INVESTIGATION OF ANAEROBIC UP-FLOW BATCH REACTOR FOR TREATMENT OF GREYWATER IN UN-SEWERED SETTLEMENTS

by

CHRISTOPHE MUANDA

Thesis submitted in fulfilment of **the requirements for the degree**

Magister Technologiae: Civil Engineering

in the Faculty of Engineering

at the

Cape Peninsula University of Technology

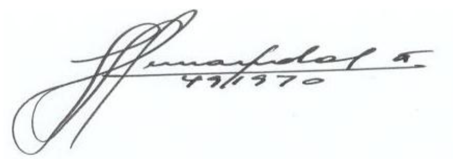
Supervisor: Prof. Alvin Lagardien

Bellville
November 2009

Declaration

I, **Christophe Muanda**, declare that the contents of this thesis represent my own unaided work, and that the thesis has not previously been submitted for academic examination towards any qualification. Furthermore, it represents my own opinions and not necessarily those of the Cape Peninsula University of Technology.

Christophe Muanda

Signed  **Date: 04 November 2009**

Abstract

Un-sewered settlements are provided with the basic water and sanitation systems that comprise, in most cases, of dry sanitation and standpipes. Substantial amounts of wastewater (including greywater) generated from households are discarded untreated into streets, open spaces between shacks, streams and rivers due to the lack of adequate disposal or treatment infrastructures. The negative impacts from unsafe disposal of greywater generated in un-sewered settlements affect both human health and the general environment.

Several treatment technologies ranging from the simplest to the more sophisticated have been developed and made available for consideration to deal with the adverse impacts caused by the unsafe discharge of greywater. Some of these treatment technologies have been implemented successfully in certain developing countries worldwide. Amongst these is the anaerobic up-flow batch reactor (AnUBR) which was successfully used for the first time to treat greywater from sewered areas in Jordan, Lebanon and Sri Lanka.

The AnUBR has emerged as a localised greywater treatment technology alternative to conventional treatment methods in areas not served by sewer networks. This technology holds promise because of its simplicity of design, high pollutant removal efficiency, absence of energy or chemical consumption, ease with which it can be implemented, cost effectiveness, and low operation and maintenance costs. This technology was originally developed for treating sewage and high strength greywater from hotels. Recently it was further pioneered by INWRDAM (Inter-Islamic Network on Water Resources Development and Management) in the treatment of greywater from sewered areas of developing countries.

This technology has not been tested in un-sewered settlements of developing countries which are characterised by the lack of disposal infrastructures despite being suitable for tropical countries. This treatment system is able to produce effluent that meets the quality standard for discharge and irrigation. However, new applications of the AnUBR require further investigation in order to ascertain its feasibility and evaluate its performance in the un-sewered settlement context.

Given the promising results reported for the AnUBR application for greywater treatment, this study aims to investigate the performance of the AnUBR as an alternative technology for the treatment of greywater generated in un-sewered settlements and its application in developing countries.

Abstract

A laboratory scale plant encompassing the AnUBR was designed, constructed and investigated using influent greywater collected from two selected case study settlements representing sewered and un-sewered areas. The plant was operated for 20 consecutives days using greywater from both selected sites separately. The influent greywater was analysed prior to feeding the plant and fed intermittently by batch as per designed feeding schedule. The performance of the AnUBR was evaluated mainly by analysing the quality of effluent produced, while the typical application was recommended based on the ability of the plant to produce effluent complying with local regulations and ability to treat greywater regardless of its source.

The daily characteristics of influent greywater from both sites during the period of investigation were found to be as follows: temperature: 24 – 29ºC, pH: 7.1 – 7.2, TSS: 117.72 – 2,246.6mg/l, TN: 5.66 – 12.29mg/l, TP: 12.27 – 116.46mg/l, COD: 223.17 – 1,135.32mg/l, BOD_5: 98.0 – 383.6mg/l, O&G: 52.22 – 475.29mg/l, e-coli: 8.87×10^4 – 2.17×10^7cfu/100ml, and Faecal coliform: 1.49×10^5 – 2.41×10^7cfu/100ml. The AnUBR managed to treat greywater to a quality that comply with the general standards for discharge into natural water resources. The final effluent showed a significant decrease in the level of pollutants from the initial values presented above to the following: temperature: 27 – 29 ºC, pH: 7.1 – 7.2, TSS: 5.12 – 12.82mg/l, TN 0.91 – 1.09mg/l, TP: 0.93 – 7.47mg/l, COD: 24.67 – 40.45mg/l, BOD_5: 8.59 – 16.0mg/l, O&G: 1.15 – 1.72mg/l, e-coli: 213.3 – 1.12×10^3cfu/100ml, and Faecal coliform: 461.6 – 1.5×10^3cfu/100ml.

Results obtained showed that the quality of influent greywater (from un-sewered settlements) is similar regardless of the water and sanitation technology. Following the operation of the AnUBR, significant removal of pollutants was observed in all processes. The overall removal efficiency averaged 80 to 95% for O&G and TSS respectively and 50 to 85% for TN and TP. The COD and BOD_5 removal averaged 70 to 85% while that of micro-organisms averaged 90 to 99%. However, despite the high removal efficiency recorded the AnUBR may still require a post treatment step in order to improve the quality of effluent.

It was concluded that the AnUBR is a viable alternative greywater treatment technology for un-sewered settlements, households or businesses such as hotels and restaurants. The AnUBR is able of treating high polluted greywater to effluent of quality that meets the standards for discharge or reuse provided a post treatment to ensure the complete killing of pathogenic organisms. The result of this study confirms the performance of the AnUBR for the treatment of greywater and provides an understanding of its concept as an alternative to conventional treatment and its application in un-sewered settlements based on local practical investigations.

Acknowledgements

I wish to thank:

- Prof. A. Lagardien for the opportunity and support to complete this study
- Dr M. Thamae and L. Cloete for their assistance during the experimental work
- Ncediwe, Mabuwa and Obadia for their assistance during the experimental work at the plant and laboratory.

The financial assistance of the Community Water Supply and Sanitation Unit towards this research is acknowledged. Opinions expressed in this thesis and the conclusions arrived at, are those of the author, and are not necessarily to be attributed to the Community Water Supply and Sanitation Unit.

Dedication

To the loving memory of my son the late **Percy Malombu Muanda**

To my wife Sylvie Nsono Muanda,

To my sons Andy Kanga Muanda, Chris Muanda Jr and Emmanuel Malombu Muanda

To my daughter Jenny Kobo Muanda

To my brothers Jean, Emmanuel, Gilbert and Bernard Muanda

To my sisters Marceline, Christine, Leonie, Petronie and Astrid Muanda

To my nieces and nephews

To all who assisted me during my study

Lastly, to the Almighty God

Table of contents

Chapter 3 Experimental work

Chapter 4: Results of experimental work

Chapter 5: Analysis and discussion of results

List of figures

List of tables

Abbreviations and Variables

APHA	American Public health Association
AnUBR	Anaerobic Up-flow Batch Reactor
BOD_5	Biological Oxygen Demand at 5 days
$CaCO_3$	Calcium carbonate
COD	Chemical Oxygen Demand
CO_2	Carbon dioxide
CH_4	Methane
D	Density (in number of dwelling per hectare
DWAF	Department of Water Affairs and Forestry
FC	Faecal coliform
FT	Feed tank
G_g	Greywater generated
h	Hour
HRT	Hydraulic Retention Time
INWRDAM	Inter-Islamic Network on Water Resources Development and Management
l	Litre
l/s	Litre per second
m	Metre
m/h	Meter per hour
m^2	Meter square
m^3	Cubic metre
m^2/d	Meter square per day
mg	Milligram
mg/l	Milligram per litre
ml	Millilitre
mm	Millimetre
m/s	Metre per second
MPM	Most probable number
NH_3	Ammonia
nm	Nanometer
NO_2	Nitrite
NO_3	Nitrate
NTU	Nephelometric turbidity unit
O&G	Oil and Grease
P_1	Process 1 referred as settling tank
P_2	Process 2 referred as primary filtration
P_3	Process 3 referred as secondary filtration
P_4	Process 4 referred as clear water storage tank
Q	Water consumption in litre
TKN	Total Kjeldahl Nitrogen
TN	Total nitrogen
TP	Total phosphorous
TSS	Total suspended solids
WHO	World Health Organisation

Glossary of terms and acronyms

Terms and Acronyms	Definition/Explanation
Anaerobic digestion	Digestion of organic matter by anaerobic (absence of free oxygen) microbial action, resulting in the production of methane gas. It may refer to plant or animal waste.
Biomass	Is the mass of living biological organisms in a given area or ecosystem at a given time.
Biological oxygen demand (BOD) expressed in mg/l	A measure of the amount of oxygen used by bacteria to degrade organic matter in a wastewater sample over a 5-day period at 20ºC.
Colony forming unit (CFU)	Measure indicating the number of micro-organisms capable of multiplying in a sample.
Coliform expressed in cfu/100ml	Used as food and water quality indicator. These organisms are normally found in the aquatic environment and vegetation.
Chemical oxygen demand (COD) expressed in mg/l	Quantitative measure of the amount of oxygen required for chemical oxidation of carbonaceous (organic) material in a sample by a strong chemical oxidants.
COD/BOD_5	Ratio indicating the level of biodegradability of a sample.
Escherichia coli (E-Coli) expressed in cfu/100ml	Is a faecal coliform bacterium of almost exclusively faecal origin; Its presence in water or food indicates faecal contamination and poses a public health risk since other faecal pathogens such as viruses or parasites may also be present.
Eutrophication	Excess nutrient concentration in an aquatic ecosystem leading to: increased productivity of autotrophic green plants and to blocking out of sunlight; elevated temperatures within the aquatic system; depletion of oxygen; increased algae growth and reduction in fauna and flora variety.
Faecal coliforms (FC) expressed in cfu/100ml	Common, harmless forms of bacteria present in human intestines and found in faeces and wastewater. Faecal coliform bacteria counts are used as an indicator of the presence of pathogenic micro-organisms.
Filtration	A process whereby suspended and colloidal matter is removed from water and wastewater by passage through a granular medium.
Flotation	A process by which suspended matter is lifted to the surface of a liquid to facilitate its removal.
Hydraulic loading rate (HLR)	The amount of water applied to a given treatment process, typically expressed as a volume per unit time or volume per unit time per unit surface area (m/d).

Hydraulic retention time (HRT) (expressed in unit of time).	The average length of time that a soluble compound remains in a system (such as a tank or filter). Its influence is determined by the volume of the system and the flow rate of the soluble compound.
Indicator	A chemical or biological parameter used to indicate the possible presence of other contaminants. The presence of faecal coliform in an aquatic system indicates a contamination by faecal matter.
Micro-organisms	Simple unicellular or multi-cellular organisms such as protozoa, algae, fungi, viruses and bacteria.
Nutrients	Essential chemical elements and compounds (mainly nitrogen, phosphorous, potassium) needed for plant growth. Excessive amount of nutrients in water can cause eutrophication (degradation of water quality and growth of excessive algae). Some of nutrients can be toxic at high concentrations.
Oil and Grease (O&G) expressed in mg/l	Are insoluble group of substances (including fats, waxes, free fats acids, calcium and magnesium soaps, minerals oil and certain non-fatty materials) that can be removed by natural flotation skimming.
Pathogen	Infectious biological agent (bacteria, protozoa, fungi, parasites, viruses) causing disease or illness to its host.
pH	A logarithmic scale determining whether a solution is acid, neutral or basic, and derived from the number of hydrogen ions present. The pH scale commonly in use range from 0 to 14, where 7 indicates a neutral solution, less than 7 an acidic one and more than 7 a basic solution.
Sedimentation	Settling by gravity of solids particles in a liquid system. Also called settling.
Sewer	An underground pipe or open channel in a sewage system for carrying water or sewage to a treatment system before disposal.
Total nitrogen in mg/l (TN)	Include TKN (ammonia + organic nitrogen) + nitrite + nitrate;
Total phosphorous (TP) in mg/l	Phosphorous is a nutrient essential to the growth of organisms, and is commonly the limiting factor in the primary productivity of surface water. Wastewater is a typical source of phosphorous possibly contributing to the eutrophication of surfaces waters.
Total suspended solids (TSS) expressed in mg/l	Refers to the amount of insoluble solids floating and suspended in wastewater. They are determined by filtration or centrifugation followed by drying.
Xenobiotic	Refers to a chemical compounds that are foreign to the body of living organisms.

Chapter 1: Introduction

1.1 Background

South Africa, as many other developing countries is facing a massive rural exodus problem caused by the lack of job opportunities in rural areas and poor living conditions. Private land is squatted on and transformed into settlements without planning and adequate infrastructure. The emergency water and dry sanitation system provided by municipalities does not take into account the disposal of greywater, thus leaving the settlement with the burden of pollution created by the unsafe disposal of greywater.

The South African Constitution section 24a stipulates that, "Everyone has the right to an environment that is not harmful to their health or well-being" (RSA, 1996). The White Paper on sanitation (giving effects to the constitution requirements) defines the minimum basic level of sanitation as including a system for disposing of human excreta, household wastewater and refuse which does not have deleterious impact on the environment (RSA, 1997).

The conventional means of disposing wastewater is to channel it into sewers. With wastewater treatment works overloaded and lack of sewerage within the settlement, the alternative means of reducing the health risks caused by the unsafe disposal of greywater is to look at localised on-site treatment systems that could treat influent to comply with the general requirements for disposal.

Against this background, health and environmental impacts caused by greywater becomes an issue that should be addressed and researched in order to find a corrective action to assist in reducing or alleviating the problem.

1.2 Statement of the research problem

The issue of greywater is steadily gaining importance in low income and un-sewered settlements of developing countries where inadequate wastewater management and lack of basic infrastructure (such as sewers, storm water reticulation systems and adequate water and sanitation infrastructure) has a detrimental impact on public health and the environment. In these settlements, greywater is discharged untreated onto ground, open field and natural aquatic systems; and sometimes used for agricultural purposes, thereby leading to environmental degradation and exposing the population to health risks.

The lack of adequate sanitation systems in informal settlements leads communities to turn to unsafe and unhealthy sanitation practices. At some stage, the greywater generated is mixed with faeces (night soil) and discharged onto ground, open spaces or at greywater discharge points. The unsafe disposal of untreated greywater/wastewater has exacerbated the spread of water borne diseases, breeding of mosquitoes, smell and pollution of natural water resources which causes a threat to aquatic life and environment.

In order to overcome this situation, several sanitation technologies has been made available for choice; amongst these is the anaerobic up-flow batch reactor (AnUBR) that was introduced for the treatment of greywater. This technology has not yet been applied in the natural setting of un-sewered settlements.

In this context, it was hypothesised that the application of the AnUBR (as greywater treatment technology) could provide a solution to the greywater problem in un-sewered settlements. With reference to these issues and for the purpose of the study, it was assumed that greywater from un-sewered settlements is polluted and contains high concentration of pollutants that may be a threat to human health and the general environment.

1.3 Research question

The key question addressed by the study is: what is the performance of the anaerobic up-flow batch reactor (AnUBR) in the treatment of greywater generated in un-sewered settlements? Additional questions addressed by the study are:

- What is the quality of influent greywater feed in the AnUBR?
- What is the quality of treated effluent produced by the AnUBR?
- Is the AnUBR capable, effective and efficient in removing greywater pollutants content?
- What is the typical application of the AnUBR?

1.4 Objectives of the study

The aim of the study was to investigate the performance and typical application of the AnUBR in un-sewered settlements. In order to achieve this aim, objectives to be met were to:

a) Determine the quality of influent greywater used to feed the plant;
b) Determine the quality of effluent produced by the AnUBR;
c) Assess the treatment capabilities and evaluate the performance of the AnUBR in un-sewered settlements;
d) Make recommendations regarding the typical application of the technology.

1.5 Scope of the report

The scope of the report is presented in steps to describe how the study was structured and how objectives could be met. This work combines literature review and experimental work. The background, the work and its significance are outlined in the following chapters:

- Introduction which highlights the overview of the study (chapter 1)
- Literature review and theory (chapter 2) comprising of desktop study accumulated to gain knowledge regarding several greywater aspects aligned from generation to the treatment. This section of the study provides a review of literature which includes the extent of greywater problem and greywater characteristics; an overview of different on-site low-cost treatment system and disposal requirements as well as the pilot plant study which cover design and evaluation criteria for small treatment works.
- Experimental work (chapter 3) mainly consisted of designing, building and setting up as well as monitoring a pilot AnUBR. Laboratory experiments consisted mainly of collecting samples and conducting analysis (for selected quality parameters) in the laboratory. This phase of the study was achieved by determining the quality of influent and effluent greywater collected from selected case study sites by sampling and testing quality parameters indicators.
- Presentation of results (chapter 4) highlighted results obtained from experimental works undertaken in the previous chapter.
- Discussion and analysis of results (chapter 5) was conducted after collecting results and comparing the effluent quality to the available values found in the literature and quality standards for discharge applicable in South Africa.
- Conclusions and recommendations (chapter 6) on the treatment performance and typical application of the AnUBR were made following the analysis of results and after comparison of the effluent quality to the standards.

Following the study objectives, the methodology applied comprised four steps namely:

- The characteristics of fed greywater were obtained by analysing influent greywater collected from selected case study sewered and un-sewered areas prior to feeding the plant. Parameters analysed were namely temperature, pH, TSS, TN, TP, O&G, COD, BOD_5 e-coli and faecal coliform. Given the nature of the AnUBR an attempt was made to determine the presence of common gases such as CH_4, NH_3 and CO_2. The choice of sewered areas were selected for control purposes in order to verify the feasibility of the AnUBR.

- The pilot laboratory scale AnUBR was developed based on existing design features which emphasis the HRT (hydraulic retention time) and the volume of effluent to be treatment as main design parameters.
- The performance of the AnUBR was assessed by monitoring quality parameters at each unit process and recording the removal efficiency. The feasibility was assessed by comparing the performance (in terms of removal efficiency) of the AnUBR in sewered areas to the literature.
- The treatment capability and performance were evaluated using the evaluation criteria applicable to the AnUBR.

1.6 Delineation of the study

The study was limited to the investigation of the performance of the AnUBR in treating greywater from un-sewered settlements (based on performance criteria which emphasise the removal efficiency), testing of greywater and monitoring specific quality parameters known for their effects on human health and impacts on the environment. An attempt was made to determine the presence of common gases (that may occur from the decomposition of organic matters) based on the volume of sludge produced.

The design and use of the AnUBR was referred as part of the experimental work set up while the analysis of gases and sludge produced were not the main focus of the study. However, following the study objectives, a pilot laboratory scale plant was to be designed and monitored in order to collect required data. Other aspects such as modelling of the treatment plant, the use of bio-kinetic to model the removal efficiency, sludge and gas characteristics, conveyance of greywater, disposal of effluent, operation and maintenance, social impacts, legal and operational requirements and training, community and institutional factors were beyond the scope of the study.

1.7 Relevance and Benefits of the research

The study was conducted to provide inputs to a practical greywater problem in order to improve the quality of life of the community living in un-sewered settlements. The investigation seeks to confirm the feasibility, performance and typical application of the AnUBR for greywater treatment with regards to its ability to remove pollutants content of greywater. The outcomes were set to contribute to the improvement of quality of effluent discharged and assist in reducing environmental pollution and health risks that may be caused by unsafe discharge of un-treated greywater and serve as a model for municipal replicability.

Chapter 2: Literature review and theory

2.1 Introduction

The sustainability of conventional sanitation concepts which consist of a sewer system and a wastewater treatment plant – technical or natural treatment system, compared to alternative solutions based on source control and separation of the wastewater's constituent parts, have been widely discussed throughout the world in recent years (Werner, 2003). A report by Rand Water (2008) indicates that the cost of conventional sewerage is not affordable in many low-cost un-sewered settlements; hence alternative options should be considered in order to provide safe disposal of sewage to protect the environment.

There is a general trend to return to small treatment systems (or package plant) in order to deal with the problem at source (DWAF, 2007). Small treatment systems are promoted as the best means of dealing with increasing water pollution problems caused by the overloading of bulk treatment plants and unsafe discharge of greywater and illegal dumping of solids waste (Gaydon et al., 2007).

Small treatment systems are generally employed in areas not served by larger treatment works, such as informal settlements (Gaydon et al., 2007). These treatment systems are often viewed as a cheaper operating option in the long term. Their selection is influenced by reduced capital costs, the perception of innovative technologies and the ease of operation (Hulsman & Swartz, 1993).

