Sustainable Sanitation

Practice

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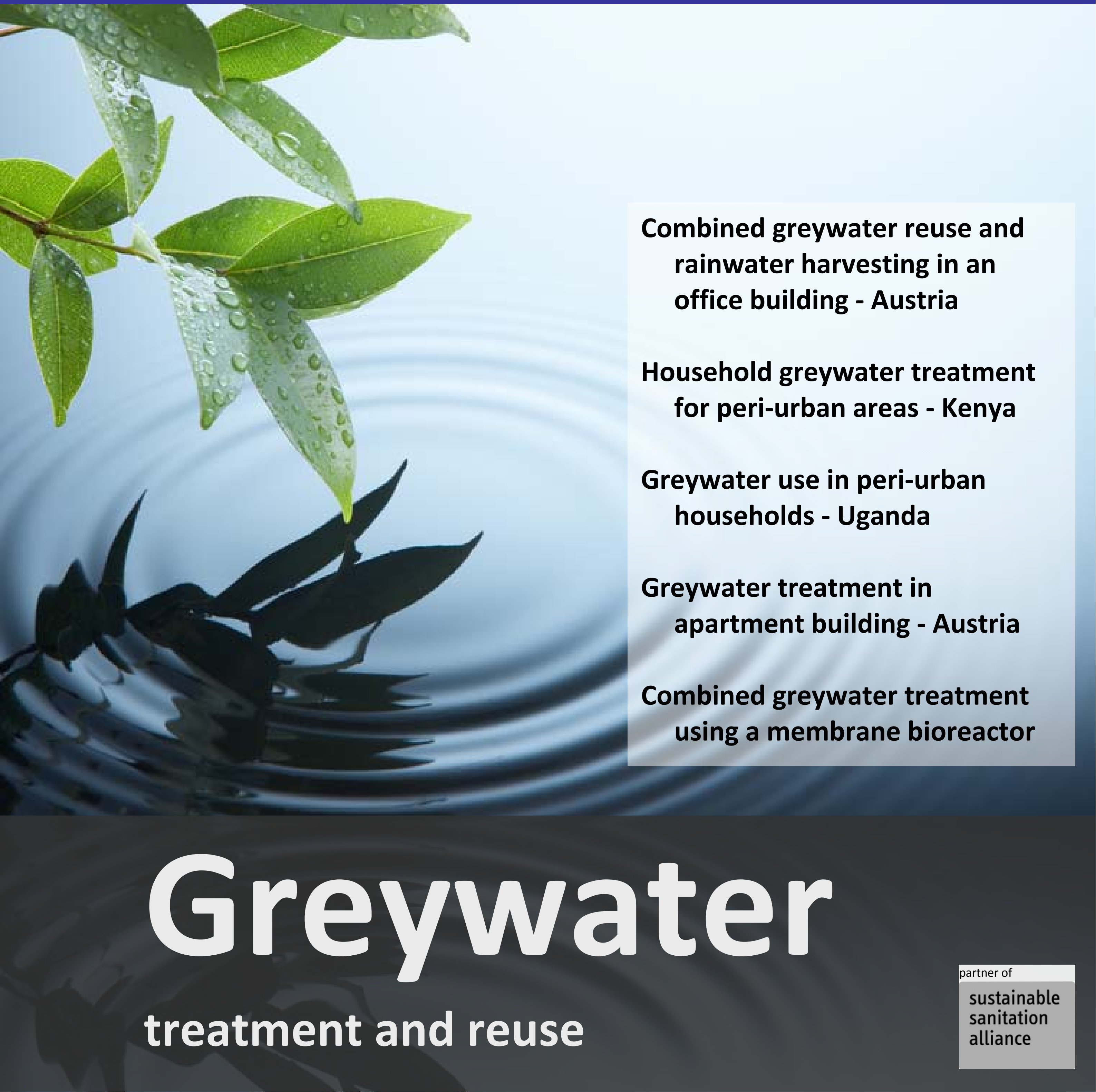

Combined greywater reuse and rainwater harvesting in an office building - Austria

Household greywater treatment for peri-urban areas - Kenya

Greywater use in peri-urban households - Uganda

Greywater treatment in apartment building - Austria

Combined greywater treatment using a membrane bioreactor

Greywater

treatment and reuse

partner of
sustainable
sanitation
alliance

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Sustainable Sanitation Practice (SSP) aims to make available high quality information on practical experiences with sustainable sanitation systems. For SSP a sanitation system is sustainable when it is not only economically viable, socially acceptable and technically and institutionally appropriate, but it should also protect the environment and the natural resources. SSP is therefore fully in line with SuSanA, the Sustainable Sanitation Alliance (www.susana.org). • SSP targets people that are interested in sustainable sanitation systems and the practical approach to it. • Articles are published after blind review only. • Sustainable Sanitation Practice is published quarterly. It is available for free on www.ecosan.at/ssp.

Sustainable Sanitation Practice (SSP) hat zum Ziel praxisrelevante Information in hoher Qualität im Zusammenhang mit „sustainable sanitation“ bereit zu stellen. „sustainable“ also nachhaltig ist ein Sanitärsystem für SSP wenn es wirtschaftlich machbar, soziokulturell akzeptiert, technisch als auch institutionell angemessen ist und die Umwelt und deren Ressourcen schützt. Diese Ansicht harmoniert mit SuSanA, the Sustainable Sanitation Alliance (www.susana.org). • SSP richtet sich an Personen, die sich für die praktische Umsetzung von „sustainable sanitation“ interessieren. • Artikel werden nur nach einer Begutachtung veröffentlicht. • Sustainable Sanitation Practice erschient vierteljährlich, kostenlos unter: www.ecosan.at/ssp.

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publisher: EcoSan Club, Schopenhauerstr. 15/8, A-1180 Vienna, Austria • chairperson: Günter Langergraber • website: http://www.ecosan.at/ • scope: EcoSan Club was funded as a non profit association in 2002 by a group of people active in research and development as well as planning and consultancy in the field of sanitation. The underlying aim is the realisation of ecological concepts to close material cycles in settlements.

Medieninhaber: EcoSan Club, Schopenhauerstr. 15/8, A-1180 Vienna, Austria • Obmann: Günter Langergraber • Gegenstand des Vereins: Der EcoSan Club wurde 2002 als gemeinnütziger Verein von einer Gruppe von Personen gegründet, die in Forschung, Entwicklung, Planung und Beratung in der Siedlungshygiene - Sammlung, Behandlung oder Beseitigung flüssiger und fester Abfälle aus Siedlungen - tätig waren und sind. Das Ziel des EcoSan Clubs ist die Umsetzung kreislauforientierter Siedlungshygienekonzepte (EcoSan Konzepte) zu fördern, um einen Beitrag zum Schutz der Umwelt zu leisten.

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Editorial

With *Sustainable Sanitation Practice (SSP)* we try to make available high quality information on practical experiences with available sustainable sanitation systems. SSP should fill a gap that we have identified in the last few years in which sustainable sanitation has become an important issue that is discussed among many disciplines. For SSP a sanitation system is sustainable when it is not only economically viable, socially acceptable and technically and institutionally appropriate, but it should also protect the environment and the natural resources. SSP is therefore fully in line with SuSanA, the Sustainable Sanitation Alliance (www.susana.org).

SSP is planned to be published quarterly, it will be available online from the journal homepage at the EcoSan Club website (www.ecosan.at/ssp/) for free. Thematic issues shall tackle selected fields of sustainable sanitation systems.

Issue 1 is dedicated to "*Greywater*". Five contributions showing results from projects, in which members of the EcoSan Club Austria have been involved. The papers highlight experiences from East Africa, the Middle East and Europe. Each manuscript has been reviewed by two reviewers. By following this procedure we think that we could meet our expected quality standards.

Greywater is wastewater generated from domestic processes such as dish washing, laundry and bathing, i.e. the part of the wastewater that was not in contact with human excreta. The general quality of greywater can be characterised by low contents of nutrients (nitrogen and phosphorus) and low microbiological contamination (indicator organisms and pathogens). Greywater can be treated effectively and is a good quality source to be reused for various purposes. However, if greywater is not treated and discharged in the environment it can cause serious problems. Greywater issues are therefore an important part within sustainable sanitation systems.

The second issue is currently under preparation. The topic of Issue 2 will be "*Successful models for operation and maintenance of sanitation systems*" and will be published in January 2010. For this issue also experiences from outside EcoSan Club Austria will be presented.

We would like to invite all interested persons to contribute articles to SSP, be available as reviewers and/or suggest topics for future issues. If you are interested and want to contribute as author and/or reviewer please contact for further details the responsible person for the SSP editorial office, Ms. Isabelle Pavese (Email: ssp@ecosan.at). We think that only with this participatory approach it will be possible to target the content of SSP towards the expectations of the readers.

With best regards,
Günter Langergraber, Markus Lechner, Elke Müllegger
EcoSan Club Austria (www.ecosan.at/ssp)

Content:

overall project:

NASPA

Combined greywater reuse and rainwater harvesting in an office building in Austria: analyses of practical operation

Authors: N. Weissenbacher, E. Müllegger

Abstract

The combined system of greywater treatment and reuse in a multi storey office building has been investigated over one year of operation. The system consists of an indoor constructed wetland, rainwater harvesting and water saving measures. The analyses covered quantitative and qualitative aspects like the water saving potential and physico-chemical and microbiological parameters. The existing system has been compared to three other water use scenarios by the calculation of capital cost (investments, re-investments) and operating costs (materials, labour and energy). The results showed that the system was capable to fulfil the physico-chemical requirements suggest by different guidelines but could not ensure the hygienic quality for all operating conditions. In comparison to a conventional system the combined system was capable to reduce the fresh water demand by more than 60%. The economic comparison revealed that the installed system is more expensive than rainwater harvesting only but cheaper than greywater treatment only. The difference to the conventional system was mainly due to the additional labour costs for maintenance and operation. Non-monetary benefits like the positive effect of indoor water treatment on the climate of the building have to be considered within the overall evaluation of such systems.

Figure 1: Rainwater storage canal (left) and indoor greywater treatment (right).

Introduction

Modern water use concepts for buildings aim on saving natural resources ensuring minimum emissions like carbon dioxide and wastewater. Beside the ecological benefits, economic but also additional benefits arise: using the internal water cycle as a visible design element and improving the climate within the building at the same time. In contrast to easily accountable benefits like reduced freshwater consumption the former are more difficult to account for. Nevertheless, they have to be considered to allow a broader application of so called ‘green technologies’. A broad application of such technologies would be an important contribution to freshwater conservation. Before looking for alternative water sources, the first thing to consider is water saving measures. Nowadays, a variety of sanitary equipment to reduce the daily water consumption is available. Low flush toilettes and dry urinals have become common in many public and commercial buildings. Alternatives for fresh water sources are rainwater harvesting and reuse of separated and treated wastewater streams like greywater (wastewater of non-toilet origin). Rainwater harvesting is dependent on the availability of sufficient precipitation. Collection and storage of rainwater is more or less common for single households. The use of treated greywater for applications with lower water quality requirements like irrigation and toilette flushing is not new. Water reuse via greywater has been integrated as component of innovative building concepts since decades (Nolde, 1999). Although, the composition of greywater is different to domestic wastewater in terms of organics, nutrients and microbiological contamination, the treatment concepts applied mainly originate from wastewater treatment (Eriksson et al., 2009; Li et al., 2009). The applied systems vary from extensive biological treatment such as constructed wetlands (CWs) to more sophisticated methods (Knerr et al., 2008). Within the planning process, the three options of water saving, rainwater harvesting and greywater reuse can be applied as single solutions or in combination. The users expect safe and clean water use at the same standard as with conventional systems. The question is how the applied alternative concepts reach these requirements (Reinoso et al., 2008). This paper attempts to describe the results of the analyses of one year operation of a combined system of water saving, rainwater harvesting and greywater reuse in a multi storey office building in Austria. According to the requirements for treated greywater stated by Nolde (1999), the aspects of hygienic safety, aesthetics, environmental impact and economic feasibility have been investigated.

