Administer a questionnaire to select ROSA project partners.

A literature review was conducted to identify the current available knowledge from scientific investigations of greywater management in water scarce regions. Of specific interest were projects in developing countries, facing similar challenges to those of the ROSA project partners. Several constraints were identified and used to focus the investigation. These include:

A. countries considered to be water scarce;
B. populations with low personal income (roughly $US1/day);
C. populations with low domestic water consumption (<100 l/c/d) habits;
D. peri-urban setting (related to population density, level of infrastructure, population demographics); and
E. greywater focus.

Given the constraints, an examination of greywater projects in three countries (South Africa, Mali, and Jordan) was conducted to identify the key elements of their success or failure and how they proceeded in achieving their development. Data relating to the environmental, social, technical, and economic conditions was collected with reference to the project stages of planning, implementation, operation, and monitoring. The researchers responsible for these projects were contacted to obtain further detail about the project. This collective information is presented herein as case studies.

In order to gain a better understanding of the water and greywater management situation in East Africa, the author participated in a field trip to Nakuru, Kenya and Arusha, Tanzania (two of the ROSA cities) from April 14, 2007 until May 3, 2007. This brief visit offered the opportunity to observe first-hand how the local people live and utilize water within their community. From April 26-29, 2007, the author participated at the 6-month ROSA project meeting in Arusha, Tanzania presenting research findings to-date and administering a written questionnaire with eight ROSA project partners, two from each participating African country. The interviewees were: members of municipal council, university researchers, and water and wastewater service providers; active in the ROSA project field work.

The written questionnaire was formulated with open and closed-ended questions to gather specific knowledge from the targeted participants. Following the questionnaire, informal personal interviews with the participants were conducted to clarify the questionnaire responses and to further understand the underlying socio-economic and environmental conditions within their communities. This was an initial attempt to establish the existing conditions concerning water and greywater management in the four ROSA cities. Collected data was compiled in a Microsoft Excel spreadsheet and shared with the ROSA project partners.

4 Conceptual Framework

Gaining an understanding of how humans relate to the hydrological system is important in designing appropriate interventions. The DPSIR (Driver–Pressure–State–Impact–Response) conceptual framework is a helpful model to illustrate the complex nature of the human-water relationship. In wider application, the DPSIR framework is useful for identifying, developing, and organizing indicators of sustainable development for natural resources management at various levels (WALMSLEY, 2002).

The five main components of the DPSIR framework include:

- *Driving forces* represent natural and social conditions which are at the core of environmental change. These are often interrelated and may have different dimensions in time and space, making them difficult to manipulate or manage (UNESCO, 2006; WALMSLEY, 2002). Population growth, for example, is often cited as a prime factor of increased demand for natural resources and environmental degradation.
- *Pressure* indicators measure the pressures on the natural resource as a result of the Driving forces. These are mostly local, human induced activities (GIUPPONI *et al*., 2006). For example, consumption habits (demands) and generated wastes are often influenced by increased economic activity (WALMSLEY, 2002).
- *State* indicators depict the condition of the resource as a result of the Pressures. For example, they may describe the quantity or quality of local water resources presently available (WALMSLEY, 2002).
- *Impact* indicators refer to the consequence of an environmental State change affecting the ecological integrity and use value. This may occur at various temporal and spatial scales. The perceived existence of relevant impacts stimulates or provokes Response (GIUPPONI *et al*., 2006).
- *Responses* aim to prevent, compensate, or mitigate the negative outcomes of state changes. The reaction may include policy and management options targeted to modify or mediate the Driving forces; eliminate, reduce, or prevent the Pressures; restore or influence the State of the environment; and compensate or mitigate the Impacts (GIUPPONI *et al*., 2006; UNESCO, 2006).

This study applies the DPSIR framework, with a focus on domestic greywater, in order to support an understanding of the interrelated components with respect to greywater in arid and semi-arid regions; identifying numerous options employed as part of an integrated management response. Herein, greywater is presented as the State variable; influenced by the level of water supply (both natural and anthropogenic), household water use habits or demand, and the capacity to manage greywater. Figure 4 illustrates the DPSIR framework applied to greywater.

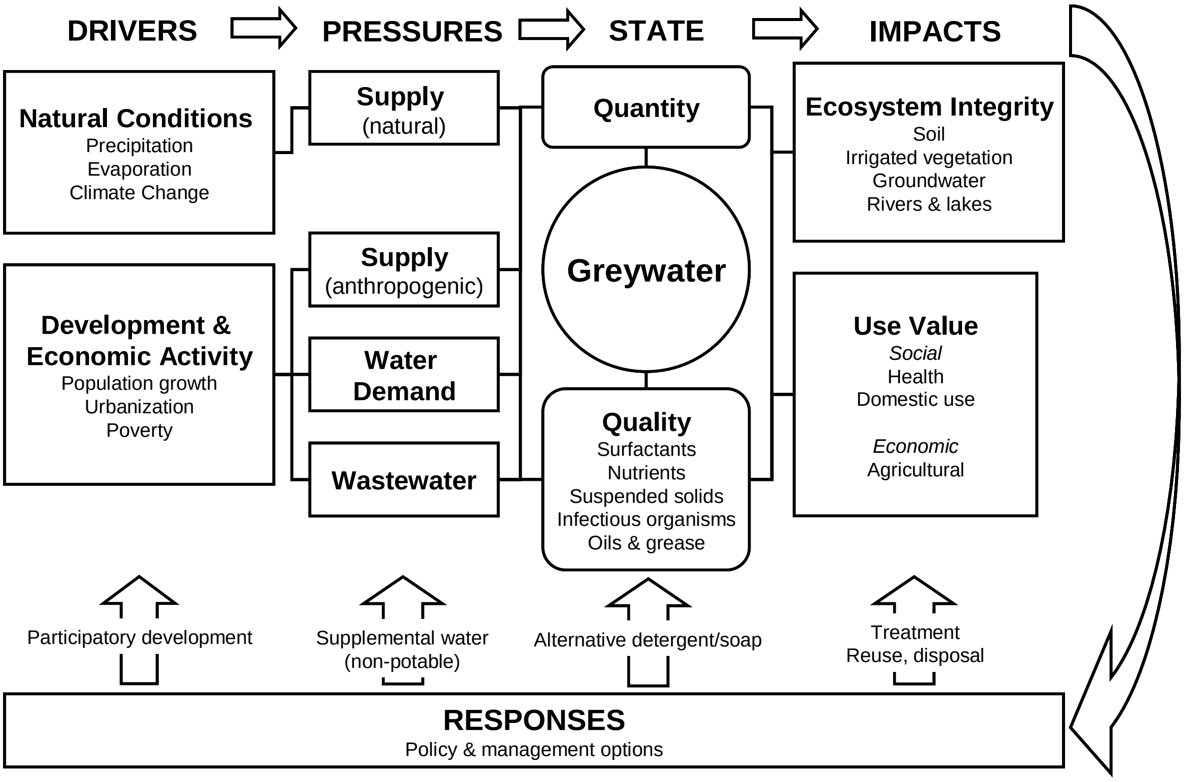

Figure 4: DPSIR conceptual framework applied to greywater (adapted from WALMSLEY, 2002)

The information gathered through the questionnaire and case study assessments are also discussed with reference to the DPSIR conceptual framework, identifying numerous indicators of importance to greywater management in arid and semi-arid regions.

Indicators provide a means of communicating information about a system in a simple and calculated form; aimed at supporting decision makers in assessing policy implementation and impacts. Indicators help organize, create, and use information for measuring, monitoring, and reporting on development initiatives (WALMSLEY, 2002).

5 Case Studies

The following three case studies describe greywater management experiences in the water scarce regions of South Africa, Mali, and Jordan. They are chosen as they closely match the constraints identified in the methodology. In many cases, greywater is perceived as a problem which requires effective means of disposal, as is the case in Mali and areas of South Africa. However, it is also identified as a resource, as in Jordan; benefiting poor households to increase agricultural output from small garden systems.

Five low-cost decentralized treatment systems are presented; four offer greywater reuse possibilities and the other is a system of disposal. Some details of the natural and social conditions are given to briefly describe the local context. Furthermore, the objectives, activities, and results of the projects are presented. Where possible, details of the social, economic, technical, and environmental considerations are also given.

5.1 Management of Greywater in South Africa

This chapter presents three separate efforts towards managing greywater in South Africa including: an assessment of greywater quantity and quality from non-sewered settlements; reuse of greywater in household “tower gardens”; and microbiological testing of vegetables irrigated with untreated greywater.

Context

Water scarcity is a limiting factor for development in South Africa. Physical water resources are limited by an average annual rainfall of 450 mm. Due to high temporal and spatial variation in rainfall, high evaporation, and the locations of water users, water availability is limited to less than 500 m^3/c/y (UNESCO, 2006).

Access to water supply and sanitation services is also limited. Nine million people still lack access to water supply and 16 million still do not have adequate sanitation facilities (UNESCO, 2006). Addressing this need, the South African Government is committed to delivering basic access to clean water (minimum 25 l/c/d) by 2008 and basic sanitation (onsite dry latrines) by 2010 to the entire population. As a result of this campaign, many low-income settlements have been connected to the municipal water supply; frequently neglecting to consider how the non-sewered settlements will deal with their domestic greywater (WINTER *et al.*, 2006). At present, most greywater is disposed directly on the ground outside of the residences creating potential negative environmental and health impacts which is particularly distressing in high density settlements (CARDEN *et al.*, 2005).

Table 3: Population Demographics of South Africa

National population	48 million	UNESCO, 2006
Population growth rate	1.5%	WHO, 2000c
Percent urban	59%	UNESCO, 2006
Proportion of population living on <$2/day	34%	UNESCO, 2006
Life Expectancy	54.7 years	WHO, 2000c

5.1.1 Assessment of Greywater in Non-sewered Settlements

In response to a request by the Water Research Commission of South Africa (WRC), the University of Cape Town conducted a two-year study investigating the use and disposal of greywater in non-sewered areas of South Africa. The main aim of the research was to quantify the greywater problem in these areas and develop potential management options. The quantity and quality of greywater was assessed at 39 settlements in 6 of 9 provinces in South Africa. Onsite surveys were conducted over a period of approximately one year, employing a standardised questionnaire. The information sought included: general site characteristics, general household information, available services and water use habits, and methods of greywater management. The volume of generated greywater per household was estimated as 75% of the amount of household water consumed (CARDEN *et al*., 2007a). A limited number of greywater and source water samples were taken and analyzed to gain a better understanding of the quality of the greywater generated from the non-sewered areas. In most cases, field test kits were used for water quality analysis, supported with laboratory testing (CARDEN *et al*., 2007a).

Sites for analysis were selected using census data, topographical maps, discussions with local authorities, and informal discussions with local residents (CARDEN *et al*., 2007a).

Water consumption was estimated at between 20-200 litres per dwelling per day (l/du/d), with an average daily consumption of 104 l/du/d. With an average household size of 3.8 people, this equates to an approximate water consumption of 26 l/c/d. Households with access to a standpipe in the yard consumed 30-80 l/c/d. Where water had to be fetched from external sources, more than 250 m away, a mean consumption of 9 to 50 l/c/d could be expected (CARDEN *et al*., 2007a).

Table 4 and Table 5 detail the variability in greywater quality characteristics. It is evident from Table 4 that households in high density settlements generate a more concentrated greywater, with respect to nitrogen and phosphorus.

Table 4: Comparison of averages for water use and water quality between lower and upper quartile ranges with reference to settlement density (WINTER *et al*., 2006)

Value	Density (du/ha)	Average water use (l/du/d)	Generated greywater (l/ha/d)	NH_3 (mg/l)	TKN (mg/l)	TP (mg/l)
Lower quartile: low settlement density						
Minimum	3	80	225	3	7	2
Mean	4	130	412	5	31	27
Maximum	5	180	675	13	56	112
Upper quartile: high settlement density						
Minimum	25	55	1196	2	43	5
Mean	45	88	3029	9	113	92
Maximum	162	140	13365	22	172	240

Table 5: Greywater quality results from non-sewered settlements in South Africa (CARDEN *et al*., 2007a)

Parameter	Unit	Low	High	Average
COD	mg/l	32	11451	4770
pH		3.3	10.9	8.8
Ammonia nitrogen	mg/l	0.2	44.7	
TKN	mg/l	0.6	488	72
Phosphate (PO_4-P)	mg/l	0.7	769	
Oil & Grease	mg/l	8.0	4650	730
Electrical conductivity*	mS/m	28	1763	366
Sodium	mg/l	96	1700	970

* equivalent units of measurement: 1 dS/m = 100 mS/m = 1 mS/cm = 1000 µS/cm

Results, from the limited microbiological testing, reveal faecal contamination of greywater, with greater than 1800 organisms/100ml, indicating the potential presence of pathogenic organisms (CARDEN *et al*., 2007a).

Furthermore, it was observed that the socio-economic conditions of the households influence the amount of water used, as well as the type of detergents used, and the frequency of washing, thus affecting the greywater quantity and quality (CARDEN *et al*., 2007b).

CARDEN *et al*. (2007b) note a number of health concerns, identified by residents, in the high density settlements: greywater disposed directly onto poorly draining soils causes water to pool; stagnate and smell; attract mosquitoes and flies; and children often become ill after playing in the water. Runoff of greywater from settlements close to sensitive surface waters is also a serious environmental hazard.

Given the pollutant load of the greywater, and the population densities of the non-sewered settlements, reuse of greywater is limited, and not recommended unless risk factors can be controlled. In fact, people are suspicious of efforts to promote greywater reuse, claiming they will get an inferior product. Some people have experienced that certain crops, such as maize, not do tolerate being watered with greywater, likely due to the elevated salt concentration and other chemicals (CARDEN *et al*., 2007b).

Settlement densities together with household consumption of water appear to be the most critical factors in determining potential greywater management options. Following recommendations by the South African Department of Water Affairs and Forestry, CARDEN *et al*. (2007b) propose offsite disposal of greywater is most appropriate under the individual or combined circumstances where:

1. Settlement density >50 du/ha;
2. Volume of greywater generated >2500 l/ha/d;
3. Surfaces are hard-packed and impervious (heavy clay/rock);
4. Slope >30%;
5. Depth to water table <1 m; or
6. Settlement is in close proximity to sensitive environments (i.e. within floodplain).

CARDEN *et al*. (2007b) state that no definitive health regulations or guidelines for the use and/or disposal of greywater in non-sewered areas currently exist in South Africa; although a few municipalities, for example the City of Cape Town and eThekwini Municipality, have taken notice of the greywater issue and are developing management strategies.

Where site conditions permit, onsite management of greywater may prove successful. The next section presents a clever small garden system adopted by numerous rural households in South Africa.

5.1.2 Greywater Tower Garden: tested in South Africa

The tower garden is a simple, innovative system, which uses greywater for growing vegetables on a small footprint (<1 m^2) (Figure 5). The design is similar to the sack garden, used in Kenya. The tower garden can be self constructed with a few materials. All that is required is:

1. 5 poles, approximately 2 m in length;
2. shade cloth, 2.5 m by 1.2 m;
3. nylon string or fishing line, to join up the end of the shade cloth;
4. flat stones, several buckets of (round stones do not filter the water evenly into the soil);
5. bucket with no bottom, approximately 30 cm in diameter;
6. soil mixture, consisting of 3 parts soil, 2 parts manure, 1 part ash;
7. string and peg, to draw out a circle on the ground (CROSBY, 2005).

CROSBY (2005) illustrates how to construct the tower garden with the given materials. When built, the tower stands just over a metre high with a core of stones in the middle. Greywater is poured directly onto the stones which allow the water to drain downwards wetting the soil mixture surrounding the column. The shape of the stones is important for the even distribution of water through the soil in the tower; round stones drain the water too quickly (CROSBY, 2005).

Operation and maintenance requirements of this system are minimal. It is recommended to flush the stone column with two buckets of clean water once a week to clear the drain of accumulated soap. Pre-treatment of the greywater via a grease/grit trap is also recommended, to remove any solids and grease, prior to application onto the tower garden (CROSBY, 2005).

Leafy vegetables, such as spinach, are planted through holes in the side of the shade cloth. These holes should be staggered diagonally to provide more room for root development. Tomatoes and onions can be grown on top (CROSBY, 2005).

Households prefer to locate the tower garden close to the home for convenient watering. 2-3 buckets of greywater should be applied daily to prevent the soil from drying out (MOREL and DIENER, 2006). However, if water spills out the bottom of the tower, too much water is being applied and a second tower may be required (CROSBY, 2005).

Figure 5: Watering a tower garden with greywater (CROSBY, 2005)

Investigating the risk of consuming vegetables irrigated with greywater in South Africa is presented in the next study.