Several treatment technologies have been developed and implemented successfully worldwide. From investigations on the performance of these treatment systems it emerges that the anaerobic treatment is simplest and most effective in terms of removal efficiency (Voigtländer & Kulle, 1994). These treatment systems range from the simplest low cost to the most sophisticated plants. In this perspective, the anaerobic up-flow batch reactor was selected amongst other anaerobic treatments due to its simplicity of design, low operation and maintenance, the quality of effluent produced and the ease with which it can be implemented, which results in its wide application in sewered settlements (Voigtländer & Kulle, 1994). However, the good performance of the AnUBR has not been tested in the natural setting of un-sewered settlements, which is the focus of the current study.

This chapter presents the theory and literature relevant to the study. Different definitions of greywater, the extent of greywater problems and greywater characteristics are outlined.

In addition, the pilot plant study and an overview of selected greywater treatment options is described with an emphasis on the anaerobic up-flow batch reactor (AnUBR) treatment system. The criteria for evaluating small treatment plants and the quality standards are discussed. Finally, the treatment and disposal requirements are discussed. The chapter concludes with the research aspects identified through the literature reviewed.

2.2 Definition of greywater

Greywater is defined as wastewater from the kitchen, bath and laundry, excluding wastewater from toilets, and therefore containing lower concentrations of excreta (WHO, 2006). This definition was also used by Carden et al., (2007) and Wood et al., (2001) who defined greywater as any domestic wastewater produced, excluding sewage.

In turn, Morel & Diener (2006) added more details by defining greywater as wastewater from baths, showers, hand basins, washing machines and dishwashers, laundries and kitchen sinks. Other authors like Dixon et al.; (1999), Eriksson et al.; (2002), Ledin et al.; (2001), Ottoson & Stenstrom (2003) and Elmitwalli (2006) used the same definition but tried to exclude wastewater originating from kitchen sinks due to its high content of oil and food particles.

In the informal settlement context, greywater is defined as wastewater produced from washing clothes, dishes, food, body washing and cooking food; water that is often used more than once and can contain significant e-coli content (McLachlan, 2004). It includes also water spilt from collecting and carrying water, leaking standpipes and wasted water. Due to the lack of proper disposal infrastructure, greywater from informal settlements may include contents such as motor oil, paraffin, clothes dyes and candle wax (DWAF, 2005).

In view of all these definitions MacLachlan, (2004) suggested that greywater should be defined in the context of particular areas and sources of generation.

2.3 Extent of greywater problem in un-sewered settlements

2.3.1 Overview of greywater problem in un-sewered settlements

Most cities in developing countries like South Africa have communities that are characterised by overcrowding. There are large numbers of impoverished inhabitants, poor housing and inadequate water and sanitation services (DWAF, 2005). These settlements consist of housing areas with no formal urban design or planning and they lack disposal points for dirty water (DWAF, 2004).

Standpipes shared by 20 to 100 users are provided to supply water free of charge resulting in large quantity of greywater (from washing clothes, children, kitchen utensils and vehicles) which is often discharged onto the ground around shacks (Wood et al., 2001). Significant problems arise at these standpipes where abuse of taps and leaking pipes are common. In the absence of formal disposal facilities, discarded greywater commonly pools around standpipes and forms contaminated streams along roads and natural drainage channels (MacLachlan, 2004).

Figure 2-1: Greywater runoff at standpipe along the street

Research by the City of Cape Town (2005) and DWAF (2005) revealed that in un-sewered settlements, communities often use containers to defecate during the night because of inadequate sanitation provision. In the morning, these containers are often emptied into a storm water outlet, ditch or open space due to the long waiting at the public facilities. This untreated wastewater which includes greywater flows to the nearest river, watercourse, or is discharged onto open spaces (as shown in figure 2-1).

A report by Wood et al.; (2001) concluded that greywater is generated by the failure to provide, operate and maintain basic services in the form of water supply, sanitation, solid waste and storm water management and represents a significant human health and environmental threat. All these issues make greywater a problem in un-sewered settlements that should be taken seriously in order to prevent health risks and severe environmental pollution (City of Cape Town, 2005).

According to DWAF (2005), the typical greywater problems in un-sewered informal settlements results from inadequate sanitation system, pollution due to slaughtering areas, high densities, solid waste removal, water standpipes, open channels, lack of disposal facilities and backyard dwellings amongst many others. Morel & Diener (2006) found that in areas where drainage and sewer systems are missing, greywater is often discharged in the streets or open ground, thereby leading to negative impacts on public health, local economy and living conditions.

It is clear from the above that factors affecting greywater problems are related to water supply, sanitation, solid waste, storm water management and mainly to the lack of safe disposal facilities. In view of the aspects described above, greywater which may be considered as a source for nutrients for plants when used in irrigation in developed countries is seen as a problem in developing countries particularly in all categories of un-sewered settlements (Wood et al.; 2001). Hence, there is a need to address the greywater as part of overall health, pollution and environmental degradation problems within and downstream of informal and under-serviced areas.

2.3.2 Health and Environmental effects of greywater

Lindstrom (2000) revealed that greywater discharged into a stream, lake or surface water may have a more immediate impact on the recipient body of water at the discharge point due to its rapid decomposition rate. Due to its pollutant contents, greywater may decompose faster in soil after infiltration and may pollute groundwater if discharged continuously (Lindstrom, 2000). Therefore, to effectively and safely prevent negative environmental impacts and health risks untreated greywater should be kept out of water, be it either surface or ground (Ledin et al., 2001).

Greywater, particularly from informal settlements contains numerous contaminants. These include waterborne bacteria, viruses, parasites, chemical compounds and heavy metals, all of which may cause disease or illness (DWAF, 2005).

2.3.2.1 Reasons for treating greywater

Earlier water protection efforts focused almost entirely on sewage treatment to reduce primary, secondary and bacteria pollution. Discharge into surface water is the most common way of returning greywater to the natural environment, especially in urban and peri-urban areas (Lindstrom, 2000).

In most low and middle-income countries, greywater is discharged untreated, thus causing serious contamination of the receiving water and posing a risk to the population downstream using this polluted water for recreational or irrigation purposes (INWRDAM, 2003). Severe oxygen depletion, high loads of micro-organisms and eutrophication are but a few of the main pollution effects caused by the discharge of untreated greywater into surface water.

In this context, experience showed that greywater and black water must be treated and retrieved on-site before it get mixed with other non-organic substances (Bino, 2003). The basic objectives of greywater treatment are to protect public health and environment and comply with national and international regulations and standards (Elmitwalli, 2006). In South Africa, it should be aligned with DWAF (1999) regulation that stipulates that "… *effluent should be returned in a similar or better quality than that of receiving body"*.

Greywater treatment reduces pollution loads to an acceptable level and thereby also negative impacts on humans as well as aquatic and terrestrial environments (Friedler, 2004). The different treatment steps remove organic pollutants and reduce the levels of suspended solids, pathogenic organisms and other problematic substances (Idriss et al., 2005).

It is therefore imperative that greywater should be treated prior to discharge into the environment since uncontrolled discharge may be a source of potential health risks and environment pollution (Ghougassian, 2003). Adequate greywater treatment prior to discharge into surface waters maintains the ecological value of receiving waters and also enhances resilience of the ecosystem (Jefferson et al.; 2003).

2.3.2.2 Effects of greywater

According to DWAF (2004) the primary concern regarding greywater is the discharge of pollutants in natural water resources and the effects thereof on the health of the local and surrounding communities. Uncontrolled discharge or use of greywater may affect the soil, human health, the water resources and the general environment (City of Cape Town, 2004).

a) Soil

The main effects known to affect the soil are a tendency to raise the soil alkalinity and salinity and a reduction in the ability of soil to absorb and retain water (CSBE, 2003). According to (Gross, 2005) the increases in alkalinity will arise due to the presence of sodium, potassium or calcium salts in the greywater, particularly from laundry detergents. Water retention also is affected by some forms of sodium – an effect measured by a parameter known as the sodium adsorption ratio – SAR (CSBE, 2003).

CSBE (2003) study and Murphy (2006) confirmed that if a soil has been irrigated with untreated greywater for an extended period, sodium levels may build up, resulting in poor drainage and potential damage to plants; high levels of sodium may be detected by conducting a pH test of the soil. A pH of 7.5 or above may suggest that the soil has become overloaded with sodium.

The dilution of greywater by rainfall or fresh water irrigation helps flush the soil of sodium, excess salts, and other soil contaminants that might be building up (Mohammed, 2003).

Fats, oil and grease (FOG) found in greywater tend to fill the voids in the soil, particularly after being solidified by traffic. They increase storm water runoff into the storm water system, decreasing groundwater recharge and retention times and causing storm water pollution (DWAF, 2005). It was also reported that foodstuff and other nutrients that collect on the soil surface encourage the breeding of flies, cockroaches and mosquitoes as well as parasites and pathogens where polluted greywater can pond (Dixon et al., 1999). Inadequate reuse of greywater can have detrimental effects on soil; suspended solids, colloids and excessive discharge of surfactants can clog soil pores and change the hydro-chemical characteristics of soils (Morel & Diener, 2006).

b) *Water resources*

Depending on its sources, greywater may contain significant amounts of pollutants varying in concentration (Muanda & Lagardien, 2008). In informal settlements the lack of infrastructure leads communities to discard greywater into storm water outlets or over the ground outside, from where it reaches the river (Carden et al.; 2007). If discharged untreated, these flows of greywater may harm the eco-system and threaten the aquatic and marine life (City of Cape Town, 2005).

c) *Human health*

According to Murphy (2006), the health risks associated with greywater are related to microbial quality. Greywater as per its characteristics may contain concentrations of human excretions that can transmit infectious diseases (WHO, 2006). Human exposure to greywater is also much less an issue since all domestic greywater was initially produced by humans and has already come into contact with them (Al Beiruti, 2007); However, this water may contain contaminants that could be a risk to human health for those outside the source of generation (CSBE, 2003).

The main risks arise from physical contact with greywater in areas where children play, or by eating fruit or vegetables that were irrigated with greywater without cooking (Alcock, 2002).

d) *Environment*

CSBE (2003) investigation on greywater effects revealed that one of the main environmental risks from greywater is the pollution of groundwater depending on the geology of the area. The main risks when discharging greywater onto the ground is the contamination of the soil and the receiving groundwater body (Ledin et al., 2001). Waterborne pathogens contained in greywater can degrade the environment through their ability to penetrate vegetables and fruits and infect human and farms animals when eating raw or lightly cooked foods (DWAF, 2005).

It is clear from this review that greywater remains a concern especially in areas not served by sewer networks. Greywater (as a wastewater) has a certain level of contaminants which is considered harmful to both humans and environment (if not treated or discharged correctly). Given its composition, it is certain that greywater has adverse effects on the receiving environment if not treated or discharged in the right stream. Greywater has to be treated in order to prevent its polluting effects on the environment and threats to human health and to comply with disposal requirements.

2.4 Quality of greywater

The characterisation of wastewater fractions is an essential requirement in the design of the treatment process (Musvoto & Ramphao, 2007; Marais, 2007). It is commonly known that the largest proportion of the volume of domestic wastewater comes from sources other than the toilet (kitchens, bathrooms and laundries) (Laber & Haberl, 1999).

The quality of greywater is very site-specific, varying in strength and composition (Werner, 2003). Greywater from the first world is very different in composition to that generated in the third world (Lindstrom, 2000). The properties of greywater may vary from settlement to settlement with the type of existing infrastructures (City of Cape Town, 2005).

Generally it can be said that greywater contains only low fractions of organic matter, nutrients and additionally has a low microbial contamination (Werner, 2003). According to Laber & Haberl (1999), a separate collection of blackwater and greywater is a logical consequence when planning to improve overloaded sewage works. Hence, separating urine and faeces from wastewater leads up to a reduction of up to 90% nitrogen as well as 80% phosphorus in the remaining wastewater (known as greywater); knowing that nitrogen and phosphorus are found in urine and faeces (Werner, 2003; Mara, 2003; Lindstrom, 2000; Laber & Haberl, 1999).

The amount of greywater generated varies significantly with water availability and household hygienic habits amongst many other factors; about 2/3 of the total wastewater volume can be assumed to be greywater (Jefferson et al., 2001; Werner, 2003). In order to characterise greywater, factors affecting its quality need to be understood (Muanda, 2007).

2.4.1 Characteristics of greywater from different sources

Since greywater is a reflection of household activities, its main characteristics strongly depend on factors such as cultural habits, living standard, household demography, type of household chemicals used etc. (Morel & Diener, 2006). The study by Ledin et al. (2002) and Casanova et al. (2001) (presented in table 2-1 below) categorise greywater according to their sources..

2.4.1.1 Kitchen greywater

Kitchen greywater includes that produced from dishwashing and work at the kitchen sink, and contains food residues, high amounts of oil and fat, and detergents. In addition, it occasionally contains drain cleaners and bleach. Kitchen greywater is high in nutrients and suspended solids. Dishwasher greywater may be very alkaline (due to builders); show high suspended solids and salt concentration (US EPA, 1992).

2.4.1.2 Bathroom greywater

This category includes greywater from shower, hand wash basin and bath and is regarded as the least contaminated greywater source within a household. It contains soaps, shampoos, toothpaste, body-fats, lint, and traces of urine and faeces. Greywater originating from shower and bath may thus be contaminated with pathogenic micro-organisms.

2.4.1.3 Laundry greywater

This category include greywater from washing machines and hand washing and contains high concentrations of chemicals from soap powders (such as sodium, phosphorous, surfactants and nitrogen) as well as bleaches, suspended solids and possibly oil, paints, solvents, and non-degradable fibres from clothing. Laundry greywater can contain high amounts of pathogens when nappies are washed.

Table 2-1: Greywater quality according to the sources (Ledin et al., 2002; Casanova et al., 2001)

Parameter	Laundry	Bathroom	Kitchen sink
pH	9.3 – 10	5 -8.1	6.3 – 7.4
BOD_7 (mg/l)	150	170	387 – 10^3
TN (mg/l)	6 – 21	0.6 -7.3	13 – 60
TP (mg/l)	0.062 – 57	0.11 – 2.2	3.1 – 10
Chloride (mg/l)	9.0 – 88	3.1 – 18	-
Sodium (mg/l)	44 – 480	7.4 – 21	29 – 180
Potassium (mg/l)	1.1 – 17	1.5 – 6.6	19 – 59
Calcium (mg/l)	3.9 – 14	3.5 – 21	13 – 30
Magnesium (mg/l)	1.1 – 3.1	1.4 – 6.6	3.3 – 7.3
e-coli (cfu/100ml)	83×10^5	32×10^6	$13 \times 10^4 – 25 \times 10^7$
FC (cfu/100ml)	$9 – 16 \times 10^3$	$1 – 8 \times 10^6$	-

2.4.1.4 Other sources

a) Animal slaughtering areas

In many informal settlements, slaughtering of sheep, cattle and chickens is practiced and happens at central places and often on the sidewalk near a standpipe so that the resulting mess can be washed away (DWAF, 2005). Blood, faecal matters and stomach contents are washed out into storm water and open spaces where they get mixed with wastewater of other origin to form a flow of greywater that may flow directly into storm water, or form a pool of stagnant greywater (Page, 2008).

b) Car wash

Informal activities that take place in informal settlements range from car wash to the local breweries. These activities are often carried out in the backyard or on the sidewalk and generate substantial amounts of greywater that flows into the street or to the nearest water source or storm water (Page, 2008).

c) Domestic reuse

Greywater generated in households is often used more than once; water from clothes-washing is used for house sweeping and ends up being discarded into open spaces or the street (Page, 2008).

Since greywater is generated from household activities; its properties may vary from house to house based on certain factors such as cultural habits and lifestyle. In the informal settlement context, most household activities take place outdoors and greywater generated has specific characteristics which were found generally to be more polluted (Carden et al., 2007). The quality of greywater is very dependent on the source, with highest quality coming from the bathroom, the second highest from clothes washing, and the poorest quality coming from dishwashing activities (Murphy, 2006).

2.4.2 Greywater quality

According to Ridderstolpe (2004), the characteristics of greywater vary greatly, reflecting the lifestyle of the residents and the choice of chemicals for laundry and bathing. It also depends on the sources from where the water is drawn, as well as the use to which this water is put (Carden et al., 2007).

The characteristics of greywater varies depending on the volume of fresh water used per person in a household; it is also a factor of the chemical quality of water used and depends on the greywater sources (kitchen, laundry, bathroom), and chemicals used (Murphy, 2006; Morel & Diener, 2006. In general, the concentration of plant nutrients (nitrogen, posphorous and potassium) and pathogens of health concern are low in greywater due to the fact that the majority of these are found in excreta (Ottoson & Stenström, 2003).

The choice of treatment system depends on the characteristics of the greywater to be treated (Muanda, 2007). It serves to determine the extent of pollution by comparing the quality of greywater generated to the quality standards. Greywater characteristics are determined by sampling and testing of selected water quality parameters (based on their value as water quality indicators) (OPS/CEPIS, 2002).

2.4.2.1 Categorisation of greywater

A study by Marais (2007) tended to classify the constituent contents of wastewater in 3 broad categories, namely conventional, non-conventional and endocrines disrupters. The term conventional is used to define those constituents measured in mg/l that have served as the basis for design most of conventional treatment works. These are namely TSS, COD/BOD, NO_3/NO_2, TN, PO_4 and micro-organisms. These constituents may be removed from wastewater using various treatment processes and high removal efficiency can be attained.

Non-conventional applies to those constituents that may to be removed or reduced using advanced treatment processes. This category consists of refractory organics, volatile organic compounds, surfactants, metals and total dissolved solids. The endocrines disrupters consist of home care products, veterinary and household products, sex and steroidal hormones and prescriptions or on prescriptions drugs (Marais, 2007).

The conventional constituents (of wastewater) are in turn classified according to their characteristics; which are physical, chemical or microbiological (Erikson et al., 2005; Dallas, 2001). Generally, greywater is characterized by its content which varies from house to house and may contain lower levels of organic matter and nutrients compared to ordinary domestic wastewater and high concentration of biodegradable organic, pathogens and other pollutants (Sall, 2006). Other parameters such as gases and surfactants emanate from the decomposition or mixture of various chemicals and are categorised under chemical characteristics (Laine, 2001).

From analytical chemistry and microbiology, wastewaters are subdivided into three category described previously as physical, chemical and microbiological (Morel & Diener, 2006).

a) Physical characteristics of greywater

The physical characteristics of relevance are temperature, turbidity, colour and suspended solids (Mohammed, 2003).

The temperature of greywater is often higher than that of potable water because of the addition of warm water from household and varies within a range of 18 – 35ºC depending on the geographic location (Tchobanoglous & Franklin, 2003). These rather high temperatures are attributed to the use of warm water for personal hygiene and discharge of cooking water (Morel & Diener, 2006).

The temperature of water is a very important parameter because of its effect on chemical reactions and reactions rates, aquatic life and the suitability of the water for beneficial reuse (Tchobanoglous & Franklin, 2003). These temperatures are not critical for biological treatment processes (aerobic and anaerobic digestion occurs within a range of 15 – 50ºC, with an optimal range of 25 – 35ºC) (Crites and Tchobanoglous, 1998). However, higher temperatures can cause increased bacterial growth and decreased $CaCO_3$ solubility, causing precipitation in storage tanks or piping systems; at low temperature (of about 15ºC) methane producing bacteria becomes inactive (Tchobanoglous & Franklin, 2003).

Most anaerobic systems are designed to operate in the mesophilic temperature range (between 25 and 40ºC). Temperatures changes greater than 1ºC per day affect the process performance (Tchobanoglous & Franklin, 2003).

Suspended solids consist of food, oil and soil particles from kitchen sinks, or hair and fibres from laundry. These particles and colloids cause turbidity in the water and may even result in physical clogging of pipes, pumps and filters used in the treatment processes (Morel & Diener, 2006).

b) Chemical characteristics of greywater

The chemical characteristics of greywater are dependent partly on the chemical quality of source water (Murphy, 2006). The chemical parameters of relevance are hydrochemical parameters such as pH, alkalinity, electrical conductivity, sodium adsorption ratio, biological and chemical oxygen demand (BOD, COD), nutrient content (TN and TP) and problematic substances such as heavy metals, disinfectants, bleach, surfactants or organic pollutants in detergents (Morel & Diener, 2006).

In addition to these, chemicals detergents contribute with chemicals such as sodium and boron, and washing contributes with organic particles, fats, hair and lint (Alcock, 2002; CSBE, 2003, Murphy, 2006). Other groups of chemical found in greywater are those emanating from the decomposition of organic matters and mixtures of chemicals. These are:

- *Surfactants and other household chemicals*

Surfactants (also known as surface-active-agents) are organic chemicals altering the properties of water. The best known are alcohol ether sulphate and alcohol ethoxylate which still being used in developing countries (Friedler, 2004).