Materials and methods

The investigated building is a three story office building with a total floor space of 2090 m^2 and roof area of 460 m^2. The building is workplace for nine fulltime and five half-time employees. Water is also used for the affiliated car wash and garage. Beside the normal operation, the building serves also as venue for conferences and meetings. The building has been constructed under the Austrian standards for green housing with energy consumption below 10 kWh per square meter and year. Construction was finished in 2003. It is connected to the public water supply and sewer system. The integrated water concept of the building comprises the following components:

- Water saving measures: Low flush toilets and dry urinals
- Rainwater harvesting: Roof collection and outdoor storage in an open canal (Figure 1, left)
- Greywater treatment: In-door CW treatment (Figure 1, right)

Quantitative and qualitative measurements

Treated greywater and rainwater is mixed in the water storage tank for non-potable use (16 m^3) and partly circulated over the indoor-CW to avoid odour. Also the rainwater stored out-door was circulated via a separate line. The scheme of the combined treatment system is shown in Figure 2. Water flow was measured continuously at the sampling points Q1-07 over a period of one year. Additionally, the following parameters were analysed at the sampling points Q5, Q7 and Q8 (Figure 2):

- Organics: BOD_5, COD, TOC.
- Nutrients: Total Nitrogen, Ammonium, Nitrite, Nitrate, Total phosphorus.
- Microbiological parameters: Total coliforms, E.coli, Enterococci.
- Suspended matter: Total suspended solids.
- On-site parameters: Dissolved oxygen (DO), Electrical conductivity, Redox potential, pH and Temperature.

The lab analyses were carried out during three different sampling periods with monthly grab sampling (during one year), daily grab sampling (for one week) and 2h mixed samples (for two days).

The applied indoor- greywater treatment is a vertical flow sub surface CW with a surface area of 3 m^2. The configuration of the CW was 10 cm top layer of coarse gravel, 60 cm main layer (1 -4 mm) and 20 cm drainage layer. The inflow was intermitted at a flow rate of 15 L/min for one minute every eight minutes (100 L/h). The system was sparesly planted with *Philodendron sp.* and *Spathiphyllun sp*.

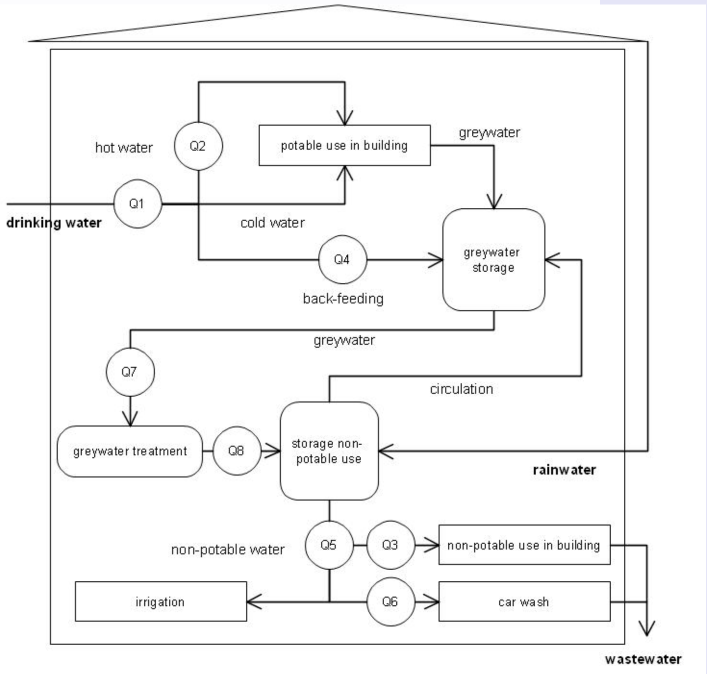

Figure 2: Scheme of the combined greywater and rainwater system. Quantitative measurements have been carried out at points Q1 to Q7, qualitative sampling at points Q5, Q7 and Q8, respectively.

Economic analyses

The economic analyses are based on a dynamic cost calculation using an overall interest rate of three percent for a life span of the system of 25 years and 12 years for mechanical and electrical equipment, respectively (LAWA, 2005). The analyses comprised investment costs, re-investment costs and operation and maintenance costs. The latter cover energy costs, labour and material costs. Data was collected by interviews with the responsible operator. To compare the existing system with other possible options, the estimated costs of the system components reported at the planning stage have been used. The following planning scenarios were investigated:

- Conventional system
- Greywater treatment and reuse only
- Rainwater harvesting only
- Combined system (existing)

It is important to mention that the water saving measures have been considered as option for every planning scenario since the water consumption patterns directly influence the economics of the different variants. The economic benefit of water saving was calculates based on the local tariffs for public drinking water supply and wastewater disposal. For the calculation of labour costs, standard costs for technicians in Austria have been used.

Results and Discussion

Greywater treatment

The median influent nutrient ratio of COD: N: P= 5:1:1 was unfavourable for the biological community compared to the optimum value of 100:20:1 (Metcalf and Eddy, 1991) due to the high dilution rate by the circulation (average 1:10). Also, the organics and nutrient concentrations were very low in comparison to usually reported values for greywater in central Europe (FBR, 2005). Average load conditions and removal rates are shown in Table 1.

The 60% load reduction was obtained from measurements - considering the mentioned dilution rate one can estimate a maximum BOD removal of 85% from incoming raw and undiluted greywater. The nutrient content remained more or less unchanged. Having in mind that CWs may easily reach more than 95 % of BOD removal in wastewater treatment (Haberl and Pressl, 2005) these results are unsatisfying. The phosphorus load was observed to be exceptionally high compared to literature values (Li et al., 2009) – the reason could be the use of industrial cleaning agents containing phosphates. The high hydraulic loading resulted in periodic blocking of the filter media and very low nitrification (median of ammonium elimination was zero) due to limited oxygen transfer. Besides that, circulation of the mixed greywater and rainwater resulted in a substantial additional energy demand.

Table 1: Average load conditions and removal rates of organics and nutrients over one year.

Parameter	Daily		Reduction	
Organic load (BOD)	22 g/d	7,3 g/(m^2.d)	60 %	4,4 g/(m^2.d)
Nitrogen load	12 g/d	4,0 g/(m^2.d)	0 %	0 g/(m^2.d)
Phosphorous load	34 g/d	11,3 g/(m^2.d)	0 %	0 g/(m^2.d)
Hydraulic load	3 m^3/d	1 m^3/(m^2.d)	-	

n.a.…not available; n.d…not detectable

1) EU bathing water directive (Directive 2006/7/EC)
2) German guidelines for greywater recycling.
3) Austrian guidelines for irrigation water quality.
4) German standards for irrigation water quality.

An important aspect for non-potable water use in buildings is the hygienic quality. Quality standards for greywater recycling are given by FBR (2005). The given suggestions are a combination of the microbiological standards of the German drinking water regulation and the European guidelines for the quality of bathing water (Directive 2006/7/EC). The requirements of the different regulations, standards and guidelines available in Germany and Austria are shown in Table 2.

40 % of the analysed CW effluent samples reached the quality standards of the EU bathing water quality directive and the half reached standards suggested by FBR (2005). Comparable results for other CWs have been reported and the need for subsequent disinfection was stated elsewhere (Li et al., 2009; Reinoso et al. 2008). The standards for irrigation water quality given by OEWAV A011 and DIN 19650 were reached by 50% and 80% of the monthly samples, respectively. The quality requirements for other than microbiological parameters like organic load and oxygen conditions suggested by FBR (2005) and suspended solids (Asano, 2007) were fulfilled by the system.

Beside the maintenance efforts for cleaning the screening and pre-treatment of the indoor CW, the operator is satisfied with the systems operation so far. Additional efforts arise occasionally by the algae bloom in the outdoor water canal and due to blocking of the indoor constructed wetland.

Rainwater harvesting

The quantitative measurements showed that about 25% of the yearly non-potable water consumption was covered by rainwater. Due to the cold weather conditions during December and January, the rainwater collection was put out of

Table 2: Summary of microbiological parameters suggested for different applications.

Parameter	Bathing water	Non-potable water	Irrigation water	
	1) EU-Dir.	2) FBR	3) OEWAV A011	4) DIN 19650
E. Coli /100ml	<1,000	<1,000	<2,000	<2,000
Enterococci/100ml	<400	n.a.	<1,000	-
Salmonella /100ml	n.a.	n.a.	n.a.	n.d.
Coliforms /100ml	n.a.	<10,000	n.a.	n.a.
Pseudomonas Aeruginosa /100ml	n.a.	<100	n.a.	n.a.

service during those two months. During this time period potable water was added to the storage tank for non potable use by back feeding (Figure 2). The circulation of rainwater in the out-door canal resulted in additional energy consumption.

Water saving potential

The water balance resulted in total water consumption of 145 m^3 per year and a drinking water consumption of 83 m^3 per year. The average water consumption was about 20 L per employee and day which is 20 % below the standard amount of 25 L given by the German guidelines for office buildings (VDI 3807). The combined greywater and rainwater use leads to an overall reduction of potable water demand of more than 60%. Since the wastewater discharge tariffs are linked to the drinking water consumption, this reduction also reduces the wastewater fees significantly. The daily drinking water consumption was 240 L/d (median) and the daily non-potable water consumption was 320 L/d (median). During conferences and meetings, the drinking water consumption and hence the greywater production was increased up to 2300 L/d. The monthly averages of the daily water consumption are shown in Figure 3.

The results confirm the assumptions of the system design (300 l/d estimated for non-potable use). The non-potable use showed no significant yearly variation (Figure 4). This was not unexpected since no non-potable water has been used for irrigation during the observations.

Economics

Three additional system scenarios have been calculated to compare the costs and benefits of the existing system to other technical options. The scenarios can be described as follows:

- Scenario 0 (a/b): Conventional system.
- Scenario 1 (a/b): Combined rainwater harvesting - greywater reuse system (existing).
- Scenario 2 (a/b): Greywater reuse system.
- Scenario 3 (a/b): Rainwater harvesting system.

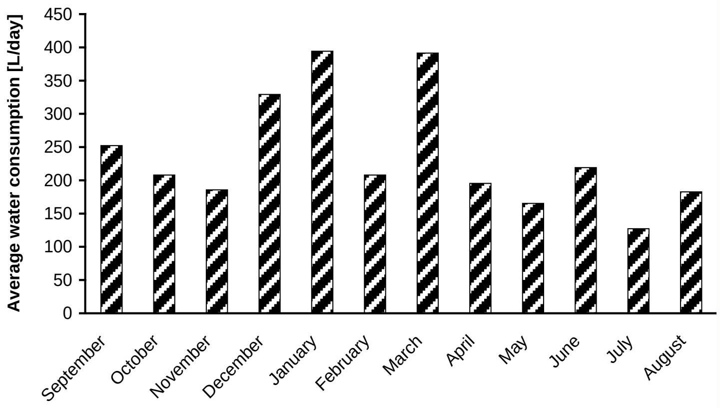

Figure 3: Average daily potable water consumption over one year.

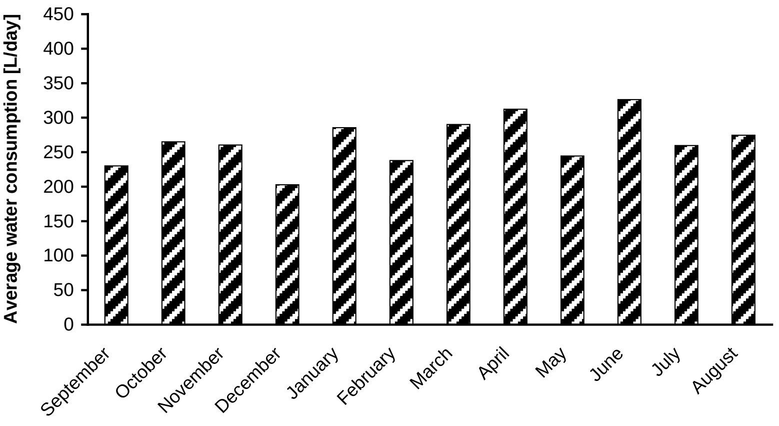

Figure 4: Average daily non-potable water consumption over one year.

As mentioned above, water saving measures have been considered for every technical option (sub scenarios (a) with and scenarios (b) without water saving measures). The capital value represents the total project costs at the start of operation. Financial benefits due to lower water supply and disposal fees are included in the operating costs. The results in Table 3 show that the conventional solution is not the cheapest. The difference between the conventional scenario and the existing system lies with the relatively high personal costs for operation and maintenance. The low operating costs and medium investment costs lead to the good result for rainwater harvesting. Energy costs for pumping are relatively high when circulation of rainwater or treated greywater is necessary but low in comparison to labour costs for maintenance. Nevertheless, energy demands should be reduced as far as possible to foster the sustainable character of non-potable water use systems.

Table 3: Comparison of the costs and the water saving potentials of the different water use scenarios (life span 25 years, re-investment period 12 years, interest rate 3% p.a.).