5.1.3 Assessment of Vegetables Irrigated with Greywater

To address the issues of food security and water scarcity the eThekwini Municipality, South Africa is interested in the potential of using greywater to irrigate food crops.

In 2003, a joint research project between eThekwini Water and Sanitation and the University of KwaZulu-Natal was initiated to assess the effects of irrigating vegetable crops with domestic greywater (SALUKAZANA *et al.*, 2005; JACKSON *et al.*, 2006).

In preliminary trials, households in two communities, one rural and one informal peri-urban, were provided with a greywater collection tank, plant seedlings, and instruction. After the one year pilot project, the quality of the crops was assessed; attaining a satisfactory or good grade by the community involved (SALUKAZANA *et al.*, 2005).

In 2005, the first controlled semi-field trial was set up at the University of KwaZulu-Natal to test the microbiological safety of vegetables irrigated with greywater. Spinach, green peppers, madumbis (indigenous yam), potatoes, onions, beetroot and carrots were grown in plastic bags with sterile, low nutrient Berea red sand soil and drip irrigated through a plastic bottle. The vegetables were watered daily with 500 ml of either municipal tap water, untreated greywater, or a hydroponic solution.

Greywater was sourced from eight nearby households in Cato Crest, a low-income peri-urban settlement located in Durban. The households each supplied a 20 litre bucket of greywater on a weekly basis, which was then mixed in a 200 litre container before being used to irrigate the experimental vegetable crops (SALUKAZANA *et al.*, 2005). Greywater was analysed for chemical and microbiological characteristics at the beginning and end of the study (JACKSON *et al*., 2006).

A comparison of the plant growth showed a consistent increase in plant height when crops were irrigated with nutrient solution and with greywater, as compared to tap water (SALUKAZANA *et al*., 2005).

Upon harvest, vegetable samples were tested for total coliforms, *E. coli*, *Enterococcus*, *Staphylococcus*, Pseudomonas, coliphages, and Ascaris. As a control, the same vegetables were bought from the market and put through the same analytical procedures as the experimentally grown vegetables (JACKSON *et al*., 2006).

Results confirmed that the total coliform count was highest on the outside of the vegetables. Unexpected, however, was a high number of micro-organisms (>100 cfu/100ml) within the vegetables. This may have been the result of ineffective disinfection of the vegetables' exterior surface prior to processing or due to genuine uptake of organisms. These results could not be clarified; proposing further investigation would be necessary. Very few *E. coli* were detected on the outside of the vegetables, with no significant difference in the results from each treatment. Zero *E. coli* bacteria were detected within the flesh of any of the vegetables sampled. No coliphage or *Ascarsis* ova were detected in any of the samples analysed (JACKSON *et al*., 2006). Bacterial levels on the market bought vegetables were generally similar to or in some cases higher than the recorded bacterial levels of the crops grown in the semi-field trials. Identifying the bacteria within the total coliform population will be identified in future investigations (SALUKAZANA *et al*., 2005).

As many of the vegetables examined are often eaten raw, a risk analysis was done using the *Enterococcus* and *Staphylococcus* results. The results, when compared, showed no significant difference between the various treatments and the vegetables bought from the market. Therefore, consumption of vegetables irrigated with greywater, it was concluded, appears unlikely to cause additional disease within the community (JACKSON *et al*., 2006).

5.2 Household Greywater Infiltration in Djenné, Mali

When the city of Djenné, in central Mali, had a water supply network implemented in the early 1990's no provision was made to manage the domestic greywater, leading to problems with open disposal of greywater on the streets. This case study describes the development of a decentralized greywater infiltration system implemented at household level within the city of Djenné.

Context

Djenné is one of the oldest cities in West Africa (ALDERLIESTE, 2002). It is renowned for its adobe architecture and is listed as a UNESCO World Heritage Site since 1988. The population is approximately 20,000 inhabitants (MOREL and DIENER, 2006). The total population of Mali is approximately 11.2 million, with an annual growth rate of 2.4% (WHO, 2000b). Mali is considered one of the poorest countries in the world, where 73% of the population live on less than US$1 per day (UNDP, 2006).

Djenné is situated in the inner delta of the Niger River where annual flooding renders the city an island of approximately 70 ha within the submerged floodplains (ALDERLIESTE and LANGEVELD, 2005). The climate is Sub-Saharan with an average annual temperature of 20 to 30°C, with maximum temperatures reaching 40 to 45°C. Annual precipitation is approximately 500 mm, raining primarily between July and October (ALDERLIESTE and LANGEVELD, 2005). Available water resources offer a per capita water usage of 159 m^3/c/y of which the agricultural sector accounts for 97% (WHO, 2000b). The groundwater depth ranges between 5 to 10 m below the surface depending on the location within the city and on the season (rainy or dry season). In the flood plains, outside the city, the groundwater depth can be shallower (ALDERLIESTE, 2007b).

Total sanitation coverage in Mali is 69%, whereby urban and rural sanitation coverage equals 93% and 58%, respectively (WHO, 2000b). In Djenné, the traditional sanitation system includes an elevated urine diversion latrine, which produces dry and stable compost. The streets are swept clean on a daily basis, except during the rainy season. All water related activities, such as washing and bathing are performed near the river. These systems "functioned well" until the implementation of a drinking water supply network (ALDERLIESTE and LANGEVELD, 2005).

5.2.1 Addressing the Greywater Challenge

With water made available at public taps and private connections, the domestic water use behaviour changed. Water related activities now take place in and around the house, with generated greywater discharged directly onto the streets (ALDERLIESTE and LANGEVELD, 2005).

The aggravating problem of wastewater in the streets was acknowledged in 1995, during a project to rehabilitate and conserve 168 adobe houses. The accumulated wastewater in the streets had negative impacts on public health, caused moisture problems in the adobe buildings, restricted movement on the unpaved streets, and was perceived as a threat to tourism. Street cleaning was also impaired; limiting the removal of solid waste which accumulated in the streets (ALDERLIESTE and LANGEVELD, 2005).

Finding a solution to the wastewater problem was finally initiated in 2000, with a preliminary assessment. Several options for the disposal of greywater were investigated, including on- and off-site systems. Local infiltration was chosen as the most viable option (ALDERLIESTE and LANGEVELD, 2005). Reuse of greywater was not considered feasible as there is no urban agriculture within the city of Djenné (ALDERLIESTE, 2007a). A sewer system was also deemed inappropriate; considering the extremely high amount of grit and sediment released within the city, and a very low dry weather flow that would cause blockages (ALDERLIESTE and LANGEVELD, 2005).

"Providing each household with an individual infiltration system increases the personal involvement and commitment, as malfunctioning of the system due to misuse or lack of maintenance of the system is directly visible to a specific household" (ALDERLIESTE and LANGEVELD, 2005).

In 2002, a feasibility study was undertaken to design and construct the greywater infiltration system on a pilot scale. Delft University of Technology, in the Netherlands, was recruited as the technical advisor. The Dutch government provided funding, and local support was offered by both the Mission Culturelle and the restoration project in Djenné.

Over one year, one hundred infiltration trenches were built in the city using local material and labour as much as possible. Local craftsmen were trained to design and construct the infiltration systems (ALDERLIESTE and LANGEVELD, 2005) and took responsibility for the project after two months (ALDERLIESTE, 2002). Figure 6 depicts the phases of the project, including the components of the feasibility study.

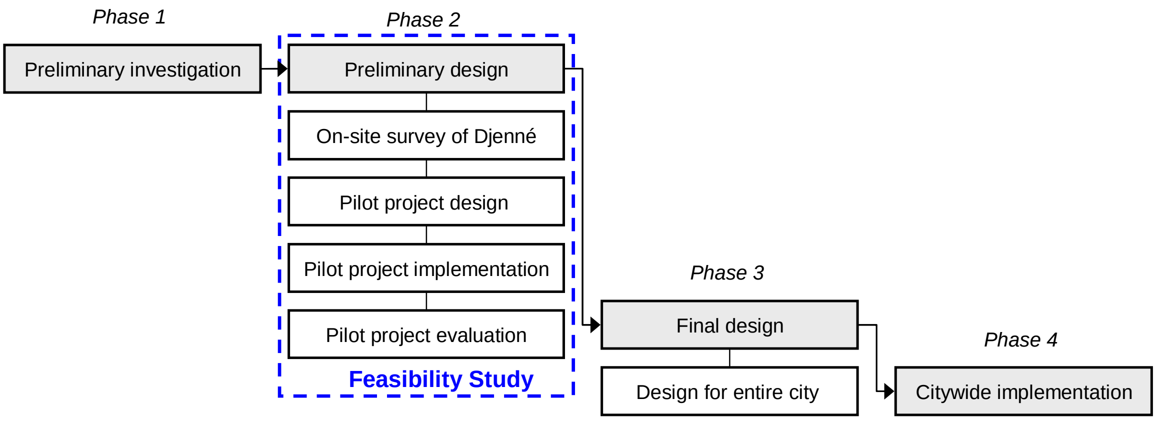

Figure 6: Schematic of project phases (ALDERLIESTE and LANGEVELD, 2003)

5.2.2 Selecting the Location of the Pilot Project

The criteria used for selecting the site of the pilot project included:

1. choice by the community leader;
2. area not influenced by upstream drainage;
3. households with high water use;
4. variety of physical characteristics (size of houses, street width, public & private water supply); and
5. involvement of high profile influential people (ALDERLIESTE, 2007a).

An onsite survey was conducted to characterise the area of the pilot project including: household water consumption; geophysical properties, including the infiltration capacity of the soil; and the urban morphology, including the number of houses and runoff drainage pattern (ALDERLIESTE, 2002). The acquired information was documented and mapped.

Boreholes drilled to a depth of 2 m identified relatively homogeneous soil structure, consisting of organic clay, within the pilot project area. With help from the locals, the soil infiltration capacity was established with falling head tests; measuring the hydraulic conductivity (K = 278.9 $l/m^2/d$) in the pilot study area (ALDERLIESTE, 2002). A similar method to assess the percolation rate is included in the appendix.

The maximum water consumption of the households participating in the pilot project was calculated to be approximately 500 l/household/day, equivalent to 50 l/c/d (ALDERLIESTE, 2002). Thirty litres per capita per day was the average water consumption calculated (ALDERLIESTE and LANGEVELD, 2005).

The district of Yoboukaïna was selected as a suitable site for the pilot project, consisting of 50 houses, except that the community leader did not live there. This necessitated splitting the pilot project into two study sites, one which included the house of the community leader. The first test infiltration trench was built at the Mission Culturelle as a demonstration. Here the soil infiltration capacity was lower than in Yoboukaïna (K = 42.1 $l/m^2/d$), as a result of the location on heavier clay soils (ALDERLIESTE, 2002).

5.2.3 Infiltration System Design

The selected greywater infiltration system design, depicted in Figure 7, consists of four main components:

A. a PVC pipe (Ø110 mm) delivers greywater from within the house to
B. a solids/grease trap, which drains through
C. a flexible pipe (Ø40 mm) into
D. an excavated infiltration trench filled with gravel.

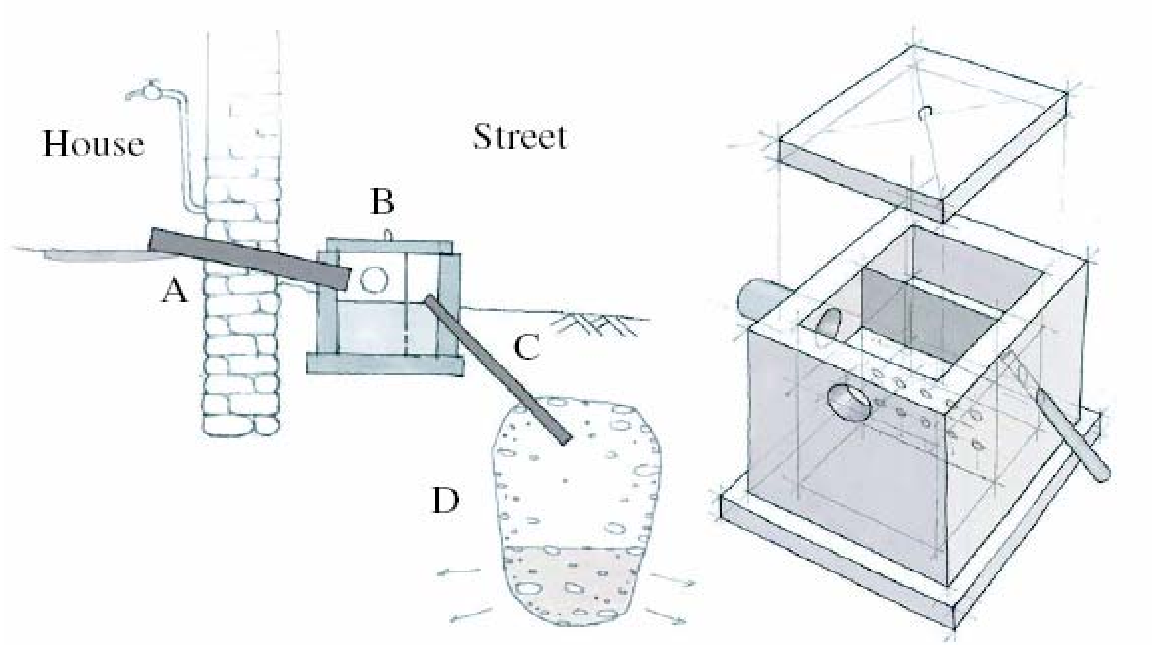

Figure 7: Illustration of the household infiltration trench system in Djenné (ALDERLIESTE and LANGEVELD, 2005)

The large diameter pipe (A) from the house to the solids trap is encased with handmade pottery and plastered within the wall to satisfy the architectural requirements (ALDERLIESTE, 2002).

The solids/grease trap (B) is constructed of poured concrete in situ, with internal dimensions of 500 mm x 300 mm, 500 mm deep, 100 mm thick walls, and topped with a concrete lid. A baffle plate divides the basin in two; with the first compartment accepting 2/3 of the water volume. An overflow hole in the basin permits excess water to escape onto the ground surface. Located outside of the house, either in the street or in the inner courtyard, the solids/grease trap is easily accessible for maintenance (ALDERLIESTE, 2002; ALDERLIESTE and LANGEVELD, 2003).

The flexible pipe (C) is sized such that it can drain 20 l/min and is installed with 75 cm fall from the solids/grease trap to the infiltration trench (ALDERLIESTE, 2002).

The infiltration trench (D) is dimensioned based on the maximum daily water consumption per household and the infiltration rate of the soil, with each household receiving a tailor made system. If the infiltration rate of the soil is high, the filling capacity becomes the main design parameter for calculating the dimensions of the infiltration trench; thus, establishing the volume of the trench which will also comply with the infiltration surface (ALDERLIESTE, 2007b). Each infiltration trench is manually excavated to 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 using the following equation, assuming no infiltration takes place through the bottom of the trench (ALDERLIESTE and LANGEVELD, 2005):

$$L = n \cdot Q / (2 \cdot d \cdot I)$$

where L = length of trench (m)
n = number of users
Q = greywater volume per capita per day (l/c/d)
d = effective depth (m)
I = infiltration rate (l/m^2/d)

For example, a household of 10 people with a maximum greywater production of 50 l/c/d, an effective trench depth of 1.0 m, and a soil infiltration rate of 50 $l/m^2/d$, the trench length would equal 5 m.

The infiltration trench is filled with gravel (average diameter of 25 mm) and covered with at least 0.5 m of soil (ALDERLIESTE and LANGEVELD, 2005). In areas where the infiltration rate is greater than 100 $l/m^2/d$, the dimensions were calculated according to the filling capacity[1] of the gravel filled trench, assuming a porosity of 0.25 (ALDERLIESTE, 2002).

The infiltration systems were installed in a sequential order; working from the highest point to the lowest, such that the existing surface drainage of greywater would not negatively impact the installation (ALDERLIESTE, 2002). Construction teams could install a complete infiltration system in two working days (ALDERLIESTE and LANGEVELD, 2005).

As all the system components are very basic and durable, it is expected that the system will work for a very long time if it is properly maintained (ALDERLIESTE, 2007b).

5.2.4 Operation & Maintenance

Operation and maintenance requirements include cleaning of the solids/grease trap once a month, generally performed by the women in the households (ALDERLIESTE, 2007a).

During the pilot project, clogging of the system was frequently reported; caused by a lack of maintenance and floating materials, such as plastic bags, clogging the outlet pipe (ALDERLIESTE and LANGEVELD, 2005). Occasionally, the infiltration trench would require excavation to clear a clogged pipe (ALDERLIESTE, 2007a).