- *Gases*

According to Tchobanoglous & Franklin (2003) gases may found within untreated wastewater. These include nitrogen, oxygen, carbon dioxide, hydrogen sulphide, ammonia and methane. The first three are common gases of the atmosphere and may be found in all water exposed to air while the latter are derived from decomposition of the organic matter present in wastewater and are of concern with regard to health.

The same study describes methane gas as a by product from the anaerobic decomposition of the organic matter in wastewater. Normally, large quantities are not encountered in untreated wastewater because even small amounts of oxygen tend to be toxic to the organisms responsible for the production of methane.

c) Microbiological characteristics of greywater

According to Morel & Diener (2006), the microbiological characteristics of greywater refer to the presence of pathogenic micro-organisms such bacteria, helminths, protozoa and viruses); therefore greywater may pose a health risk given its contamination with pathogens. Ledin et al., (2001) reported that the presence of micro-organisms in greywater originate from hand washing after toilet use, washing of babies and children after defecation, nappy changes and body washing. Some micro-organisms enter the greywater system through washing of vegetables and raw meat. However, pathogens of faecal origin pose the main health risks (Eriksson et al., 2002). In culture where water is used for anal cleansing, pathogens organisms may be found in greywater from shower if discharged (Idris et al., 2005)

2.4.2.2 *Factors affecting greywater characteristics*

a) Settlement density

Settlement density (measured in dwelling units or number of households per hectare) is the simplest criteria to establish and it has a significant impact on greywater management (Carden et al., 2007; City of Cape Town, 2005).

A report by DWAF (2005) indicated that when the density of un-serviced settlements increases, the disposal of greywater becomes problematic. With low densities and sufficient space between shacks greywater is usually disposed of on the ground where a combination of evaporation and infiltration ensures that it is not an immediate visible problem. However, as densities increase, the amount of greywater disposed of onto open spaces results in wet areas, higher water tables and problems such as smells, breeding of flies and mosquitoes and flooding (DWAF, 2005).

It was concluded that greywater impacts increase exponentially in very dense settlements since the amount of open space decreases markedly with density (Carden et al., 2007). The same study showed that the concentration of pollutants in greywater generated from high density settlements was higher compared to that generated in low or medium density settlements.

b) Waste management methods

To decide on the management options of greywater, it is recommended to look first at existing options (in terms of disposal practices). Topography and soil properties are important factors to look at due to their influence in the conveyance system (which is part of the disposal system) and final disposal (City of Cape Town, 2005).

Solid waste collection systems should be planned and managed accordingly. The poor management of solid waste may affect the greywater characteristics. Rainwater is often contaminated after washing over collected piles of rubbish or waste gathered in the skip. This contaminated rainwater ends up polluting either the groundwater or river through the storm water system (DWAF, 2005).

c) Rainfall

Greywater is more manageable in areas with low rainfall but the specific impacts of varying rainfall are difficult to quantify (Carden et al., 2007). Rainfall conveys polluted surface water to low-lying areas and gets mixed with the existing pool of greywater thus raising the volume and deteriorating the quality of greywater (Jefferson et al., 2004).

d) Water supply and household activities

The water supply system impacts on the quantity of water used on a daily basis by the household. It appeared that one of the most important factors relating to greywater quality is daily per capita water consumption (i.e. where consumption is lower, greywater quality tends to decrease, based on concentration of pollutants, mostly in the form of detergents).

According to Carden et al., (2007) the daily per capita for both cases is different due to the distance covered to fetch water. Where communities have to fetch water a distance from the house, the consumption is lower in comparison to those who have water in close proximity (City of Cape Town, 2005).

The use of chemical and other cleaning products such as bleach, detergents and antiseptic soaps affects the quality of greywater. These products have certain concentration of toxicity; once released after use it affects the quality of greywater and contributes to the pollution of the environment (Laine, 2001).

e) Sanitation services

The level of sanitation services is a parameter to consider in the management of greywater in informal settlements. In the South Africa context, informal settlements generally are provided with a dry sanitation system that does not allow for greywater disposal. This sanitation is often not maintained and users are forced to use buckets to defecate and discard it at the standpipes, open spaces or nearby roadside (Wood et al., 2001).

Several studies concluded that the level and functioning of sanitation service in the settlement makes a huge difference - where there is no service, or in places where it is dysfunctional, the likelihood of the greywater being contaminated with sewage increases. Besides these factors, Eriksson et al.; (2002) considered that the composition of the system that transports both grey and drinking water affects significantly the quality of greywater.

2.4.2.3 Quality parameter indicators and their significance

The quality parameters are those related to the quality of greywater generated. The following variables are chosen based on their value as a water quality indicator according to selected chemistry and water quality reference books and articles (Carden et al., 2007; DWAF, 1998a; Sanders et al., 1987).

Greywater is characterised by its physical, chemical and microbiological composition and related quality parameters. These parameters are classified into three categories, namely, physical, chemical and microbiological (Ledin et al., 2001) and their concentration may vary from settlement to settlement in function of certain factors discussed previously.

Eriksson et al; (2002) described some characteristics of grey wastewater with regard to its components, content and related environmental effects. The study by Morel & Diener (2006) and Crites & Tchobanoglous (1998) (presented in table 2-2) summarises the typical greywater quality parameters and associated risks. These characteristics are physical, chemical and microbiological*.*

Table 2-2: Quality parameters and their significance (adapted in part from Crites & Tchobanoglous, 1998)

Parameter	Description/source	Significance and risk
Temperature	The temperature impacts on the treatment process (especially anaerobic treatment). Most greywater have temperature above 18ºC. Temperature between 25-30ºC is favourable for biological treatment process to perform optimally.	The temperature of water is very important parameter because of its effect on chemical reactions and reaction rates, aquatic life (Tchobanoglous & Franklin, 2003). High temperatures can cause increased bacterial growth and decreased $CaCO_3$ solubility, causing precipitation in storage tanks or piping systems (Morel & Diener, 2006).
Suspended solids	Suspended solids give rise to the turbidity (or murkiness) of a sewage and indicate the presence of various chemical and microbiological pollutants.	Can lead to the development of sludge deposits and anaerobic conditions if discharged untreated into water resources. Used to assess the reuse potential and determine suitable type of operations and treatment process.
pH	A measure of the acidity or basicity of an aqueous solution. pH >7 indicate basicity and pH <7) indicate acidity.	The pH value of water is related to a large number of dissolved substances and is therefore a good indicator of the quality of water. Measurements are taken to determine availability and toxicity of specific chemical elements present in water.
Oil and grease	It can be of biological (animal fat, vegetable oil) or mineral (petroleum hydrocarbons) origin, or they can be synthetic compounds.	Greywater from kitchen processes generally has higher levels of oil & grease. Can lead to clogging of soil surfaces, leading to smells etc.
COD	COD derives from household chemicals like dishwashing and laundry detergents which are primary source of phosphates and sodium.	COD is used as a measurement of organic contamination in wastewater.
BOD	BOD describes biological oxidation through bacteria within a certain time (normally 5 days).	When discharged into surface water (stream, river or lake) it depletes the dissolved oxygen concentration and can lead to a long list of serious water quality changes such as colour, taste, odour, mobilisation of toxic metals, change in fish speciation and even fish kills (Dallas, 2001; Morel & Diener, 2006).
Dissolved Oxygen	Measurement of the amount of oxygen dissolved in the water relates to the amount of oxygen available for living organisms.	Low levels of dissolved oxygen may indicate organic pollution of the sample.
Phosphates	Polyphosphates are used in detergents in order to provide the alkaline solution, necessary for effective cleansing and therefore are found in large amounts in greywater.	Phosphate is an algal nutrient (associated with the eutrophication of water bodies), and is indicative of pollution, e.g. from detergents, fertilizers, sewage etc. It is used as a measure of the nutrients present and the degree of decomposition in wastewater.
Ammonia	Quantity of ammonia depends on the pH and temperature of the sample.	Used to determine the level of contamination. Water containing ammonia should not be allowed to enter any surface or ground water system.
E. coli and faecal coliform	An indication of pollution by faecal matter from warm-blooded animals, the number of e. coli in a given volume of wastewater can be used to indicate the level of risk to human health where there is contact with this wastewater (Murphy, 2006).	Risk to human health, presence of faecal coliform indicates faecal contamination (Murphy, 2006). Used to assess the presence of pathogenic bacteria and specific organisms.

2.4.2.4 Concentration of pollutants in greywater

The production of waste from human activities is unavoidable; however, almost all humans produce the same amount of waste (IRDC, 2006). The amount and type of waste produced in households is influenced by the behaviour, lifestyle and standard of living of a population as well as the technical and juridical framework by which people are surrounded (Ledin et al.; 2001).

Greywater generated in the informal settlement varies in volume and composition according to the dynamic of the settlement (Carden et al.; 2007). In the literature reviewed, wide ranges of values for pollutants have been published; showing TSS value averaging 450 to 2,450mg/l, pH 6.1 to 9.3, COD 13 to over 2,000mg/l, BOD 90 to up to 2,000mg/l; TN 4 – 14 mg/l and TP (depending on the use of detergents with or without phosphates) and micro-organisms from 10^3 - 10^8cfu/100ml (as indicated in table 2-3). Depending on the environment and sources, the concentrations of pollutant may vary widely from one area to another based on local conditions, lifestyle and custom (Ledin et al., 2001)

a) Suspended solids

The concentration of suspended solids depends strongly on the amount of water used; the typical concentration ranges from 50 – 300mg/l and can be as high as 1,500mg/l in certain cases (Del Porto & Steinfeld, 1999). The highest concentrations of suspended solids are typically from kitchen and laundry greywater; however, the concentration (of suspended solids) depends on the amount of water used (Ledin et al., 2001). Al-Jayyousi (2003) noted that greywater collected from clothes washers, bathtubs, showers and basins is relatively low in suspended solids and turbidity, indicating that most contaminants are dissolved. However, values above 2,450mg/l were reported in un-sewered settlements of developing countries.

b) pH

pH is an indication of the state of a liquid (alkaline or acidic). Since greywater is generated from household activities, the pH value ranges is 6.7 – 7.6 (Dixon et al., 1999) and 5.0 – 7.0 (Rose et al., 1991). For easier treatment and to avoid negative impacts on soil and plants when reused, the pH of greywater should be 6.5 – 8.4 (USEPA, 2004).

The pH of greywater depends strongly on the pH value of water supply and usually lies within optimal range. Values of 9.3 to 10 were observed in laundry greywater by Christova Boal et al., (1996). However, greywater with high pH values alone is not problematic when applied as irrigation water but the combination of high pH and high alkalinity is of concern (Ledin et al., 2001). For treated effluents discharged into the environment the allowable pH range usually varies from 6.5 to 8.5 (Tchobanoglous & Franklin, 2003).

c) Organic compounds (COD and BOD)

The BOD and COD are parameters used to measure the organic pollution of water; COD describes the amount of oxygen required to oxidise all organic matter found in greywater while BOD describes biological oxidation through bacteria within a certain time (normally 5 days) (Morel & Diener, 2006).

The main groups of organic substances found in wastewater comprise proteins from food, carbohydrates (sugar and cellulose), fats and oils as well as different synthetic organic molecules such as surfactants that are not easily degradable (Mara, 2003).

BOD and COD concentrations in greywater strongly depend on the amount of water and products used in the household (especially soaps, detergents, oils and fats). High BOD and COD concentrations were observed in areas with low water consumption; Dallas et al., (2004) observed an average BOD_5 of 167mg/l in mixed greywater with an average water consumption of 107l/p/d. In Burnat & Mahmoud's (2005) study in sewered areas of Palestine where greywater volume attains 40l/c/d, the average concentrations of BOD were found to be as high as 590mg/l and exceeded 2,000mg/l in isolated cases.

According to Rittman, Love & Siegrist (2008), the biological oxygen demand (BOD) is the famous and traditional wastewater pollutant. When discharged into surface water (stream, river or lake) it depletes the dissolved oxygen concentration and can lead to a long list of serious water quality changes such as colour, taste, odour, mobilisation of toxic metals, change in fish speciation and even fish kills (Dallas, 2001; Morel & Diener, 2006).

The COD concentration in wastewater is found in most cases to be above the BOD level; the typical COD concentration may vary from 120 to 1,200mg/l depending on the amount of water use (Dixon et al., 1999). In un-sewered settlements of developing countries, the COD concentration was found to be 1,580mg/l and in some isolated case attaining 2,100mg/l (Jefferson et al., 2001).

The COD/BOD ratio is a good indicator of greywater biodegradability and in most cases COD is higher than BOD_5; the higher the ratio the less the biodegradability of wastewater. The biodegradable range of wastewater is less than 3 (Tchobanoglous, 1991).

A COD/BOD_5 ratio below 2 – 2.5 indicates easily biodegradable wastewater; ratio from 3 to 7 indicates that the wastewater is moderately biodegradable and above 10 indicates a low biodegradable wastewater (Papadopoulos et al., 2001). The decrease in COD/BOD ratio indicates that wastewater is becoming more biodegradable (Jefferson et al., 2000). The ratio values depend on the nature of wastewater and vary considerably with the degree of treatment wastewater has undergone (Tchobanoglous, 1991).

Generally greywater is considered as easily biodegradable with BOD accounting for up to 90% of the ultimate oxygen demand (Del Porto & Steinfeld, 2000); other studies (Al Jayyousi, 2003; Jefferson et al., 2004) indicate low greywater biodegradability which was attributed to the type of synthetic surfactants used in detergents and on the amount of oil and fat present.

d) Nutrients (TN and TP)

Several studies indicated that greywater contains low levels of nutrients compared to toilet wastewater. Nonetheless, nutrients such as nitrogen and phosphorous are important parameters given their fertilising value for plants, their relevance for natural treatment processes and their potential negative impact on the aquatic environment (Morel & Diener, 2006; Franklin & Tchobanoglous, 2003).

The concentration of nitrogen in greywater is relatively low (urine being the main nitrogen contributor to domestic wastewater). Nitrogen is also found in kitchen wastewater and at a low level in bath and laundry greywater. Nitrogen in greywater originates from ammonia and ammonia-containing cleansing products as well as from proteins in meats, vegetables, protein-containing shampoos, and other household products (Del Porto & Steinfeld, 2000). The research on greywater characteristics conducted by Lindstrom (2000) revealed that the concentration of nutrients in greywater depends on the per capita mass discharge and the water use.

According to Tchobanoglous & Franklin (2003), the principal sources of nitrogen are nitrogen compounds of plant and animal origin, sodium nitrate and atmospheric nitrogen. Typical values of nitrogen in mixed household greywater are found within a range of 5 – 50mg/l with extreme values of 76mg/l in kitchen greywater (Lindstrom, 2000). Sasse (1998) revealed that low nitrogen limits microbial processes, thus hindering degradation of organic matter in biological treatment processes.

The average concentrations are typically found in the range of 4 – 14mg/l in regions where non-phosphorous detergents are used (Eriksson et al., 2002). However, the concentrations can be higher as 45 – 280mg/l in households where phosphorous detergents are used such as in Israel (Friedler, 2004).

Phosphorous is another essential element to the growth of algae and other biological organisms. The usual values observed in mixed household wastewater may vary from 4 to 16mg/l of phosphorous (Tchobanoglous & Franklin, 2003). Despite these values, the level of phosphorous in greywater strongly depends on the presence or absence of phosphorous in laundry and dishwater detergents; and high values may be expected where phosphorous-based products are used in the household (Morel & Diener, 2006).

A study by Källerfelt & Nördberg (2004) showed that the concentrations of plant nutrients (nitrogen, phosphorous and potassium) of health concern are low in greywater due to the fact that the majority of these are found in excreta. Greywater contributes 10-30% of the total phosphorous input to a combined wastewater system, and the concentrations are governed by the type of detergents used. If phosphorous-containing detergents are used, concentrations typically range from 3 to 7mg/l, but if phosphate-free detergents are used, the concentrations are about 1mg/l (Mohammed, 2003).

This hypothesis was confirmed by Ottoson & Stenström (2003) stating that greywater contains 10% or less of the total nitrogen content in wastewater and the nitrogen concentration is often 10 mg/l or less, prior to treatment. Laber & Haberl, (1999) confirmed these figures by showing that greywater contributes from 50 to 80% of the total domestic wastewater and has a low contribution of nitrogen, phosphates and potassium (respectively 3, 10 and 34%) to domestic wastewater. Compared to municipal wastewater, greywater contains fewer nutrients due to the lower urine content (Werner, 2003).

e) Oil and Grease

Greywater typically contains high concentrations of easily degradable organic material, such as fat and oil from cooking, tensides and other residues from soap and other detergents (Ridderstolpe, 2004).

Greywater may contain significant amounts of fat such as O&G originating mainly from kitchen sinks and dishwashers as well as bathroom and laundry greywater (Christova Boal, 1996). The concentrations range between 37 – 78mg/l.

The O&G content of kitchen greywater depends strongly on the cooking and disposal habits of the household. Concentration as high as 230mg/l was found in mixed greywater in Jordan (Al Jayyousi, 2003), while concentrations ranging from 1,000 to 2,000mg/l were observed is restaurant wastewater (Crites & Tchobanoglous, 1998).

f) Surfactants and other household chemicals

The amount of these products depends on type and amount of detergent used. Several studies revealed surfactant concentrations ranging from 1 – 60mg/l, and averaging 17 – 40mg/l (Friedler, 2004; Gross et al., 2005).

g) Gases

The actual quantity of gas that can be presented in solution is governed by the solubility of the gas, the partial pressure of the gas in the atmosphere, the temperature and the concentration of the impurities (such as suspended solids) in the water (Tchobanoglous & Franklin, 2003). The total gas production is usually estimated from the volume of volatile solids reduction (Berktay, 2008); typical values vary from 0.75 - 1.12m^3/kg of volatile solids destroyed. Gas production can fluctuate over a wide range depending on the volatile solids content of sludge feed and the biological activity of the digester (Tchobanoglous & Franklin, 2003).

h) Microbiological parameters

The concentrations of micro-organism in greywater are low (compared to a typical wastewater) due to the fact that the majority of these are found in excreta (Källerfelt & Nördberg, 2004). However, households with babies or small children produce greywater with higher faecal counts (Carden et al.; 2007). Pathogens essentially exist in the greywater fraction if contaminated with faeces; the number of $10x10^5$cfu/100ml is possible and may increase on storage (Al-Jayyousi, 2003). The average concentration is reported to be around 10^3 – 10^8cfu/100ml; however, contamination can be as higher as 10^7 – 10^8cfu/100ml in laundry and shower greywater as observed in Jordan (Al Jayyousi, 2003).

In informal settlements context, greywater can be contaminated by discharging night soil, human and animal faeces, blood and stomach content from animal slaughtering areas (DWAF, 2005). It can be therefore assumed that greywater from informal settlements has the same characteristics as raw sewage and should be treated accordingly (MacMahalan, 2004). The microbial contamination of greywater is, however, significant and must be taken into account when calculating risks and selecteing treatment methods (Ottoson & Strenstrom, 2003).

The microbiological contamination of greywater is typically about a factor 10 lower compared to municipal wastewater. However the concentrations of phosphorus, heavy metals, and xenobiotic organic pollutants are around the same level (Werner, 2003; Ledin et al., 2001).

Research by Eriksson et al.; (2002) concluded that greywater contains 50% or more of the readily degradable organic matter in household sewage-measured as biological (BOD) or as chemical oxygen demand (COD) - but the concentrations are highly variable, depending on household practices.

In industrialised countries, excessive amounts of detergents, including shampoos, shower oils, cleansing powders, glues and preservatives are common and responsible for substantial BOD input, in addition to O&G used in food preparation (Kallefert & Nordberg, 2004). In cultures where use of cooking oil is common, the greywater organic content becomes very high and may call for special care when designing the treatment systems; but if collected separately, O&G can increase biogas yield in anaerobic digestion (Eriksson et al., 2002).