Scenarios	Investments €	Re-Investments €	Operating costs €/a	Drinking water demand m^3/a	Capital value €
0 a- Conventional	9,100	1,500	1,500	145	36,900
0 b- Conventional	8,400	900	1,700	170	38,000
1 a- Combined	17,300	3,100	2,200	62	47,400
1 b- Combined	16,600	2,500	2,200	62	43,400
2 a- Greywater	16,740	3,100	2,300	73	49,100
2 b- Greywater	16,000	2,500	2,400	104	52,000
3 a- Rainwater	13,750	2,500	1,200	83	28,800
3 b- Rainwater	13,000	1,920	1,200	88	25,900

Further, the results indicate that greywater reuse only or rainwater harvesting only result in a higher drinking water demand and lower water saving potential. The influence of the water saving measures is evident for the scenarios 0 and 2. The influence on scenario 3 is relatively low, because the water saving measured impact the drinking water demand only in months without sufficient rainfall (winter months in Austria). The existing system showed the highest potential for water saving. Only about one third of the conventional scenario was consumed. The capital value of the installed system is more than 20,000 € higher than the cheapest scenario (rainwater harvesting). For the comparison of scenarios for decision making it is necessary to include non-monetary aspects into the evaluation. The positive effect of indoor treatment plants of the buildings climate and the company's reputation as green player may change the results above.

Conclusions

Summarizing the main results from above, the following conclusions can be given:

- The removal performance of the indoor greywater treatment system in terms of organic matter and nutrients was below the reported performance of other comparable systems, but the required quality of the mixed non-potable water for the physico-chemical parameters was sufficient according to various guidelines. The required reduction of microbiological parameters could not be ensured for all operating conditions.
- The aesthetics of the non-potable water was sufficient for all operating conditions, the use of mixed greywater and rainwater did not lead to any disorders over five years of operation.
- It was shown that the combined system of water saving, greywater reuse and rainwater harvesting leads to the highest fresh water savings. The existing combination allows a freshwater consumption of only one third of a conventional system.
- A comparison of the capital costs of the existing combined system to three additional water use scenarios shows that the existing system is more expensive than rainwater harvesting but cheaper than greywater reuse only. The difference to a conventional concept is rather low and the additional costs are mainly due to the high labour costs for operation and maintenance. Non-monetary benefits like the positive climatic effect for the building can be also accounted for the installed system.

Within five years of practical experience, the system fulfilled the expectations of the operator of this multi storey office building. Drawbacks are the high energy demand of the greywater treatment system due to the circulation and the related adverse influence on the treatment performance and filter permeability. Dilution and intensive circulation over the constructed wetland should be avoided.

Acknowledgements

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overall project:

Household greywater treatment for peri-urban areas of Nakuru Municipality, Kenya

Within the EU funded ROSA-project (Resource oriented Sanitation concepts in peri-urban areas in Africa) different greywater treatment pilot systems were implemented and assessed in Nakuru municipality.

Authors: J. Raude, B. Mutua, M. Chemelil, L. Kraft, K. Sleytr

Abstract

Within the EU funded project ROSA (Resource oriented Sanitation concepts in peri-urban areas in Africa) a baseline survey was carried out to asses the current greywater disposal situation, the quantity and quality of greywater in the peri urban areas of Nakuru, Kenya. It was found out that most of the produced greywater is not used, not reused and not treated although contaminated with nutrients and bacteria. Therefore there is a big demand for adequate treatment systems which are implemented within the ROSA project and presented in this article.

Introduction

Around the entire world, insufficient access to safe water and basic sanitation has led to more deaths than in military conflicts. According to estimates by UNDP (2006), for every single minute, over 3 children lose their lives due to diseases related to unsafe water and poor sanitation. The World Health Organization (WHO) attributes 13-17% mortality from diarrhoea for children less than 5 years of age. Safe water and basic sanitation must be regarded as a basic human right and should therefore be accessible and affordable to all (MWI, 2007). To achieve the UN Millennium Development Goals (MDGs) and the national strategy in the Economic Recovery Strategy for Wealth and Employment Creation (ERS-WEC), it is important to address sanitation challenges in urban and peri-urban areas. Kenya faces serious challenges with regard to water and sanitation services. Despite the efforts of investments provided in the past years by the government and development partners, existing facilities have continued to deteriorate and have also failed to meet the demand of the equally increasing population (MWI, 2007). These challenges are particularly severe in many rural and rapidly growing settlements of urban poor where over 60% of the urban populations live. With a population growth of about 8% in the low income urban settlements (MWI, 2007), many unplanned structures still continue to be built.

Greywater (wastewater stream from kitchen, laundry, sinks, bath-tubs and showers) produced by the average household is the largest in volume. When freshly released, it contains a relatively lower number of potentially harmful compounds. Consequently, it is often discharged untreated into a watercourse or any available empty space under the assumption that serious damage might not result. These practices however present potential risks of transmission of a large number of water-related diseases. Hence, there is need for proper management of aquatic resources and also of the pollutants. A sensible management strategy involves analysis of the composition of greywater and creating a barrier through quality improvement before reuse or safe disposal. Therefore in this study greywater was characterized in quantity and quality to define, design and build adequate treatment options.

Current situation in Nakuru

Nakuru municipality in Kenya, where centralised sewerage connection is inadequate, faces a serious challenge of sustainable access to safe wastewater disposal in the unplanned settlements. In such areas, safe wastewater disposal can be achieved by in-situ separation of domestic wastewater in various streams (grey, yellow, beige, brown and black water) at the source of generation and handling each stream individually. Beige water is anal cleansing water; yellow water is wastewater stream made up of urine and flush water. Black water is a combination of brown and yellow water which is also referred to as night soil while brown water is wastewater stream composed of faeces and flush water. Source separation allows for adequate treatment of different wastewater flows according to their characteristics.

The generated amount of greywater is influenced by factors such as existing water supply services and infrastructure, number of household members, age distribution, lifestyle characteristics etc. (Morel and Diener, 2006). It greatly varies as a function of these dynamics of the households. Table 1 shows daily produced greywater amounts per household in 4 selected areas in Nakuru. Greywater is disposed of in any open spaces available, plastic paper filled storm water drains (Figure 1) or sometimes re-used with limited pre-treatment.

Table 1: Calculated amount of produced greywater per household (Kraft, 2009)

Sampling area	Daily water use [l/d]	Greywater produced [l/d]
Kaptembwo	85	64
Kwa Rhonda	90	67
Mwariki	97	72
Lake View	77	57

Figure 1: Greywater disposal to storm water drain in Nakuru

The common practice in the investigated settlements is to dispose greywater in septic tanks and pit-latrines (29 %) as presented in Figure 2. As a result, most pit-latrines emit foul smell and are full of flies. However, though to a limited extend (3 %) greywater is reused for cleaning pit-latrines thus increasing the problem even further.

This common practice has resulted in a major environmental and public health concern to the residents. The choice of technology in these areas for basic wastewater management is a household decision because ownership and acceptance by the household is a key to sustainable greywater treatment. Decentralized wastewater treatment systems range in size from individual on-site systems serving one household to shared facilities serving about 40 households or public facilities for several households sharing one sanitary facility. However, there is need to develop different treatment options to offer technical solutions in order to reduce health and environmental risks as a result of domestic greywater pollution. This work proposed promoting resources-oriented sanitation, where available nutrients in the effluent can be utilized while reducing environmental pollution. This can drastically reduce fertilizer usage whose price is beyond the reach of urban farmers.

Resources-oriented sanitation that also includes greywater and solid waste management offers economically, ecologically sustainable and

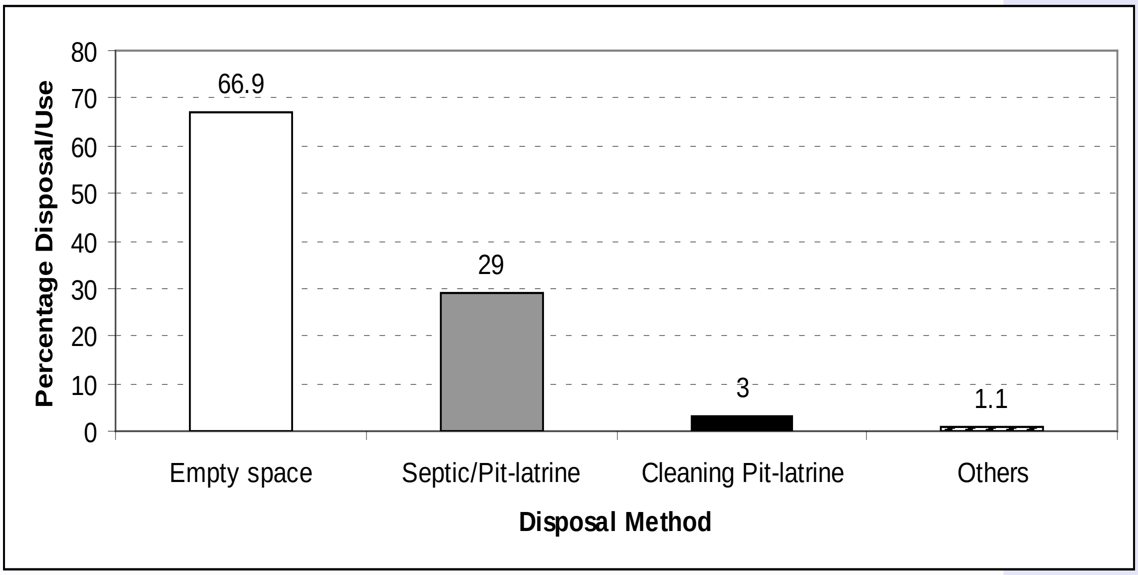

Figure 2: Main greywater disposal practice in the investigated areas of Nakuru

culturally acceptable systems that aim at closing the natural nutrient and water cycle. This can be achieved through best sanitation management practices aimed at improving public health and general environment. Since good hygiene and adequate sanitation are pre-requisites for good health, safe disposal or reuse of greywater can be a solution to achieving good hygiene. Population density however presents itself as a challenge since sanitation related health risks are high in densely populated urban areas. Furthermore, the unplanned settlement structures, like most of the peri urban areas inhibit the integration of sanitation systems. As a result, sewerage connections become technically impossible to construct and sometimes to operate leading to current greywater disposal methods in use that involve emptying in any available open space including roads and foot paths. For safe disposal, greywater can be treated by subjecting it to an on-site treatment system such as the household based constructed wetland at Lake View settlement (Figure 3) and Crater View Secondary School in Nakuru Municipality, Kenya.

Figure 3: Lake View settlement area

To address this problem a horizontal-sub-surface flow constructed wetland (HSSF CW) was established at Lake View and Crater View Secondary School through the support of ROSA project (Langergraber et al, 2008). Within this project a survey to identify and characterise greywater generation and disposal habits in Nakuru provided the basis for designing and implementing resource-oriented greywater treatment systems. In Table 2 the mean values for the following physico-chemical and bacteriological parameters are given: Temperature, pH, Dissolved Oxygen (DO), 5-day Biochemical Oxygen Demand (BOD_5), electrical conductivity (EC), salinity, Total Dissolved Solids (TDS), turbidity, Total Suspended Solids (TSS), organic- and inorganic content, total phosphorus, ortho-phosphohate, ammonia-nitrogen (NH_4-N), nitrate-nitrogen (NO_3-N), nitrite-nitrogen (NO_2-N)and Faecal Coliforms (FC) of 59 greywater samples (24 samples from kitchen, 25 samples from laundry, 10 samples from combined greywater and additional five source water samples). All methods used for the greywater analyses were according to the Manual for Water Quality Analysis, Egerton University, Kenya (Oduor, 2008)

Table 2: Summary of the greywater and source water characteristics (median values) (Kraft, 2009)

Parameter	Unit	Kitchen	Laundry	Combined	Source
Amount	l/d	5.5	56	65.5	87.5
Temperature	°C	20.7	20.0	18.3	23.4
pH		8.1	9.4	8.4	7.0
DO	mg/l	2.17	3.98	1.16	3.50
BOD_5	mg/l	445	449	455	13
EC	µS/cm	974	1365	1247	323
Salinity	g/l	0.45	0.50	0.55	0.20
TDS	mg/l	800	993	981	223
TSS	mg/l	1255	1090	775	2.00
Org. content	mg/l	1200	870	545	1.60
Inorg. content	mg/l	80	260	220	n. d.
TP	mg/l	7.59	9.02	8.28	0.04
SRP	mg/l	3.82	2.77	4.96	0.05
NH_4-N	mg/l	2.13	5.29	7.32	n. d.
NO_3-N	mg/l	3.68	2.44	1.97	3.49
NO_2-N	mg/l	2.63	8.61	2.71	n. d.
FC	log cfu/ 100ml	7.05	5.49	7.04	1.19

n.d. ..not detectable

Piloting area- Nakuru Municipality

Nakuru municipality is on the floor of Great Eastern branch of the Rift Valley and the fourth largest city in Kenya. It is also the administrative headquarters of Rift Valley province and a hub of the province’s commercial activities. The town lies between latitude 0° 10’ and 0° 20’ South and longitude 36° 10’ East and at 1859 m above sea level (MCN et al., 1999). It covers an area of 290 km² of which Nakuru National park takes 188 km² leaving 102 km² to town functions. The population is estimated at 450,000 people (MCN et al., 1999). This municipality like many other urban centres in Kenya has experienced a rapid population growth

Figure 4: Greywater disposal in Nakuru

Figure 5 Greywater disposal in Nakuru

Figure 6: Greywater sampling

thus exerting pressure on existing water and wastewater management facilities.