In recognition of these problems, meetings with the local community, especially the women, were organised to further instruct them in maintaining the system operation. Penalties for not cleaning the traps were also introduced by the municipality. In addition, modifications were made to the solids trap, to prevent floating materials from clogging the outlet. Since these interventions, it is reported that these systems are functioning properly (ALDERLIESTE and LANGEVELD, 2005).

Following the pilot project, the water utility (managed by a Water User Association), was tasked with the job of checking whether the systems are functioning. This job is done in conjunction with taking the water readings. It is simple to see if the trap is clogged as it overflows (ALDERLIESTE, 2007a).

5.2.5 System Performance

An evaluation of the pilot project was conducted in 2003; with inspections of every installed system. The results proved largely successful: the majority of inhabitants were very satisfied with the functionality and ease of operation of the system; the streets were dry and passable

[1] $V_{infiltration\ trench} = V_{max} / porosity_{fill\ material}$

(Figure 8). Systems that were not maintained could easily be identified. No significant amount of wear was observed, and nowhere did the soil appear to have lost its infiltration capacity. Negative results included a few poorly maintained solids traps and an elevated road surface burying a number of traps. These issues were addressed by means of technical and organisational improvements (ALDERLIESTE and LANGEVELD, 2003).

ALDERLIESTE (2007b) reports that the solids/grease trap was “quite effective” in separating solids. “Only a proportion of fine solids and grease would infiltrate which will eventually lead to clogging of the pipe to the infiltration bed. However, as the technology is very basic, it is a matter of hours to clean the pipe and top part of the infiltration bed”. No odour problems were observed.

Figure 8: Street in Djenné: before implementation of the greywater infiltration trenches (left) and one year after implementation (right) (ALDERLIESTE and LANGEVELD, 2005)

Local involvement is seen as a major component of the success of the pilot project. Clear roles and responsibilities were established and intensive training was offered early on. The project was largely coordinated by a local craftsman, with trained masons working together with labourers in the construction, and a local women’s group producing the pottery (ALDERLIESTE and LANGEVELD, 2005).

5.2.6 Up-scaling

Following the results of the pilot project, it was proposed that each household in Djenné receive a greywater infiltration system, effectively scaling up the project to citywide implementation (ALDERLIESTE and LANGEVELD, 2005). “Most households were anxious to participate as they recognized the greywater in the streets as a serious problem” (ALDERLIESTE, 2007b). By 2004, more than 600 houses were provided with infiltration facilities, with households expected to pay half of the system cost, payable in monthly instalments, as well as a maintenance service fee; this revenue would be used to invest in new systems (ALDERLIESTE and LANGEVELD, 2005; FAGGIANELLI, 2005). FAGGIANELLI (2005) reports on the challenges of up-scaling the greywater management project to improve conditions for human health and the environment. Noteworthy, is the efforts of sociologists hired to deliver the marketing campaign; going house to house with illustrated posters to raise awareness of the problems and the benefits of the proposed infiltration system; essentially trying to convince households to adopt the system. The Water User Association was entrusted with the responsibility of coordinating the work and the finances, as they already manage 800 water supply connections and had the human resources to manage these tasks; as well as the obvious synergies between the services of drinking water and hygiene (FAGGIANELLI, 2005). Furthermore, scaling up of the project allows for materials to be purchased in bulk at cheaper prices (ALDERLIESTE, 2007a).

5.2.7 Costs & Benefits

The implementation cost per infiltration unit is approximately Fcfa 53,000 (US$117, €80) Households are expected to pay half of the expenses. Since the launch of a maintenance service in 2004, a monthly maintenance fee of Fcfa 500 (US$1.10, €0.76) per infiltration trench is charged. Recovering these fees, however, has been a challenge and complicated by politics (FAGGIANELLI, 2005).

On the positive side, transport costs of goods decreased significantly due to improved road conditions. Transport of 100 kg of grain, in the implemented areas, now costs Fcfa 75–100 compared to Fcfa 250 before project implementation. Furthermore, groundwater samples taken from 10 wells did not reveal any groundwater contamination caused by the greywater disposal system (FAGGIANELLI, 2005).

5.3 Greywater Treatment for Reuse in Irrigation in Jordan

The Kingdom of Jordan is one of the ten most water scarce countries in the world, yet coping relatively well (IDRC, 2006b). In response to domestic water shortages and poverty, authorities have investigated the reuse of domestic greywater in the home-gardens of peri-urban households. This case study presents some details of the Jordanian greywater management experiences, including three onsite greywater treatment system designs.

Context

Jordan is a small land locked country in the Middle East with water resources that are characterized by “scarcity, variability, and uncertainty” (AL-JAYYOUSI, 2002). Annual precipitation varies with location; the northwest receiving approximately 600 mm/y and the eastern and southern deserts, which form about 91% of the surface area, receiving less than 200 mm/y (AL-JAYYOUSI, 2003). Evaporation is estimated at about 90% (AL-JAYYOUSI, 2002).

Jordan’s population is approximately 5.7 million people, with a growth rate of 2.7% (IDRC, 2006b). Currently, 73% of the population lives in urban areas and this number is expected to increase to 80% by 2015. “This trend has greatly threatened the food and water security of the poor, who increasingly find themselves in towns and cities” (FARUQUI and AL-JAYYOUSI, 2002).

Jordan has a moderately high human development index in comparison to other developing countries; however, 7% of the population still earns less than $US1 per day. The per capita average annual income is $US 1,680 (FARUQUI and AL-JAYYOUSI, 2002).

Per capita water availability equates to less than 198 m^3/c/y; due in part to a high population growth over the past twenty years (AL-BEIRUTI, 2005). In terms of the natural water supply, Jordan is at a deficit; mining non-renewable groundwater to meet demand (AL-JAYYOUSI, 2003; SMIRAT, 2006).

The average per capita water consumption is 120 l/c/d including garden irrigation (Table 6) (AL-BEIRUTI, 2006). Poor households use less water, approximately 50 l/c/d (AL-JAYYOUSI, 2002). Residents in the capital city, Amman, receive on average less than 100 l/c/d of drinking water, delivered altogether only 1 or 2 days a week (AL-JAYYOUSI, 2003).

Table 6: Average daily domestic water consumption (l/c/d) in Jordan (AL-BEIRUTI, 2006)

Drinking & cooking	10
Washing dishes	15
Washing clothes (laundry)	20
Personal hygiene (baths & shower)	20
Toilet, non-flush	15
Watering garden & other purposes	40
Total	**120**

To address the problems of water scarcity in Jordan, the use of fresh water resources have been prioritized where its social and economic value is highest: for drinking and domestic purposes. Inter-sectoral water transfers from agriculture to cities have limited agricultural production, requiring Jordan to import food, particularly cereals. Still, 75% of renewable water is used in agriculture. To limit the impact to the agricultural sector, the majority of domestic wastewater is treated and reused for agricultural irrigation, with fresh water reserved for salt-sensitive fruits and vegetable crops eaten raw (FARUQUI and AL-JAYYOUSI, 2002).

Since 1993, Jordan has initiated water policy reforms, adopting demand management and decentralizing water management services, increasing the commercial focus of operations (AL-JAYYOUSI, 2003). Recovering the costs of water supply, treatment and distribution services has changed the perception of water to that of an economic good, which should be valued and managed in a rational manner (AL-BEIRUTI, 2005; AL-JAYYOUSI, 2003). Households are charged according to metered water consumption on a quarterly (every 3 months) basis (FARUQUI and AL-JAYYOUSI, 2002). The municipal water pricing structure of Tufileh Governate is presented in Figure 9 .

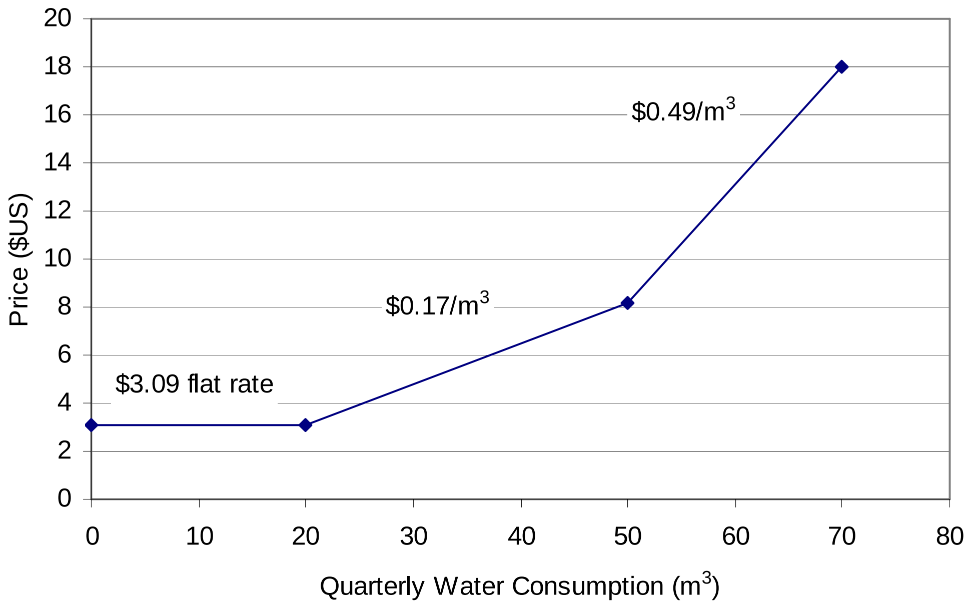

Figure 9: Municipal water tariff structure, Tufileh, Jordan
(values from FARUQUI and AL-JAYYOUSI, 2002)

Wastewater management in peri-urban and rural settings primarily consist of household septic tanks. These tanks often leak, posing environmentally hazardous to shallow groundwater aquifers (AL-BEIRUTI, 2005). Frequent pump outs cost households at least $US 60 per year (FARUQUI, 2002). Conventional sewerage systems are considered largely inappropriate due to their expense and large water demand; requiring a minimum of 100 l/c/d for problem free operation (AL-BEIRUTI, 2005).

In order to address the issues of water scarcity and food security of the peri-urban poor, authorities are investigating participatory water management solutions on a local level (AL-JAYYOUSI, 2002). Communities have shown willingness to input time and energy to utilize greywater in their home gardens (AL-BEIRUTI, 2005), empowering the poor to take responsibility for addressing their own food and water insecurity (FARUQUI and AL-JAYYOUSI, 2002).

5.3.1 History of Development

Numerous projects over the past decade have contributed to the current level of expertise in greywater management in Jordan. A short description of these experiences is presented. Figure 10 was created to illustrate the development timeline; identifying the nature of the projects as either conceptual, implementation, or evaluation.

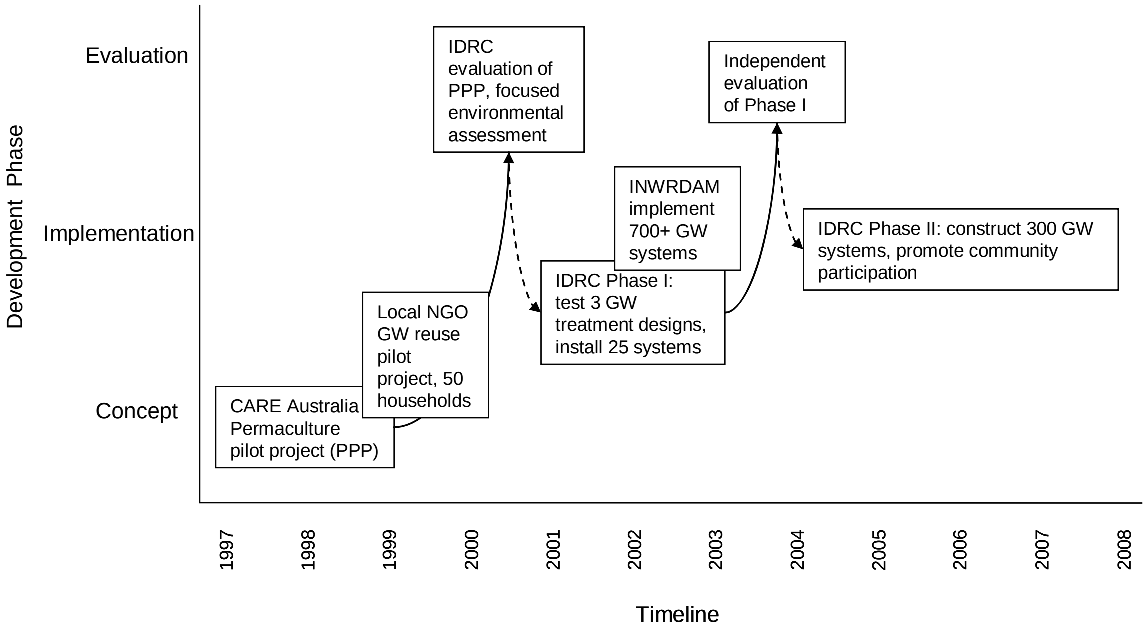

Figure 10: Development timeline of greywater management experiences in Jordan

In 1997-1999, CARE Australia implemented a Permaculture Pilot Project (PPP) at a kindergarten in Ein Al-Baida, Tufileh Governate, in southern Jordan. CARE worked with a local community-based NGO, Ein Al-Baida Voluntary Society, to demonstrate soil and water conserving urban agriculture techniques, including rainwater harvesting and greywater reuse as a supplement water source to municipal water supplies (FARUQUI and AL-JAYYOUSI, 2002).

Following the success of the PPP, the Ein Al-Baida Voluntary Society initiated a greywater reuse pilot project, offering loans to 50 families through a revolving fund for the purpose of setting-up permaculture gardens and greywater reuse systems in their own homes. Most of the families used part of the loan to make some plumbing modifications in order to use greywater to irrigate vegetables, fruits, and herbs. Greywater was predominantly sourced from the kitchen and used, untreated, directly in the home gardens. Domestic water consumption was calculated to be around 78 l/c/d (FARUQUI and AL-JAYYOUSI, 2002). Table 7 presents quality analyses from six representative untreated greywater samples.

Table 7: Untreated greywater quality of peri-urban households in Ein Al Beida, Tufileh, Jordan (FARUQUI and AL-JAYYOUSI, 2002)

Parameter	Measurement	Comment
BOD_5	275 – 2287 mg/l	BOD_5 typically higher in kitchen greywater, sampled
MBAS	45 – 170 mg/l	Measure of detergent concentration
pH	3 samples > 8.35 3 samples < 6.7	$pH_{\text{tap water}} = 8.35$
EC*	457 – 1135 µS/cm, average 818 µS/cm	Nearly double the salinity of the domestic fresh water
SAR	1 – 6.8, average 3	$SAR_{\text{tap water}} = 0.83$; higher SAR corresponds to higher detergent content, sodium increases alkalinity

* equivalent units of measurement: 1 dS/m = 100 mS/m = 1 mS/cm = 1000 µS/cm

An evaluation of the PPP was funded by the International Development Research Centre (IDRC) and involved a detailed survey of 15 families to determine reuse habits and the environmental, social, and economic impacts of the project (FARUQUI and AL-JAYYOUSI, 2002). Broad economic and social impacts were identified including: raised incomes of participating families, in part as a result of water savings and sales of surplus crop production; strengthened community cooperation, especially benefiting the women; enhanced sense of home economics and marketing, and better understanding of water conservation and reuse (FARUQUI and AL-JAYYOUSI, 2002; IDRC, 2006a). No negative health impacts were recorded. Improvements to the long-term nutrition in the area are expected. The likelihood of groundwater contamination was considered low (FARUQUI and AL-JAYYOUSI, 2002). A focused environmental assessment concluded that greywater reuse is feasible under specific conditions (AL-JAYYOUSI, 2002).

In 2001-2003 the IDRC sponsored Phase I of the Greywater Treatment and Reuse Project, a research project conducted in partnership with the Inter-Islamic Network on Water Resources Development & Management (INWRDAM), aiming to improve a system for reusing greywater in home gardens in Jordan. The wider scope of the project aimed to "help the peri-urban poor preserve fresh water, achieve food security, and generate income, while helping to protect the environment" (IDRC, 2006a). The steps taken and treatment system designs tested are described below.

5.3.2 Baseline Assessment

Baseline data concerning domestic water consumption, greywater quality, and type of crops grown in the area was collected. The willingness of the households to participate in the greywater reuse research project was also established. Twenty-five low-income households, including a girl's high school and the main mosque participated in the study (AL-BEIRUTI, 2006). Table 6 presents a breakdown of the per capita household water usage. An average of 120 l/c/d, including garden irrigation, was estimated. Raw greywater quality was reported as similar to that of the previous study; see Table 7.

Based on the values presented in Table 6, the volume of greywater produced is approximately 55 l/c/d; sourced from dish washing, laundry, and showers.

The background soil salinity, measured as the sodium adsorption ratio (SAR) was about 2 (AL-BEIRUTI, 2006).