Table 2-3: Concentration of pollutants in greywater (adapted from Morel & Diener, 2006)

Reference	pH	TSS (mg/l)	COD (mg/l)	BOD_5 (mg/l)	PO_4 (mg/l)	O&G (mg/l)	TKN (mg/l)	NH_3/N (mg/l)
Combined greywater Jeppesen & Solly (1994)[1]	6.6 – 8.7	45 - 330	-	90 - 120	-	-	-	-
Combined greywater Casanova et al., (2001)[1]	7.47	35	-	65	-	-	-	-
Bathroom greywater Christova – Boal et al., (1995)[2]	6.4 – 8.1	43 - 380	-	45 - 330	-	-	-	-
Laundry greywater Christova – Boal et al., (1995)[2]	6.3 – 9.5	26 - 400	-	10 – 520	-	-	-	-
Combined greywater Källefert & Nordberg (2004)[2]	6.09 - 7.03	69.0 - 1420	530- 3520	-	14.8-56.2	-	-	-
Combined greywater Eriksson et al. (2005)[1]	5.0 – 8.7	6.4 - 330	13 – 549	-	0.6 - 68	3.1 - 12	2.1-31.5	0.03-25.4
Mixed greywater Pollution Research group (2005)[2]	5.8 – 6.3		1135	-	11	-	24 - 30	20
Stephenson et al., (2006)[1]	-	265 - 1261	999 - 1625	-	0.3-18.9	-	-	-
Mixed greywater Carden et al., (2006)[3]	3.3 – 10.9	-	32 - 11451	-	0.7 - 769	8 - 4650	0.6 - 488	0.2-44.7

[1] First world greywater (sewered areas in developed countries); [2] Third world greywater (case of sewered areas in South Africa); [3] Third world greywater (case of un-sewered settlements in South Africa)

Greywater also contains chemicals such as boron, surfactants and sodium as well as nutrients of phosphorus and ammonia. These chemicals and nutrients are harmful to the environment as discharging them directly into the environment by pouring them onto the garden ultimately leads to polluting groundwater and run off to streams (Bino, 2003).

2.4.2.5 Constituents of concern in greywater

Tchobanoglous & Franklin (2003), Murphy (2006) and Malan (2006) showed that certain constituents are of concern in wastewater, viz suspended solids, biodegradables organics such as COD/BOD, O&G, pathogens such as e-coli, faecal coliform, nutrients such as phosphates and nitrogen. The effects of each of these constituents are described as follows:

a) <u>Suspended solids</u> can lead to the development of sludge deposits and anaerobic conditions when untreated wastewater is discharged in the aquatic environment. Food, oil and soil particles from kitchen sinks, or hair and fibres from laundry can lead to high solids content in greywater.

b) <u>Biodegradable organics</u>: composed principally of proteins (mainly from food), carbohydrates (such as sugar and cellulose), oil and fats. The chemical and biological oxygen demand (COD/BOD) are parameters to measure the organic pollution in water or a measure of biodegradable organics compounds contained in wastewater. COD describes the amount of oxygen required to oxidise all organic matter found in greywater; while BOD describes biological oxidation through bacteria within a certain time span (normally 5 days and is called BOD_5).

   Most COD derives from household chemicals like dishwashing and laundry detergents which are also the primary source of phosphates (PO_4) and sodium (Na) in the greywater. If discharged untreated into the environment, the biological stabilisation can lead to the depletion of natural oxygen resources and to the development of septic conditions.

   The COD/BOD concentrations in greywater strongly depend on the volume of water and products used in the household especially detergents, soaps, oils and fats (Morel & Diener, 2006). The COD/BOD is high where water consumption is low.

c) <u>Nutrients (nitrogen and phosphorous)</u> are essential for vegetal growth; if discharged to the aquatic environment, these nutrients can lead to the growth of undesirable aquatic life. The excess discharge on land may lead to the pollution of groundwater. The total nitrogen content of greywater in lower than in domestic sewage as urine is generally not present. In general greywater contains lower levels of organic matter and nutrients compared to ordinary domestic wastewater.

d) Micro-organisms such as e-coli and faecal coliform are an indication of human contamination. These pathogens can transmit communicable diseases present in wastewater. Pathogens are introduced into greywater from bath, laundry and kitchen wash waters (Ottoson, 2003).

e) Other pollutants such as refractory organic, heavy metals and dissolved organics are less frequent in wastewater; if industrial and commercial effluents are discharged, these compounds may be found in wastewater. Other pollutant of concern are mineral salts and organic substances (derived from plants: they include food wastes, milk, sugar, faeces, urine, sweat and dirt from clothes) (Malan, 2002).

2.4.3 Quality of greywater in South Africa

The variability of the quality of greywater depends on the volume of fresh water used in a household, on the chemical quality of this water, on the greywater source (bathroom, kitchen, laundry etc.), on chemicals used in the washing/bathing process, and on the amount of greywater reuse carried out in the home before the final greywater is disposed of (Murphy, 2006).

Following a study by Dallas (2001), it was found that inorganic constituents may be found at lower levels in greywater. In a South African context the study by Alcock (2002) in middle income sewered areas revealed that greywater was generally alkaline and had a high chloride and potassium level; and a variable level of nitrogen and phosphate. Another study by Källefert & Nordberg (2004) showed that the bacteriological quality of the greywater varied considerably and depended on the specific water use (such as preparation of food, hand washing etc.). Stephenson et al., (2006) study's on the characteristics of greywater from seven settlements showed variable concentration of pollutants in samples collected; this was attributed to the cultural habits (such as diet, hygiene and type of household chemical used).

Most recently Carden et al., (2007) attempted to characterise greywater from selected informal settlements throughout South Africa. Results obtained showed the average COD value of 4,770mg/l, pH averaged 8.8 and O&G was found about 730mg/l. The study concluded that greywater in densely populated settlements has high concentrations of pollutant load compared to low density settlements. These results are presented in the table 2-6 and give an indication of greywater quality in South African informal settlements.

2.4.3.1 Greywater quality standard (in South Africa)

The prime motivation for publication of standards is the protection of the aquatic and other environment; ideally the water returned to the environment should be of an equal or better quality than that existing already in the environment (Gaydon et al., 2007).

According to Morel & Diener (2006), the qualitative and quantitative effluent standards have to maintain or even enhance the quality of receiving waters, to ensure soil fertility and protect public health. The quality standards requirements for discharging of domestic wastewater and greywater into water resource (presented in table 2-4) are given by the guidelines set by the Department of Water Affairs and Forestry (DWAF, 1999). These guidelines give the general and special recommendable limit for discharging wastewater (including greywater into water resources or sensitive environment). Wastewater (effluent) should therefore comply with these regulations prior to discharge otherwise treatment should be required. These guidelines are regulated in order to prevent environmental pollution and related health impact caused by unsafe disposal.

Table 2-4: Wastewater quality standards (adapted from DWAF, 1999)

Substance/Parameter	General limit	Special limit
Suspended solids (mg/l)	25	10
pH	5.5 – 9.5	5.5 – 7.5
Ammonia as Nitrogen (in mgN/l)	3	2
Nitrite, Nitrate as Nitrogen (in mg/l)	15	1.5
Chemical oxygen demand (COD) (in mgO_2/l)	75*	30*
Biological Oxygen Demand (BOD) (in mg/l)	Not specified	Not specified
Ortho-phosphate as phosphorous (in mg/l)	10	1 – 2.5 max
Soap, oil or grease (in mg/l)	2.5	0
Faecal coliform (cfu/100ml)	<1000	0
E-coli (cfu/100ml)	< 1000	0

*After removal of algae

These guidelines are reinforced by the WHO (2006) general guidelines which extend their application to the reuse of the effluent for agriculture, aquaculture and other purposes.

2.4.4 Quality of greywater in selected countries

Greywater quality may vary from country to country based on certain factors discussed previously. The table 2-5 below gives an indication of the quality of greywater from sewered areas of selected developing countries.

Table 2-5: Greywater characteristics in selected countries (adapted from Morel & Diener, 2006).

Variable	Costa Rica[1]	Palestine[2]	Israel[3]	Nepal[4]	Malaysia[5]	Jordan[6]	Sri Lanka[7]
pH	-	6.7– 8.35	6.5 – 8.2	-	-	6.7 – 8.35	7.2 – 8.9
COD (mg/l)	-	1270	822	411	212	-	56 – 890
BOD (mg/l)	167	590	477	200	129	275-2287	324
TSS (mg/l)	-	1396	330	98	76	316	325-1500
TN (mg/l)	-	-	-	-	37	-	58
NH_4-N (mg/l)	-	3.8	1.6	13.3	13	-	-
TP (mg/l)	-	-	-	-	2.4	-	12 -70
PO_4-P (mg/l)	16	4.4	126	3.1	-		35
FC (cfu/100 ml)	$1.5\text{-}4.6x10^8$	$3.1x\ 10^4$	$2.5x10^6$	-	-	$1.0x10^7$	10^8
O&G (mg/l)	-	-	193	-	190	7-230	37 - 1200

[1]Dallas et al. (2004); [2]Burnat & Mahmoud, (2005); [3]Friedler (2004); [4]Shrestha et al. (2001); [5]Martin (2005); [6]Al-Jayyousi (2003), [6]Franqui & Al-Jayyousi (2002), [6]Bino (2004), [7]Harindra Corea (2001)

Results in this table indicate a large variability and highlight differences in the quality of greywater from the sewered areas in developing countries. These results show high levels of pollution emanating from the use of household chemicals and detergents and conclude that greywater from un-sewered settlements (of the third world) is unfit for use unless under controlled conditions (Carden et al., 2007; Murphy, 2006).

2.4.5 Pollution measurement and Quality parameters analysis

When a wastewater sample is to be evaluated, many analyses may be done; there are, however a few key determinations which will give a fair indication of the state of the wastewater (Malan, 2002). These parameters are indicative for measuring pollution or health risks; they include oxygen demand, pH, nitrogen, total phosphorous, suspended solids, oxygen absorbed, TKN, ammonia and micro-organisms (such as e-coli and faecal coliform) (Gross, 2005) and should be included in the analysis of greywater quality (Davies, 2008).

These parameters are described (by Malan, 2002) as follows:

- pH which is a measure of whether the water is acid or alkaline.
- Chemical Oxygen Demand caused by the presence of organic substances which give rise to an oxygen demand when utilised by bacteria
- Nitrogen: present in the form of organic nitrogen and as ammonia nitrogen. According to Malan (2002), nutrients are essential for plant growth but may be detrimental if the water is released into water resources. They will stimulate algae growth and will result in forming organic sludge on the bottom which in turn exerts an oxygen demand when it decomposes.
- Total phosphorous: present as phosphates and phosphorus

- Suspended solids: is a measure of quantity of materials that can be removed by filtration, which represents the substances that will settle in rivers and dams and form a sludge layer on the bottom.
- Micro-organisms: (e-coli, faecal coliform, and total coliform) give an indication of the safety of the effluent for release into a public stream.

The quality of greywater depends on many factors. Among these are water availability and hygienic habits (Morel & Diener, 2006). The quality parameters analysis serves primarily to ensure that greywater leaving the source of generation or the treatment facility complies with the statutory requirements (DWAF, 1999). It is advantageous that certain key parameters be tested on-site. As the character of raw wastewater and/or greywater changes dramatically over any 24 hour period, correct sampling procedures are of the utmost importance (Jefferson et al., 2004).

2.4.6 Greywater volume

The general amount of greywater greatly varies as a function of the dynamics of the household. It is influenced by factors such as existing water supply service, and infrastructure, number of household members, age distribution, lifestyle characteristics, typical water usage patterns, cultural and eating habits (WHO, 2006; Morel & Diener, 2006).

Research by Carden et al., (2007) pointed out that the generation of greywater is directly related to the consumption of water and is dependent on a number of factors such as the level of service provision, tolerance of residents to pollution and the communities' level of awareness of health and environmental risks. Alcock (2002) in turn added other factors contributing to the volume of greywater generated. These are the cost of water, diet habits, technological level (yard taps or distant from the house), water losses through leaks, educational standing, social and business activities (such as car wash) and other alternative supplies.

The main sources of greywater generation are laundry, bathroom and kitchen (WHO, 2006). Murphy (2006) noted that the volume of greywater generated may be estimated from the water consumption of a household, given some knowledge of how much of this water is used outside the house. The statement was further confirmed by Carden et al., (2007) by formulating the equation $G_g = Q \times D$ which is function of water consumption Q per density D. Wood et al., (2001) noted that there is a general absence of data on the quantification of greywater in dense informal settlements owing to the fact that generally there is no proper measurement of services in these areas, and assumptions based on population estimates are indicative at best.

In South Africa, given the free basic water and sanitation services, some of the factors enumerated above do not affect the generation of greywater in the context of informal settlements (Muanda & Lagardien, 2008). Different estimates were provided by different authors on the average greywater volume generated by household in poor low income settlements. Based on factors enumerated previously, Alcock (2002) considered that 30 to 80l of greywater may be produced in a household with more than one tap in the home. Studies by Ridderstolpe (2004) and Winblad & Simpson – Herbert (2004) estimated that greywater volume produced may be as low as 20 – 30l/p/d in poor areas where water is carried from taps.

Carden et al., (2007) indicated that a greywater production is estimated by assuming that 75% of water consumed should be used to estimate the volume of greywater being generated in un-sewered settlements in South Africa. However, Morel & Diener (2006) believe that the greywater fraction may even reach 100 percent in household where dry sanitation is used.

Tchobanoglous & Franklin (2003) reported that depending on the assessment of the study area and based the level of service which is limited to dry sanitation and standpipes within 25 to 100m of household; it is generally assumed that 75 to 80% of water consumed ends up as greywater. In areas where dry sanitation and standpipes are provided, wastewater generated is considered as greywater and should therefore be given due attention (Ridderstolpe, 2004). The volume of greywater generated is therefore estimated based on water consumption figures rather than mathematical formulae or simple estimate (Muanda & Lagardien, 2008).

In conclusion, greywater is considered as wastewater despite the low concentration of pollutants; its characteristics vary from settlement to settlement as a function of cultural habits, household chemical used and living conditions. The greywater volume depends on water consumption and has little impact on the greywater quality. In un-sewered settlement context, the quality of greywater depends on many factors such as the sanitation system, solid waste management and activities that take place within the settlements.

However, the variability in concentration of pollutant, the quality is an important factor to consider for evaluating the performance of a treatment process. Some of these pollutants (described abiove) were identified as of concern according to their effects on human health and pollution to the environment. It is therefore recommended to monitor these constituents in order to comply with the general requirements standards in terms of disposal.

In South Africa, the quality standards developed by DWAF are applicable to all types of wastewater. Therefore, the quality standards described previously in this chapter are applicable to greywater as well.

In view of factors indicated as affecting greywater characteristics, the quality of greywater is affected specifically by the type of household chemical used and the waste management systems. The settlement density and rainfall contribute essentially to the volume of greywater generated; the dilution factor (caused mainly by the rainfall and leaking standpipes) and the volume generated in high density settlements have little effect on the treatment capability. However, it (the volume generated) remains an important parameter to consider for the design of the full scale treatment system.

Referring to these issues, the quality parameters to be considered from health impacts and environmental pollution perspectives are namely suspended solids, nutrients (nitrates/nitrites, phosphates), COD/BOD and pathogens indicator organisms (e-coli and faecal coliform). Other parameters such as pH and temperature have to be considered as affecting the treatment process while electrical conductivity should be considered when the treated effluent is to be discharged into natural water resources.

Since there are variable values for greywater quality and given the lack of suitable greywater quality data for un-sewered settlements in developing countries, the average values presented in table 2-4 above are considered as benchmark for the purpose of this current study.

2.5 Overview of greywater treatment technologies

The bulk of the small systems being proposed for the treatment of greywater fall into one of three categories – physical, biological, or natural systems (Jefferson et al., 2001; Jefferson et al., 1999).

Physical treatment systems usually involve some type of coarse filtration followed by disinfection of the filtrate (Costner, 1990). BOD removal between 60 and 80% has been reported for physical systems. Biological treatment systems are not usually capable of treating greywater to an acceptable level for reuse without the addition of a physical system to retain the biomass (Laine, 2001). While these combined systems can produce an excellent quality effluent, they are complex systems requiring routine maintenance and tend to be too expensive for use by a single household. Natural treatment systems depend on soil infiltration and/or nutrient uptake by plants to remove contaminants; and have been reported to have excellent BOD removal (95 – 100%).

A greywater treatment system collects, stores and treats greywater to a high standard (CSBE, 2003). It may include components such as wetlands, sand or soil filters, septic tanks or any other (Gustafson et al., 2002). The treatment process varies according to how the greywater is used and how and where it will be ultimately disposed (Morel & Diener, 2006). Most greywater treatment plants include a one or two step septic tank system for pre-treatment (Otterpohl et al., 1999). The treatment process needs both physical and biological processes for removal of particles and dissolved organic matter (Jefferson et al., 1999) The treatment process may include the settling of solids, floatation of lighter materials, anaerobic digestion in a septic tank, aeration, clarification and finally disinfection (Mohammed, 2006).

The treatment options vary also with the regulations in terms of discharge requirements. Small treatment plants are employed in areas not served by larger centralised sewage treatment works, and vary widely in the level of technology (Gaydon et al., 2006). The following section gives an overview of the treatment technologies that were designed, tested and implemented in certain countries.

2.5.1 On-site treatment systems

2.5.1.1 Three stage septic tank system

This system usually consists of a three stage septic tank that caters for sludge and grease separation, resulting in effluent that is anaerobic. After the septic tank is a sand filter which serves to stimulate aerobic conditions, after which greywater is routed to the planter bed (Carden et al., 2007). This results in purified water of quality near to potable. The treatment system is frequently used in low and middle income countries. It was reported to be one of the most effective, simple to maintain on-site treatment techniques and is recommended for the treatment of greywater containing significant quantities of food waste in the greywater to be treated (Carden et al., 2007).

2.5.1.2 Planter soil box

The system is designed to act as retarding mechanisms within sandy soils to slow down greywater so that sufficient treatment can be accomplished. After solids separation (oil and grease traps), greywater is allow to flow in the box containing sand (as filter medium) which acts as filter (Lindstrom, 2000).

2.5.1.3 Soil Infiltration

Soil infiltration is a simple and suitable method for on-site greywater treatment, for which comprehensive experience exists regarding both separated greywater and combined wastewater (WHO, 2006). In literature, there are various names found for the soil infiltration systems; some authors prefer use the terms vertical soil filter, rapid infiltration system or high rate infiltration system (Ridderstolpe, 2004).

According to Ridderstolpe (2004), the soil infiltration systems are often appropriate for greywater treatment due to their simplicity. Polluted water is typically applied to the filter from the top, whereupon it pours down through the medium vertically by gravity. To work properly, the water is allowed to percolate through the soil in an unsaturated flow. In such a flow water pours hygroscopically within the finest pores while the bigger pores are left open and aerated.

Results showed removal efficiency for suspended solids and BOD around 90 to 99% while pathogens removal also proved to be around 95 to 99%, about 30% for nitrogen and 30 to 95% removal for phosphorous, 20% FOG (Ridderstolpe, 2004). Soil clogging was found to be the weakness of the soil infiltration treatment system.

2.5.2 Localised treatment systems

2.5.2.1 Ponds

Wastewater stabilization ponds are developed for combined wastewater treatment but are also suitable for greywater (WHO, 2006). This treatment system usually consists of a number of ponds linked in series and designed to minimize hydraulic short-circuiting. For greywater treatment, an anaerobic stage is not required (WHO, 2006). This system is common in rural areas, particularly where combined sewages are treated (Gaydon et al., 2006).

Ponds systems show many advantages to more technically orientated solutions because of their simplicity and tremendous equalisation capability; however the system is particularly effective when used in combination with other treatment system such as anaerobic digestions (Voigtländer & Kulle, 1994).

2.5.2.2 Constructed wetlands

A wetland system is per definition a system where wastewater is treated by allowing it to flow over (and partially through) either natural soil, or a constructed porous bed (Malan, 2002). Constructed wetlands with subsurface flow are well suited for greywater treatment. They give a high reduction of BOD and total nitrogen, while phosphorous removal is dependent on the adsorption capacity of the media (WHO, 2006).

2.5.3 Case study low-cost treatment options

The variation in the greywater characteristics in terms of quantity and quality even on the same source level makes given general recommendations regarding planning and design of greywater plant difficult (Morel & Diener, 2006).

A number of technologies have been applied for greywater treatment worldwide varying in both complexity and performance (Jefferson et al., 2001). These technologies range from systems for single households (using disinfected untreated greywater for toilet flushing), to physical treatment systems (such as sand filters or membranes), biological treatment options (such as rotating biological contactors and membrane bioreactors), and natural treatment systems (such as constructed wetlands and infiltration systems) (Werner, 2003).
The following overview highlights the working principle, design criteria and removal efficiency. It also discusses the strength and weaknesses of the system as well as typical application following a review by Morel & Diener (2006).

2.5.3.1 Coarse filtration

Following the studies by Von Sperling & Chernicharo (2005); INWRDAM (2003); Tchobanoglous (1991), the coarse filtration is a primary treatment option to prevent solid matter from entering subsequent treatment steps or disposal. In this process, particles of certain size are retained by screens or filter media and only small particles are filtered out.