Implementation of greywater treatment options

Results from Table 1 and Table 2 were used as a guide in developing site specific greywater quality improvement systems ideal for the high density population, low income peri-urban settlements. Table 3 presents some of the considerations in design and construction of the HSSF CW system at Crater View Secondary School and Lake View residential area. The design of the wetland was based on the rule of thumb such as the Austrian and German design standards (ÖNORM B 2505, 2008, and DIN A-262, 2006, respectively) without considering and quantifying the processes occurring inside such filters in detail. More recently, however, efforts have been made to understand and quantify processes in pilot facilities (Langergraber, 2008). To avoid creating another environmental problem in form of malaria mosquito breeding sites, horizontal subsurface flow (HSSF) constructed wetland (CW) system was chosen and water surface maintained at 15-30 cm below the ground level. To sensitize a wider group from Nakuru Municipality, the pilots were established at one residential area (Lake View) and a secondary school (Crater View).

Development of a greywater treatment system involved consideration of institutional and social issues in addition to technical factors. These issues influenced controlled decision making during the planning and preliminary design stages. Also, it involved using a guide to project development after Reeds et al. (1995) involving characterization of greywater by defining the volume and composition to be treated. Concept feasibility which involves determining if any of the natural systems are compatible with site conditions and requirements for greywater treatment.

Table 3: Design details

No	Name	Description
1	Pre-treatment	Two chamber (0.25 & 0.75 m³) litter trap, coarse organic matter; grease trap of cleaning interval not more than 4 times/yr
2	Surface area	Horizontal sub-surface flow constructed wetland (HSSF CW); length = 2m, width = 1m
3	Inlet	Stone distributor; slotted pipe for greywater distribution, inlet depth = 0.86m
4	Treatment volume	Fine gravel (D60 = 3.5mm, Cu = 1.8); initial porosity = 40%; with an average wetted depth of 0.875m; Hydraulic conductivity was 17m/day
5	Outlet	Outlet depth = 0.9m; variable effluent outlet height
6	Flow	Flow rate is set at 1m3/day; hydraulic loading rate (HLR) is 500mm/day
7	Other design considerations	bottom slope of 1-2%; gravel media; geo membrane liner of 1mm thickness
8	Filter material	Building sand cheap and locally available (3-8mm grain-size)
9	Plants	Vetiver grass (*Vetiveria zizanioides*)
10	Retention time	2 days
11	Cost	Treatment system including hand-wash facility Euros 1, 500

Figure 7: Washing facility- Crater View Secondary School

Figure 8: James and Laura – sampling at the HSSF CWs

Results and discussion

The removal rates of the HSSF CW based on an average percentage pollutant reduction are presented in Table 4: BOD_5 99.7%, TSS 97%, TP 88.%, NH_4-N 97% and FC 18% . Sampling commenced four months later after the plants had established. This greywater treatment system was designed with a retention period of less than 48 hours in the settling tank. However, water flow from a nearby borehole through the washing facility was highly variable. The variability was caused by pumping power fluctuations as a result of blackouts and power rationing affecting the entire country. Low electricity output occasioned by low water levels in the hydro-power stations influenced the systems. Consequently, greywater turned septic due to longer storage periods in the settling tanks. A fence had to be built around the site to avoid possible health risks for students that wanted to investigate the system by digging holes into the filter bed and to protect the plants from being eaten by animals.

The general reaction from the school community was positive though with some disappointments. They had a very high expectation of using the effluent for irrigation in the school kitchen garden but due to its high bacterial contamination the outflow of the pilot system could not be recommended for save use. In consecutive studies it is planned to adapt the greywater treatment systems to improve the effluent quality so it can be used safely.

Conclusion

Based on these results and further piloting, HSSF CWs are a promising technology in urban and peri-urban areas that are not served by the central sewer system. Within Nakuru municipality, many poor households are unable to access wastewater collection, transport and treatment services that could save the lives of children and adults from water related ailments. Unless these services reach the poorest, universal coverage will not be achieved. New sanitation policies and initiatives often pay little attention to the greywater handling systems. Population growth and urbanization are a major challenge and present themselves as the main obstacle in integrating sanitation in these settlements. Meanwhile, urban residents continue to suffer from poor sanitation. High child mortality due to poor hygienic conditions is a harsh illustration of the inequalities in society. Generally, problems of poverty are inextricably linked with those of water; its availability, proximity, quantity and quality. The combination of safe drinking water and hygienic sanitation facilities as presented in this case of household based greywater treatment is a pre-condition for good health and success in the fight against poverty, hunger, child deaths and gender inequality. This is also one way of unlocking the billions of people locked in the cycle of poverty and diseases worldwide. Thus, piloting is a tool that helps mobilize community members towards collective action and empowers them to take further action in the future. The outcomes illustrate what communities can achieve by undertaking further initiatives for their own environmental management.

Table 4: Results from influent – effluent laboratory sample analysis

Parameter	EC	Salinity	DO	TDS	BOD_5	TSS	TP	FC	NH_4^+
Units	µS/cm	g/l	mg/l	mg/l	mg/l	mg/l	mg/l	Log 10 FC/100ml	mg/l
Influent	1929	1.0	3.01	1257	104.0	255	2.43	4.97	3.17
Effluent	1644	0.8	0.08	1084	0.33	9	0.29	4.09	0.09
Reduction [%]	14	20	-	14	99.7	97	88	18	97

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Greywater use in peri-urban households in Kitgum, Uganda

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Abstract

In this study, undertaken within the ROSA project (Resource oriented Sanitation concepts in peri-urban areas in Africa), an understanding of greywater characteristics is created to demonstrate a low cost reuse option involving direct application of untreated greywater to small so called “greywater towers” at household level in peri-urban settlements in Kitgum Town Council. It can be concluded that greywater towers provide a simple method to treat and use greywater for gardening.

Introduction

Urbanization in cities of the developing world like Uganda is virtually synonymous with formation of dense human settlements inhabited by the poor, lack of adequate safe drinking water, lack or inadequate sanitation (excreta, greywater and solid waste) and generally a degraded environment. The high populations living under such conditions are subject to health risks. With the increasing demand for freshwater, it is of paramount importance that water consumption shifts towards one, which promotes consumption of adequate amounts of water of acceptable quality. However, this shift requires that alternative sources of water are identified. Experiences elsewhere in the world including several arid and semi-arid countries indicates that greywater can be a cost effective alternative source of water (Morel and Diener, 2006). Greywater is water coming from cloth washers, bathtubs, showers, kitchen sinks and dishwashers and comprises between 50 to 80% of residential wastewater (Al-Jayyousi, 2003).

Governments allocate substantial amounts of money to develop, treat and transport water resources. On the other hand, more money is spent to collect wastewater, treat it and then transport it to distant places for potential uses. To address the externalities of this paradigm, attention is to be focused on small-scale and on-site treatment of wastewater/greywater. In Uganda, very few households particularly in the peri-urban settlements are connected to the sewerage system. In Kampala, the capital city of Uganda < 7% of the city’s households are connected to the sewerage system with the majority using on-site sanitation systems while in Kitgum Town Council (KTC), a semi-arid town in Northern Uganda, on-site sanitation systems predominate (ROSA, 2007).

In the peri-urban areas of Kitgum town like in most cities of developing countries, greywater is disposed of, untreated onto the ground and into open storm water drains. The unsanitary disposal results in creation of malaria mosquito breeding grounds, smelly stagnant waters, children falling ill after playing in the wastewater, etc. (ROSA, 2007). The majority of the communities in the peri-urban settlements of KTC do not reuse the greywater and yet frequently experience water supply shortages following power outages (pumping from the central water supply stalls) and have an inadequate number of boreholes (ROSA, 2007). According to Imhof and Muhlemann (2005), the main barrier for wider and faster dissemination of suitable greywater management systems at household level in the developing countries, is the lack of knowledge and experience. Scientific knowledge is sparse regarding greywater characteristics allowing its reuse. This study, undertaken within the ROSA project (Langergraber et al., 2008), seeks to create an understanding of greywater characteristics and demonstrate a low cost reuse option involving direct application to small gardens at household level in peri-urban settlements in KTC.

Technical detail:

- greywater tower gardens; poles (wooden, iron bars or fence posts) and shading material surrounding the soil and a central stone-packed drain; vegetables (e.g. tomatoes, spinach) are planted into slits of the shading material in the soil;

Background

The project ROSA (Resource-Oriented Sanitation concepts for peri-urban areas in Africa, Langergraber et al., 2008) promotes resource-oriented sanitation concepts as a route to sustainable and ecological sound sanitation in order to meet the UN Millennium Development Goals (MDGs). The project is undertaken in four pilot cities in East Africa namely Arba Minch (Ethiopia), Nakuru (Kenya), Arusha (Tanzania) and Kitgum (Uganda). These cities have a population from several 10,000 up to 500,000 inhabitants and share common problems, e.g. they are situated in rather dry regions resulting in lack of water, have relatively high population growth rates and poor sanitation facilities, if available at all.

Kitgum district is located in Northern Uganda, 452 km from Kampala. The district has experienced civil war characterized with death, abduction, rape, and destruction of social infrastructures and displacement of the people for the last two decades. As a result of this instability, poor sanitation and lack of safe water are the biggest problems encountered in Kitgum. The project study area KTC is the districts headquarter and commercial center of Kitgum district. The town council has an area of 30 km^2 with a population of 62,000 inhabitants spread over 11 parishes and 36 villages. The area includes urban, peri urban and rural typical settlement structures in terms of housing and population density.

Material and methods

Research baseline

To ascertain the baseline situation in the study area regarding greywater reuse practices (if any), a review of available publications and or reports was undertaken. Additionally, interviews were held with 38 households within Kitgum Town Council area.

Identification and sensitisation of study households

The characterization of greywater and installation of greywater towers was limited to selected households in Pondwongo village in KTC. Pondwongo was selected because it is a semi-arid area with water scarcity problems necessitating alternative water sources for agriculture. The selection of the study households involved consultations with the town council authorities, community leaders and local residents by the research team. Seven households categorized as i) high class: households with iron roofed houses with cemented floors and plastered walls; ii) medium class: households with iron roofed houses, could lack cement and/or not plastered and, and iii) low class: households with grass thatched were selected. The selected households were sensitized on how greywater could be utilised through agriculture and the associated potential benefits (Figure 1).

Figure 1 Sensitisation of the households by the research team

For greywater treatment the technology of greywater towers (as described in Crosby, 2005) was selected as it is a simple, innovative system, which uses greywater for growing vegetables on a small footprint (<1 m^2) and can be easy self constructed with a few and local materials. Further more it is easy to operate and maintain.

Setting up of the greywater towers

3 greywater towers were set up at each of the selected households. At one household, a control tower garden was set up in exactly the same way as the greywater tower. It was also planted with the same vegetables, but with the only difference that it was being fed with groundwater and not with greywater. Greywater towers are a user friendly and innovative way of using greywater for gardening in low and middle income countries and have been implemented for example in Kenya, South Africa and Ethiopia. The study households were trained by the research team on how to set up the greywater towers as well as on the operation and maintenance aspects of these for effective performance.

When setting up a greywater tower garden, a circle was marked out on the ground with a diameter as that of the shade cloth (Figure 2a). This circle was dug out to form the bottom layer of the tower garden. Side wooden poles (2m high) were planted firmly into the bottom following which a shade cloth was tied around the poles to make a cylinder (Figure 2b). The sides of the shade cloth were then rolled cylinder out before back filling (Figure 2c).

Figure 2 Setting up of a tower garden at one of the households in KTC

The back fill consisted of a mixture of three parts of soil, two parts of animal manure and one part of ash to provide facility. The different parts were measured out by volume using a bucket (Figure 2d). The backfill was then well mixed before applying it (Figure 2e). A bucket with its bottom removed was placed at the bottom in the middle of the tower (Figure 2f). Stones were carefully packed in the bucket in such a way that did not permit fast flow of the water through (Figure 2g). The sides of the bucket were back filled with the soil mixture (Figure 2h). The bucket was then partially pulled out leaving the stones in position. The bucket was placed again and filled with stones and sides back filled (Figure 2i). This was repeated for each soil layer until the top layer of the tower garden (Figure 2j and Figure 2k).