Most households were not resistant by religious or cultural barriers to the use of greywater and women were willing to learn new methods of irrigation and home gardening (AL-BEIRUTI, 2006). The average household is made up of 6.8 persons (AL-BEIRUTI, 2005).

5.3.3 Criteria for Site Selection

Sites for implementation were selected based on the following criteria:

- willingness and ability for the household to utilize greywater;
- adequate water consumption in the household;
- sufficient agricultural land area;
- appropriate soil quality for agriculture; and
- sufficient rainfall to contribute in supplementary irrigation (AL-BEIRUTI, 2005).

The local mosque proved a very good demonstration site for the community; offering worshippers the chance to see the greywater system and the benefits of irrigating the local landscape. Perhaps more importantly, the Imam was able to convince many sceptics that greywater, if appropriately treated, was not unclean and could be reused for irrigation purposes (IDRC, 2006b).

Another strategic location of implementation was the local girl's school with 500 students. Greywater captured from water facets was used to irrigate olive trees in the school garden effectively demonstrating wise water use to a wider audience. Other schools have since asked to do the same (IDRC, 2006b).

5.3.4 Treatment System Design

Several pre-treatment and treatment systems were developed and tested in Jordan (AL-BEIRUTI, 2005). INWRDAM considered the following design objectives for the onsite greywater systems:

- cheap and easy to construct;
- low operation and maintenance costs; and
- effluent quality suitable for restricted irrigation (AL-BEIRUTI, 2006).

5.3.4.1 Two-barrel system

As the name implies, this system consists of two connected 160 l plastic barrels; the first barrel acts as a settling tank retaining oil, grease, and settleable solids; the second barrel acts a storage and pump tank. Raw greywater flows into the first barrel, with overflow spilling into the second barrel. Once the second barrel is full, a float switch triggers a small pump to come on and feed a drip irrigation system. The barrels are interconnected with 50 mm PVC pipes and covered with tight fitting removable lids. Only primary treatment is achieved by this system (AL-BEIRUTI, 2006).

5.3.4.2 Four-barrel system

This system consists of two 160 l and two 220 l plastic barrels connected in series (Figure 11). The first barrel (160 l) acts as a settling tank retaining oil, grease, and settleable solids. The second and third barrels (both 220 l) are filled with gravel (Ø2-3 cm) and form the up-flow anaerobic treatment filter, whereby greywater enters from the bottom and leaves from the top into the next barrel. The final barrel (160 l) is the storage tank and pump chamber with a float switch assembly connected to a pump. The barrels are interconnected with 50 mm PVC pipes and covered with tight fitting removable lids.

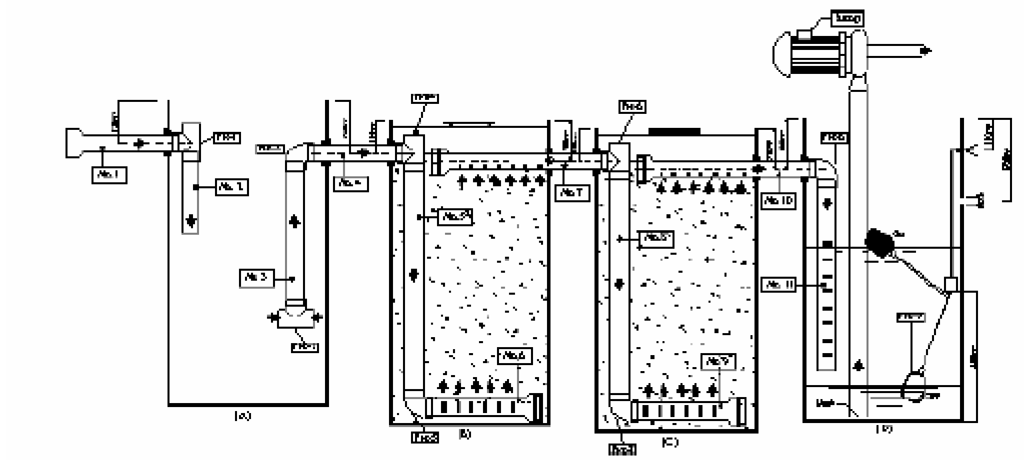

Figure 11: Design of the 4-barrel greywater treatment system (AL-BEIRUTI, 2005)

The hydraulic retention time in the two anaerobic filter barrels is approximately 1-2 days (AL-BEIRUTI, 2005). The primary and secondary treatment achieves an effluent quality suitable for restricted irrigation, as prescribed by WHO guidelines (AL-BEIRUTI, 2005).

Treated greywater is pumped through a drip irrigation network; irrigating 20-30 olive and fruit trees planted in family gardens (AL-BEIRUTI, 2005).

5.3.4.3 Confined trench system

The confined trench system (Figure 12) consists of a 160 l plastic barrel settling tank, a lined trench filled with gravel, and a 160 l plastic barrel storage tank. The trench (3 m x 1 m x 1 m) is dug with a 2 degree slope from inlet to outlet (primary treatment barrel to storage barrel); lined with an impermeable polyethylene sheet (3 m x 5 m, 400-500 µm thickness); side walls plastered with mud; barrels put in place; and filled with gravel (Ø2-3 cm). The mud plaster helps to prevent stones from puncturing the polyethylene sheet (AL-BEIRUTI, 2005).

Primary treatment of the greywater is achieved in the settling tank (first barrel). Greywater then enters the horizontal flow filter at the bottom and flows through the gravel filter media, under mainly anaerobic conditions, from inlet to outlet. The hydraulic retention time within the filter media is approximately 2-3 days. Treated water drains into the perforated storage tank where it is automatically pumped out when full through a drip irrigation network (AL-BEIRUTI, 2005).

Figure 12: Confined trench greywater treatment system installed at a household in Jordan (AL-BEIRUTI, 2005)

The confined trench system can serve more than one family sharing the same garden plot, equivalent to a capacity for 12 people (AL-BEIRUTI, 2005).

Table 8 presents a comparison of the three systems. Life expectancies of all the systems are estimated to be more than 10 years (AL-BEIRUTI, 2005).

Table 8: Comparison of greywater treatment options assessed in Jordan (AL-BEIRUTI, 2005)

System Type	Cost *	System Capacity	Level of Treatment
2-Barrel	US$ 230	6 persons (330 l/d)	Primary
4-Barrel	US$ 370	6 persons (330 l/d)	Primary & Secondary
Confined Trench	US$ 500	12 persons (660 l/d)	Primary & Secondary

* cost includes drip irrigation system for 2000 m^2

5.3.5 Operation & Maintenance

All systems operate under anaerobic conditions, with the potential to create odours. Operation and maintenance of the greywater treatment units is carried out by specifically trained local technicians (AL-BEIRUTI, 2006), although details of the maintenance requirements were not specified in the available literature. It is reported, however, that regular cleaning of the primary settling tank resulted in "big improvements" in treatment performance and "reduction of coliform counts" (AL-BEIRUTI, 2005). MOREL and DIENER (2006) suggest that removal of accumulated scum and sludge from the settling tank and backwashing of the anaerobic filter "will certainly be necessary from time to time".

5.3.6 Measure of Treatment System Performance

Quality analyses of treated greywater effluent are presented in Table 9. There is a high variability in the results and comparisons among treatment systems were not made as influent concentrations may have been different.

Table 9: Quality analyses of greywater following treatment

Quality Parameter Measured	Unit	Raw Greywater[a]	Treated Greywater Effluent[b]			Jordanian Standards for Treated Effluent Use[c]
			2-Barrel System	4-Barrel System	Confined Trench System	
BOD_5	mg/l	1500	159 (12-518)	450 (225-844)	171 (14-467)	30
COD	mg/l	-	-	-	204 (87-327)	100
TSS	mg/l	316	47 (2-94)	128 (76-183)	156 (22-398)	50
Oil & Grease	mg/l	141	37 (14-96)	31 (7-44)	-	8
pH		6	7.2 (6.4-8.3)	6.7 (4.7-8.2)	7.5 (7.2-7.7)	6-9

[a] AL-JAYYOUSI, 2003
[b] AL-BEIRUTI, 2005
[c] GOVERNMENT OF JORDAN, 2003 (referenced in MOREL and DIENER, 2006)

MOREL and DIENER (2006) report that the average BOD_5 and TSS effluent values for the confined trench system were strongly influenced by the first measurements of 467 mg/l and 398 mg/l, respectively. Effluent samples analysed for BOD_5 and TSS in later months are considerably lower 14-32 mg/l and 22-48 mg/l, respectively. These decreases are likely a result of established microbial populations (AL-BEIRUTI, 2005; MOREL and DIENER, 2006). A reduction in average faecal coliform values from 10^7 cfu/100ml in raw greywater to 10^5 cfu/100ml in treated greywater is reported by AL-JAYYOUSI (2003).

5.3.7 Alternative Detergent

In addition to developing household greywater treatment systems to manage the existing greywater, INWRDAM investigated possibilities of influencing the initial greywater quality. They developed an environmentally friendly liquid dish washing detergent and shampoo with a formula containing potassium or magnesium ions instead of sodium ions to help control the long-term impact of the detergents (AL-BEIRUTI, 2005).

5.3.8 Impact Assessment

After two years of irrigating with treated greywater, the negative impact on the soil and plants is considered minimal; soil SAR levels were slightly higher, but below the level that could affect plant yield; and no contamination of crops with faecal coliforms were reported. Plant growth rates were improved as a result of the supplementary irrigation water (AL-BEIRUTI, 2005).

All greywater users realised a decrease in their domestic water consumption by about 30%, as a result of greywater supplementing irrigation demands (AL-BEIRUTI, 2006). Figure 13 illustrates the separation of household water consumption before and after greywater recovery, based on values presented by AL-BEIRUTI (2006). In this case, 79% of domestic wastewater, as greywater, is being recovered, treated and reused for irrigation purposes.

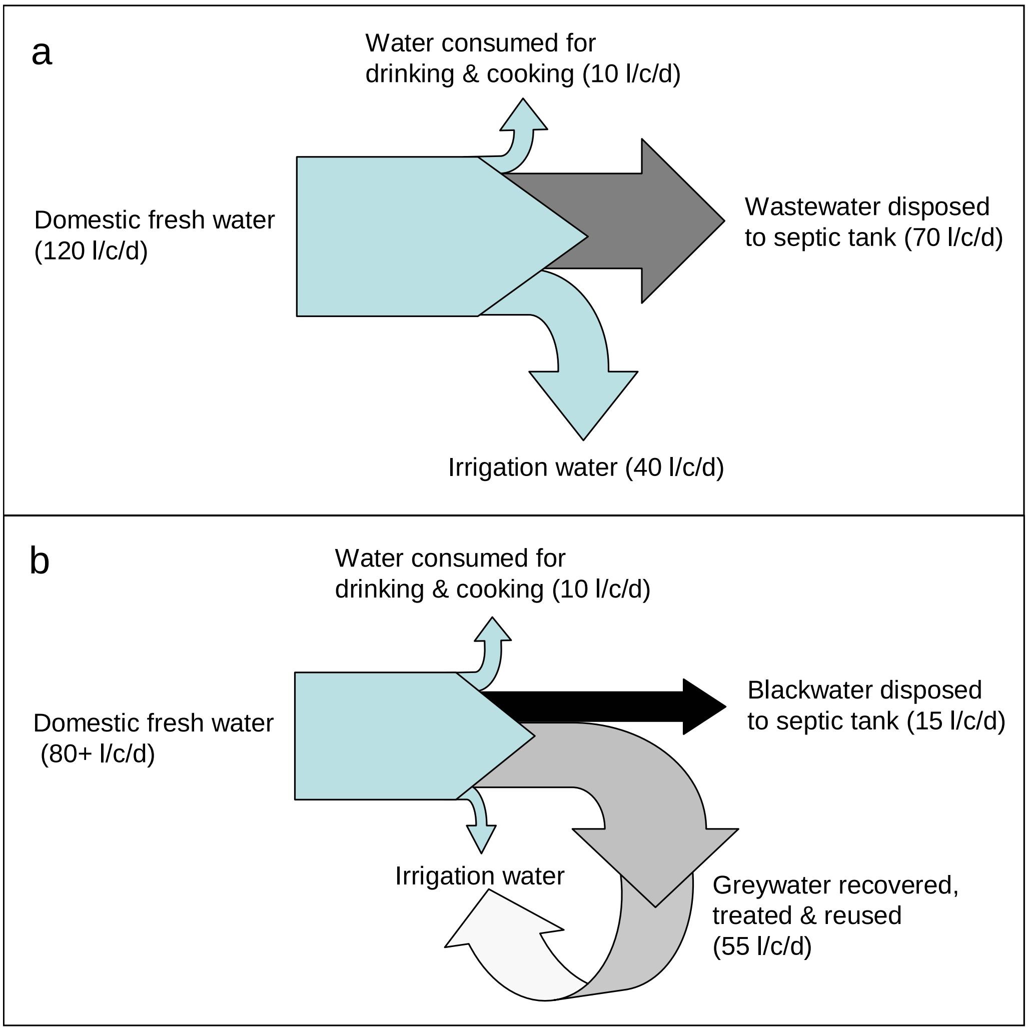

Figure 13: Household water flow diagram before (a) and after (b) greywater recovery and reuse

A cost/benefit study indicated an increase in household income in the range of 10-30 Jordanian dinars (US$ 14-42) per month as a result of:

- Reduced domestic freshwater bill;
- Cost savings from fewer septic tank pump outs; and
- Improved crop yields (AL-BEIRUTI, 2005).

These savings allow a payback period for the treatment systems of less than 3 years (AL-BEIRUTI, 2005). The cost/benefit ratio was calculated as 1:5, mainly from increased agricultural production (IDRC, 2004).

Social impacts of the Phase I project sees the women in the community benefiting most; from training workshops, dialogue and learning by doing, and acquired new skills to build productive garden and management skills (AL-BEIRUTI, 2006).

Women community leaders were identified and trained as trainers of other women on subjects such as pollution source control, wise use of detergents, appropriate dishwashing practices, and permaculture practices (AL-BEIRUTI, 2006).

The lessons learned from the project are even being adapted by Jordan's Ministry of Social Development to teach new skills to the poor. These include: plumbing and agricultural techniques, financial and administrative management, communications, and networking (IDRC, 2006a).

The project achievements included (IDRC, 2006a):

- Increased greywater recovery, making it easier and safer to handle;
- Minimized environmental impacts, by encouraging the production and marketing of cheaper environmentally friendly soaps;
- Improved irrigation systems and promoted the adoption of new crops more tolerant to greywater;
- Promoted policy changes that will encourage wider greywater acceptance in Jordan.

5.3.9 Continued Developments

The results of Phase I convinced the Jordanian Ministry of Planning and International Cooperation that household greywater reuse was worthwhile; funding the implementation of more than 700 greywater treatment and reuse units in 90 peri-urban sites throughout Jordan in 2002-2003 (AL-BEIRUTI, 2006).

A post project evaluation of Phase I by an independent planning and management consultancy firm recommended that more local involvement, especially women, in project planning and decision making was needed (AL-BEIRUTI and BINO, 2005; SMIRAT, 2006).

Phase II (2004-2008) of the IDRC funded greywater reuse project aims to construct a further 300 greywater treatment systems for low-income families in selected peri-urban areas, promoting community participation in all stages of the project development. Cooperation between the various agencies concerned with wastewater use, social development, building codes and public health is also anticipated (AL-BEIRUTI, 2006).

The objective of Phase II is "to evaluate the previous greywater reuse projects in Jordan, validate existing approaches, address social and institutional obstacles to scaling-up greywater use, and monitor and refine systems to ensure long-term sustainability" (AL-BEIRUTI, 2006).

5.3.10 Factors Supporting & Constraining Acceptance

IDRC (2006a) present some insight as to what worked and what still requires work, with respect to the greywater management project in Jordan. Factors which contributed to the success of the project include (IDRC, 2006a):

- Strategic use of limited resources;
- Lessons learned in one project were applied to subsequent projects;
- Partnerships created;
- Sympathetic political environment in Jordan;
- Reputation and credibility of the highly respected individuals and organisations involved in implementation;

- Wide dissemination of research findings using different communication formats appropriate to different audiences (workshops, conferences, websites, videos[2]);
- Linking environmental sustainability (wastewater recovery) with economic development (poverty alleviation) the research project was successful in attracting political support; and
- Adoption of a household centred approach (AL-BEIRUTI, 2006).

Some listed deficiencies of the projects include (IDRC, 2006a):

- Failure to focus on gender equality as a core research theme and policy goal;
- Insufficient funding for project evaluation;
- "lack of a learning environment" in some sectors of the Jordanian government; and
- Insufficient use of mass media.