- Working principle: O&G are removed through flotation and grits are removed through sedimentation.
- Design criteria: HRT: 15-30 minutes, V_{min}: 200-300l; 1-2 vertical baffles.
- Removal efficiency: BOD≤20%, TSS≤ 20%, TN≤ 10%, TP≤ 10%, O&G≈70%.
- Strengths: cheaper option than septic tank, efficient O&G removal if well designed and maintained.
- Weaknesses: Low TSS and BOD removal efficiency requires frequent maintenance; odour nuisance if not sealed; unpleasant cleaning.
- Typical application: primary treatment step for kitchen greywater before treatment in septic tank or a mulch system or prior reuse in garden irrigation. The system was successfully implemented in Mali.

2.5.3.2 Sedimentation tanks

The sedimentation or septic tank is the most common small scale treatment system worldwide. The study by Anda et al., (2001) revealed the system is designed for gravity separation, combined sedimentation and flotation of settleable solids and grease. Substances denser than water settle at the bottom of the tank, while fat, oil and grease (FOG) float to form a scum layer. The organic matter retained at the bottom of the tank undergoes anaerobic decomposition and is converted into more stable compounds and gases (Koottatep et al., 2006; Dama et al., 2002 and Sasse, 1998).

- Working principle: vertical baffles in the tank force wastewater to flow under and over them and pass from the inlet to the outlet, thus guaranteeing intense contact between wastewater and resident sludge (Ghaniyari, 2009).
- Design criteria: HRT: 48h, V_{max}: 1.4 – 2m/h; 1 sedimentation chamber and 3 up-flow chambers.
- Removal efficiency: BOD≤80%, TSS≤ 80%, TN≤ 20%, O&G≈70%.
- Strengths: High treatment performance, high resilience to hydraulic and organic shock loadings; long biomass retention times, low sludge yield; ability to partially separate the various phases of anaerobic catabolism.
- Weaknesses: complex construction and maintenance; no clear design guidelines available and high costs.
- Typical application: mainly used to treat toilet wastewater and was first used successfully for greywater in Malaysia.

2.5.3.3 Anaerobic filtration

The anaerobic filtration system is widely used as a secondary treatment step in household greywater treatment system (Sasse, 1998). Based on Harindra Corea (2001) study the treatment system comprises of a watertight tank containing several layers of submerged media, which provide surface area for bacteria to settle. As the water flows through the filter – usually from the bottom to the top (up-flow) – it comes into contact with the biomass on the filter and is subjected to anaerobic degradation (Von Sperling & Chernicharo, 2005).

- Working principle: dissolved and non-settleable solids are removed through close contact with anaerobic bacteria attached to the filter media under exclusion of oxygen (anaerobic condition).
- Design criteria: HRT: 0.5 – 1.5 days, HLR≤ 2.8m/d, filter depth ≥ 1m, filter material: gravel, rock, cinder plastic with a specific surface of 90 – 300m²/m³ and 12 -55mm grain size; 2-3 layers; sealed and ventilated.
- Removal efficiency: BOD: 50-80%, TSS: 50-80%, TN≤ 15%, TC: 100-200cfu/100ml.
- Strengths: High treatment performance (TSS, TDS), high resilience to hydraulic and organic shock loadings; long biomass retention times and low sludge yield (Ji, 2009).

- Weaknesses: limited removal of nutrients, pathogens and surfactants.
- Typical application: a secondary treatment after primary treatment in a septic tank. Effluent can be treated further in planted filters or reused as irrigation water. The system was fully implemented in Jordan, Sri-Lanka and Lebanon and its application was successful.

2.5.3.4 Percolation bed (or vertical-flow filter)

According to Ridderstolpe (2004), the vertical-flow filters are frequently and successfully applied as secondary treatment of domestic greywater throughout the world, even in cold regions. The same study describes the system as comprising of a watertight box filled with filter material in which greywater is applied to the top of the filter and allow to percolate through an unsaturated zone of porous materials and then collected in a drainage system.

- Working principle: pre-treated greywater is applied intermittently to a surface of a filter medium, percolates through an unsaturated filter zone where physical, biological and chemical processes treat the water. The treated greywater is collected in a drainage network or infiltrates the underlying soil.
- Design criteria: HLR: 5-10cm/d; OLR: 20 -25g BODm²/d; filter depth: 0.8-1.2m; filter material: sand, pea gravel, crushed glass, area: 0.4 -0.6m²/p.
- Removal efficiency: BOD: 80-90%, TSS: 65-85%, TN: 30-40%, FC: 100-200cfu/100ml.
- Strengths: efficient removal of suspended solid and dissolved organic matter, nutrients, pathogens and surfactants; no odour problems as wastewater is not above the ground level.
- Weaknesses: uneven distribution causes zone clogging and plug flows with reduced treatment performance. High quality filter material is not always available and can be expensive; requires expertise for design, construction and operation monitoring.
- Typical application: as a secondary treatment step after primary treatment in a septic tank or grease trap. The effluent is reused in irrigation, infiltrates the soil or discharged into surface water.

2.5.3.5 Constructed wetlands (horizontal and vertical -flow planted filters)

The studies by Crites & Tchobanoglous (1998); Dallas & Ho (2005); Ridderstolpe (2004); Sasse (1998) and Kadlec & Knight (1996) classified the constructed wetlands into two categories namely the horizontal-flow and the vertical-flow planted filters. The first type consists of a bed lined with impermeable material (solid clay packing, concrete or plastic foils) and filled with sand or gravel. The greywater entering the filter bed through an inlet zone devoid of vegetation flows horizontally through the bed. The water line lies below the filter surface and is controlled by a simple swivelling elbow device located at the outlet (10-15cm below the filter surface). The second type is different from the first because of the shallow excavations and the feeding system.

a) *Horizontal and vertical -flow planted filters*

- Working principle: pre-treated greywater flows continuously and horizontally through a planted filter medium. Plants provide appropriate environments for microbial attachment, growth and transfer of oxygen to the root zone. Organic matter and suspended solids are removed by filtration and microbial degradation in aerobic, anoxic and anaerobic conditions.
- Design criteria: HRT: 3-7d; HLR: 5-8cm/d, OLR: 6-10g BODm²/d, filter depth: 0.6m; filter material: sand, pea gravel, crushed glass, area: 1-3m²/p.
- Removal efficiency: BOD: 80-90%, TSS: 80-95%, TN: 15-40%, TP: 30-45; FC: 200-300 cfu/100ml.
- Strengths: efficient removal of suspended solids and dissolved organic matters; cheap to construct if filter materials are available.
- Weaknesses: high permanent space requires extensive construction knowledge and experience, risk of clogging if greywater is not well pre-treated.
- Typical application: as a secondary treatment step after primary treatment in a septic tank. The effluent can be reused for irrigation, infiltration into the soil or discharge into surface water.

b) *Vertical -flow planted filters*

- Working principle: pre-treated greywater is applied intermittently to a planted filter surface, percolates through the unsaturated filter media where physical, biological and chemical processes purify the water. The treated greywater is collected in a drainage network.
- Design criteria: HLR: 10-20cm/d; OLR: 10 -20g BODm²/d; filter depth: 0.8-1.2m; filter material: sand, pea gravel, crushed glass, area: 0.8 -1.2m²/p.
- Removal efficiency: BOD: 75-95%, TSS: 65-85%, TN < 60%, TP < 35%; FC: 200-300 cfu/100ml.
- Strengths: efficient removal of suspended solids and dissolved organic matters, nutrients and pathogens.

- Weaknesses: uneven distribution on filter bed causes clogging zones and up-flows with reduced treatment performance; high quality filters material not always available; requires expertise for design, construction and monitoring.
- Typical application: as a secondary and tertiary treatment step after primary treatment in septic tanks. Effluent can be reused for irrigation or discharged into surface water.

Following this review, several treatment technologies are developed and applied in different contexts; these technologies range from the highly sophisticated to the low cost. However, the ultimate objective of applying these technologies is to have effluent quality that meets the standards. In view of the technologies described above, the removal efficiency is the most important factor that should be considered for their evaluation. Therefore, the low removal efficiency of most the treatment technology leads researchers to look at alternative and innovative treatment options.

In the light of this, the use of anaerobic processes has become an attractive economic alternative for domestic wastewater treatment (Chernicharo & Machado, 1998); it was generally agreed that the simplest low cost technology is anaerobic treatment systems such as septic tank, soil drains or anaerobic filter that require no separate energy and are virtually maintenance free (Gaydon et al., 2006; Voigtländer & Kulle, 1994). Systems making use of only of anaerobic processes are probably the simplest and least demanding to operate and maintain of any on-site system, and have an established history for single dwellings or even remote collective units provided the soil conditions for tank effluent drainage are suitable (Gaydon et al., 2006).

The anaerobic up-flow batch reactor is one of the promising technologies for application which was selected amongst other localised treatment systems due to its effective treatment processes, biogas recovery with limited maintenance and sludge disposal as well as the quality of effluent produced (Chernicharo & Machado, 1998). This treatment technology does not require aeration thus saving energy cost, low investment and operating cost, generate low amount of solids (Machdar et al., 1997). The technology is described in the section that follows.

2.5.4 The anaerobic up-flow batch reactor (AnUBR)

2.5.4.1 Definitions

The anaerobic up-flow batch reactor (AnUBR) is an improved concept of an anaerobic up-flow filter. In the AnUBR process, greywater to be treated in introduced in the bottom of the reactor through gravitational forces; it flows upward through the filter from the bottom to top (Kobayashi et al., 1983). The treatment occurs as greywater comes in contact with the filter.

This treatment system is a combination of physical and biological treatment processes in which greywater comes into contact with biomass on the filter and is subject to anaerobic degradation (Morel & Diener, 2006; INWRDAM, 2003; Harindra Corea, 2001).

The feeding tank transfers a batch of greywater (to be treated) over a period of time and a small amount is left as a starter for the next operation (Harindra Corea, 2001). Specifically, the batch flow mode of operation treats the influent in batches so that each reactor performs treatment steps on a batch quantity of wastewater (Sasse, 1998).

A study by Dague et al., (1992) showed that the treatment system is operated as an up-flow anaerobic reactor. As used herein the term anaerobic means that there is not a substantial amount of oxygen added to the fluid within the reactor, as is done in aerobic type reactors (Haddad & Kai, 2007). It is possible that a certain amount of dissolved oxygen, which enters the anaerobic reactor with the wastewater or otherwise, may be found within the reactor, but the major difference in comparison to aerobic processes, is that substantial quantities of oxygen are not added to the fluid within the reactor. This enhances the growth of anaerobic type bacteria and other micro-organisms rather than aerobic type micro-organisms (Dague et al., 1992).

2.5.4.2 The need for testing the AnUBR

Localised greywater treatments are required to alleviate greywater problems especially in un-sewered settlements. Of many local treatment options described previously in this report, the AnUBR holds the most promise due to its capability to treat greywater containing nutrients and organic compounds and high removal efficiency of suspended solids resulting in high quality effluent used in irrigation; low operation and maintenance, absence of energy and chemical requirements and low capital costs (INWRDAM, 2003).

The AnUBR is widely used in several countries (such Palestine, Jordan and Sri-Lanka) as a secondary treatment step in household greywater treatment after removal of O&G and settleable coarse particles (Harindrea Corea, 2001). The technology was found suitable for developing countries with tropical climate.

The use of low cost greywater treatment systems based on up-flow anaerobic filters has been pioneered by INWRDAM in Jordan since 2001. Compared to other low cost treatment systems, the AnUBR shows high capacity in removing pollutants of concern in greywater (INWRDAM, 2003). However, the technology was not yet tested or implemented in un-sewered settlements which are characterised by the lack of sewers. Following these issues the AnUBR is considered worth investigating in the context of informal un-sewered settlements.

2.5.4.3 Components of the AnUBR

The treatment kit is based on anaerobic up-flow filters (Morel & Diener, 2006; INWRDAM, 2003). It consists of four plastic (PE) barrels (as process), lined up and interconnected with PVC pipes (as illustrated in figure 2-2 below).

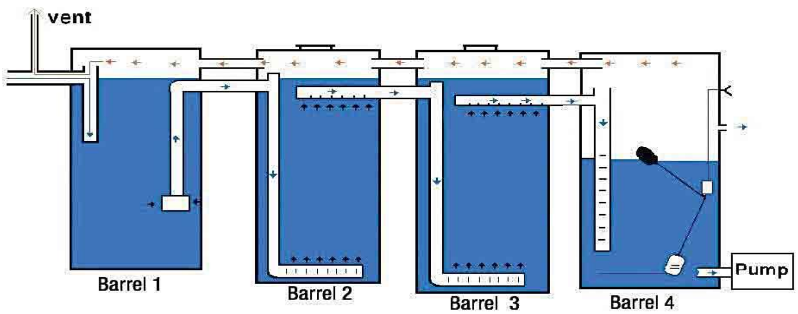


Figure 2-2: Layout of the anaerobic up-flow batch reactor (Haddad & Kai, 2007)

a) *The first tank* acts as a settling tank: prior to this, a feed tank is used to collect influent greywater and may be used as pre-treatment process prior to the main treatment process. At this process, influent greywater is allowed to settle for a designed HRT (based on the volume to be treated); settleable particles are retained in the bottom of the tank and form sludge.

b) *Filtration processes*: is the process of separating suspended and dissolved solids from a fluid as it flows through a porous media. In the AnUBR, the middle processes act as the main treatment processes in which anaerobic digestion is achieved. The filtration process may be classified as medium, cake and depth filtration depending on the quality of effluent required.

The AnUBR uses the in depth filtration process during which particles smaller than the filter pores and dissolved materials are intercepted and retained within the filter section due to the impact on or attraction to the walls of the pore channels.

In these two processes, filters develop a biofilm (consisting of fungi, protozoa, rotifera, bacteria and range of aquatic insect larvae) attached to special support media where anaerobic and facultative bacteria grow by taking the substrate from wastewater (Morel &

Diener, 2006). As greywater pass through the biofilm, particles are trapped in the matrix and dissolved organic materials is adsorbed, absorbed and metabolised by micro-organisms (fungi, protozoa and bacteria) and then mineralises both in biochemical reactions.

c) *Clear water storage tank*: the last tank acts as a treated water storage tank which may be used for disinfection or polishing.

A flow control device aiming to control the flow of incoming greywater is fitted between the feed tank (pre-treatment process) and the settling tank. Since greywater is fed into the process by gravity, the flow control device should deliver constant flow under variable head in the feeder tank (Harindrea Corea, 2001).

2.5.4.4 Mechanisms of the AnUBR

The AnUBR aims at removing non-settleable and dissolved solids. It comprises a watertight tank containing one to three layers of submerged media, which provide surface area for bacteria to settle. As the wastewater (greywater) flows through the filter it comes into contact with the biomass on the filter and is subject to anaerobic degradation (Sasse, 1998).

The operation of the AnUBR consists of four steps namely feed; settle during which influent greywater goes through decomposition of organic compounds resulting in liquid-solid separation; and filtration processes during which effluent from the previous process pass through the filter media (Franklin & Tchobanoglous, 2003). The mechanism of the AnUBR is explained by Von Sperling & Chernicharo (2005) and INWRDAM (2003) as follows:

The first barrel (or process) is a grease, oil and solids separator and thus acts as a pre-treatment or primary treatment chamber, where the solid matter from the influent greywater settles and the floating components, such as grease and soap foam floats. This barrel has a large cover to allow cleaning from both floating and settled materials.

Once solids and floating material are trapped in the first barrel, the relatively clear water from the first barrel enters into the bottom of the second barrel. Next, the water from the top of the second barrel enters into the bottom of the third barrel, and in the same way it is taken into the fourth. In these two middle barrels anaerobic bacteria work on breaking down components of the organic material found in the greywater. The last barrel acts as a storage tank for treated greywater and as soon as it is filled, a floating device switches on an opening device which then delivers the treated water to the discharge or collection point.

2.5.4.5 Design criteria

After years of experience, Harindra Corea (2001); Von Sperling & Chernicharo (2005) suggested the following design criteria for a full scale AnUBR:

- Hydraulic Retention Time (HRT) of 0.5 to 1.5 days;
- Hydraulic Loading Rate (HLR) ≤ 2.8m/d;
- Filter depth ≥ 1m; rocks or plastic with a specific surface of 90 – 300m²/m³ and grain size of 12 to 55mm placed in 2 to 3 layers or a special fabric such as geo-textile (of 0.2 to 0.5 mm thick) may be used as well.
- Velocity of flow: not exceeding 0.5m/h

Besides these criteria, Nyakutsika (1993) provided some broad design guidelines for on-site greywater treatment system which gives the designer the flexibility of designing the process based on local conditions. These design features are screening, sedimentation, filtration, biological and chemical processes; these features can be applied to all greywater treatment facilities.

The study by Young (1991) on 30 full-scale AnUBR in USA, Canada and Europe concluded that the HRT is the most important design parameter influencing the treatment performance. The HRT affects the contact time in which wastewater treatment may occur, and indirectly, the up-flow velocity, that controls solids/sludge retention. It is also the parameter that dictates the size of the reactor (working volume) and therefore has a significant effect on the capital cost of the system (Foxon & Buckely, 2007).

The typical HRT should be 12 to 36h and may vary according to the volume of greywater to be treated (Harindra Corea, 2001; Sasse, 1998). The minimum retention time for the first process (floatation or O&G traps) range between 0.25 to 0.5h; this may vary with the size of the process and the quantity of greywater influent (Crites & Tchobanoglous, 1998).

Good filter material enhances good treatment of greywater; gravel, rocks, cinder or specially formed plastic pieces and geo-textiles are used as filter material (Sasse, 1998). The water level should cover the filter media by at least 0.3m to guarantee an even flow regime through the filter (Von Sperling & Chernicharo, 2005).

Geo-textiles are manufactured from polypropylene (PP) or polyester (PET) in many types (woven, needle and punched or heat set); their use as filter media was pioneered by Christopher

& Fischer (1992); Gourc & Faure (1990). After extensive use of geo-textiles, Gourc & Faure (1990) concluded that the performance of geo-textile is affected by the pore size and thickness and the flow rate affect its clogging. From this study, nonwoven geo-textiles were found to be displaying high filtration properties and were recommended for use in water and wastewater treatment.

Despite these design features, there is little literature available to assist in the design of an anaerobic up-flow batch reactor. The design of the AnUBR is based on a previous study that used empirical equations to determine key design parameters such as hydraulic retention time and flow rate. According to DWAF (2005), most package plants such as AnUBR are designed to meet the general limit values in terms of section 39 of the National Water Act (NWA).

2.5.4.6 Operation and maintenance requirements

Small treatment systems are considered as low cost in terms of operation and maintenance and do not require skilled operators (Kerry & Brady, 1997). The operation and maintenance (according to DWAF, 2005) involve mainly sludge handling, raking, skimming and clearing of O&G traps, change of filters and handling of fatty deposits by addition of additives.

The AnUBR produce methane (inflammable) gases and foul odours that need to be controlled and evacuated (Morel & Diener, 2006). According to Kerry & Brady, (1997); Sasse (1998); access to the inlet and outlet should be provided to allow for cleaning and servicing. Cleaning is required when the bacterial film on the filter media becomes too thick. The filter mass is removed and cleaned outside the reactor. More frequently the filter is not removed but cleaned by backwashing or the flushing pressure water on the filter surface (if special fabric is used).

2.5.4.7 Practical performances of the AnUBR

The efficiency of The AnUBR depends on the condition and quality of influent greywater; a well designed and operated AnUBR should be able to produce effluent of good quality (Chernicharo & Machado, 1998). Recent researches by Mufid (2007) (which results are presented in table 2-6) and INWRDAM (2003) revealed the following removal efficiency achieved by the AnUBR: BOD_5 (50 to 80%), TSS (85 to 90%), TN (≤ 15%), and TC (50 – 90%).

In Jordan Faruqui & Al-Jayyousi (2002) recorded the performance averaging 72% for BOD_5 (1500 to 450mg/l); 88% for TSS (316 to 36 mg/l); 78% for O&G (141 to 31mg/l) and 99% for FC (1.0x107 to 200cfu/100ml).

These results were in line with those found in the literature. In Bilal (Lebanon), the study by Mufid (2007) revealed the following performance:

Table 2-6: Process performance of the AnUBR in Bilal (adapted from Mufid, 2007)

Parameter	**Influent**	**Process 1**	**Process 2**	**Process 3**	**Process 4**	**Effluent**
pH	6.7	-	-	-	-	8.2
TSS (mg/l)	316	285	176	145	132	128
COD (mg/l)	1270	-	-	-	-	45
BOD_5 (mg/l)	167	140	-	74	46	30
O&G (mg/l)	230	1.5	1.28	1.0	1.0	1.0
TN (mg/l)	37	31	29	-	-	25
TP (mg/l)	126	-	-	-	-	1.5
e-coli (cfu/100ml)	-	-	-	-	-	-
FC (cfu/100ml)	$10x10^7$	-	-	1000	200	200

Process 1: Floatation; Process 2: Settling; Process 3: Filtration; Process 4: Filtration

The anaerobic systems has a low organic pollutant removal capacity (around 35%) of the influent load and can achieve high microbial and suspended solids removal provided retention time is maintained (Panswad & Kolomethee, 1997 cited by Gaydon et al., 2007).