Operation of the greywater towers

Greywater towers were operated in such a way that greywater from the bathroom and laundry was applied on a daily basis. On average each greywater tower could receive about 3 litres of greywater per day. Over the weekend, the greywater towers were splashed with 2 buckets (about 10litres) of clean water to wash away the soap. Selected vegetables such as tomatoes and onions were planted on the greywater towers. The control tower garden received about 3 litres of groundwater per day that was used by the household for domestic purposes.

Greywater sample collection and analysis

Samples were collected from 6 households every two to three weeks from 3 greywater streams (kitchen, laundry and bathroom) for a period of 6 months. Physico-chemical and bacteriological analyses of the greywater were determined for the selected parameters: pH, Dissolved Oxygen (DO), Electrical conductivity (EC), Temperature, Total Dissolved Solids (TDS), Turbidity, Chemical Oxygen Demand (COD), 5-day Biochemical Oxygen Demand (BOD_5), Ammonia-Nitrogen (NH_3-N), Ortho

Phosphorus, Total Phosphorus, Sodium Adsorption Ratio (SAR) and E. Coli. The parameters pH, DO, EC and Temperature were determined in-situ using a calibrated multi-parameter meter (Quanta-Hydrolab). Samples for physico-chemical and bacteriological analyses were collected in acid rinsed and steriled bottles respectively, stored in a cool box at 4^oC and transported for analysis to the Public Health and Environmental Engineering Laboratory at Makerere University in Kampala. Prior to the analysis for ortho and total phosphorus, and ammonia nitrogen. The samples were filtered through a 1.2 μm Whatman glass microfibre filter paper (GF/C). COD was determined using the Closed Reflux, Titrimetric method (APHA/AWWA/WEF, 1998). BOD_5 was determined by pressure difference within a closed system (BOD_5 CW7000 direct reading apparatus) according to the instrument manual. Total phosphorus was determined using the ascorbic acid method with persulfate digestion while Ortho phosphorus was measured using the ascorbic acid method (APHA/AWWF/WEF, 1998). NH_3-N was determined using the Direct Nesslerization method (APHA/AWWF/WEF, 1998). Potassium, sodium, calcium and magnesium were determined using atomic absorption spectrometry (Perkin-Elmer 2380). Sodium Adsorption ratio was calculated from the measured concentrations of sodium, calcium and magnesium ions (Alit et al., 2006). E.Coli determination was according to the membrane filtration technique using Chromocult agar (APHA/AWWF/WEF, 1998).

Soil sample collection and analysis

To ascertain the impact of the greywater on the soils, soil samples were collected at each household initially prior to greywater application and analyzed for pH, organic matter content, nitrogen, phosphorus and potassium. After the application of greywater, soil samples from the greywater towers were later picked on a monthly basis for a period of 3 months and analysed for the same parameters at the Soil Science Laboratory at Makerere University, Kampala, according to analytical techniques in Okalebo (2002). pH was measured using the electrode method in a soil-water suspension using a 1:2.5 (w/v) ratio, organic matter determination was according to the Walkley and Black Method, Total nitrogen was analysed using the Kjeldahl method, potassium was determined by flame photometry method while measurement of phosphorus was according to the Bray method (Okalebo, 2002). Given the close proximity of the households in the area, the soils used in the greywater towers were loam soils.

Plant measurements

To assess the impact of greywater application on plant growth, measurements at two households with greywater towers and the control were taken. This involved measurements of stems, leaves, number of seeds, number of leaves, and length of internodes.

Results

Greywater reuse

A review of the baseline study report (ROSA, 2007) indicated that there was no greywater reuse in the study area. The generated greywater is either disposed of in open places (68%) and or open channels traversing the area and where possible, in soak pits by 21% of the households (ROSA, 2007). These findings were corroborated by the interview findings in this study with the majority of the respondent households, 61% and 76% disposing of kitchen and laundry wastewater respectively on the ground. Most of the respondent households (71%) discharge their bathroom wastewater into soak pits. Interestingly, a few respondent households (11%) pour their kitchen greywater into the gardens. Interviews with the locals indicated that they were not aware of any greywater disposal best practices but expressed willingness to reuse greywater if taught how. Responses from the study households indicated that they had no objection to having the demonstration units for greywater reuse (greywater towers) set up at their homes.

Amount of greywater produced

The generation of grey water by households is directly related to the consumption of water. Of the 38 households interviewed, the majority (63%) use 3 to 5 jerrycans of water daily for domestic cores including drinking. Given that each jerrycan holds 20 liters, about 60 to 80 liters of water are used daily for washing kitchen utensils, laundry, bathing and drinking by each household. Since no wastewater enters the sewers in Paradwong parish in KTC, the quantity of greywater generated daily per household may be estimated to be 80% of the water consumption (Punimia, 1998). This means that approximately 48 to 64 liters of grey water are being produced on a daily basis by each household in Ktigum town council. As a result of the water scarcity in the region the quantity of greywater produced is low. The greywater quality generated by these households is therefore highly polluted (section 4.3) as small quantities of water are used for a number of domestic purposes before eventual disposal, as observed in informal settlements worldwide (Armitage et al., 2009).

Physicochemical characteristics of the greywater

The characteristics of the greywater from the different sources (n=35) are presented in Figure 3. The results depict some variation of the measured parameters between source types. The greywater is moderately alkaline with the laundry water having pH values that fall outside the effluent discharge standards (i.e. 6-8, NEMA 1999) but is in line with the range observed elsewhere (i.e. 8-10, Eriksson et al., 2002). The high pH values of the laundry water may be due to the alkalinity of the detergents and or soaps that are used (Christova-Boal et al., 1996). However, given the pH range for other greywater types, the alkalinity of the freshwater used in the area which is primarily groundwater, may also be important (ROSA, 2007).

The SAR is higher in laundry water followed by bathroom and kitchen water in that order. The high laundry SAR values may be a result of the type of detergents or soaps used. Long term application of water with a high SAR can be detrimental to the hydraulic conductivity and physical properties of soils and associated plant systems (Wiel-Shafran et al., 2006). Most commercially available bathroom/laundry products are currently manufactured using various types and quantities of sodium salts. Hence given the SAR values of the greywater validates the need to apply freshwater to the greywater towers as a control measure against soil damage (clogging).

The temperature is relatively highest for bathroom waters with the kitchen and laundry waters having almost similar average values. The probable explanation for this discrepancy is that waters for bathing purposes particularly in the mornings are warmed up. All the greywater source types exhibit high turbidity, with mean values greater than the stipulated national effluent discharge standard (i.e. >100 NTU, NEMA 1999). The laundry waters have the highest turbidity most likely due to more soap use compared to that in the kitchen and bathroom. During sample analysis the laundry greywater was blue in colour with a cloudy appearance which was thought to result from more soap use. Turbidity in these wastewaters may also be related to the presence of high content of suspended solid material in the wastewaters (Eriksson et al., 2002). Here, possible high suspended solid material content is found in laundry water followed by bathroom water. The likely explanation may be the dirty laundry and bathing by the children who were the majority in the households visited.

The average TDS content of kitchen and bathroom greywater sources are generally within the national effluent discharge standards (i.e. <1000 mg/l, NEMA 1999) which is not the case with the values occurring in laundry water. The total dissolved solids content of the greywater types follows a similar trend to that of electrical conductivity with laundry exhibiting higher values (Figure 3).

All the greywater sources have mean phosphorus levels with in the national effluent discharge standards (i.e. < 5 and 10 mg/l for Ortho and Total-P, respectively) as indicated in Figure 3. The total phosphorus levels indicate that phosphorus containing detergents are used (i.e. > 3mg/l, WHO, 2006). Despite this, phosphorus when disposed to the greywater tower is not a problem since it is a plant nutrient. However, problems may accrue if the soils become phosphate saturated resulting in leaching to the groundwater and or to run-off to a surface water source. The ammonia nitrogen levels for the greywater obtained here, are higher than values cited in other studies in the developed countries with the greywater in these cases considered light (Birks and Hills, 2007; Eriksson et al., 2002).

The greywater types exhibit high mean BOD_5 and COD values well above the national effluent discharge standards (i.e. >30 mg BOD_5/l and 100 mg COD/l). The high COD in Kitchen greywater is in line with the high COD values recorded for the developed countries (Travis et al., 2008). Laundry greywater exhibits the highest BOD_5 values followed by kitchen greywater.

Bacteriological characteristics of greywater

E.coli were used to characterize the bacteriological quality of the greywater from the 3 sources. There was not much variation in the E.coli results for the different greywater source types with the bathroom greywater having less E.coli counts compared to the other 2 sources (Table 1). The bacteriological counts of the greywater sources is similar to that of raw sewage as observed for greywater discharging from informal settlements (Carden et al., 2007). The high E.coli counts exhibited in the kitchen greywater may be due to the sources of water used which are mainly open streams and waters from River Pager, given the limited availability of boreholes. According to a water quality survey by Oxfam, Environmental Researchers and KTC Health Department and Water Sector in January 2007, sampled streams and rivers had E. Coli counts of≥ 100 cfu/100ml. It was noted that the counts are most likely higher in the wet season given the poor environmental sanitation in the area. Additionally, the children who frequently wash kitchen utensils have dirty and contaminated fingers.

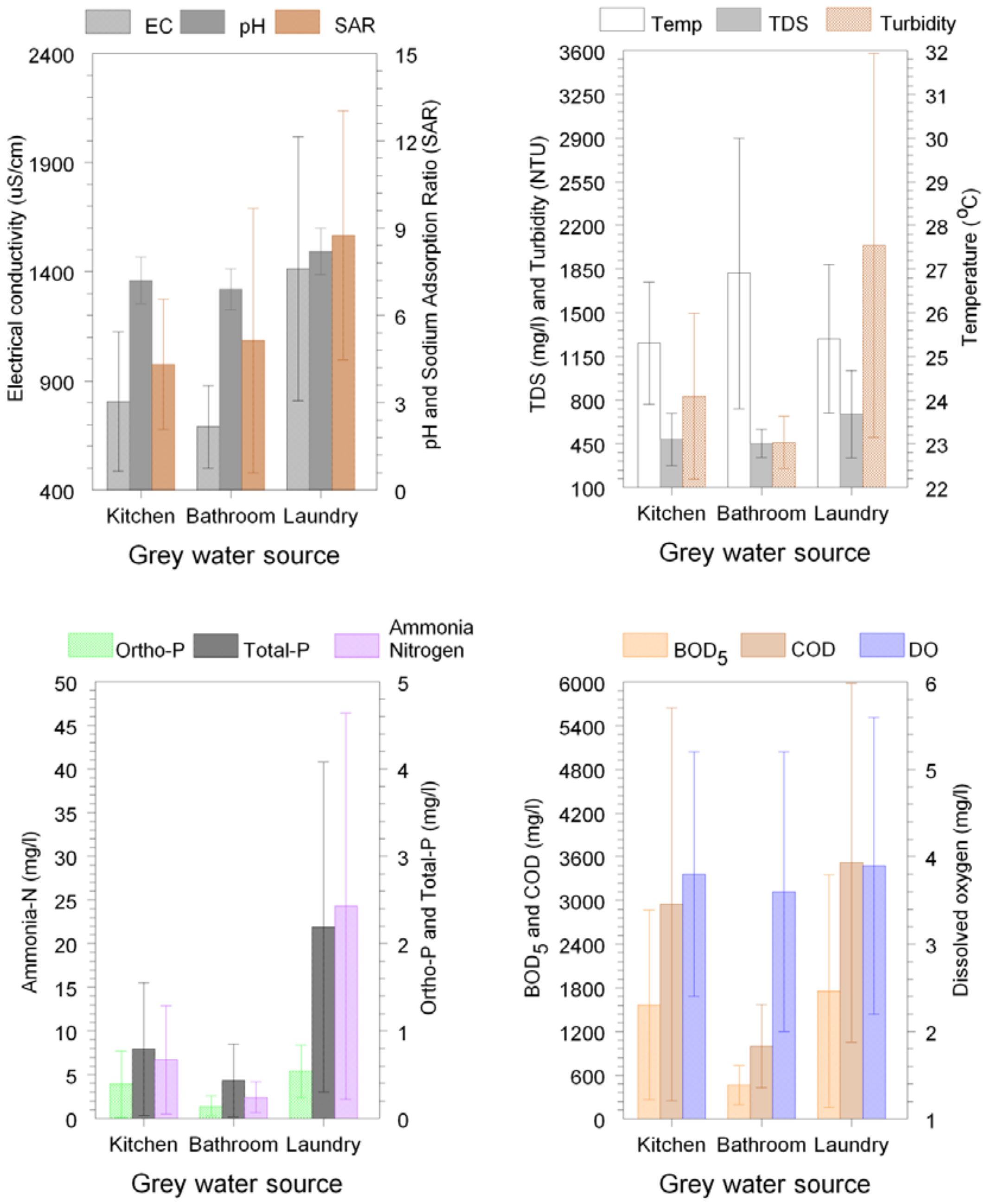

Figure 3 Characteristics of greywater from different sources in Kitgum Town Council (bars represent mean values ± standard deviation; n ≥ 35)

Table 1 Bacteriological quality (E.Coli) of the greywater source types (n = 8; Log 10 E.coli/100 ml)

Greywater source	Average value	Range
Kitchen	8.42	<0- 9.32
Bathroom	7.50	<0- 8.24
Laundry	8.53	<0- 9.40

<u>Soil Characteristics</u>

The initial characteristics of the soils at the study households prior to application of greywater are presented in Table 2. The results indicate largely alkaline soils with high phosphorus contents (> 15 mg/kg, Landon, 1991) and low nitrogen, potassium and organic matter. The phosphate decrease in the soils following greywater application may be attributed to plant uptake as indicated by the healthy appearance of these (Figure 4). Despite the high ammonia-nitrogen levels in the greywater (Figure 3), the nitrogen content in the soils following greywater application are hardly affected. This may be attributed to uptake by plants and also to a less degree the relatively high pH values (pH>7) leading to ammonia volatilization and loss to the atmosphere as nitrogen (Zimmo et al., 2003).