5.3.11 Scaling Up

"There was some resistance to the idea of using greywater, both among householders and by local officials. Some were sceptical and unconvinced that the systems would work, or afraid that it would be too expensive and hard to maintain. Others worried about odours and mosquitoes. But once the system was demonstrated the community quickly become enthusiastic" (IDRC, 2006b). Many families replicated and adopted greywater reuse systems following their neighbour's experiences (AL-BEIRUTI, 2006).

The key to success was the involvement of a local NGO as a major stakeholder in the pilot project. Members were given training in water conservation as well as techniques for separating and treating greywater. The NGOs helped put on workshops providing training in system maintenance and irrigation techniques. A manual on greywater treatment was produced and made available at meetings and workshops (IDRC, 2006b).

Other communities within Jordan and even neighbouring countries are now adopting the innovative greywater treatment and reuse system. This replication is attributed to the strength of the networks created and involved in the project, and further encouraged by the continually evolving project structure (IDRC, 2006a).

[2] http://www.youtube.com/watch?v=FPjLo0YDuJ4 & http://www.youtube.com/watch?v=7fAuYt882d0

6 Greywater Challenges in East Africa – the ROSA Context

The ROSA project may be considered the fourth case study in this thesis, where investigations of greywater management in peri-urban areas are still in the early stages. All cities participating in the ROSA project face similar challenges with greywater disposal and their contextual similarities offer the opportunity to cooperatively examine potential greywater management solutions. Presented below are 1) observations made during a field trip to Nakuru, Kenya and Arusha, Tanzania; 2) results from a questionnaire administered to selected ROSA project team members; and 3) baseline conditions reported by the ROSA project partners from the African cities.

It is recognized that "the generation of greywater by households is directly related to the consumption of water, which is dependent on the level of service, tolerance of residents to pollution and the level of awareness of health and environmental risks" (ROSA KITGUM, 2007).

6.1 *Natural and Social Conditions*

Natural Conditions

The ROSA cities of Arba Minch, Ethiopia; Kitgum, Uganda; Nakuru, Kenya; and Arusha, Tanzania all share a similar arid or semi-arid climate and receive two rainy seasons annually. Mean annual precipitation and temperature are approximately 800-900 mm and 25°C, respectively.

Soil conditions and groundwater depth vary with location. In Kitgum, the soils are reported to be well drained sandy loam, with patches of clay loam along streams and rivers. In Arba Minch, the ground is reported to be hard and rocky, making it difficult to dig pits deeper than 1 m. The soil is sandy loam with a high percolation rate. The groundwater table is 20-25 m below the surface. In Nakuru, the water table depth is reported to be between 60 and 130 m (ROSA NAKURU, 2007).

The per capita water availability of Kenya is 650 m^3/c/y but is projected to drop to 359 m^3/c/y by the year 2020 as a result of population growth (UNESCO, 2006). Uganda, on the other hand, is better off than many other African countries with an annual average water availability of 2,800 m^3/c/y (UNESCO, 2006). Uganda's total water withdrawals however, only equate to 20 m^3/c/y. Water availability figures for Ethiopia and Tanzania could not be obtained but their total water withdrawals are reported as 48 m^3/c/y and 36 m^3/c/y, respectively (WHO, 2000a; WHO, 2000d).

Social Context

General population demographics are presented in Table 10, with residential population densities given in brackets. Population densities vary among settlements, with higher income areas typically having lower densities. The highest population densities are in low-income unplanned peri-urban settlements. The population growth rates of all the cities exceed 4%.

Table 10: Comparison of population demographics of ROSA cities

Location	Population	Population density (persons/ha)	Average size of household (persons)	Growth rate (%)	Source
Arba Minch, Ethiopia	78,843	59 (154)	5.8	4.5	ROSA ARBA MINCH, 2007
Kitgum, Uganda	42,493	14*	6	4.1	ROSA KITGUM, 2007
Nakuru, Kenya	500,000	49*	3.4	7	ROSA NAKURU, 2007
Arusha, Tanzania	341,000	47 (10-310)	5	4.9	ROSA ARUSHA, 2007

* estimate based on the reported population and area

ROSA KITGUM (2007) reports a high population growth and influx of commuters in Kitgum as a result of the insecurity in the area caused by the civil war in Northern Uganda. Continued urbanization of Arba Minch is expected to cause an increase in the population density to approximately 250 persons/ha (ROSA ARBA MINCH, 2007). A high population growth rate of Nakuru and Arusha will undoubtedly also increase the population densities. Currently, over 65% of the settlements in Arusha are unplanned (ROSA ARUSHA, 2007). Likewise, residential housing accounts for 70% of land uses in Nakuru (ROSA NAKURU, 2007). Half of the Kenyan urban population live in informal settlements (UNESCO, 2006).

Information concerning personal income level was not obtained from ROSA sources. However, UNESCO (2006) reports that as of 2002, approximately 40% of Uganda's population lives below the poverty line. In Ethiopia, 58% of the urban population live below their national poverty line. Similarly, 42% of the Kenyan population is below the national poverty line; measured as US$ 35 per adult per month for urban settlements and about US$ 16 for rural settlements (UNESCO, 2006).

6.2 Sanitation Coverage

The ROSA cities are primarily non-sewered. Only Arusha and Nakuru have partial coverage with a sewerage system, which serves 12% and 19% of the city area, respectively (ROSA ARUSHA, 2007; ROSA NAKURU, 2007).

Pit latrines are the primary sanitation system utilized by the majority of the people in Arba Minch (64%), Kitgum (93%), Nakuru (85%) and Arusha (94%). Septic tanks serve a small portion of the remaining population.

Responsibility of onsite sanitation systems typically lies with the homeowners, who are often not willing or unable to invest in sanitation services as water, electricity, and other services are of higher priority (ROSA ARBA MINCH, 2007). Homeowner involvement in the planning and implementation of sanitation facilities at the municipal level is very limited (ROSA NAKURU, 2007).

Reuse of wastewater from the municipal treatment plants has been observed for irrigation of household gardens, especially during the dry season in Arusha and Nakuru.

6.3 Water Supply

Groundwater is the primary water source for municipal supply systems of the ROSA cities; serving their populations via household connections to the piped distribution network and shared public standpipes. Alternate sources of water include private water vendors, private and shared wells, nearby river, or captured rainwater. Table 11 outlines the sources of water in the peri-urban settlements of the ROSA cities.

Table 11: Sources of water in peri-urban settlements of ROSA cities

Location	Connected to municipal supply network	Shared public taps	Buy from private vendors	Other water source
Arba Minch, Ethiopia	X	X	X	Kulfo River
Kitgum, Uganda	X			Shared boreholes
Nakuru, Kenya		X	X	Collect from river, rainwater catchment
Arusha, Tanzania	X	X		

Arba Minch in Amharic means “40 springs”; suggesting water resources are relatively abundant. Approximately 83% of the population of Arba Minch have access to piped water; consisting of 3% with household connection, 58% with yard connection, and 22% with access to public stand pipes. All connections and public taps are metered. Spring water, the main source of water for the town of Arba Minch, is described as having excellent physical and chemical properties (ROSA ARBA MINCH, 2007). Conversely, the nearby Kulfo River is considered turbid. The Arba Minch Town Water Service is the autonomous governmental organization responsible for managing water supply services and sewage collection and disposal, although thus far it is only involved with water supply. Private purchase accounts for 21% of water supply (ROSA ARBA MINCH, 2007).

In Kitgum, Uganda, only 9% of the population is connected to the central water system, which does not treat the water prior to distribution. The majority of people get water from groundwater boreholes, with the burden of fetching water predominantly undertaken by women. Forty-five percent of households boil drinking water and 27% disinfect their water with chlorine tablets (ROSA KITGUM, 2007).

In Arusha, Tanzania, water kiosks and public stand pipes serve a large proportion of the population which are not directly connected to the water supply network. Access varies between the various settlements. The Arusha Urban Water and Sewerage Authority (AUWSA) currently meet 90% of municipal water demand (ROSA ARUSHA, 2007).

In Nakuru, water supplies are described as “very limited” with service provision at least two days a week. In newly settled areas water supply is mainly through private enterprises, such as water vendors. Three water kiosks are in operation. They are, however, deemed inadequate in meeting the water demands of the densely populated areas. The kiosks are operated by local Community Based Organizations (CBOs) and managed voluntarily (ROSA NAKURU, 2007). Figure 14 depicts a water kiosk in Kaptembwo settlement in Nakuru. Water is collected in 20 litre plastic jerry cans and carried home by foot or loaded onto a bicycle.

Figure 14: Water kiosk in Kaptembwo Settlement Nakuru, Kenya

6.4 Water Demand

Values for domestic water usage were often given on a per household basis; from which a per capita domestic water usage was calculated. Table 12 compares the domestic water demand of the four ROSA cities. The size of the households ranges from 5 to 7 persons.

Table 12: Domestic water demand and price in the ROSA cities

Location	Average per capita water usage (l/c/d)	Price of water ($US/m^3)	Variation in seasonal usage?
Arba Minch, Ethiopia	57	0.11-0.17	Yes
Kitgum, Uganda	12	0.74-2.96	-
Nakuru, Kenya	65	2.97-7.43	Yes
Arusha, Tanzania	45	0.20-1.98	Yes

The price of water was reported in dissimilar units. Arba Minch gave a price per household per month, whereas Kitgum, Nakuru, and Arusha reported water prices per 20 litre jerry can. Prices also varied with source. The highest price is commonly charged by private water vendors. In Nakuru, people typically pay 10 Kenyan shillings (Ksh) ($US 0.15, €0.10) per 20 litres of drinking water. In Arusha, the price of water varies from 5 to 50 Tanzanian shillings (Tsh), typically 20Tsh ($US0.02, €0.01) per 20 l jerry can. People think the cost of water is affordable as compared to electricity (ROSA ARUSHA, 2007).

In Kitgum, households pay a monthly service fee of between 200 and 500 Ugandan Shillings ($US0.29, €0.20), depending on location, to cover maintenance of the water supply carried out by the Water User Committee. Population growth, economic development, and to a lesser extent the expansion of irrigated agriculture are contributing to an increase in water demand in Uganda. Water shortages are common and the economically disadvantaged, in particular, often lack accessibility to clean safe drinking water (ROSA KITGUM, 2007).

In 2004, domestic water consumption in Nakuru accounted for 11% of water supplied. This value is perhaps not all together accurate as 60% of the water supply is unaccounted for. With improved efficiency, the privatized Nakuru Water and Sanitation Services Company (NAWASSCO) estimates domestic consumers will consume around 40% of the water supply (ROSA NAKURU, 2007).

Respondents from Arba Minch, Kitgum, and Nakuru agree that different water sources are used for different purposes. For instance, drinking water is sourced from the municipal supply network and wash water collected from rainwater and river water.

When asked about seasonal variations in the use of water, answers were varied. For example, the respondent from Nakuru stated that water is rationed during the dry season from January to March; whereas in Arba Minch people are said to use more water for drinking and bathing during the dry season. No specific quantities were reported.

ROSA ARBA MINCH (2007) suggest that households in Arba Minch with a connection to the water supply network use more than double the amount of water than households with a yard connection or public stand pipe (Table 13).

Table 13: Estimated per capita demand for piped water in Arba Minch, by purpose and water supply source (ROSA ARBA MINCH, 2007).

Purpose of water use	Water demand (l/c/d)		
	Household connection	Yard connection	Public stand pipe
Drinking	2.5	2.5	2.5
Cooking	7.5	5.5	4.5
Washing dishes	5	4	4
Washing clothes (laundry)	15	8	7
Baths & showers	20	4	3
Flushing toilet	6	1	0
Water garden	0	0	0
Ablution	17	12	7
House cleaning	7	3	2
Total	**80**	**40**	**30**

During the field trip to Nakuru and Arusha, numerous water use behaviours were observed in the peri-urban areas. Most notably, clothes’ washing is done by women who hand-wash the clothes in plastic basins at home or at the river’s edge (Figure 15).

Figure 15: Washing clothes and cars at the river's edge in Arusha, Tanzania
(photo by LANGERGRABER, 2007)

6.5 Greywater Production

Where given, a breakdown of domestic water consumption values supports an estimate calculation of greywater volume. For example, the values presented in Table 13 suggest generated greywater quantities in the range of 20-60 l/c/d, depending on the type of connection to the piped water supply. The ROSA project partners who participated in the questionnaire indicate that a detailed onsite assessment characterising actual household water usage and generated greywater quantity and quality is still required.

Typically hard soaps as well as washing powder are used for washing clothes. Liquid detergents are used for washing dishes. Brand names, including OMO and Ariel were cited, as common cleaning products in Nakuru. The ingredients of OMO washing powder include: surfactants, phosphates, silicates, soda ash, enzymes, polycarboxylates, optical brighteners, and perfume (Figure 16).

Figure 16: Washing powder package with a listing of the ingredients

A quick survey of cleaning products in a major supermarket in Nakuru, identified the cheapest soap was an unpackaged 700 g hard soap bar, costing 40 Ksh ($US0.60, €0.42). It is assumed this may be the soap of choice for the poorest residents. A 100 g package of OMO washing powder costs 20 Ksh ($US0.30, €0.21). Absent from both products were suggested dosages or clear instructions of use.

6.6 Greywater Management

Within all the ROSA cities, household greywater produced from washing activities is generally disposed, untreated, onto the ground outside of the residence. This practise of open disposal is considered by all questionnaire respondents to be a problem, negatively impacting human health and the local environment.

In the non-sewered areas of Nakuru, greywater is often disposed into stormwater drains (as observed in Figure 17), onto the road, or the ground outside of the residence, or dumped into the pit latrine (ROSA NAKURU, 2007).

Figure 17: Stormwater (and greywater) drainage in a peri-urban settlement of Nakuru, Kenya (photo by LANGERGRABER, 2007)

In Kitgum, 55% of households are reported to have soak pits to infiltrate greywater, with the remaining households disposing greywater directly onto the ground or into open drainage channels. Limited space has hindered most households from digging soak pits in their compounds. In areas with poor drainage, residents complain about mosquitoes, smelly stagnant water, and children falling ill after playing in the discarded wastewater (ROSA KITGUM, 2007).

In Arusha, the greywater management practices are similar; greywater is often disposed into the latrines, on the roadside, or in the backyard (ROSA ARUSHA, 2007).

Open disposal of greywater within the household compound is the primary greywater management strategy in Arba Minch (Figure 18). ROSA ARBA MINCH (2007) report that hotels, restaurants, and institutions which produce larger volumes of greywater also experience problems with its disposal.

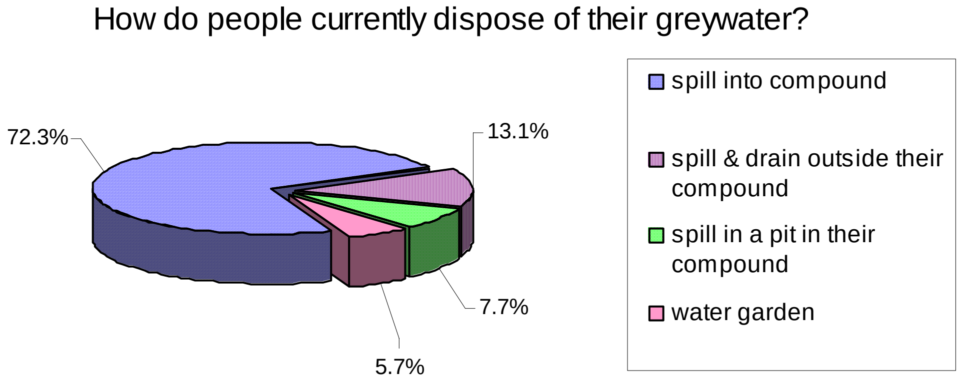

Figure 18: Current greywater management strategies in Arba Minch, Ethiopia
(ROSA ARBA MINCH, 2007)

According to the survey participants, greywater reuse is already practised in all four ROSA cities. Greywater is used to clean floors, irrigate small gardens, flush toilets, and also sprinkled onto the ground to reduce dust. Figure 18 illustrates that greywater reuse in Arba Minch is practiced only by a small minority of the population. Irrigating gardens with greywater has been abandoned by some people because of observed negative impacts on the plants, namely vegetables drying up (ROSA ARBA MINCH, 2007).

When asked whether peri-urban residents of Arba Minch, Kitgum, Nakuru, and Arusha want to reuse greywater, all questionnaire respondents replied affirmatively; signifying that there is a demand for greywater as a resource, primarily during the dry season.

Currently, specific treatment of household greywater is not practised in any of the ROSA cities. Technical advice related to potential treatment systems is sought.