The AnUBR achieves a high treatment performance (in removing TSS, TC, and BOD); it show high resilience to hydraulic and organic shock loadings; has a long biomass retention time, a low sludge yield and produces a stabilised sludge (Morel & Diener, 2006; IWRDAM, 2003). The average performance of the AnUBR based on data from 30 plants is summarised in the table below 2-7. The removal efficiency may increase significantly in the last process if chemicals or UV light are used.

Table 2-7: Performance of a four stages AnUBR

Parameter	**Pre-treat.**	**P_1**	**P_2**	**P_3**	**P_4**	**Total**
TSS (mg/l)[1]	≤ 20	80 – 95	10 – 30	10 – 20	0 – 10	85 – 90
TN (mg/l)[2]	0 – 20	≤20	35 – 80	20 – 50	0 – 10	10 – 50
TP (mg/l)[2]	0 – 20	10 – 20	35 – 80	20 – 50	0 – 10	15 – 60
COD (mg/l)[1]	10 – 20	50 – 80	50 – 80	50 – 80	0 – 10	50 – 80
BOD_5 (mg/l)[1]	10 – 20	50 – 80	50 – 80	50 – 80	0 – 10	50 – 80
O&G (mg/l)[3]	70 – 90	50 – 70	10 – 30	10 – 20	0 – 10	85 – 90
e-coli (cfu/100 ml)[4]	0 – 10	10 – 20	50 – 95	50 – 95	10 – 20*	80 – 90
FC (cfu/100 ml)[4]	0 – 10	10 – 20	50 – 95	50 – 95	10 – 20*	80 – 90

[1]Morel & Diener (2006); [2]Harrindra Corea (2001); [3]Von Sperling & Chernicharo (2005); [4]Young (1991)

Following the study by the University of Norway (cited by Morel & Diener, 2006), the removal efficiency after the anaerobic filter was found to be higher for organic compounds, ammonia and TSS (as indicated in table 2-8). The nutrients removal was also higher averaging 80%.

Table 2-8: Performance of the anaerobic filter (greywater treatment system)

Parameter	Influent	After anaerobic filter	% Removal	Effluent	% Removal
BOD_5 (mg/l)	129	<2	98.45	<2	98.45
COD (mg/l)	212	12	94.34	11	94.8
TSS (mg/l)	76	6	92.11	3	96.05
TN (mg/l)	37	14	62.16	9	75.68
TP (mg/l)	2.4	-	-	0.3	87.5
Ammonia (mg/l)	12.6	2.1	83.3	0.8	93.65
Nitrate (mg/l)	2.1	5.4	0	5.3	0
e-coli (cfu/100 ml)	-	5,600	-	650	88.39
FC (cfu/100 ml)	-	580	-	390	32.76

2.5.4.8 Limitation of the AnUBR

There are limitations to the application of the AnUBR; results from several studies show that the system is not able to remove a sufficient amount of nutrients (nitrogen and phosphorous) and therefore may require further treatment processes (Harindra Corea, 2001). However, significant removal of solids, organic compounds and pathogen indicator organisms is achieved. Nevertheless, the effluent pathogen quality was also sufficiently high to be considered not posing a risk to human health. In case of mixtures of greywater and black water, the system may require disinfection for killing of pathogens. Surfactants are also reported being removed at a lower rate (Von Sperling & Chernicharo, 2005).

On-site small treatments wastewater treatment systems can provide a financially attractive alternative to a sewer connection in a location far from the existing sewer network (informal settlements for example). However, these systems are relatively new and designed to suit certain conditions and achieve a performance that meets the legal effluent standards (as per general recommendations for discharging into water resources).

The AnUBR was developed in order to improve the treatment performance (in terms of pollutant removal) considered as key outcome of the application of the technology. Following its wide application in certain countries (specifically in sewered areas), the AnUBR showed good results in the quality of effluent produced compared to other low cost technologies described above. Other advantages of the AnUBR are the low operating and maintenance cost.

2.6 Greywater treatment and disposal requirements

There are controversial beliefs on effects of greywater on the environment and human health in general. For these reasons, a wide range of technologies has been implemented or is being developed for treatment of greywater in order to comply with the disposal requirements (Gustafson et al., 2002).

According to Jefferson et al., (2004), the selection of the technology depends on many factors such as the scale of operation, end use of water and socio-economic factors including customs and practices. Through greater understanding of the reasons for treating greywater and the disposal requirements, the selection of treatment technologies could be enhanced. However, the treatment technology should produce effluent that meets the standards if it is to be discharged into storm water systems and subsequently rivers (with reference to general limits values in terms of section 39 of the National Water Act) (DWAF, 2007).

2.6.1 Key considerations of the treatment process

2.6.1.1 Treatment process

The treatment process includes the removal of pollutants of concern in order to discharge only effluent containing pollutant load as recommended in the regulations (Gross, 2006). The treatment process may be physico-chemical process technology or biological processes (Malan, 2002).

2.6.1.2 Evaluation of the treatment process

According to Gaydon et al., (2007) and Malan (2002) the end product of greywater will be treated water, which may have a varying degree of remaining contamination, and some form of solid residue or sludge. Following the study by Gross (2006) and Gaydon et al., (2007), the efficiency of a treatment process can be considered in terms of:

- The chemistry of the product water;
- The nature of sludge, its volume, toxicity/potential hazards and disposal requirements;
- Whether any material or product is recoverable.

The performance criteria to use in the evaluation and comparison of wastewater treatment options (as suggested by Gaydon et al., 2007) are as follows: applicability – (raw water quality or key constituents of concern); removal efficiency (process efficiency and effluent requirements), process principle and critical design features and structure, plant reliability and life expectancy, risk management; treatment and disposal of residues of process; previous successful implementation/examples (pilot or full scale), environmental and social impacts, operating and investment/capital costs, personnel requirements and training and lastly legal requirements (licences).

2.6.1.3 Key considerations

It is important that the selection of a (wastewater) treatment process is done after careful, informed consideration of the process criteria, as an incorrect process may have negative environmental and economical impact (DWAF, 2007). Studies by Malan (2002) and DWAF (2007) recommended that the selection of the suitable treatment process should take cognisance of many factors and considerations. For example it should define:

- Areas earmarked in terms of water quantity and quality: establish a disposal facility which complies with the Water Act.
- Key water constituents of concern (quality);
- Operational and maintenance requirements;
- The consequences of failure or reduced performance of the treatment plant on subsequent/downstream areas.

2.6.2 Factors influencing the technology choice

According to Brikké et al., (1997), there are many factors influencing the technologies choice in water, wastewater and sanitation technologies; these factors have general and specific criteria. The choice of greywater management strategy is highly dependent on the end use of the effluent produced (Mara, 2003). The treatment strategy should therefore be adapted to a specified purpose such as generating effluent suitable for reuse or whose quality allows its safe discharge into inland or coastal waters (Morel & Diener, 2006).

2.6.2.1 Technical factors

The technical factors are those related to the specification of the technology. General criteria are based on technical standards, availability of construction materials, lifespan, cost of construction and design preference. The operation and maintenance criteria are related to O&M requirements ease of access and use of decomposed waste.

2.6.2.2 Environmental factors

The general criteria that may be used as benchmark are related to the soil texture, stability, permeability, ground water level, control of environmental pollution and water availability. The specific criteria refer to the O&M implication for environmental protection and ground water contamination. The treatment technology should prevent eutrophication and pollution of sensitive aquatic systems (surface water, groundwater). It should create a physical barrier between contaminated greywater and user, as well as odour emissions and stagnant water leading to breeding sites for mosquitoes (Morel & Diener, 2006).

2.6.2.3 Institutional factors

The existing national or local strategies, roles and responsibilities of decisions makers, training capacity of operators, availability of funds and monitoring process are general criteria that require to be institutionalised. Specific criteria are linked to the potential involvement of private sector, budget allocation, and training.

2.6.2.4 Community factors

Community as users have an important role to play in the success or failure of the technology. The general criteria emanating from these factors are of socio-cultural, motivational, social organisation and other aspects such as population densities and limited spaces. The treatment system should account for the willingness and ability of users to operate the system and comply with relevant legislation and regulations (Morel & Diener, 2006)

Apart from these factors, the choice of the package plant is also based on other considerations such as hydraulic and organic loadings, cost and design considerations (DWAF, 2005). Since design is a creative process, the selection of a suitable purification process for a particular set of circumstances must take cognisance of many factors (Malan, 2002). Apart from the factors indicated above, Malan (2002) suggested the following:

- Establishment of the disposal facility complying with the requirements of the Water Act;
- The selection of the processes and design should be compatible with the operational skills likely to be available in the areas;
- Taking into account climatic conditions given that the wastewater purification is a biological process, the activity rate of the micro-organisms is markedly affected by temperature (roughly 50% decreases for a 10º C drop in temperature);
- The design of the plant to cater for breakthrough or disruptive conditions.

2.6.3 Legal considerations

The primary objective of the regulations is to ensure that the quality of effluent discharged complies with the legal requirement as stipulated in the guidelines and standards (WHO, 2006). In South Africa, several regulations are drafted at national, provincial and local levels to prevent pollution and health which could emanate from unsafe discharge of wastewater into the general environment.

The constitution of South Africa (Act 108 of 1996) on its section 4 has established the right to an environment that is not harmful to the wellbeing of communities and the right to an environment protected for the benefit of present and future generations (RSA, 1996). Section 7 includes local government's mandate to promote a safe and healthy environment as well as the management of water resources.

The Municipal Systems Act (Act 32 of 2000) provides that the duties of a municipal council include the provision of services to local communities in a financially and environmentally sustainable manner and to promote a safe and healthy environment in the municipality (RSA, 2000). The main objective of the Water Services Act (WSA) 108 of 1997 is to provide for the right of access to basic water supply to ensure sufficient water and basic sanitation necessary to secure an environment that is not harmful to human health and wellbeing (RSA, 1997).

The National Water Act (36 of 1998) part 4 deals with the prevention of water pollution, particularly where pollution occurs as a result of activities on land (RSA, 1998b). There is no specific reference to greywater in the NWA, although the sections concerning water resource management do apply. *The National Environmental Management Act (NEMA)* Act no 107 of 1998 establishes the principles for decision making on matters affecting the environment. Provision 2 of the Act prohibits all activities that could disturb the ecosystem (RSA, 1998c).

To end this series of legislation related to the protection of human health and the environment, the National Health Act (NHA) (Act 61 of 2003) requests every local authority to take all necessary, reasonable and practical measures to maintain a hygienic and clean environment at all times and to prevent the occurrence of any nuisance or unhygienic condition (RSA, 2003).

In view of these legislations, it is therefore considered that the treatment process and the quality of effluent treated should comply with specific requirements in order to produce effluent of acceptable quality that could be discharged safely. Health risks and pollution are prevented only by safely discharging effluent according to the discharge requirements in terms as per relevant legislation (Jefferson et al., 2001).

2.6.4 Greywater disposal requirements

2.6.4.1 Collection of greywater

According to Page (2008), there are many technical options to collect greywater. Those most used in un-sewered informal settlements are channelling into storm water or sewer through open channel, trenches or piped channel. However, in areas where storm water and sewers systems are lacking, greywater is discharged into soakaway, open space or near rivers or streams (City of Cape Town, 2005).

2.6.4.2 Storage of greywater

Differences of opinion exist with regard to whether greywater should be stored or not; there is a common misconception that stored greywater becomes more and more contaminated (CSBE, 2003). This is because of the odours that may develop through time as the organic content in the greywater begins to digest (Kobayashi et al., 1983). Murphy (2006) suggested that greywater should not be stored or allowed to pond for a period exceeding 24 hours, in case it represents an increased health risk and become a source of public nuisance in terms of insect breeding and odour generation.

According to CSBE (2003), this process of digestion is a form of anaerobic treatment of the greywater, and the resulting water will contain less organic material and generally be 'cleaner'. However, the odours may be an unpleasant side effect and should be controlled by venting the greywater storage tank away from places where the odours would become a nuisance. In many countries, domestic plumbing will have odours traps that are vented to the roof to prevent odours from entering the house through the piping system. However, provided the greywater storage tank itself is sealed, there ought to be no significant odours problems.

Conversely to black water, greywater is not malodorous immediately after discharge. However, if collected in a tank, it will very quickly use up its oxygen and become anaerobic (Lindstrom, 2000). Once it reaches the septic state, greywater forms sludge that either sinks or floats depending on its gas content and density. Septic greywater can be as foul-smelling as black waste and will contain anaerobic bacteria, some of which can be human pathogens (Kobayashi et al., 1983).

Even if the greywater is to be stored for a substantial period of time, some authors consider treatment to be unnecessary, provided that odours are controlled (CSBE, 2003; Dallas, 2001). Others, however, recommend it, and suggest filtration to reduce the amount of organic material present, and disinfection to reduce the amount of micro-organisms presents (Al Beiruti, 2007).

Gross (2006) and CSBE (2003) reported that simpler treatment systems will not need storage of the greywater; direct reuse without storage is favoured as it minimizes the problems of micro-organism growth and odour. However, even if storage is not required, each greywater system should be capable of handling sudden foreseeable inputs of greywater (for example from a bath or a washing machine rinse cycle) without overloading or saturating the soil.

Even if no storage is provided, an odour problem may also arise if greywater is allowed to pool in parts of the pipe bends, tanks or other parts of the network (Gross, 2005). If a greywater system becomes unused for a period of time (for example the householders go on holiday) then there is risk that pools of greywater in the system will begin to digest anaerobically and cause unpleasant odours (Gustafson et al., 2002). Most design recommends that all pipes be at a gradient, and that all tank bases, etc be angled, with provision for drainage, so that the entire system can be emptied of water, if necessary (CSBE, 2003).

2.6.4.3 Disinfection of greywater

Disinfection is the last treatment process applied to eliminate pathogenic micro-organism. According to Al-Beiruti (2007), the efficiency of this process is measured by the amount of thermo-tolerant coliform in the greywater. Sunlight is one of the natural disinfection methods used for decades, although its effectiveness is neutralised by shade. Disinfection is then used when people, animal and insects may come into contact with treated greywater (Gross, 2005).

2.6.4.4 Requirements of the Water Act

The Department of Water Affairs and Forestry (DWAF, 1999) provides guidelines to discharge wastewater in water resources. The guidelines refer to certain parameters with which the quality should comply prior to discharging. The Water Act (Act no 36 of 1998) published in the government notice 1191 (RSA, 1998a) distinguishes four categories of wastewater volumes for which different requirements are applicable (Malan, 2002).

According to the Act (DWAF, 1999) suggest the following:

- Volume less than 50 and between 50 and 500m^3/day, the effluent may be disposed of by irrigation provided that it falls within the following limits: conductivity (<200ms/m), pH (6 – 9), COD (<5000mg/l and <400mg/l respectively), faecal coliform (<10x 10^5cfu/100ml) and SAR (<5).
- Volume between 500 and 2000m^3/day, the effluent should be purified and returned to a public stream. The requirements for such purification depend on whether discharge takes place to a listed or unlisted stream. The effluent should therefore comply with the standard limits provided DWAF as indicated in table 2.4 above.

- Volume in excess of 2000m³/day: for effluent falling within this category, an extensive environmental impact assessment should be undertaken to determine its standard for low impact on the environment.

Treatment of effluent should therefore meet DWAF standards if it is to be discharged into storm water systems and subsequently in water resources (DWAF, 2005).

2.7 Pilot plant study

2.7.1 Definition and purposes of the pilot plant study

A pilot plant can be defined as a physical embodiment of the conception of a process or processes, constructed on a small-scale for the evaluation of the process at the extent desired, while providing for the ease of control, monitoring or even modification, if necessary, at reasonable costs (Otterphol, 2003; Mwiinga, 1998).

A pilot plant consists of equipment and materials used to simulate a full scale process. It is built to collect process design and operation data, but it is constructed on a smaller scale for ease of operation, installation and manipulation (Baruth, 2002).

The pilot plants (according to Baruth (2002) are generally used to:

- Investigate and compare alternative or new treatment processes
- Solve treatment problems by investigating alternative modifications
- Demonstrate confidence in recommended treatment processes
- Meet regulatory requirements
- Establish design criteria.

The wastewater or water pilot plant study relies on simple measurements that can be read quickly so that decisions can be made regarding the process efficiency and capabilities (Otterphol, 1997). The pilot plant studies are set to evaluate and predict the performance of the full-scale treatment system. The difference between the full-scale and the pilot scale resides in the vertical dimensions; however, certain features are designed based on the volume of the treatment system in question (Stoodley, 1989, Hanna, 1994).

2.7.2 Design criteria

The designs of the pilot scale treatment system (be it in water or wastewater) have the same principles; the difference in design resides on the vertical scale (Mwiinga, 2008). Generally the design of the small scale pilot plant treatment system is based on empirical equations. The design of the plant should be done according to the expected flow and strength of the influent to be treated (Gaydon et al., 2006). The dimensions are designed according to the required capacity of the treatment system while other parameters such filtration rate, retention time and structure or layout of the system remain similar to the full scale (Young, 1991). The basic equation used is the following:

The HRT = V/Q (Tchobanoglous & Franklin, 2003) (2-1)

Where HRT is the hydraulic retention time (per hour)

V: volume of the reactor (in litre)

Q: the volumetric flow rate (in litre per hour)

The reasons for failures in processes in various small scale treatment plants are many; amongst these, the most important is the hydraulic retention time and the flow patterns (Hanna et al., 1994; Stoodley, 1989). Excessive hydraulic retention time can also lead to failure of the process to adequately treat the influent; therefore the designed HRT should be determined using the existing approach based on empirical equation (Hanna, 1994).

The study by Gaydon et al., (2006) proposed the following design parameters for the small treatment plants:

- Influent quality: it is important to ensure that the influent quality is properly evaluated.
- Flow rate: to be evaluated in order to ensure that there is no flow variations which might disturb the treatment process. In case occurrence of flow variation, a flow equalisation tank may be required.
- The hydraulic retention time: to be estimated according to the volume of influent to treat; remembering that long retention time may lead to poor performance of the treatment processes.

2.7.3 Feeding regime

The pilot plants are often constructed in the vicinity of a potential feeding source. In situation where this possibility is not feasible, the external feeding sources may be envisaged. The feeding wastewater may be obtained by simulation or collection from an external source of generation (Dallas, 2001).

Stoodley's (1989) investigation into small treatment plant designs found that many operational problems encountered are attributed to the effects of extreme fluctuations in diurnal flow patterns. The intermittent feeding system on the process was accepted as such to prevent this problem (Hanna et al., 1994). Depending on the specific requirements of the process, the feeding system may be continuous or intermittent (Stoodley, 1989). The batch mode system uses the intermittent feeding system which is the case of most of pilot or laboratory-scale experiments.

The most important design for feature is the HRT. The feeding system impacts on the plant's performance; the batch mode is the most common feeding system used for pilot scale plant when situated far from a potential feeding source.

2.7.4 Monitoring process and system assessment

The purposes of the monitoring process are to validate or prove that the system is capable of meeting its design requirements; provide information regarding the functioning of individual components of the health and environmental protection measures; and verify at the end of the process in order to ensure that the system is achieving the specified targets (WHO, 2006).

In the case of new technology, the operational monitoring is used on a routine basis to indicate that the processes are working as expected (WHO, 2006 and Bennett, 2002). The validation monitoring is performed in order to test or prove that the system is capable of meeting specified targets; while the verification monitoring is used to show that the end product (effluent) meets the treatment target and ultimately health based targets (WHO, 2006). Verification monitoring is further used to indicate trends over time in terms of efficiency and capability of the system (WHO, 2006). The treatment system should be assessed regularly in order to ensure that all processes are performing according to the design criteria and the effluent quality complies with the desired quality standards (Gross, 2005).

2.7.5 Extent and duration of tests

Samples for water quality analysis are generally taken at the feeder (or inlet) and at the outlet of each process (Mwiinga, 1998). The frequency of monitoring various parameters is dependent on the extent of evaluation desired (Bennett, 2002; Mwiinga, 1998). However, for the parameters of concern, the monitoring programme should be carried out on daily basis (Davies, 2008).

Mwiinga (1998) suggested that the investigation period should be long enough to cover the range of conditions expected in practice; this is particularly important to raw water quality variations. Further the National Water Demand Management Centre (NWDMC, 2000) recommended that the plant should not be operated for years for evaluation; sufficient information can be obtained by operating at those times of the year when adverse conditions are expected.