Table 2 Soil chemical characteristics at the study households prior to and after application of greywater (Average values±SD; initial: n = 7; after application: n=14)

Parameter	Initial	After application
pH	9.06±0.85	8.79±0.66
Nitrogen (%)	0.086±0.021	0.085±0.015
Phosphorus (mg/kg)	21.89±7.80	19.79±20.82
Potassium (meq/100g dry soil)	2.52±0.90	2.22±0.83
Organic matter (%)	1.61±0.53	1.55±0.42

Figure 4 (a) Growth of tomatoes (on top) and onions (in the sides (b) flowering of tomatoe plants

Plant growth Observations and Measurements

The observations of the planted vegetables are shown in Figure 4. The observations revealed healthy growth of the planted vegetables.

Plant measurement results carried out at 2 households (A & B) and control greywater towers are presented in Table 3. The results show that the tomato and onion plants receiving greywater at household B generally performed well compared to those that received the groundwater (control). The relatively lower performance by the plants in the greywater towers at household A may have been a result of the poor operation. Also it suffices to point out that during growth, the vegetables in most of the greywater towers were attacked by pests, leading to stunted growth and or death.

Community perceptions and challenges to greywater reuse using greywater towers

Informal interviews held with the locals in Paradwong village in Kitgum Town Council reveal that they currently have knowledge of the greywater tower and would want to have one at their homes. A walk through the area, revealed fifteen additional households that set up greywater towers after seeing the benefits associated with the study units. Additionally, more households have set up small gardens of vegetables on their land and are applying greywater directly to the plants. Where vegetables have been harvested from the greywater towers, the households have converted the area into small gardens irrigated with greywater (Figure 5).

Table 3 Plant measurements

	Control	A	B
Tomatoes			
Length of 1st Stem (cm)	3	3	3.4
Length of 1st leaf (cm)	43.3	27.2	37.5
Length of leaflet (cm)	10.4	8	11.7
No of flowers	16	7	18
No of seeds	1	5	5
Length of inter-node (cm)	14.5	17.2	18
No of branches	4	4	7
Onions			
No of leaves	9	10	8
Length of leaf (cm)	8.7	15	19

The use of the greywater towers had some challenges as observed and reported by the residents. Little greywater is produced particularly from laundry since 1) many of the households do not wash their clothes on a daily basis and 2) the general water scarcity in Kitgum. The shade cloth used was attacked by roaming animals in the area and tore within two months. Here, some protection fences had to be installed around the greywater towers. The planted vegetables were attacked by pests and diseases implying the need for pest control.

Figure. 5 Area around greywater towers used as a small garden and planted with pumpkins.

Conclusions

- Greywater is poorly managed in Kitgum Town Council with the largest population of the community (68%) pouring the greywater onto the ground while 21% dispose their greywater into drain channels and soak pits. Very few (11%) pour this wastewater into the garden.

- The main sources of greywater in the area are laundry, bath areas and kitchen.
- Laundry water except for temperature generally had the highest mean values of the parameters assessed followed by kitchen and bathroom greywater.
- The effect of greywater application on the soil characteristics was not significant with respect to potassium, organic matter and nitrogen content. However there was a slight decrease in phosphorus content.
- Tomato and onion plants grown in the greywater towers thrived with the greywater. However, they were attacked by pests.

Recommendations

- Given the greywater characteristics presented in this study, greywater should be properly managed to prevent contamination of the environment and disease prevalence.
- Given the positive response to the application of greywater in gardens in Kitgum Town Council, there is need to increase sensitization of the community people on greywater reuse and associated benefits to scale up this reuse option.
- There is need for research to ascertain the bacteriological quality of the leafy crops to assure safety.
- The hydraulic load of a greywater tower should be ascertained so as to guide the number of gardens needed for a particular quantity of the generated greywater for optimum performance.

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Greywater treatment in apartment building in Austria

Pilot system built in water rich Austria to reduce potable water consumption

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Abstract with summary of technical data

In an apartment house with 9 apartments and a total of 14 inhabitants a separate greywater collection system, treatment and distribution plumbing was implemented as part of a comprehensive water scheme also comprising water saving, rainwater harvesting, on-site treatment of water and reuse for toilet flushing, landscape irrigation and groundwater recharge. The greywater is treated in a Pontos SBR, which includes UV disinfection and a storage tank. The treated water has a good quality for its intended purpose of toilet flushing. Compared with nationwide average supply and treatment volumes per day the scheme allows to save approximately 65 litres of potable water and around 40 litres of wastewater per capita and day.

Description

A dilapidated complex of farm buildings, comprising the farm house, the stable, a barn and other annexes was to be refurbished and transformed into apartments. The farm lies in Pöllau in Styria in the South-East of Austria, a hilly region with a mild climate and a relatively even rainfall distribution with an average rainfall of 800 mm per year, average monthly rainfall varying between 31 mm in January and 126 mm in July (at Graz).

The concept used for the refurbishment of the apartment house (Pöllau 18, Figure 1) aims at overall sustainability. This concept comprises construction materials and construction physics aspects, energy for heating and water. The concept extends to the surroundings of the house with the plan to convert a vineyard to biological farming. Three buildings comprise 9 apartments, with 14 inhabitants at the end of the monitoring period, a function room for events, a common wine cellar and office space.

As far as possible materials from the previously existing buildings, especially bricks, were reused. The old structures were rebuilt with adapted techniques, including the vaulted ceiling of the function room. Thorough insulation and special windows adapted to the traditional architecture but with triple glazing ensure low energy demand and high quality of living conditions.

The energy supply relies on 100 % renewable sources with a 42 kW (60 m²) solar collector and a 50 kW wood chip boiler for space and water heating. Local farmers provide the wood chips. Energy contained in greywater is also recycled into the space heating system. A 17 m² photovoltaic system is generating part of the electric power needed. As far as possible the energy supply is CO_2 neutral. Heat is distributed to the building complex

Figure 1: The building

from the central heating room via a 2-conduit network and decentralised heat transfer stations in the apartments and other heat consumers.

Despite the relative water richness auf the region and Austria in general the owner also wanted a sustainable water concept for the complex, partly to match the sustainable energy concept, but also to reduce dependency on centralised supply infrastructure and operation cost to a possible minimum.

Water is supplied from three sources, the village water mains, rainwater from the roofs and recycled greywater from the bathrooms. The wastewater treatment comprises a septic tank followed by a constructed wetland, which treats the wastewater on site for infiltration into the ground or, at a later stage, possibly irrigation.

Thus an example of a comprehensively ecological housing estate was created, combining local traditions and modern solutions and making use of a range of available techniques in contrast to usually one single solution relying on centralised systems only.

Water system

The potable water supply comes from the communal water mains. Due to the high location of the house the water is distributed with a booster pump.

Potable water supply is supplemented by a rainwater harvesting system collecting water from 580 m² of roof surface with a total storage volume of 42 m³. The rainwater is used for laundry, a fire fighting reserve, landscaping and irrigation of a wine yard. For laundry two common highly efficient washing machines are provided, where the water is externally heated from the central heating system through a heat transfer station for each washing machine. The fire fighting reserve was necessary as the apartment buildings are located at the end of a branch of the water mains, which is not able to supply a sufficient flow for fire fighting. The overflow of the tanks fills a pond where it is infiltrated into the ground.

Additionally greywater from the bathrooms is collected separately and treated for reuse in a PONTOS Aquacycle 1500, a sequencing batch reactor (SBR) with a capacity of 1000 l/d. It comprises a two step biological treatment with bacteria growing on a fixed bed of foam cubes, a UV-lamp for disinfection of the treated greywater before storage, and a buffer tank with a volume of 600 litre. The treated greywater is used for toilet flushing. In case of greywater shortage the toilet flushing needs are first covered from the available rainwater before eventually switching to potable water if the rainwater is exhausted. Switching from one water source to another is done automatically. The energy contained in the greywater is recycled into the heating system via a cross flow stainless steel greywater heat exchanger with a total surface of 2,60 m² and a capacity of 28 l/min (ThermoCycle WGR 355, Forstner Speichertechnik GmbH), which is approximately equivalent to 4 showers. The heat exchanger is interposed in the main greywater collector.

Figure 2: PONTOS Aquacycle 1500, SBR greywater treatment

The blackwater and excess greywater are treated in a train comprising a 3-chamber septic tank of 7,5 m³, a vertical subsurface flow constructed wetland and a surface infiltration area. The constructed wetland has a length of 26,6, a width of 4,7 and a depth of 1,1 m. It is fed in batches from a feeding chamber located downstream of the septic tank and comprising a special “pipe valve” acting as a float and intermittent outlet device. No pumps or electronic devices are needed, which leads to a robust system and simple operation and maintenance. The treatment is designed for 25 population equivalents. This is the planned final population of the complex but was not reached during the monitoring period. The outlet of the plant has to comply with Austrian regulations for small plants (Table 1). It is planned to use the treated wastewater for fertigation of agricultural crops.

Table 1: Austrian effluent standards for small wastewater treatment plants (less than 50 people equivalent, 1.AEVkA, 1996).

Parameter	Limit
BSB_5 (mg O_2/l)	25
CSB (mg O_2/l)	90
TOC (mg /l)	30
NH_4-N (mg/l) [1]	10

Austria so far has no specific regulations concerning the implementation of greywater systems or quality criteria for greywater. There are however guidelines of professional bodies, which give some indications concerning the implementation, e.g. supply pipes and taps have to be clearly marked as supplying non-potable water. As for greywater quality, depending on the intended use, guidelines for specific types of water uses, e.g. for irrigation water, for bathing water, can serve as a rule for a minimum quality of the treated wastewater. Guidelines for the use of excreta and greywater in agriculture exist from the WHO (2006) but are not yet applied in Austria. Directive 2006/7/EC from the European Union "concerning the management of bathing water quality" is often referred to for the quality requirements of greywater used for domestic purposes. The "bathing water directive" provides quality criteria for prolonged full-body water contact.

In the present case the treated greywater is used for toilet flushing. It must not be assumed that toilet flushing leads to prolonged full-body water contact. It hardly leads to any water contact. Thus the requirements of Directive 2006/7/EC may not apply. Instead of protection of users from chemical or microbial hazards, the most important issues to take into consideration are technical durability of the greywater supply system, i.e. no unacceptable deposits in pipes, and sensorial aspects of the water and the toilet, e.g. turbidity, odour, colour of the water and possible deposits in the toilet bowl.

After completion of the first stage refurbishment of the buildings a monitoring of the water scheme was started. This comprised flow measurements to allow a water balance and water quality measurements of the various water flows including raw and treated greywater. The monitoring was partly constrained by the progressive moving in of inhabitants, the number reaching 14 only towards the end of the monitoring period. An extension of the monitoring is planned.

Cost

The following system costs are real costs of the implementation. The greywater treatment and the related plumbing added up to just below 11.000 Euro. The wastewater collection and treatment under the present configuration was built for 20.500 Euro (Table 2).

The costs of the rainwater harvesting are equivalent to those of the greywater system, even though there is no treatment included. However the reservoirs comprise the fire fighting volume. A detailed assessment of the cost for mains with a sufficient capacity for fire fighting was not made but the remoteness of the building suggests the cost would have been comparable. The rainwater harvesting system, which is comprising an infiltration pond, is also part of the drainage scheme, thus serving a third purpose besides providing extra water and storing the fire fighting reserve.

The costs for the standard plumbing are not available unfortunately. Therefore no comparison of the costs for overall plumbing to the additional greywater collection and distribution system can be made.