Septic tanks may classify as the only onsite wastewater management strategy currently available in Kitgum, Nakuru, and Arusha. All cities have material and labour resources available to construct and operate such treatment systems. Electricity is lacking in some areas. The space available for potential greywater treatment systems is variable, requiring further surveys. Households in Arba Minch, including the built up areas, have approximately 40-100 m^2 of space available for a greywater treatment system.

6.6.1 Regulatory Conditions

Regulations concerning greywater disposal and reuse in Nakuru stipulate that greywater should not be disposed into any open water bodies and is prohibited for use in irrigation. All greywater should be discharged into a sewer network to undergo conventional wastewater treatment. In Arba Minch, there is no separate regulation for greywater; it is considered together with wastewater. No information concerning greywater regulation was available for Kitgum and Arusha.

7 Discussion

For water scarce developing countries challenged with greywater management there is a real need for practical know-how for developing their own greywater management strategies. A starting point may be to gain a better understanding of how greywater fits into their specific context. The DPSIR conceptual framework, adapted to greywater (Figure 4), is used here for this purpose. It describes and structures the relevant components of the situation, identifying their connectivity via a cause-and-effect relationship, and helps to identify useful indicators and management options. This is seen as a necessary step of integrated water resources management. WALMSLEY (2002) reasons that “one of the critical success factors for effective water resources management is the appropriate assessment of the diverse, interacting components of catchment processes, and the resource management actions that impact the water resources in a catchment”. SULLIVAN and MEIGH (2007) contend that “any system of environmental management, to be operationally sustainable, needs to be based on a truly holistic assessment of all relevant factors influencing it”.

ALDERLIESTE (2007a) confirms that understanding the context has been a key element in the design and implementation of the greywater infiltration project in Djenné, Mali.

7.1 Context of Investigation

This thesis focuses on specific context criteria, related to natural and socio-economic conditions to identify similarities in driving forces creating the demand for greywater management in water scarce developing countries.

The natural conditions characterising arid and semi-arid regions are low precipitation and high evaporation, which largely determine the limited availability of fresh water resources. The spatial and temporal variability in rainfall further influences the availability of fresh water resources. Jordan, South Africa, and Kenya are considered physically water scarce according to reported per capita water availability values of less than 1000 m^3/c/y. Taking the Water Poverty Index (WPI)[3] as an indicator of economic and social (second and third order) water scarcity, it is evident that Mali, Ethiopia, Uganda, and Tanzania are also water scarce with WPI scores (out of 100) of 40.8, 35.3, 44, and 48.3 respectively, which rank them within the bottom third of 141 countries. Jordan, South Africa, and Kenya have similar WPI values of 46.4, 52.2, and 47.3, respectively (LAWRENCE *et al*., 2002). The WPI for these countries is graphically represented in Figure 20 and Figure 19. BBC (2007) and IWMI (2006) also depict the Sub-Saharan African countries as economically water scarce (Figure 1).

[3] The WPI aims to support a more comprehensive assessment of water scarcity issues, combining physical, social, economic and environmental information. The five key components include: physical water quality and availability (Resources); measures of access (Access); water for food and other productive purposes (Use), effectiveness of people’s ability to manage water (Capacity), and evaluation of the environmental integrity related to water (Environment) (SULLIVAN *et al*., 2003).

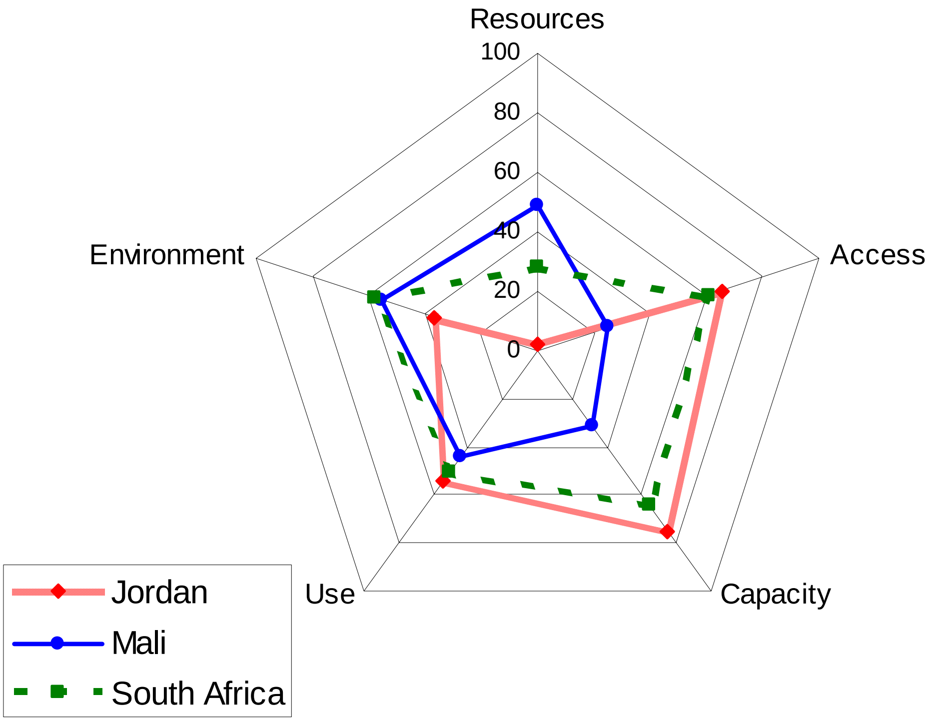

Figure 19: Water Poverty Index values of Jordan, Mali, and South Africa
(values from LAWRENCE *et al.*, 2002)

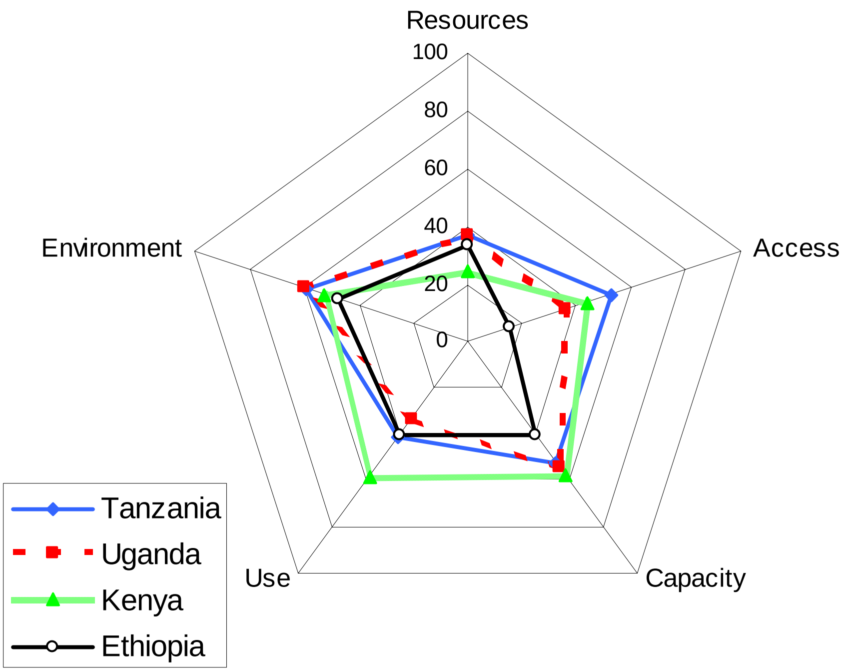

Figure 20: Water Poverty Index values of East African countries participating in ROSA project
(values from LAWRENCE *et al.*, 2002)

WPI diagrams are decision support tools which help raise awareness and support policy makers target attention to the specific issues (SULLIVAN and MEIGH, 2007). Jordan, for example, scores extremely low in water resources, yet has a significant capacity to manage the limited water resources available. It is important to note that these WPI values are based on national data, which "provides only a broad spectrum analysis" and may not represent the situation of any individual communities (SULLIVAN and MEIGH, 2007). It is possible however, to also develop and apply the WPI at the community scale (SULLIVAN *et al*., 2003).

"Demographic factors, such as population growth, are arguably the most important driving forces impacting water resources globally" (BOBERG, 2005). Urbanization, low household income, consumption habits, and management capacity are also identified as major influences on water supply, demand, and pollution in water scarce developing countries. Adapting to more extreme variability in climate (e.g. seasonal precipitation) caused by climate change is also recognized as an important driving force in water resources management (PAHL-WOSTL, 2007).

Population and settlement densities are considered to be very important factors in terms of the pollution load created and the amount of space available for implementing onsite greywater treatment systems. As a result, the greywater management options proposed in South Africa are based on the settlement density (WINTER *et al*., 2006). This is further discussed in the management responses section. The number of people in the household also affects the water demand and rate of wastewater production, based on the economies of scale (BOBERG, 2005).

The trend towards decentralisation of responsibility for water and wastewater services offers communities new opportunities and challenges for local involvement in managing their own systems. This was the case in Mali, where local communities have been entrusted with the responsibility of managing their own water supply and wastewater disposal. FAGGIANELLI (2005) reports that this reform has been a challenge to institutionalise, and will require more time and investments to help build the management capacity of the local council.

7.2 Water Supply & Demand

The reality of water scarcity is evident in the low domestic water consumption values of the countries investigated. This is largely related to water accessibility and affordability. THOMPSON *et al*. (2000) identify that "the most important factor affecting urban water use in East Africa is whether or not a household has access to a functioning piped system". The peri-urban poor living in non-sewered areas of South Africa use an average of 26 l/c/d, with residents having access to a standpipe in the yard using more than those having to fetch their water (CARDEN *et al*., 2007a). In Jordan, poor households use approximately 50 l/c/d of water from a piped supply (AL-JAYYOUSI, 2002). Residents of the ROSA cities use similar per capita quantities of water for domestic purposes from a variety of sources and range of prices. The data from Ethiopia illustrate that water demand differs considerably depending on the type of connection. Household connections are expected to use 80 l/c/d, double the volume of water used by households with yard taps (40 l/c/d) or access to public stand pipes (30 l/c/d) (ROSA ARBA MINCH, 2007). Less water in the home means less water available for water-related hygiene, such as washing hands after defecating, cleaning utensils, and personal bathing (THOMPSON *et al*., 2000).

In East Africa, low-income urban households without access to piped water supplies pay almost twice the amount for water that piped households paid. Vendors often charge five times more than the average cost per litre for piped households (THOMPSON *et al*., 2000). This supply-cost relationship could not be confirmed with the ROSA baseline data although it is evident there is an extreme price difference for water between the cities. Arba Minch has the cheapest and

Nakuru has the most expensive water supply. This is most likely related to the sources of water. It is suggested that comparing the cost of water to the average household income would indicate the affordability, and in turn, reflect the need for greywater reuse.

The water tariff structure in Tufileh, Jordan (Figure 9) charges those who use more water at a higher rate. Here, an economic advantage is created when greywater reuse is practiced since the domestic water consumption can be reduced by 33%, enough to drop households to a lower price category, equating to a water bill savings of 56%.

The results of the questionnaire and review of the ROSA baseline study reports suggest that detailed onsite investigations are still required to further clarify where residents get their water from, what its quality is, and how they use it. Assessing the seasonal variation in water supply and demand will also give a clearer picture of how water is managed in the household. Identifying these factors and their influence on greywater production at a local scale is important in developing appropriate greywater management strategies.

7.3 Greywater Quantity & Quality

It is generally accepted that low domestic water use in water scarce countries is directly responsible for the quantity and quality of greywater generated. The greywater quantity values of 20-60 l/c/d generated by the populations of the ROSA cities are similar to those of case study projects. This suggests that the treatment systems presented are of an appropriate scale, capacity-wise.

In general, 75% of domestic water use activities generate greywater. This offers the possibility to estimate the quantity of greywater generated from domestic water use values. Onsite surveys and field observations are possibly the best methods to account for the volume of water used and how it is used.

The objective to find information regarding the composition of greywater in water scarce developing countries was achieved by recovering data from projects in Jordan (FARUQUI and AL-JAYYOUSI, 2002; AL-JAYYOUSI, 2003) and South Africa (CARDEN *et al*., 2007a; SALUKAZANA *et al*., 2005; JACKSON *et al*., 2006). The limited number of published papers identify a high variability in greywater quality.

Greywater from laundry is typically alkaline with a pH value in the range of 8-10. However, pH in greywater also depends largely on the pH and alkalinity of the original water supply sources (ERIKSSON *et al*., 2002).

Greywater from the kitchen contains the highest levels of nitrogen, whereas laundry detergents are the primary source of phosphates and sodium. Concentrations of 6 to 23 mg/l total phosphorus (TP) can be found in traditional wastewaters where phosphorus detergents are used (ERIKSSON *et al*., 2002). Greywater TP values from the South African studies are much higher than this. Excess phosphorus can pose serious problems to ecologically sensitive waters, accelerating eutrophication (TCHOBANOGLOUS and SCHROEDER, 1985). Elevated TP values can be expected in the greywater of the ROSA cities as well, assuming many of their detergents contain phosphates[4].

Microbiological analyses of greywater from the case study projects were very limited and inconsistent. For example, SALUKAZANA *et al*. (2005) and JACKSON *et al*. (2006) both present greywater quality characteristics from the same study, yet many of the values differ. Furthermore, it is unclear where and when the samples were taken. If greywater is stored, “bacteria multiply to blackwater levels” (LUDWIG, 2000). Only the Jordan case study offered information that treated greywater could meet the WHO guidelines for restricted irrigation. Treatment offered a 2-log reduction in faecal coliforms (AL-JAYYOUSI, 2003). All other results could not be assessed in relation to the WHO guidelines.

Household greywater quality was never tested in Djenné, Mali (ALDERLIESTE, 2007b), perhaps because reuse was not considered feasible. The minimal use of chemicals in Djenné households led project staff to believe that the infiltration of pre-treated greywater would not contaminate the groundwater (ALDERLIESTE, 2007b). However, an evaluation of the greywater quality may support this hypothesis and a further understanding of its potential impacts on the groundwater and human health, as well as on the long term functionality of the infiltration trench. For example, grease and oils, as well as suspended solids, can accumulate on the surfaces of the soil absorption system, ultimately leading to a reduction in the infiltration capacity (METCALF & EDDY, 1991). ALDERLIESTE (2007b) cited that, in Djenné, grease was considered a problem at the greywater drainage outlets from the residential courtyards, where the cooking takes place.

A better understanding of the connection between the source water quality, cleaning habits, and detergent use as it relates to greywater quality is needed. For example, the temperature and hardness of the wash water can affect the amount of soap or detergent required. Researchers in South Africa observed that “in the absence of hot water, residents of low-income settlements tended to leave the ubiquitous green detergent bar (example ‘Sunlight Soap’) in the laundry water for several hours, resulting in large amounts of detergent dissolving in the water” (CARDEN *et al*., 2007a). This may explain the high concentrations of chemicals found in the greywater.

Information on the biodegradability of the detergents used is also lacking. For example, the surfactant alkyl-benzene-sulfonate (ABS) is difficult to treat biologically and has since been replaced in the United States with linear-alkyl-sulfonate (LAS), which is biodegradable. ABS-type detergents, however, are still in use in other countries (TCHOBANOGLOUS and SCHROEDER, 1985).

In cases where greywater is used to irrigate a garden, it is suggested that household detergents should be carefully selected to prevent toxic effects on plants and soil deterioration (MOREL and DIENER, 2006). Of particular concern for irrigation are potential high concentrations of sodium, boron, and nitrogen. FAO (2003) present threshold values of notable water quality parameters as guidelines for irrigation; included in the appendix.

[4] Phosphate based [sodium tripolyphosphate (STPP)] detergents are widely banned in developed countries because of environmental regulation aimed at protecting ecologically sensitive waters. They are widely replaced by non-phosphate Zeolite A based detergents (ECED, 2002).

7.4 Greywater Impacts

Impacts from domestic greywater may be perceived as either positive or negative. If it is safely recovered and reused as a supplemental source of water to irrigate a crop it can prove socially beneficial, securing additional food, reducing fresh water demand, and creating employment opportunities. The increased awareness of the economic benefits of reusing greywater is showcased in Jordan. However, if greywater is simply discharged onto the ground, as it is often done in the densely populated non-sewered settlements of South Africa, in Djenné, Mali, and in the ROSA cities, the cumulative effect has the potential to create a number of negative environmental and health impacts. Stagnant water is a breeding ground for mosquitoes, a vector of malaria in many tropical countries.

Measuring the health and environmental impacts related to open disposal of untreated greywater is weakly reported in the literature, perhaps because it is difficult to isolate the specific causes. MUJWAHUZI (2002) suggests that low water use negatively impacts on people's health. For example, "skin diseases and diarrhoea were found to be prevalent in areas with low per capita water use for cleaning and bathing".