Baruth (2002) reported that pilot studies for water treatment are often used to demonstrate treatment process over extended periods and under varying water conditions due to seasonal fluctuations, daily water quality changes which are amongst occurrences that can disrupt a treatment process.

The testing regime for the pilot plant is done according to the specific requirements of the treatment process; however, it is common practice to test the processes at each stage of the treatment in order to ensure its performance (Young, 1991).

2.7.6 Analytical procedures

There are general analytical procedures standards implemented worldwide; these procedures are set to meet the local, national or international regulations. In America, the APHA standards are used to determine the quality of water and wastewater while in South Africa the South Africa National Standard (SANS) method is used. These standards describe methods for the detection and enumeration of substances of concern in potable water, non-potable water and effluent water. The analytical procedures should therefore be followed strictly for accuracy of analysis.

2.7.6.1 Microbiological examination

There are many methods used to determine microbiological contents of greywater; amongst these are:

- Membrane filter method: method used to determine total coliform, faecal coliform bacteria and e-coli.
- Most probable number method (MPN): method used to determine total coliform, faecal coliform bacteria and e-coli.

2.7.6.2 Chemical examination

Several methods are used to analyse chemical parameters; the colorimetric and titration are commonly used to determine the level of nutrients as per procedures detailed in to appendix A.

2.7.6.3 Physical examination

This examination consists of determining the level of contaminants using physical method such as filtration or liquid-solid separation amongst others based on standard methods.

2.7.7 Criteria for evaluation of the small treatment plants performance

In some countries a tendency exists to move away from major water and wastewater purification plants. To replace these, small treatment systems known as package plants are constructed and could serve up to 100 households and the treated effluent released into storm water or water resources (DWAF, 2005).

Small treatment systems (or package plant) refer to a small scale on-site sewage treatment system or a privately owned one discharging less than 20,000 m^3 per day (Gaydon et al., 2007). Where there is lack of sanitation services in townships, package plants solution are implemented to handle sewerage including greywater. Being small in size, the plant can theoretically be installed between shacks and can service a number of erven depending on its size (DWAF, 2005).

Small treatment systems are promoted as the best mean of dealing with increasing water pollution problems caused by the overloading of bulk treatment plant and unsafe discharge of greywater and illegal of solids waste (Gaydon et al., 2007). Small treatment systems are a viable alternative to traditional full-scale treatment plants, especially in remote locations where there is lack of municipal and transportation infrastructure (Gustafon et al., 2002). These plants are extremely cost-effective and, because they are pre-assembled, installation costs on-site are kept to a minimum (Gaydon et al., 2007; Gustafon et al., 2002).

2.7.7.1 Performance indicators

The study by Gaydon et al., (2007) suggested that to correctly assess the package plant performance, it is critically important that the monitoring programmes are correctly planned to enable properly representative sampling to take place. The performance of the treatment system is measured in terms of (pollutant) removal efficiency and quality of treated effluent (final product and its compliance with the legal requirements in terms of disposal) (Gaydon et al., 2007). The performance indicators are the quality parameters described previously as per comparison with the recommended standards.

The performance and effectiveness of the treatment process vary considerably with respected to the removal efficiency (Marais, 2007; Gross, 2006) and are determined through a comparison of the effluent quality against the standards.

2.7.7.2 Evaluation criteria

The criteria selected for evaluating small treatment plant performance are based on the pollutant removal capacity, O&M requirement and the cost effectiveness among others such as characteristics of wastewater (Tchobanoglous & Franklin, 2003). Other criteria such as flow, loading variations, organic concentration and temperature variation are of utmost importance (Gaydon et al., 2006).

a) <u>Pollutant removal capacity</u>

The reliability of a wastewater treatment processes can be assessed in terms of its ability to produce acceptable effluent consistently that complies with the regulatory standards (Marais, 2007).

b) <u>O&M requirements</u>

Operation and maintenance is the key to the success of the technology (Kerry & Brady, 1993). Small wastewater treatments are designed according to the local conditions; the operation and maintenance requirements should be cost effective in terms of human resources and capital costs (Kerry & Brady, 1993).

c) <u>Cost effectiveness</u>

The cost of the treatment system is one of the factors that influence the choice of the technology. Simplest systems (in terms of capital cost, lifespan and operation and maintenance) are the most suitable for low to middle income settlements (Gustafson et al., 2002).

d) <u>Characteristics of wastewater</u>

The variability of influent is a major problem encountered by most of treatment works. However, a treatment process should be designed in such a way that it accommodates variable wastewater without causing mechanical breakdown or operational deficiency (Marais, 2007; Gaydon et al., 2007). It is therefore important to evaluate the influent water quality variability and the corresponding operational reliability when designing the small wastewater treatment systems (Marais, 2007).

e) <u>Flow and loading variations</u>

The suitability of a treatment system is based on its capacity to deal with flow and loading variations especially during unforeseen circumstances (Gross, 2006; Malan, 2002). However, flow and loading variations can be prevented only by feeding the system intermittently by batch (Gustafson et al., 2002).

f) Organic concentration and temperature

The treatment system should be designed to cope with organic concentration; this can be achieved only by providing an adequate pre-treatment process prior to the main process (Kabayashi et al., 1983). In anaerobic treatment, the temperature remains a factor that impacts on the treatment process. It is therefore recommended that the treatment system should be capable of coping with temperature change at all time (Gross, 2006).

2.7.7.3 Typical application

Emerging alternative greywater treatment technologies address the issue of direct groundwater contamination as well as the indirect pollution of lakes, streams and surface water and associated health risks (Idris et al., 2005).

Small treatment plants are provided in areas not served by a bulk treatment works. Its application, however may depends on a number of factor such collection and drainage of influent greywater, solids-liquid separation (Morel & Diener, 2006). Depending on the effluent quality requirements, small treatment plant can be used as primary treatment step before the main treatment processes; and can be used as a secondary step after treatment in a septic tank (Morel & Diener, 2006).

Small treatment plants may be used as a primary treatment when the solids-liquid separation is not practiced and in areas where the collection and drainage facilities are non-existent (Sasse, 1998). It is used as a secondary treatment in areas where adequate collection and drainage system are applied and provided a suitable pre-treatment process prior to the main treatment (Young, 1991).

2.8 Summary

Greywater is wastewater generated from household activities except toilet waste. The quantity and quality varies in function of the dynamics of the household. These include the number of household members, availability of water, typical water use patterns and lifestyle. The composition of greywater varies according its source of generation; low density settlements produce low strength greywater compared to high density settlements.

In un-sewered settlements greywater is discarded untreated onto ground, open spaces, rivers and streams. Untreated greywater has effects on soil, human health, water resources and the general environment. In order to prevent health risks and environmental pollution that may be caused by unsafe and uncontrolled disposal of greywater, the quality has to be monitored.

Besides these issues, greywater as a wastewater should be regarded as a contaminant, hence must be treated prior discharging into environment.

There is a general trend worldwide to turn to alternative low cost and sustainable treatment technologies given the quantity of greywater discharged into treatment works. Several treatment technologies has been tested and implemented successfully. These technologies range from the simplest low cost to the most sophisticated. Amongst these technologies are three stage septic tank systems, greywater roughing filter, planter soil box, soil Infiltration, ponds, constructed wetlands and recently the anaerobic up-flow batch reactor.

The anaerobic up-flow batch reactor is a similar concept to an anaerobic up-flow filter in which greywater flows through the filter from the bottom to top. The anaerobic up-flow batch reactor was implemented successfully in Jordan, Sri Lanka and Lebanon. The quality of effluent from the AnUBR shows that the removal efficiency of pollutants such as BOD, TSS, FC and e-coli varies between 85 to 95%.

The AnUBR was selected amongst other technologies because of its ability to treat greywater without addition of chemicals, low operation and maintenance costs and no energy requirements amongst many other advantages. It is a portable/movable unit, easy to build, may be used at individual household or at community level.

2.9 Conclusions

It emanates from this review that greywater should be defined in the context of the source of generation. According to its sources, greywater may contain different concentration of contaminants which vary from community to community following living style, culture and water availability amongst many other factors. Certain constituents were identified as of concern due to their effects to both human health and the general environment. These are namely TSS, nutrients, organics compounds and micro-organisms.

Several localised greywater treatment technologies are developed and implemented successfully worldwide. Amongst these technologies, the AnUBR hold promise due to its capacity to treat high strength domestic greywater and low operating and maintenance cost as well as flexibility in design. The AnUBR shows high performance in the quality of effluent treated compared to other technologies. The main design parameters are the HRT and the flow rate which have an impact on the overall treatment process.

Treatment capabilities of the treatment system are evaluated based on certain criteria such as influent quality, cost effectiveness and mainly the removal efficiency. The latest should then comply with the quality and standard for the purpose of which greywater is treated. Following the review, relevant aspects related to the research objectives were identified and have been used as a conceptual framework. These aspects are related to greywater quality, design of the AnUBR, monitoring process and evaluation of the treatment system.

Chapter 3 Experimental work

3.1 Introduction

This chapter outlines the materials and methods used for the collection of data needed to meet the objectives of the study. The description of apparatus and instruments used is provided as well as a comprehensive description of experimental methodology and analytical procedures used to analyse selected water quality parameters.

The chapter is broken down into five sections. These are the location of the treatment plant, characterisation of greywater which describe the quality of greywater used for the purpose of the study; description of the design and setting up of the treatment system are highlighted; monitoring and experimental procedures are described in detail. Further, the chapter highlights the analytical methods used to analyse results obtained and describe the process used to assess the treatment capability of the anaerobic up-flow batch reactor (AnUBR).

3.2 Research design

The study is designed in accordance with the objectives assigned. This work is subdivided into four steps, namely:

- Literature review which comprise of literature and research study regarding greywater, treatment methods, sampling and testing methods and quality standards applicable to the South African context and World Health Organisation (WHO). The AnUBR is described as part of the research study based on the pilot studies undertaken in Jordan, Sri-Lanka and Lebanon.
- Experimental works which consist mainly of constructing, mounting and setting up the AnUBR based on existing design features as well as monitoring selected quality parameters variables;
- Laboratory experiments which consist mainly of collecting samples and conducting analysis (for selected quality parameters) in the laboratory;
- Analysis of data and comparison of the effluent quality to the standards.

In the context of this investigation the characteristics of greywater were used as basic for the evaluation of the treatment capabilities and efficiency of the AnUBR. Since the treatment system was applied in sewered areas of developed countries and due to the paucity of data on greywater in un-sewered settlements, it was decided to use sewered areas results as a basic to determine the feasibility of the AnUBR as a technology and assess its performance.

3.3 Location of the pilot plant

The pilot plant was built and installed at the Community Water Supply and Sanitation unit at The Cape Peninsula University of Technology due to security problems encountered in informal settlements. The (60 litres) AnUBR was positioned in such a way that greywater effluent could be drained to a sewer. The choice of the location was made to allow a strict control of the processes and to ensure working conditions given its close proximity to the offices which helped the monitoring process.

3.4 Greywater characteristics

The aim was to characterise influent greywater (used for feeding the AnUBR) in terms of its quality based on settlement profile. The classification was based on the concentration of pollutants content found in each greywater stream collected knowing that greywater characteristics are dependent on the organic strength or level of contaminants in the water (Eriksson et al., 2002). For the purpose of the study, greywater was collected from 3 different settlements and analysed in order to determine the quality from each source prior to feeding the AnUBR. This was done in order to determine the pollutants content of greywater suitable for treatment by the AnUBR.

3.5 Design and construction of the pilot plant

The purpose of the AnUBR pilot plant was to prove that the concept chosen is a technically viable approach to decentralised greywater treatment technologies, and to ascertain whether the technology would be feasible in the un-sewered settlements setting. The treatment processes were designed based on existing design features. The AnUBR under study has four treatment processes namely pre-treatment, settling and anaerobic filtration processes. The last process was used as a storage tank and may be used for disinfection if required. The process was designed in accordance with available recommendations made in the literature and on the role each process has to play in the overall treatment process.

3.5.1 Materials

3.5.1.1 Greywater storage tank and treatment kit

The storage tank and treatment kit were made of plastic barrels in which the piping system was mounted following the design features and parameters (described in table 3-1). The feeding barrel has a capacity of 60l; the 3 middle barrels have a full capacity of 60l but were designed to handle 40, 35 and 30l respectively while the last barrel has a capacity of 50l. Metallic fittings were used to connect the pipes from one tank to another.

The quantity of greywater to be treated in the 3 middle barrels was reduced (compared to the actual capacity) in order to allow the treatment process to occur according to the design parameters (such as flow rate, HRT and filtration rate). The third and fourth barrels are fitted with a removable filter (comprising of dual and single geo-textiles layers respectively).

3.5.1.2 Piping, flow control device and foundation structure

The feeding, distribution and aeration pipes were made of PVC of diameters 22 and 15mm respectively. The flow control device consisted of a calibrated valve designed to deliver a constant flow under variable head. The structure of the system was selected considering aspects such as availability, cost, ease of use and reliability. The flow control device was calibrated in order to deliver a volume of greywater corresponding to the designed retention time. The AnUBR pilot plant was built on a consolidated soil platform; the feed barrel was mounted on a brick built platform and the remainder of the treatment processes were semi-buried.

3.5.1.3 Filter media

A special fabric consisting of dual and single nonwoven geo-textiles layers was placed in the second and third process respectively. The nonwoven geo-textiles type GT_3 and GT_5 of an apparent opening size (AOS) of 0.149 and 0120 – 0.180mm were used. A strainer of 0.45mm opening size was placed at the exit (inside the feed tank) to trap and retain coarse particles such as food residues, FOG and solids entering the plant.

3.5.2 Design details

The basic parameters used for the design of the AnUBR were namely the HRT, the volume of greywater to be treated and the flow rate. Following the studies by Young (1991) and Harrindra Corea (2001), these parameters influence the performance of treatment processes. The HRT was computed based on the volume of greywater to be treated and the capacity of the treatment process. The flow rate was computed to meet the designed HRT using the equation 2-1.

Following the literature review a HRT of 0.25-0.50h (to allow effluent from the feed tank to flow into the first process). Another 2h is used for the pre-treatment process and the residence time (or HRT) required to treat greywater in the AnUBR is 12 to 36h. For the purpose of this study, 2h were used as feeding time and another 2h was applied as a residence time (HRT) resulting in approximately 16h to complete the treatment cycle as suggested by US EPA (2004), Harrindra

Corea (2001) and Sasse (1998). The HRT was uniform throughout processes and was mainly set for the settling process.

The pre-treatment process used consisted of a strainer whose main function was to trap oil, grease and fats to enter the settling process. Given the large amount of O&G found in greywater, the filter has to be removed, cleaned or changed regularly. In un-sewered settlement case, the strainer was removed and cleaned on the completion of the treatment cycle and changed every 3 days. The following values were used to design the pilot AnUBR under investigation:

Table 3-1: Design values of the AnUBR

Parameter	**Design values**	
Operation (h/day)	16	
Number of units	4	
Inflow of greywater , Q (l)*	30 - 50 (depending on the capacity of the process)	
Flow rate (l/h)	20	
Filtration rate (m/h)	0.12 - 0.29 (filtration 1 and 2)	
HRT (h)	2.00 (per feed resulting in 16h)	
Depth of the process	0.40 - 0.60m	
Filter media	Upper layer	Lower layer
- Size - Thickness - Pore size (AOS) - depth Filter 2 (second filtration)	0.30 x 0.40m 2mm & 0.20mm 0.149mm (GT_3 nonwoven PET) 2mm & 0.05mm 0.120mm (GT_5 nonwoven PP)	0.30 x 0.40m 2mm & 0.10mm 0.180mm (GT_5 nonwoven PP)
Total height of processes	0.75m	

* The quantity of greywater feed into the process;

3.5.3 Layout of the pilot plant

The AnUBR pilot plant (illustrated in figure 3-1 and 3-2 below) consists of 4 treatment processes which play particular roles in the treatment of greywater as described below. These processes are interconnected by a piping system which allows effluent to flow under gravity from one process to another upon completion of the treatment process. Downpipes are perforated to allow effluent to trickle at minimal upflow velocity.

3.5.3.1 Feed tank (pre-treatment process)

The first process of the plant is the feed tank which is also used a pre-treatment process; the process used is a coarse filtration (equipped with O&G traps) whose main function is to block fats, O&G and solids stuff entering the main treatment processes. The pre-treatment process consisted of holding tank fitted with strainer and has a holding capacity of 60l of which 20l from the bottom was used for holding settled particles (sludge). The process was designed to handle influent for 0.25h after which greywater was allowed to flow into the next process. The outlet pipe in this process was placed 0.15m from the bottom to allow for sludge handling and starter greywater influent.

3.5.3.2 Setting tank (P_1)

The process was designed to handle all solid particles. After the pre-treatment process, greywater is allowed to flow into the settling tank which was designed to handle 40l at a flow rate of 20l/h and brought to rest for a HRT of 2h. Substances denser than water settle at the bottom of the tank, while FOG float on the top to form a scum layer. Only lightly clear greywater is allowed to flow to the next process.

3.5.3.3 *Filtration processes*

The filtration process was designed to remove settleable solids, O&G and allow anaerobic degradation of suspended and dissolved solids. The two processes were designed to handle a volume of 35 and 30l of greywater respectively.

a) Primary filtration (P_2)

In this process, greywater is allowed to go through the filter media (from the bottom – up). The reminders of solid are retained by the filter, only clear water flow to the next process.

b) Secondary filtration (P_3)

The second filtration takes place when greywater is allowed to flow onto the filter media and the biological process of microbial breaking down occurs. The filter media work on breaking down bacteria in order to deliver to the next process only clear and treated greywater.

3.5.3.4 Clear water storage tank (P_4)

Used only to collect and store treated greywater. It may be used for disinfection.