Table 2: Investment cost of various components of the water system (excluding VAT)

Cost Information	Cost basis 2005
Rainwater harvesting system (tank, plumbing, pump)	€ 13.000
Greywater heat exchanger	Prototype
Greywater recycling system (SBR, plumbing)	€ 10.900
Constructed wetland for black water treatment	€ 20.500

In the present case the constructed wetland for the treatment of black water was built applying the standard Austrian dimensioning rule of 5 m² per person, without taking into consideration the reduced hydraulic and carbon load due to the greywater scheme. If the reduced hydraulic load were taken as the key dimensioning parameter the constructed wetland could have been built with 3 m² per person and would have cost an estimated 14.400 Euro.

Results

One target of the monitoring was to determine whether and to which extend water saving measures and greywater systems would contribute to water saving. A normal person in Austria uses 135 litres of potable water per day. About 120 litres of these become wastewater.

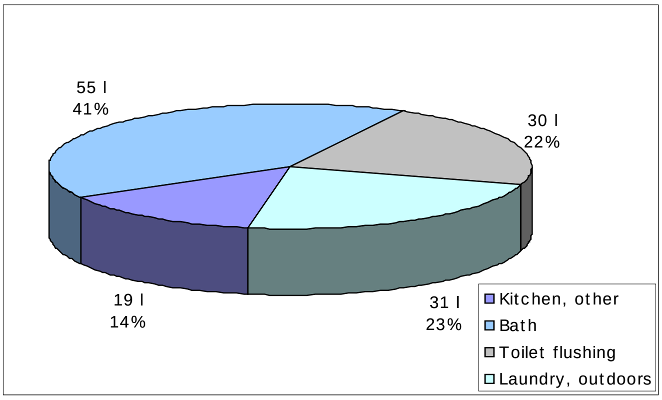

Figure 3: Average Austrian domestic water consumption per capita and day, for different consumption categories, total is 135 l/(c.d) (BMLFUW, 2009)

Figure 4: Water flows at Pöllau 18.

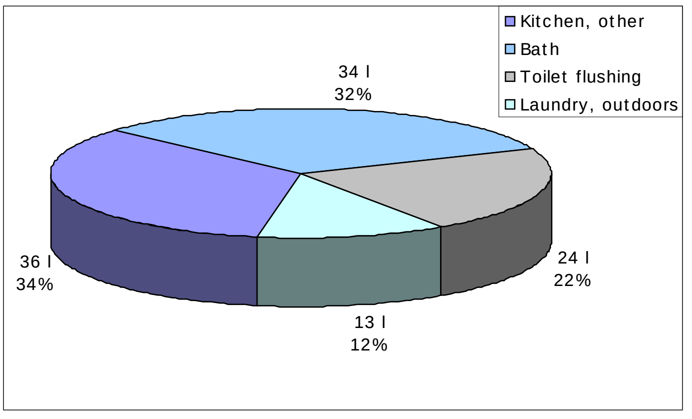

Figure 5: Water consumption at the apartment house Pöllau 18 per capita and day, for the same categories as in Figure 3, total is 107 l/(c.d)

An inhabitant at Pöllau 18 uses 107 litres of water per day. However 24 l of these are greywater and 13 are rainwater, so that only 70 l are potable water from the mains. That is almost down to half from the average figure or a yearly saving of about 24.000 litres for every person.

The respective consumptions in the category bathroom are 55 and 34 l/(c.d). This reduction by almost 40 % is probably due both to water saver fittings and a water conscious behaviour of the inhabitants. While the reduction also has an impact on the available volume of greywater, in the present case this has no consequences, as the volume of service water needed is less than the greywater collected. Additionally the next available water source is rainwater, where there is no shortage under the given circumstances.

If this were not the case, e.g. due to further service water uses, it would have been possible to add the laundry runoff to the greywater. (Figure 4)

Somehow astonishing is the comparative consumption in the “kitchen and other” category. This category is formed because at Pöllau 18 its water consumption is computed from the total potable demand minus the greywater produced in the bathroom. This amount of water should cover the demand at the kitchen and cleaning plus any other use of water from the mains, which should be rather limited. Yet the consumption is 36 litres per capita and day compared to 19 litres for Austrian average. The reason for this discrepancy cannot be explained with the available data and will have to be investigated in a further monitoring phase.

The amount of wastewater leaving the building is also down to 76 litres per capita and day, from the average 120, which corresponds to a 37 % reduction. (Figure 5)

Quality data for the raw greywater are given in Table 3. With a COD of just above 70 the raw greywater is rather less polluted than literature states for greywater from shower and bath (Eriksson et al., 2002). The COD/BOD_5 ratio of around 1.25 suggests the greywater is easily biodegradable. This is confirmed by the good

Table 3: Raw greywater quality (Sample size =8; n.d. = not detectable)

	Average	Median	Standard deviation	Max	Min
COD (mg O_2/l)	72.4	75.0	34.4	118.0	10.4
BOD_5 (mg O_2/l)	58.3	53.5	32.5	105.0	17.0
NH_4-N (mg/l)	2.4	1.3	2.8	6.9	<0.5
N_{tot} (mg/l)	10.6	5.3	15.7	49.0	1.1
P_{tot} (mg/l)	0.7	0.6	0.3	1.2	<0.5
E. coli (CFU/100 ml)	6.3E+06	0.33E+06	12E+06	35E+06	n.d.

Table 4: Service water quality (Sample size =11; n.d. = not detectable, ^{1}in 8 samples)

	Average	Median	Standard deviation	Max	Min
COD (mg O_2/l)	13.2	12.4	8.3	40.9	9.2
BOD_5 (mg O_2/l)	2.7	1.9	3.0	12.0	1.1
NH_4-N (mg/l)	<0.5	<0.5		1.1	<0.5
N_{tot} (mg/l)	3.2	2.8	1.2	5.8	1.7
P_{tot} (mg/l)	0.4	0.4	0.2	0.7	0.2
E. coli (CFU/100 ml)	145	n.d .^{1}	308	1000	n.d.

elimination of carbon as shown in Table4. The nutrient content is particularly low in this greywater. This may not always be the case, e.g. if there are babies or if the households use any detergent with some phosphorus.

The already low concentration of nitrogen is further reduced from 10 to 3 mg/l in average. Almost all ammonium is denitrified or at least oxidised. The treated service water looks clean, colourless and has no particular odour.

This SBR greywater treatment leads to water, which is well suited for purposes but direct consumption, e.g. toilet flushing, in the household. The water and wastewater savings are substantial and could help reduce the pressure on water resources especially in water scarce regions. In future implementations of such systems the cost of the greywater scheme could be partly offset by the corresponding savings made on the wastewater treatment. Any savings go automatically to the developer in the case of decentralised wastewater schemes implemented by the developer himself. In other cases this may not be achievable. If water saving measures or greywater systems are implemented upstream of centralised sewerage and wastewater treatment schemes appropriate tariffs or subsidies will be needed to transfer at least part of the overall economic advantage to the developer.

The investment costs are higher for the more complex scheme, than if a water mains connexion and a constructed wetland for wastewater treatment were implemented. However, in future such systems a more detailed knowledge of the wastewater produced will allow to reduce the size of the wastewater treatment and thus reduce the cost accordingly, thus reducing the gap between the two schemes while still maintaining the level of sustainability and autonomy.

Further investigations have to be made concerning the possible size reduction of constructed wetlands, or any wastewater treatment for that matter, in case of a greywater scheme treating part of the wastewater flow. For this purpose more data are needed concerning the hydraulic and organic load reduction at the inlet to the wastewater treatment due to the greywater scheme. This should lead to the critical parameter for the dimensioning of the wastewater treatment.

While domestic water demand has a very high priority, the potential of on-site recycling to guarantee a sufficient water supply should not be neglected. The saved water remains available for other purposes in potable water quality.

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Combined greywater treatment using a membrane bioreactor

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Abstract

The daily fresh water consumption can easily be reduced by using greywater from showers, bath tubes and wash basins, when substituting drinking water e.g. for toilet flushing, garden irrigation, cleaning purposes or industrial cooling- processes. The ecological and economic advantages of the *GEP- Watermanager* open up new possibilities of an intelligent water management. It combines a greywater- recycling- plant with rainwater management, drinking water management, a booster station and a remote control module. Based on a modular construction concept the *GEP- Watermanager* is operated as a membrane bioreactor with submerged ultra filtration membranes for precious process water. The attained output values after the recycling process are substantially below the strict limits set by the EU bathing water regulation. The little footprint and optimised energy consumption of the *GEP- Watermanager* accompanied by high filtration performance offers new interesting alternatives for in- building solutions for a decentralized water management.

The GEP- Watermanager

Since 1992 the German company GEP Umweltechnik GmbH develops and distributes solutions for an optimised water management. The first satisfying success in developing a secure in house greywater plant, based on a membrane bioreactor, took place in 2002. This was the hour of birth of the *GEP- Watermanager WME 4* – recycling with *BioMembranTechnologie® (BMT®)*.

In the meantime the process of improvement and development moved strongly forward and today GEP is able to offer fully automated, remote monitored and high efficient greywater plants for in- and outdoor installations. The *GEP- Watermanager* is designed as a modular construction and allows building contractors and engineers a wide scope of design possibilities.

The classical layouts of greywater plants by GEP are shown in Table1 in association with their main specific parameters.

Table1: ***GEP- Watermanager*** **- main specific parameters**

Model	Filter performance [l/d]	Greywater-tank [l]	Processwater-tank [l]	Energy consumption* [kWh/m^3]	Footprint** [m^2]
GEP- Wassermanager WME 4	800	250	125	3,67	1,5
GEP- Wassermanager WME 15	700	750	500	3,29	2
GEP- Wassermanager GWA 1	1.400	1.100	1.100	4,2	4,5
GEP- Wassermanager GWA 2	2.800	1.100	1.100	2,8	4,5
GEP- Wassermanager GWA 3	4.100	1.500	1.500	3,1	5
GEP- Wassermanager GWA 4	5.500	1.500	1.500	2,7	6,5
GEP- Wassermanager GWA 5	7.200	2.000	2.000	2,9	7
GEP- Wassermanager GWA 6	8.500	3.000	3.000	2,6	7,5

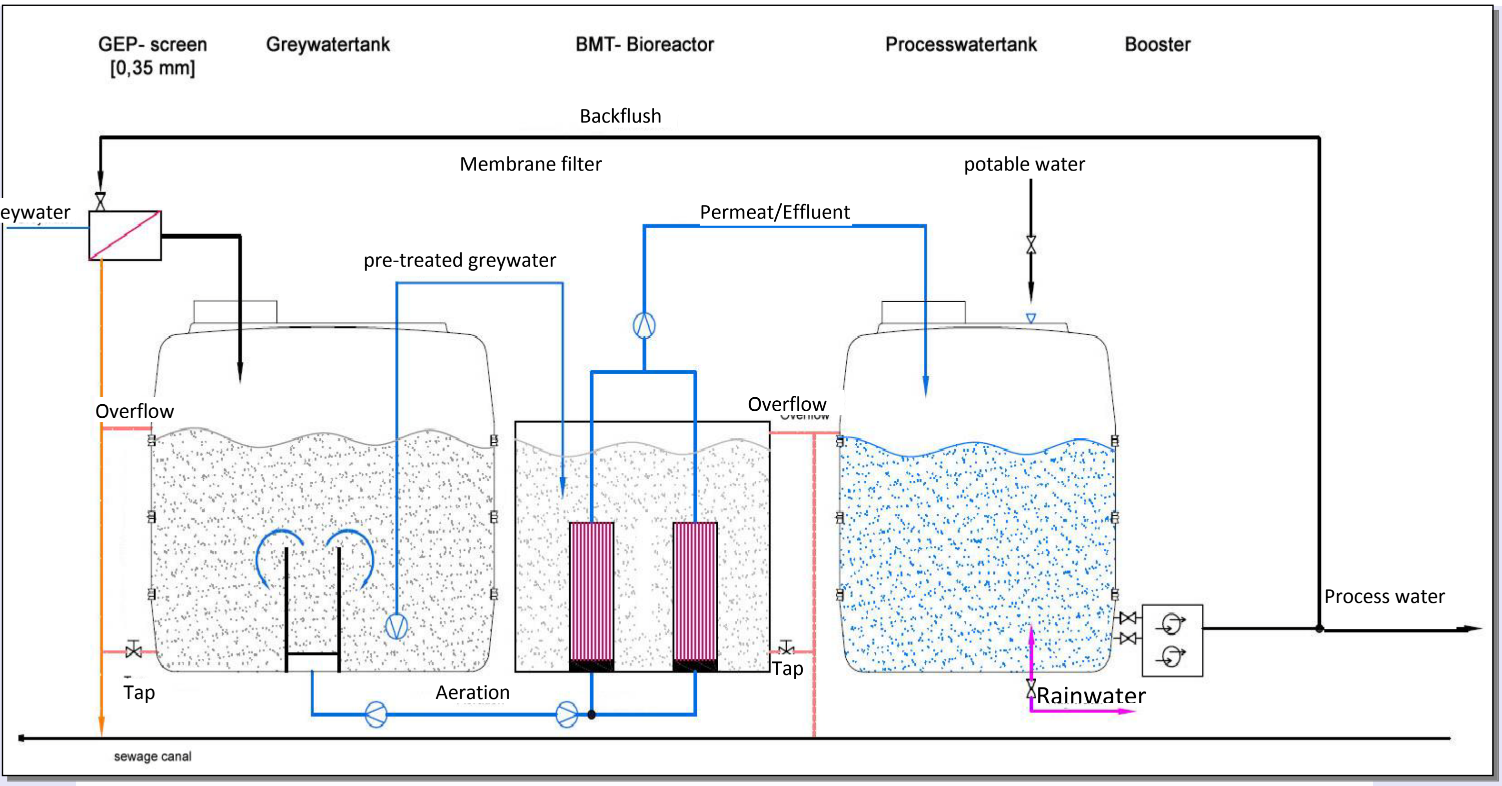


Figure 1: Principel flow chart of the *GEP- Watermanager*

The principle flow chart of *GEP- Watermanager* is shown in Figure1. First of all the separately collected greywater from showers, bathtubs and wash basins pass through a screen with a mesh size of 0.35 mm. The solids will be removed and automatically flushed into the sewer (Figure2). The pre-treated greywater flows into the first greywater tank, where bacteria with the help of artificially supplied oxygen begin to degrade the organic substances contained in the greywater.