In Djenné, Mali the impact of open water in the streets hampered the mobility of residents and the transport of goods; freedoms regained when greywater was effectively infiltrated. FAGGIANELLI (2005) reports that the quality of life and public health were improved in Djenné as a result of the greywater infiltration, but that the full impact on human health will only be obvious after all the dwellings of the city are connected.

The implementation of improved water supply by external agencies has also established a level of dependency on the service provider. In the case of South Africa, where the national government's drive to provide all residents with adequate water supplies, most of the affected residents expect the government and municipal authorities alone to also manage the generated wastewater (CARDEN *et al*., 2007b). This perception may further challenge efforts to implement decentralised greywater management systems which require local involvement.

A few studies (AL-JAYYOUSI, 2002; SALUKAZANA *et al*., 2005; WIEL-SHAFRAN *et al*., 2006) have reported on the potential environmental and health impacts of irrigating with greywater. WIEL-SHAFRAN *et al*. (2006) suggest that "surfactant accumulation in the soil due to greywater irrigation can create water-repellent soils". The salinity of greywater is also considered to have potential negative impacts on plants and the soil. CARDEN *et al*. (2007b) report that "high levels of sodium (derived from the soluble salts in detergents) in greywater that is used for irrigation can cause reduced crop yields and quality due to sodium uptake through the roots and leaves of sodium-sensitive plants, impaired soil physical conditions (reduced soil permeability) and an increased tendency for hard setting". This may explain why greywater, which is frequently spilled onto the ground, would tend to pond rather than infiltrate the ground surface.

7.5 Greywater Management

With an integrated approach and a holistic understanding of the challenges and potentials, numerous responses and interventions to manage greywater are possible. These can be specifically directed at influencing the driving forces, pressures, state, and impacts. An integrated approach will require technical, social, institutional, environmental, and economic components. Furthermore, “the systems perspective suggests that everyone shares responsibility for the problems and opportunities generated by it” (AL-JAYYOUSI, 2004).

The process of building management capacity can be described as “learning to manage, by managing to learn” (PAHL-WOSTL, 2007) and requires the involvement of numerous disciplines (WOLFE and BROOKS, 2003). Applying the steps of the social learning cycle, as part of cooperative development, calls for participatory assessment and modelling, followed by strategic planning, then implementation, and finally monitoring of the process, outcomes, and impacts (Figure 21 and Figure 22).

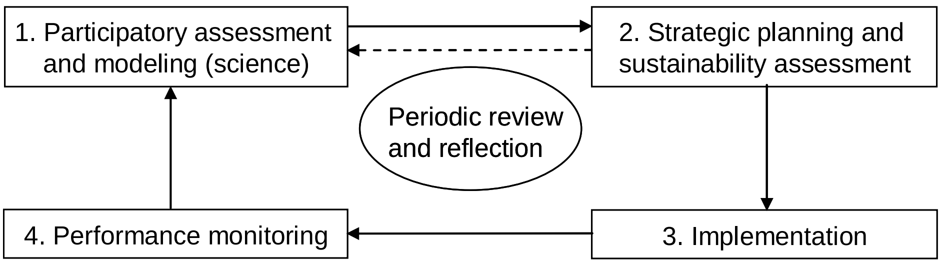

Figure 21: Social learning cycle (DOWNS, 2007)

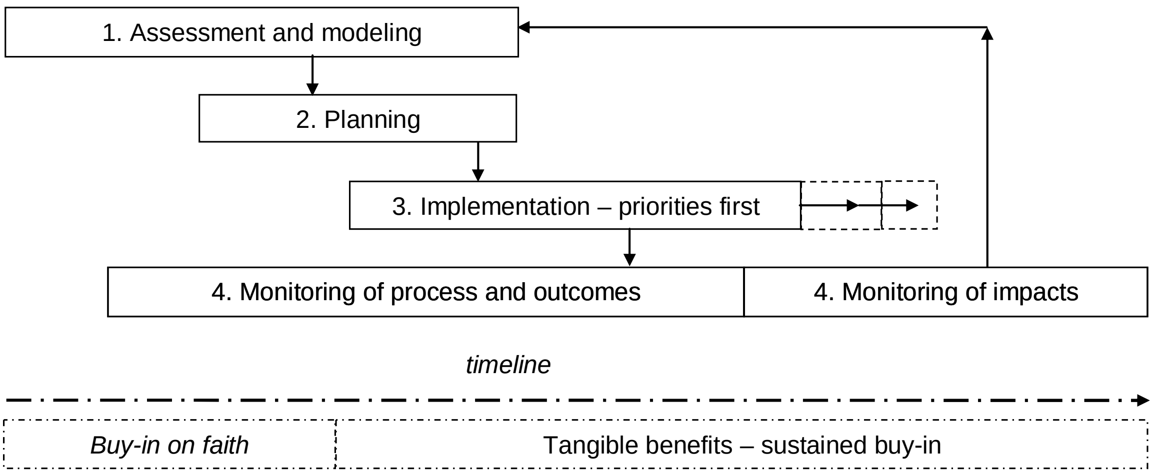

Figure 22: In practice the stages of the social learning cycle overlap (DOWNS, 2007)

These steps are most evident in the Jordan case study with the management capacity developing with each project (Figure 10).

Formulating policies specific to greywater, such as national reuse guidelines, is also an important aspect of greywater management, but discussion of this component is beyond the scope of this thesis.

7.5.1 Assessment

In applying the DPSIR framework to establish useful indicators, NIEMEIJER and DEGROOT (2008) advise it is "best to start with the pressures, as they are typically more concrete than the driving forces and then subsequently work forward from pressures to state, impact and responses and then backward from pressures to driving forces". Indicators should be: policy relevant; easy to understand for all stakeholders; analytically sound; and easily measurable (OECD, 2003).

The assessment can include social surveys, technical sampling, and focused environmental assessment (AL-JAYYOUSI, 2002). Researchers in South Africa (CARDEN *et al*., 2007b) list the most critical factors to be evaluated are:

1. Settlement density,
2. Water consumption,
3. Soil/surface properties (permeability),
4. Topography (slope),
5. Rainfall,
6. Depth to water table,
7. Proximity to sensitive environments, and
8. Current waste management methods.

ERIKSSON *et al*. (2002) strongly recommend a thorough characterisation of greywater and evaluation of possible sources of pollutants to establish proper treatment options.

The price of water, as already mentioned, influences water demand and may be a useful indicator to reflect the need and potential of greywater reuse systems.

Identifying the prevalence of scabies and diarrhoea, via qualitative assessments of health in the community, will help indicate where water is reused for personal hygiene (JUNG, 2007).

7.5.2 Planning

Planning involves defining a strategy of how, where, when, and why to design and implement a particular management response. This work must consider the constraints and criteria, identified in the assessment and is most successful if carried out as an open participatory exercise. Involving all stakeholders, especially women, in the planning phase, is important as they perform a primary role in domestic water resources management (SMIRAT, 2006).

Criteria for selecting a practical site to implement a greywater treatment system were presented in the Mali and Jordan case studies. In each of these case studies there was a focus on individuals willing to demonstrate the function of the innovative greywater management system. Once convinced, this social group of innovators and early adopters then stimulate the innovation diffusion process (ROGERS, 1995).

Coordination of activities by a trusted local institution will be required to manage social involvement and communications. A key to the success of the Jordan greywater pilot project was the involvement of a local NGO as a major stakeholder. "Members were given training in water conservation as well as techniques for separating and treating greywater. The NGOs helped put on workshops providing training in system maintenance and irrigation techniques. A manual on greywater treatment was produced and made available at meetings and workshops" (IDRC, 2006b). Furthermore, winning political support at the national level offered many benefits in scaling up the initiative (IDRC, 2006a). LABAN (2007) promotes the practice of Participatory Technology Development (PTD) to harness local knowledge. He suggests that "involving end-users better in the analysis of difficulties they face and in the design of a new technology will pay off".

Given the negative impacts that inadequate wastewater management has on society, it would be prudent to include wastewater management options when considering the implementation of any water supply system. Water and wastewater thinking must be combined. Future growth and increased demand should also be considered. FAGGIANELLI (2005) reports a 15% increase in the water supply between 1993 and 2003 in Djenné, Mali. This dramatic increase directly influences the amount of greywater produced and the consequences related to its (mis-) management.

The question of onsite versus offsite greywater management was addressed in all case studies. The recommendations outlined by WINTER *et al.* (2006) suggest that onsite greywater management only be practiced where the volume of greywater generated is <2500 l/ha/d or where settlement density <50 du/ha. How these threshold values were established is unclear. The population density in Djenné, Mali is an estimated 290 inhabitants/ha, producing a greywater volume of approximately 8700 l/ha/d, yet onsite greywater management was achieved. It is obvious any greywater management strategy should be tailored to fit the natural and social context.

Where reuse of greywater for irrigation purposes is intended, relatively salt tolerant crops should selected. Table E-2 in the appendix lists various crops by salinity tolerance.

7.5.3 Implementation

Implementation of greywater management, as mentioned, can be specifically directed at influencing the driving forces, pressures, state, and impacts. It involves putting into practice the planned technical and social interventions.

Technical components such as greywater treatment systems primarily aim to reduce the negative health and environmental impacts by purifying greywater to acceptable standards, offering reuse and safe disposal. Reuse offers additional benefits as recovered greywater effluent may reduce demand (and costs) for fresh water, improve food security, and supplement income from irrigated crops.

Construction of effective decentralised greywater treatment systems need not be complex. Locally trained craftsmen can be employed for this task, using locally sourced materials.

Some technical points to consider include:

1. Sizing of the grease/grit trap; a retention time of at least six hours is recommended for effective sedimentation (RIDDERSTOLPE, 2004).

2. Anaerobic attached biofilm systems (fixed-film reactor) are perhaps the most common greywater treatment systems operating under anaerobic conditions and offer a high resilience to hydraulic and organic shock loading (MOREL and DIENER, 2006).
3. The design and plumbing of a greywater collection system is similar to those of mixed wastewater systems. Pipe systems should be accessible for flushing to minimize chances of clogging (RIDDERSTOLPE, 2004).
4. Biological treatment systems often require a start up period of several weeks for microbial growth to establish.

Several preconditions for infiltration include:

- Relatively permeable ground, with a percolation rate (hydraulic conductivity) that allows water to infiltrate in less than 72 hours;
- Minimum depth of at least 1 metre from the bottom of the trench to the seasonal high groundwater level;
- Distance of at least 50 m to drinking water well; and
- Pre-treatment (sediment trap) to prevent clogging of the infiltration media (MCDC & BE, 2001).

As operation and maintenance requirements of decentralised treatment systems usually are more intensive, user training is essential.

The choice of detergent is perhaps one of the simplest methods of altering the composition of greywater without changing one's water use habits. Where greywater is to be reused for irrigation, liquid detergents free of boron and sodium are recommended over hard soaps or powders (LUDWIG, 2000). Using potassium based soap to avoid the effect of sodium is suggested (AL-JAYYOUSI, 2002). This recommendation was put into practice in Jordan with the development of alternative detergents. It would be interesting to learn what difference this substitution makes in terms of crop response and impact on soil.

Within the ROSA project, the first greywater tower garden systems are now being implemented in Arba Minch, Ethiopia. It will be interesting to learn how the community receives this innovation.

7.5.3.1 Adoption

Evident from the case studies is the importance of demonstration sites in creating awareness and interest in the greywater management systems. Once people were convinced of the effectiveness of the greywater system they were more willing to buy-in. Environmental and economic benefits from cleaner surroundings and increased crop yields are the major selling points of decentralised greywater management systems.

7.5.4 Monitoring

The final stage of the social learning cycle involves an evaluation of performance, although this is typically ongoing throughout the project (Figure 22). The indicators identified during the assessment phase are now measured again to determine the effectiveness of an implemented response. What worked? What didn't? Why? The case studies of Mali and Jordan both illustrate the value of monitoring, with lessons being learned and modifications addressed in the next phase of their project development.

Assessing the quality of treated greywater effluent against established guidelines can ensure effective system operation and assure users of the greywater of its safety. By employing additional health protection measures (e.g. washing or cooking crops irrigated with greywater) end users will further minimize the health risks associated with greywater reuse. The efficacy of these hygiene practices should also be monitored.

Finally, national and municipal governments need to acknowledge the realities of greywater mismanagement and the potentials of decentralised greywater reuse or disposal by establishing appropriate management policies specific to greywater.

8 Conclusions

The challenge of delivering water and sanitation services to an increasing human population is especially critical in water scarce developing countries. The ROSA project contributes to this effort, adopting an integrated approach to sanitation. This thesis examines the challenges and potentials of greywater management in arid and semi-arid developing countries and discusses the complexities of crafting decentralised greywater solutions in the context of cooperative development.

Physical, economic, and social water scarcity can severely limit development opportunities and pose as a main constraint to life.

Open discharge of greywater is a common practise in many non-sewered settlements of sub-Saharan Africa and can cause potential negative impacts to humans and the environment. Elevated phosphorus concentrations in greywater are a particular eutrophication hazard to ecologically sensitive waters. High concentrations of sodium are harmful for soils and many crops. Water borne diseases are regarded as a serious health problem, especially affecting children.

Experiences from Mali, Jordan and South Africa show that greywater can be managed successfully at household level. The infiltration trench, 2-barrel, 4-barrel, confined trench, and tower garden systems have proven reliable and successful in their greywater management applications. Greywater reuse can be appreciated as a valuable resource as it increases water productivity. Economic, environmental, and social benefits can be realised through water savings, increased crop production, and effective disposal.

Management involves a process of learning how to design, implement, and operate a management system which is appropriate to the specific context. Identified factors for successful decentralised greywater management include:

- Understanding the natural and socio-economic conditions of the target community.
- An integrated household-centred approach is necessary to design practical intervention strategies.
- Limit contamination of greywater by practising source control. This includes restricting food particles, fats, oils and greases, and excessive soaps and detergents. Biodegradable, low-sodium cleaning products (soaps and detergents) will further support biological treatment potential of the greywater.
- Local involvement in the development of the technology supports a sense of ownership of the system. Successful innovations are often modified and redesigned with local knowledge to meet local needs.
- Selling points of the greywater system include economic benefits such as increased crop production for cash and food security, as well as environmental and health benefits of cleaner surroundings.
- Engage influential community members and institutions to demonstrate the effectiveness of greywater management.
- Capacity building is a key element to empower people with knowledge and skills such that they may develop and benefit from their own system.
- Positive demonstration of greywater management techniques creates awareness and demand.

- Effective communication of activities and results builds networks crucial for diffusion of innovations.

The ROSA project is at the initial stages of developing greywater management strategies. Initial studies of the participating partner institutions show that:

1. Households obtain their water from multiple sources, influencing the volume of water consumed and the subsequent volume of greywater generated.
2. Greywater is generally discharged onto the ground outside of the residence. Reuse of greywater for garden irrigation is as yet not practised very often.
3. Greywater reuse is generally banned for regulatory reasons or regarded as wastewater.

ROSA can learn from the technical and social experiences of Mali, Jordan, and South Africa. Receptive to these ideas, the ROSA team in Arba Minch have started with implementation of several greywater tower gardens throughout the city as experimental demonstration sites.

This study shows that the DPSIR (Drivers-Pressures-State-Impact-Response) conceptual framework is a useful tool that helps to illustrate and structure the interrelated components of domestic water use, identifying numerous options for practical intervention.

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10 Appendices

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APPENDIX A: Supporting Material Addressing Water Scarcity and Integrated Management Options

Table A-1: Policy options for varying types of water scarcity (WOLFE and BROOKS, 2003)

Order of scarcity	Role of public demand	Range of policy choice	Dominant discipline	Responses
First	Forecasts based on history	Low	Engineering	Supply-side projects (dams, pipelines, canals, wells, desalination)
Second	Projections based on economic variables	Medium	Economics	Demand-side management, water as an economic good, technical fixes
Third	Scenario options based on economic & demographic variables	High	Social sciences within biophysical limitations	New options & reallocation, technological change, water-soft path

Table A-2: Capacity building options for varying orders of water scarcity
(WOLFE and BROOKS, 2003)

Order of scarcity	Objectives	Responses/activities	Key challenges
First	Train hydrologic engineers, geologists, irrigation and water treatment technicians.	Locate and develop water supplies, large scale construction of dams and irrigation schemes, urban and rural water and sewerage infrastructure.	Technical issues; supplying sufficient water for all demands. Financing supply infrastructure and services.
Second	Generate & implement (training) based on neoclassical efficiency; institutional reform in line with economic priorities.	Establish economic values of water. Utility-based conservation programmes. Rationing during droughts. Reform water institutions based on economic principles. Allocate decisions based on water-use efficiency.	Financial, administrative, technical limitations. Social resistance to water as an economic good. Inadequate attention to equity.
Third	Implementing 'water-soft' paths.	Change incentives and conditions at the individual, institutional, societal levels. Pre- and post-training activities and targeted participation, responsive to individual constraints on learning. Evaluation of operational effectiveness of capacity building for the institution and individual.	Increased systemic complexity – water institutions are embedded in social and physical context. Need for societal education.

Table A-3: Comparison between current and an integrated, adaptive water management regime
(PAHL-WOSTL, 2007)

	Prediction and control regime	Integrated, adaptive regime
Management paradigm	Prediction and control based on a mechanistic system's approach	Learning and self-organization on a complex systems approach
Governance	Centralized, hierarchical, narrow stakeholder participation	Polycentric, horizontal, broad stakeholder participation
Sectoral integration	Sectors separately analysed resulting in policy conflicts and emergent chronic problems	Cross-sectoral analysis identifies emergent problems and integrates policy implementation
Scale of analysis and operation	Transboundary problems emerge when river sub-basins are the exclusive scale of analysis and management	Transboundary issues addressed by multiple scales of analysis and management
Information management	Understanding fragmented by gaps and lack of information sources that are proprietary	Comprehensive understanding achieved by open, shared information sources that fill gaps and facilitate integration
Infrastructure	Massive, centralized infrastructure, single sources of design, power delivery	Appropriate scale, decentralized, diverse sources of design, power delivery
Finances and risk	Financial resources concentrated in structural protection (sunk costs)	Financial resources diversified using a broad set of private and public financial instruments
Environmental factors	Quantifiable variables such as BOD or nitrate concentrations that can be measured easily	Qualitative and quantitative indicators of whole ecosystem states and ecosystem services

APPENDIX B: Tables of Published Greywater Quality Characteristics

Table B-1: Physical, chemical, and microbiological characteristics of greywater sourced from urban households in Melbourne, Australia (CHRISTOVA-BOAL *et al.*, 1996)

Parameter	Units	Bathroom	Laundry
pH	-	6.4 - 8.1	9.3 - 10
EC* (salinity) at 25°C	µS/cm	82 – 250	190 - 1400
Turbidity	NTU	60 – 240	50 - 210
Suspended Solids	mg/L	48 – 120	88 - 250
Nitrate	mg/L	<0.05 - 0.20	0.10 - 0.31
Ammonia	mg/L	<0.1 – 15	<0.1 - 1.9
TKN	mg/L	4.6 – 20	1.0 - 40
Phosphorus	mg/L	0.11 - 1.8	0.062 - 42
BOD_5	mg/L	76 – 200	48 - 290
Oil & Grease	mg/L	37 – 78	8.0 - 35
Total Alkalinity as $CaCO_3$	mg/L	24 – 43	83 - 200
Calcium (Ca)	mg/L	3.5 - 7.9	3.9 - 12
Magnesium (Mg)	mg/L	1.4 - 2.3	1.1 - 2.9
Sodium (Na)	mg/L	7.4 – 18	49 - 480
Potassium (K)	mg/L	1.5 - 5.2	1.1 - 17
Iron (Fe)	mg/L	0.34 - 1.1	0.29 - 1.0
Zinc (Zn)	mg/L	0.2 - 6.3	0.09 - 0.32
Copper (Cu)	mg/L	0.06 - 0.12	<0.05 - 0.27
Aluminum (Al)	mg/L	<1.0	<1.0 - 21
Sulphur (S)	mg/L	1.2 - 3.3	9.5 - 40
Silicon (Si)	mg/L	3.2 - 4.1	3.8 - 49
Cadmium (Cd)	mg/L	<0.01	<0.01
Arsenic (As)	mg/L	0.001	0.001 - 0.007
Selenium (Se)	mg/L	<0.001	<0.001
Chloride (Cl)	mg/L	9.0 – 18	9.0 - 88
Total coliforms	MPN/100 ml	$500 - 2.4x10^7$	$2.3x10^3 - 3.3x10^5$
Faecal coliforms	MPN/100 ml	$170 - 3.3x10^3$	$110 - 1.09x10^3$
Faecal streptococci	MPN/100 ml	$79 - 2.4x10^3$	$23 - <2.4x10^3$

* equivalent units of measurement: 1 dS/m = 100 mS/m = 1 mS/cm = 1000 µS/cm

Average household water consumption = 250 000 l/y (685 l/d)

Table B-2: Characteristics of combined greywater from 8 peri-urban households in Durban, South Africa (SALUKAZANA *et al*., 2005)

Parameter	Unit	Value
Alkalinity	mg/l	300-334
Ammonia (free)	mg/l	20
BOD	mg/l	280-310
Cadmium	mg/l	<0.05
Calcium	mg/l	<5.0
Chloride	mg/l	210
Chrome	mg/l	0.11
COD	mg/l	1135
Conductivity*	mS/m	144-148
Copper	mg/l	0.1
Lead	mg/l	0.2
Magnesium	mg/l	5.6
Nickel	mg/l	<0.1
Nitrate + Nitrite	mg N/l	<0.1-1.2
Ortho phosphate	mg P/l	11
pH		5.8-6.3
Selenium	mg/l	<0.05
Sulphate	mg/l	113
Total Kjeldahl Nitrogen	mg N/l	24-30
Total phosphate	mg/l	13
Zinc	mg/l	0.22
Total coliforms	cfu/100ml	$4x10^5$
E.coli	cfu/100ml	$4x10^5$
Coliphage	pfu	0
Ascaris spp	ova	0

* equivalent units of measurement:
1 dS/m = 100 mS/m = 1 mS/cm = 1000 µS/cm

Household water consumption = 200 l/d

Table B-3: Mean chemical and microbiological analysis of irrigation solutions (JACKSON *et al*., 2006)

Parameter	Unit	Tap water	Greywater	Hydroponic
Alkalinity	mg/l $CaCO_3$	66	0	29
Ammonia (free)	mg/l N	<0.50	157	32
Boron	mg/l	<0.25	3.4	0.5
Cadmium	mg/l	<0.05	<0.05	<0.05
Calcium	mg/l	16	7.5	115
Chloride	mg/l	35	220	12
Chrome	mg/l	<0.10	0.14	0.1
Conductivity*	mS/m	30	267	223
Copper	mg/l	<0.10	0.1	<0.10
Lead	mg/l	<0.05	<0.05	0.05
Magnesium	mg/l	7.5	7.1	51
Nickel	mg/l	<0.10	<0.10	<0.10
Nitrate + nitrite	mg/l N	0.91	<0.1	88
Orthophosphate	mg/l P	0.02	40	38
pH		7.4	8.1	6.3
Potassium	mg/l	3.6	31	250
Selenium	mg/l	<0.05	<0.05	0.08
Sulphate	mg/l	15	137	576
TKN	mg/l N	<0.50	206	37
Total nitrogen	mg/l N	0.84	206	125
Total phosphate	mg/l P	0.05	69	49
E.coli	cfu/100ml	0	35	0
Enterococcus	cfu/100ml	0	>999	0
Phage	pfu/100ml	0	0	0
Staphylococcus	cfu/100ml	0	0	0
Total coliforms	cfu/100ml	0	$4x10^8$	0

* equivalent units of measurement: 1 dS/m = 100 mS/m = 1 mS/cm = 1000 µS/cm

Household water consumption = 200 l/d

APPENDIX C: **Questionnaire Administered to Select ROSA Project Partners**

Name: ________________________________
Organization: ___________________________________

Source of Water
1. How are people in peri-urban areas supplied with water?
   a) Have own connection to the municipal supply network
   b) Shared public taps
   c) Buy from water vendors
   d) Collect from other water source – please specify ___________________________

2. Do people use different sources of water for different uses? (i.e. drinking water from supply network and wash water from collected rainwater)
____
____

3. How much do people pay for water? ____

Quality of Water
4. What information is available describing the water quality (chemical, physical, biological) of the various sources? ____
____
____

Water Demand
5. How much water do people use per day in the home? ____________________________

6. For which purposes is the water in the home used? -In what proportions?
   a) Drinking ______% or ______litre
   b) Cooking ______% or ______litre
   c) Washing dishes ______% or ______litre
   d) Washing clothes ______% or ______litre
   e) Personal hygiene ______% or ______litre
   f) Flushing toilet ______% or ______litre
   g) Watering garden ______% or ______litre
   h) For other purpose – please specify ______________________________________

7. Are there any seasonal variations in the use of water? ___________________________

8. Which cleaning products do people use (for washing clothes, dishes, themselves)?
____
____

9. Is greywater reuse already practised? YES NO

10. If yes, how do people reuse it?
   a) To irrigate garden
   b) To flush toilet
   c) To wash floors
   d) For other purpose – please specify_______________________________________

10. Do people want to reuse greywater? YES NO

Greywater Management

11. Is greywater treatment already practised? If yes, how do people treat greywater?

____

____

12. How do people currently dispose of their grey water?

____

____

13. Is there a problem with open greywater disposal? YES NO

14. Are septic tanks commonly used for wastewater management? YES NO

15. What resources (material, labour, energy) are available for constructing and operating potential treatment systems?

____

____

16. How much space (e.g. m^2/household) is available for potential greywater treatment system within the peri-urban areas?

____

____

Environmental Conditions

17. What types of soils are found in the peri-urban areas?

____

____

18. What is the groundwater level? ____

19. Is current historical rainfall data available? YES NO

Regulatory Framework

20. What are the regulations concerning greywater disposal and reuse?

____

____

APPENDIX D: Protocol for Assessing Percolation Rate of Soils

Percolation Test Procedure (adapted from BCMOH, 1998)

The percolation test is used to determine the suitability of the soil to absorb sewage effluent. The procedure is as follows:

1. Dig a minimum of two percolation test holes 30 cm square to a depth of the proposed infiltration zone (usually 50 – 80 cm).
2. Remove all loose materials from the hole and roughen any smeared soil surfaces on the walls and bottom of the percolation test holes using a knife or sharp tool. This is especially important if the hole is excavated in clayey soils.
3. Pre-soak the percolation test hole if the soil contains silt and/or clay, otherwise proceed to the next step. Keep the percolation test hole filled with water for a minimum of 4 hours.
4. Fill the percolation test hole with water and allow the water to drain to within 13 cm from the bottom of the hole.
5. Refill the percolation test hole allowing the water to again drain to within 13 cm from the bottom.
6. Add enough water to the percolation test hole to raise the water level within the hole to just above 15.5 cm from the bottom of the hole.
7. When the water level reaches 15.5 cm above the bottom of the hole - start timing until the water level goes down 2.5 cm and reaches 13 cm above the bottom of the hole. Record the time.
8. Repeat steps 6 and 7 until the last two rates of fall do not vary by more than two minutes. NOTE: To help you accurately measure the water level in the test holes as you do this procedure, make a measuring stick with marks at 13 cm and 15.5 cm from the bottom.
9. The percolation rate of the soil is determined by averaging the slowest rates recorded for each percolation hole tested.

Table D-1: Approximate Relationship of Soil Type to Permeability and Percolation Times
(OMMAH, 1997)

Soil Type (Unified Soil Classification)		Coefficient of permeability k (cm/s)	Percolation time T (min/cm)	Comment
Coarse-grained (at least 50% retained by a #200 sieve, 0.075 mm)				
GW	Well-graded gravels, gravel-sand mixtures, little or no fines	10^{-1}	<1	Very permeable UNACCEPTABLE
GP	Poorly graded gravels, gravel-sand mixtures, little or no fines	10^{-1}	<1	Very permeable UNACCEPTABLE
GM	Silty gravels, gravel-silt mixtures	10^{-2}-10^{-4}	4-12	Permeable to medium permeable, depending on amount of silt
GC	Clayey gravels, gravel-sand-clay mixtures	10^{-4}-10^{-6}	12-50	ESTIMATE amount of silt and clay
SW	Well-graded sands, gravelly sands, little or no fines	10^{-1}-10^{-4}	2-12	Medium permeability
SP	Poorly graded or gravelly sand, little or no fines	10^{-1}-10^{-3}	2-8	Medium permeability
SM	Silty sands, sand-silt mixtures	10^{-3}-10^{-5}	8-20	Medium to low permeability
SC	Clayey sands, sand-clay mixtures	10^{-4}-10^{-6}	12-50	Medium to low permeability, depending on amount of clay
Fine-grained (at least 50% passing a #200 sieve)				
ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands, clayey silts with slight plasticity	10^{-5}-10^{-6}	20-50	Medium to low permeability
CL	Inorganic clays of low-to-medium plasticity, gravelly clays, sandy clays, silty clays, lean clays	$\leq 10^{-6}$	>50	UNACCEPTABLE
OL	Organic silts, organic silty clays of low plasticity; liquid limit less than 50	$\leq 10^{-5}$	20-50	ACCEPTABLE, if clay content low enough
MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts	$\leq 10^{-6}$	>50	UNACCEPTABLE
CH	Inorganic clays of medium-to-high plasticity; organic silts	$\leq 10^{-7}$	>50	UNACCEPTABLE
OH	Organic clays of medium-to-high plasticity; organic silts; liquid limit over 50	$\leq 10^{-6}$	>50	UNACCEPTABLE

APPENDIX E: Guidelines for Irrigation with Potentially Saline Water

Table E-1: Guidelines for interpretation of water quality for irrigation (FAO, 2003)

Potential Irrigation Problem			Units	Degree of Restriction on Use		
				None	Slight to Moderate	Severe
Salinity[a]						
EC_w*			dS/m	< 0.7	0.7 – 3.0	> 3.0
Or						
TDS			mg/l	< 450	450 – 2000	> 2000
Infiltration[b]						
SAR	= 0 – 3	and EC_w =	dS/m	> 0.7	0.7 – 0.2	< 0.2
	= 3 – 6	=	dS/m	> 1.2	1.2 – 0.3	< 0.3
	= 6 – 12	=	dS/m	> 1.9	1.9 – 0.5	< 0.5
	= 12 – 20	=	dS/m	> 2.9	2.9 – 1.3	< 1.3
	= 20 – 40	=	dS/m	> 5.0	5.0 – 2.9	< 2.9
Specific Ion Toxicity[c]						
Sodium (Na)[d]						
surface irrigation			SAR	< 3	3 – 9	> 9
sprinkler irrigation			meq/l	< 3	> 3	
Chloride (Cl)[d]						
surface irrigation			meq/l	< 4	4 – 10	> 10
sprinkler irrigation			meq/l	< 3	> 3	
Boron (B)			mg/l	< 0.7	0.7 – 3.0	> 3.0
Miscellaneous Effects						
Nitrogen (NO_3 - N)[e]			mg/l	< 5	5 – 30	> 30
Bicarbonate (HCO_3)			meq/l	< 1.5	1.5 – 8.5	> 8.5
pH				Normal Range 6.5 – 8.4		

* equivalent units of measurement: 1 dS/m = 100 mS/m = 1 mS/cm = 1000 µS/cm

[a] Salinity affects crop water availability.

[b] Affects infiltration rate of water into the soil. Evaluate using SAR and EC_w together. At a given SAR, infiltration rate increases as water salinity increases. Evaluate the potential infiltration problem by SAR as modified by EC_w.

[c] Affects sensitive crops.

[d] For surface irrigation, most tree crops and woody plants are sensitive to sodium and chloride; use the values shown. With overhead sprinkler irrigation and low humidity (< 30%), sodium and chloride may be absorbed through the leaves of sensitive crops.

[e] NO_3 -N means nitrate nitrogen reported in terms of elemental nitrogen (NH_4 -N and Organic-N should be included when wastewater is being tested).

Table E-2: Relative tolerance of various crops to salinity
(adapted from STERN, 1979; LANDON, 1991)

High tolerance	**Medium tolerance**	**Low tolerance**
Barley Cotton Date palm Grasses Rape Spinach	Alfalfa Broccoli Cabbage Cow pea Figs Grapes Kale Maize Oats Olives Peppers Potatoes Soybean Sorghum Wheat	Avocado Beans Carrot Citrus Clovers Mango Onion Pineapple Passion fruit Tomato

11 Curriculum Vitae

Jos received his Bachelor’s of Science degree in Water Resources Engineering in 2002 from the University of Guelph, Canada. He has worked as a field technician for the Ontario Rural Wastewater Centre; completed an internship with GTZ ecological sanitation project in Eschborn, Germany; and worked as a wastewater treatment technician for Waterloo Biofilter Systems in Rockwood, Canada. With this thesis Jos completes his Master’s of Natural Resources Management and Ecological Engineering, undertaken at Lincoln University in Christchurch, New Zealand and University of Natural Resources and Applied Life Sciences Vienna, Austria. In the future Jos is enthusiastic to increase the awareness and application of sustainable water management practices including greywater recycling and waterless sanitation systems.