After a short interval of sedimentation and flotation the biological treatment continues in the *BMT*®- Bioreactor with the biological aerobic degradation. The *BMT*®- control panel monitors and calculates permanently the optimal hydraulic retention time for high biological removal performance to achieve a long storable and odourless process water.

Figure 2: The GEP- *TridentMAX*, a screen with an mesh size of 0.35 mm separating the raw greywater from the solid ingredients

Due to the low organic loading rates in greywater (≤ 0,1 kg COD/kg/d) (Paris and Schlapp, 2009) and the high solid retention time in the *BMT*®- Bioreactor the growing rate of biomass is limited too (MLSS≈ 1-5 mg/l) (Sellner, 2009). As a consequence the growing rate of biomass is low and the period of removing sludge in the tanks is once in a year or even longer.

After the biological treatment the heart of the *GEP- Watemanager*, the submerged ultra-filtration starts its work in the *BMT*®-Bioreactor. The European patented *MicroClear*®-filter represents a true physical barrier which blocks all germs and suspended matters (Figure 3). The minute pores of only 50 nm exceed the requirements of the EU bathing water guideline 2006/7/EG (2006) and even the DIN 19650 (1999) class 2 requirements for irrigation water.

The optimised aeration (with continuously-rising, fine air bubbles spaced at intervals) ensures a permanent self- cleaning effect on the filter plates that reduces the need of chemical cleaning to an absolute minimum. In combination with a low negative pressure (0.1 bar) during the filtration process (Figure 4) and a relaxing period (aeration without filtration) the membranes lifetime achieve terms of 8 to 24 months. If the filter should be dirty, it is simply replaced by a filter that has been

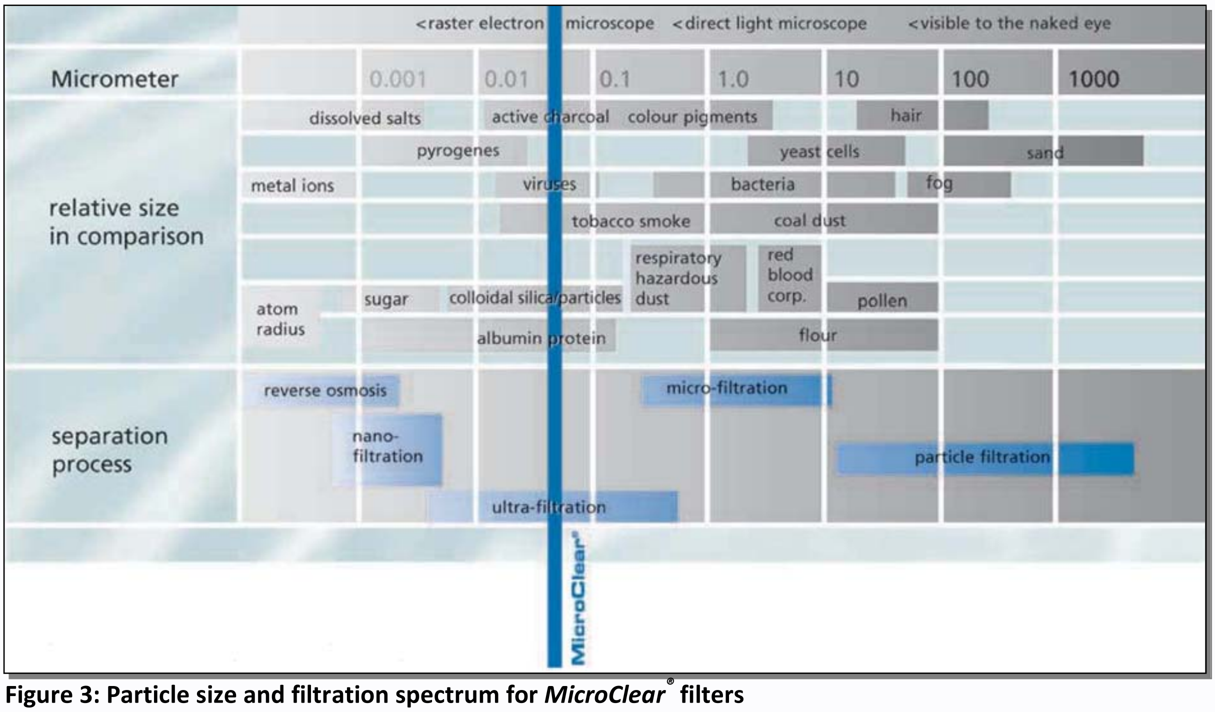


Figure 3: Particle size and filtration spectrum for *MicroClear*® filters

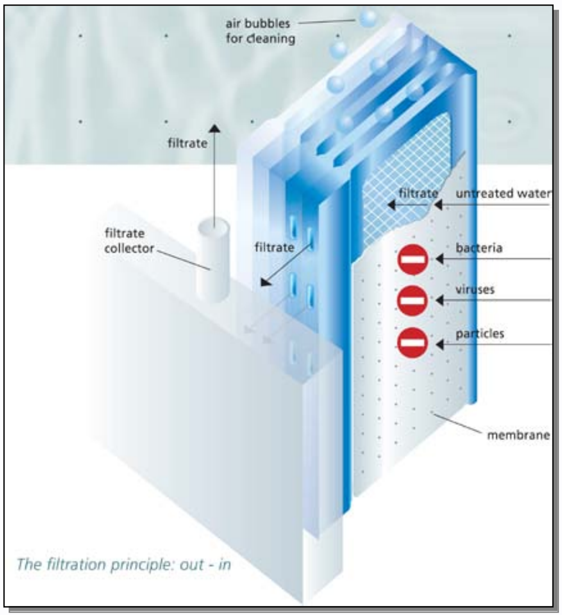


Figure 4: Operation method of filtration with the *MicroClear*®

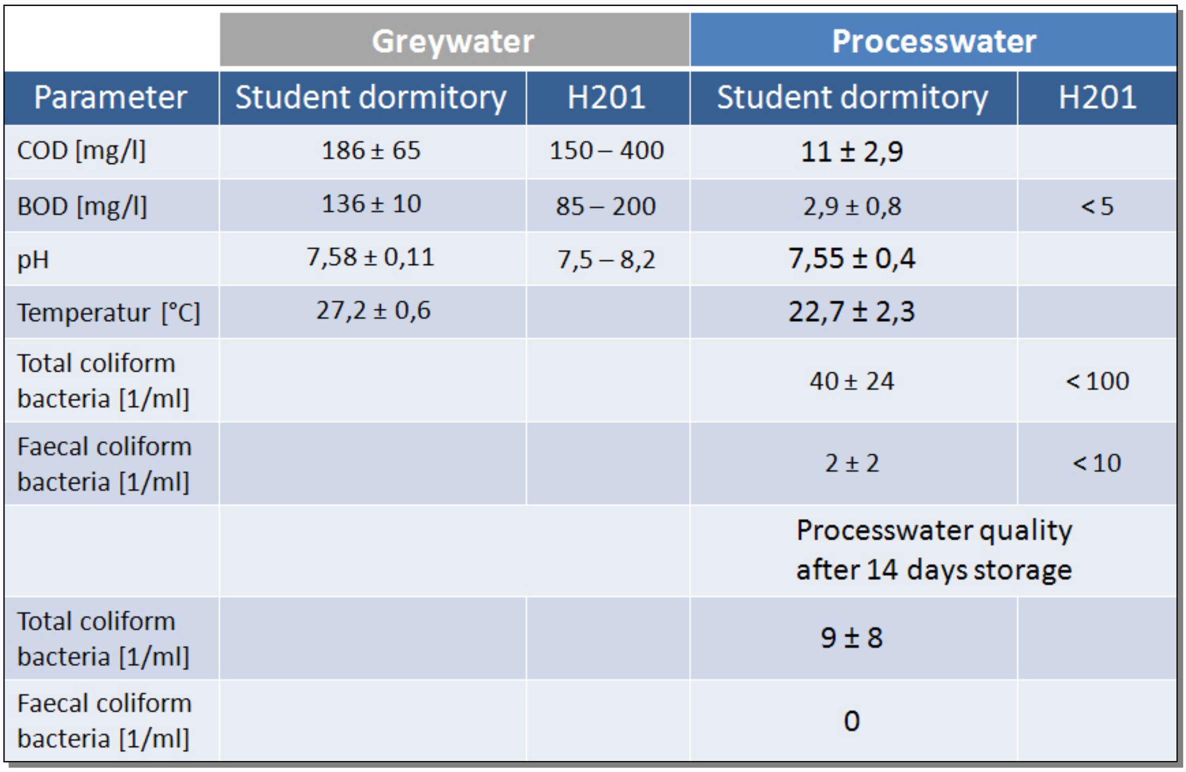
thoroughly cleaned. This permits to have a lifetime of up to 10 years per filter.

The result of this unique and safe process is a nutrient-poor, odourless, purified process water for further applications. In Table 2 the results of a nine week measurement in a student dormitory are shown. In addition to that the process water qualities guaranteed by GEP, according to the information sheet (FBR-Hinweisblatt H201, 2005), will be mentioned there as well.

The process water will be stored in a process water tank until its delivery by a booster- system to its consumers. In case of a lack of process water the requested amount of water will be automatically substituted by drinking water according to DIN EN 1717 (2001).

The control of the *GEP- Watermanger* provides user friendly completely automated and remotely operated maintenance of a high technology greywater treatment plant. It is possible to observe, to evaluate and to control the *GEP-Watermanager* entirely from the office or control centre. Hence the best moment to change the filter can be detected which economizes real maintenance and operation costs.

The *GEP-Watermanager* is quite more than an ordinary greywater treatment plant. At the same time it can be operated without any problems with drinking water, greywater, process water and rainwater. In the opinion of GEP the bonding of greywater- recycling and rainwater harvesting is currently the most sustainable manner of decentralized water management.
For this reason the *GEP- Watermanager* is composed of systems by greywater management, rainwater management, drinking water management, booster station and remote control module. The convincing modular concept and the flexibility in tank versions allow building contractors and engineers the greatest scope for designing their own individual *GEP- Watermanager* according to the current circumstances.



	Greywater		Processwater	
Parameter	Student dormitory	H201	Student dormitory	H201
COD [mg/l]	186 ± 65	150 – 400	11 ± 2,9	
BOD [mg/l]	136 ± 10	85 – 200	2,9 ± 0,8	< 5
pH	7,58 ± 0,11	7,5 – 8,2	7,55 ± 0,4	
Temperatur [°C]	27,2 ± 0,6		22,7 ± 2,3	
Total coliform bacteria [1/ml]			40 ± 24	< 100
Faecal coliform bacteria [1/ml]			2 ± 2	< 10
			Processwater quality after 14 days storage	
Total coliform bacteria [1/ml]			9 ± 8	
Faecal coliform bacteria [1/ml]			0	

Table 2: Results of a nine week measurement in a student dormitory with 174 residents (Sellner and Schildhorn, 2009) compared with the recommended values of process water (FBR-Hinweisblatt H201, 2005).

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