Figure 3-1: View of the AnUBR pilot plan

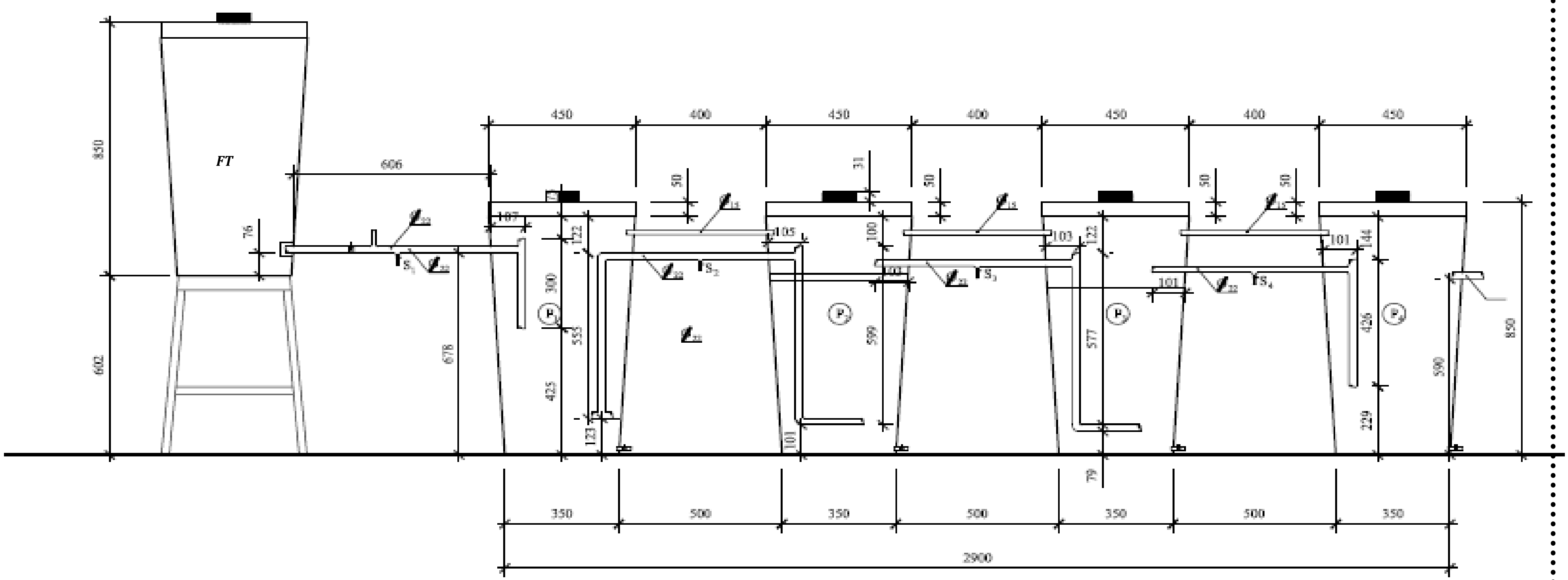


Figure 3-2: Section of the AnUBR (scale 1/100)

Keys:

- The first barrel is the feed tank (FT acting also as a pre-treatment process)
- The second barrel is the settling tank (P_1)
- The third barrel is the filtration process (P_2)
- The fourth barrel is the filtration process (P_3)
- The last barrel is the clear water storage tank (P_4)

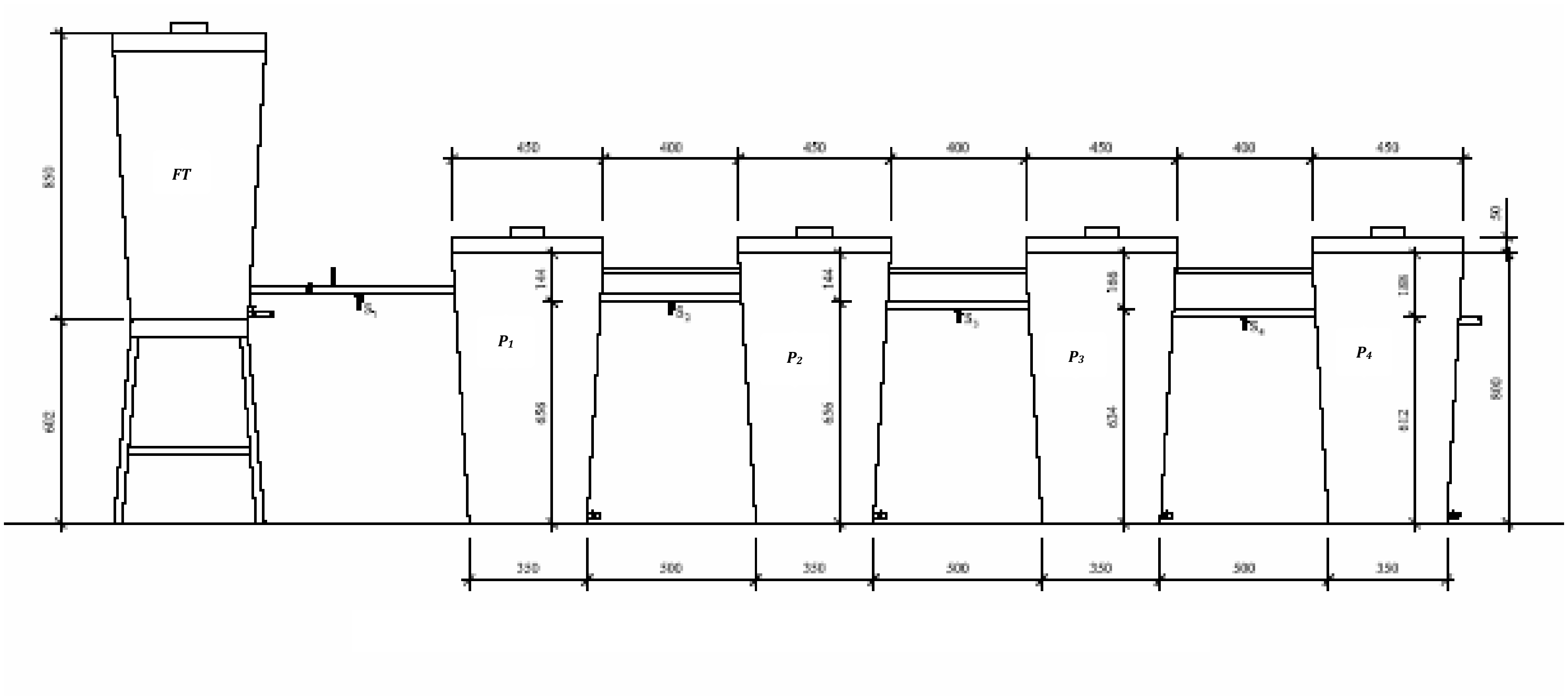


Figure 3-3: Layout of the AnUBR

Keys:

- The first barrel is the feed tank (FT acting also as a pre-treatment process)
- The second barrel is the settling tank (P_1)
- The third barrel is the filtration process (P_2)
- The fourth barrel is the filtration process (P_3)
- The last barrel is the clear water storage tank (P_4)
- S_n represents sampling point

3.5.4 Investigation of the treatment plant

3.5.4.1 Objectives

The investigation aimed to establish the treatment capability, efficiency and applicability of the AnUBR in the natural setting of the South African un-sewered settlements. The quality of greywater in these settlements varies in strength according to the source from which it is generated. In this context, understanding greywater characteristics is important to determine the treatment capabilities and performance of the treatment plant

3.5.4.2 Operating period

The AnUBR under investigation was built and set up to operate during the dry and wet season due to the seasonal fluctuations that impact on the quality of greywater. The operation period covered the end of the wet season and the start of the dry season. The operating period was designed following the recommendations that suggest that the operating period should cover all conditions under which the full-scale treatment system is expected to operate.

- Start-up: the plant was operated for 16h/d. Prior to feeding (with greywater from another site), the plant was cleaned and disinfected to ensure that there was no cross contamination from incoming greywater. The feed tank was filled with greywater directly after cleaning and disinfection.
- On-stream period: the first samples were collected 0.25h after the valve was switched on to allow greywater to flow into the next process. Subsequent samples were collected at the exit of the first process after 4h and thereafter 8h for the second process, 12h for the third process and 16h for the last process.
- Shut down: when the last samples were collected, the plant was shut- down by stopping feeding the feed tank and switching off the flow control valve.

3.5.4.3 Operating conditions

Greywater collected from each settlement was fed separately into the plant. Collected greywater was fed directly into the plant which was operated under a temperature range of 21 to 29°C and was exposed to sunlight.

The following operational parameters were considered:

- Raw water quality: the quality of greywater was analysed prior to feeding;
- Filtration rate was determined based on the volume of the process and holding time;
- HRT based on the volume of the process and the quantity of greywater to be treated.

3.5.5 Selection of the treatment process

3.5.5.1 Feeding regime

The system as indicated in the literature review is an anaerobic up-flow batch reactor treatment process which treats greywater in batch. The batch feeding mode is an intermittent feeding process which allows only a given quantity of greywater to be treated to go through the treatment process for a design period. The quantity of greywater to be treated was fed into the treatment plant and allowed to settle for the designed HRT. After completing the treatment process greywater was allowed to flow into the next process and a certain amount left as a starter for the next treatment process.

The feeding method consisted of filling the feed tank with influent greywater as per feeding schedule described below. Afterward the process is refilled until the full treatment process is completed.

3.5.5.2 Main treatment process

According to the design of the treatment plant, the main treatment process was done in 4 stages namely pre-treatment, settling, primary and secondary filtration. The pre-treatment process consisted of allowing influent greywater (after filling the feed tank) to settle for 0.25h in order to remove scum layer on the top of the tank. Particles of bigger diameters than that of strainer were retained and larger particles settled in the bottom of the tank. This process is a coarse filtration consisting of liquid – solid separation and achieved with the use of O&G strainer.

The settling process consisted of allowing particles that passed through the pre-treatment process to settle for the designed HRT. The primary and secondary filtration consisted of trapping unsettleable, dissolved organic matters and micro-organisms. The last process was only used to store final effluent and given its exposure to sunlight, it was assumed that disinfection (by UV) light may occur.

3.5.6 Working principles of the AnUBR

The AnUBR was designed to work according to the designed process. Influent greywater fed was allowed to go through a pre-treatment process for a retention time of 0.25h prior to entering the settling process. The first process called pre-treatment was used to trap FOG and light materials. During this process, solids settle in the bottom while FOG form a scum layer at the top of the process. After completion of the treatment process, greywater (between the scum and sludge layer) flows into the settling process.

The flow meter was opened to allow effluent from the pre-treatment process to flow into the settling tank at the designed flow rate corresponding to a designed feeding time and HRT. After completing the treatment process, greywater was allowed to flow upwardly into the next process at an up-flow velocity of less than 0.5m/h. While completing the treatment process, the first process was refilled 0.25h before the settling process completed its treatment; and the valve opened again to allow greywater from the pre-treatment process to flow into the settling process while effluent from this process flowed into the primary filtration process.

In the settling tank; greywater was allowed to settle for a period of 2h per feed. Once the retention time attained, the feed tank was refilled (following the feeding schedule process described below). Greywater from the first process was released (by opening the valve) and allowed to flow into the settling tank.

Greywater from the settling tank was allowed to flow from the bottom – upward to the next process which is simply a primary filtration which is fitted with a dual filter layer for pollutants removal. Effluent for this process flows upwardly into the third process (called secondary filtration) which is equipped with a single filter layer. In these two processes, filters develop a biofilm (consisting of fungi, protozoa, rotifera, bacteria and range of aquatic insect larvae) attached to special support media where anaerobic and facultative bacteria grow by taking the substrate from wastewater (Morel & Diener, 2006).

As greywater pass through the biofilm, particles and foreign matters are trapped in the matrix and dissolved organic materials is adsorbed, absorbed and metabolised by micro-organisms (fungi, protozoa and bacteria). Greywater comes into contact with the biomass on the filter and is subjected to anaerobic degradation and micro-organisms foods are retained on the filter pores and natural die-off of micro-organisms occur.

Thereafter, clearer greywater is allowed to flow into the second filtration stage process in which the remainder of bacteria are brought into contact with the biomass and trapped on the filter media. This process allows a natural die-off of the remaining bacteria; and clear greywater is allowed to flow into the last process which is a storage tank which may be used for disinfection if required. The treatment occurs as greywater comes in contact with filters which retain pollutants (Harrindra Corea, 2001).

Generally, the treatment procedure is based on the batch feeding mode. Once the feed tank is filled, processes are allowed to perform treatment as per designed retention time. The treatment was done per batch and effluent produced allowed to flow from one process to another following the filling of the feed tank.

3.6 Monitoring and Experimental procedures

3.6.1 Materials and apparatus used

Materials and apparatus used were those found in the laboratory. Each parameter analysed required specific equipment for its analysis. Some of the equipment used was namely thermometer, pH meter, autoclave, sampling bottles (glass and plastic), weighing scale and gas meter.

- Thermometer was use to measure the temperature of greywater;
- The pH meter was used to measure the pH of influent and effluent greywater;
- 25l drum was used to collect greywater used for the study;
- Sampling bottles were used to collect samples for analysis;
- Weighing scale and autoclave were used in the laboratory to weigh reagents and incubate solutions needed for analysis;
- The gas meter was used to detect and determine the volume gas generated.

3.6.2 Calibration of apparatus

Equipment used was calibrated to allow strict flow measurement. The flow control consisting of a ball valve was calibrated to deliver a constant flow of 20l/h under variable head. Other apparatus and equipment were calibrated at the Department of Science of the Cape Peninsula University of Technology (Bellville campus) as per required test calibration procedures. The calibration procedures for all apparatus used in the laboratory were not disclosed by the laboratory technician.

3.6.3 Commissioning of the treatment system and Monitoring procedures

The treatment plant was commissioned for a week (using kitchen greywater) prior to undertaking the preliminary experiments. This was done to test the equipment used (calibration of ball valve) in order to determine the flow rate equivalent to the designed HRT. The treatment process was started up as per monitoring programme indicated in table 3-2 based on the recommendations made from the trial experiments.

3.6.4 Greywater collection

3.6.4.1 Influent greywater sources and quality

Following the literature review, the quality of greywater varies according to the source of generation. Generally greywater from dense un-sewered settlements has a high concentration of pollutants compared to low density settlements. Thus it was decided to collect greywater from different settlements based on living conditions and current service provision (in terms of water and sanitation). Three settlements were selected (based on these criteria; as pilot to the project). The quality of influent greywater from each source indicated above was analysed in order to determine the pollutants concentrations prior to feeding the plant.

3.6.4.2 Selection of the sampling sites

The sampling sites were selected based on a previous study that reported that the quality of greywater in un-sewered settlements has variable levels of concentration (Carden et al.; 2007). However, the selection of sampling sites was mainly based on the type of water supply (standpipes) that impact on daily water consumption, level of sanitation services, the existing greywater disposal infrastructures and waste management systems in place. Following the literature, the quality of greywater varies considerably over time and location and is affected by these factors amongst others.

Following these reasons, the study aimed to select two separate sampling sites namely un-sewered informal settlements and sewered areas. The first site was selected for the purpose of investigating the AnUBR as per the study objectives and consisted of three different informal settlements characterised below. The later site was selected in order to compare, verify and confirm the performance of the AnUBR as indicated in the literature.

a) *<u>Case study un-sewered settlements</u>*

The selected informal settlements have the following profile:

- Phola Park (in Nyanga): the settlement is located in the Eastern suburb area and covers an area estimated to 35,330m², containing 735 dwellings (City of Cape Town, 2005). Based on this figure, the site has a density of 208 dwellings per hectare. The settlement is provided with pour flush toilets and standpipes within 25 to 100m apart from the household). Daily water consumption averaged 50l per household per day which results in 30l of greywater generated daily. In this settlement greywater generated greywater is discharged onto the ground, roadside and nearby storm water open channel (as shown in figure 3-4 below) due to the lack of greywater disposal system and solid waste management.

Figure 3-4: Discharge of greywater into open channel

- Wallacedene (Kraaifontein): the site selected is an informal settlement situated in the Northern suburb and covers a total area of 102,456m² for over 285 dwellings which result in a density of 27.82 dwellings per hectare. The settlement is provided with dry sanitation system (type chemical toilet shown in figure 3-5 below) system and standpipes within 100 to 200m apart from the household. Most of these standpipes are vandalised and run dry, resulting in low daily water use due to distance from the house to the standpipe.

Figure 3-5: Dry sanitation type container toilet

- Doornbach (Dunoon): the settlement is situated at 20Km north of Cape Town and covers 12 hectares (120, 000m²) with an average 2,300 dwellings of approximately 30 m² plot size each resulting in a density of 192du/ha (Page, 2007a). This settlement is provided with a dry sanitation system (type container toilets referred in figure 3-6 below) without greywater disposal facilities and standpipes within 50 to 250m apart from household. As result, greywater generated is used more than once for many purposes and discarded onto open space, street and the river surrounding the area.

Figure 3-6: Dry sanitation type chemical toilet

Selected settlements are characterised by a level of service provision consisting of dry sanitation (type chemical or container toilet), pour flush toilet and standpipes for water. No greywater disposal infrastructures are provided. Daily water consumption is variable from site to site due to the distance covered to fetch water, thus reducing or raising the volume of water greywater generated depending on cases.

b) <u>Case study sewered areas</u>

In order to ensure the AnUBR works according to the literature and practical performance indicated and for control purposes, greywater from sewered areas (in comparison to first world greywater) was collected and used. Three case study sites were selected based on certain criteria. The selection of the student hostel was motivated by the cultural diversity of students which impacts on the quality of greywater). The households 1 and 2 were selected based on the standard of living and the chemicals used for laundry, cultural and cooking habits. The household 1 is a typical middle income house characterised a standard lifestyle while the household 2 is a high income house characterised by a high life standard.

All these sites were characterised by a greywater collection system consisting of a piping system collecting greywater from kitchen sink, bath, hand wash basin, washing machine, dish washing etc. connected to a sewerage system situated on the boundary of the compound. In these areas, greywater was not in direct contact with the ground.

3.6.4.3 Collection and Sampling regime

<u>a) Collection</u>

In sewered areas greywater used to feed the AnUBR collected directly by connecting the container to the greywater outlet (from kitchen sink, bath and hand washing, and washing machine). Conversely, in un-sewered settlements, greywater was collected (as shown in figure 3-7 below) from a variety of washing activities taking place within the settlements, from standpipes, household ditches, and pond in the street, backyard, open spaces and the animal slaughtering areas.

In order to ensure that the investigation was carried out under the most controlled conditions possible, composite samples of greywater were collected on a daily basis from different settlements indicated above. Greywater was collected separately at each collection point using 1l cups to collect greywater from household ditches, pond, at the standpipe. Necessary precautions were made to prevent solids and mud mixing with collected greywater.

At washing posts a container (of 100l) was placed at a specific area (where greywater is generated) in the settlement to allow community to discharge into it. Greywater discharged into the containers was collected and transported to the treatment plant.

Figure 3-7: Collection of greywater in un-sewered settlements

b) Sampling regime

Greywater samples were collected following the treatment cycle. After each feed and upon completion of the treatment process samples were collected at the feeding tank (influent), at the exit of the feed tank (pre-treatment), settling and filtration processes as well as at the clear water storage tank exit after completion of the treatment cycle. The following table presents a monitoring programme, a summary of data collected and the frequency of collection.

c) Monitoring programme

The programme (presented in table 3-2 below) was set to monitor the treatment plant and water quality parameters. The plant was monitored to assess the performance of each unit process. The flow and HRT were monitored at the pre-treatment and settling process while the filtration rate and filter run were monitored at the primary and secondary filtration processes. The monitoring programme was carried out on a daily basis after each feeding.

Table 3-2: Monitoring program for the AnUBR

Parameter	Influent	Pre-treatment	Settling	Filtration 1	Filtration 2	Storage tank
T (º C)	Daily	Daily	Daily	Daily	Daily	Daily
pH	Daily	Daily	Daily	Daily	Daily	Daily
TSS (mg/l)	Daily	Daily	Daily	Daily	Daily	Daily
NO_3/NO_2 (mg/l)	Daily	Daily	Daily	Daily	Daily	Daily
PO_4 (m/l)	Daily	Daily	Daily	Daily	Daily	Daily
COD (mg/l)	Daily	Daily	Daily	Daily	Daily	Daily
BOD_5 (mg/l)	Daily	Daily	Daily	Daily	Daily	Daily
O&G (mg/l)	Daily	Daily	Daily	Daily	Daily	Daily
e-coli (cfu/100ml)	Daily	Daily	Daily	Daily	Daily	Daily
FC (cfu/100ml)	Daily	Daily	Daily	Daily	Daily	Daily
Filtration rate	-	-	-	Every 2h	Every 2h	-
Flow rate	-	Hourly	-	-	-	After 16h

3.6.5 Feeding and testing schedule

3.6.5.1 Feeding schedule

Greywater used to feed the plant was collected on daily basis for the period of the experiments as indicated above. Due to the fact that greywater quality may change over time, it was decided to collect greywater in the early hours of the morning.

Following the first phase of experimental works, it was decided to run the plant for 16h per day for 10 consecutive days using the greywater from the same area. The plant was monitored as per monitoring programme presented in table 3-2 above; and was fed intermittently as per feeding schedule presented in table 3-3 below. The feed tank was fitted with a flow control device that delivered a constant flow under different heads.

Table 3-3: Greywater feeding schedule

Feed	Time (h)	Influent (l)	Quantity feed (l)						Total (h)
			P_1	P_2	P_3	P_4	Effluent*	Total	
1	0.0	60	40	0	0	0	0	60	4.00
2	4.00	40	40	35	5	0	0	100	8.00
3	8.00	40	40	35	30	15	0	140	12.00
4	12.00	40	40	35	30	50	5	180	16.00
5	16.00	40	40	35	30	50	45	220	20.00
Total	**16.00**	**220**							**20.00**

* Overflowing effluent from the storage tank

The feed tank was designed for a full capacity of 60l; the feeding pipe was positioned at 0.20m distance from the bottom which averaged 20l. This was designed as a free board for holding greywater and sludge accumulation. Other processes were designed to handle the volume of greywater of 40, 35, 30 and 50l respectively. The quantity of greywater released from the feeder tank was allowed to settle for 2h in the settling process before another batch was fed.

The full treatment cycle required about 220l of greywater daily for a run time of 16h. The feeding schedule was carried as follows:

<u>a) Feed 1</u>: At the starting of the operation, 60l of greywater were filled into the feed tank and allowed to settle for 0.25h; after the valve was opened to release 40l of greywater into the settling process at a rate of 20l/h and 20l retained as starter for the next treatment process. Once filled, the valve was closed and greywater was allowed to rest for 2h; 0.25h prior the settling period was attained, another batch of greywater was filled into the feed tank.

<u>b) Feed 2</u>: After 4h (filling and retention time), a second batch of greywater (40l) was filled and allowed to flow at the same rate. This resulted in 2h filling and 2h retention time after which the feeder was filled again while greywater from the settling process was allowed to flow into the first filtration process. Given that the volume of greywater released was 40l which corresponds to the capacity of the settling process and more than that of the primary filtration, the effluent of greywater was allowed to flow into the primary filtration process (35l) and to overflow (5l) into the secondary filtration process. The treatment occurs when the flow of greywater flow through the filter media and treated effluent to overflow into the next process.

<u>c) Feed 3</u>: After 8h of operation, the feed tank was filled again with 40l of greywater and allowed to settle for 0.25h after which it was allowed to flow into the settling process. Greywater from the settling process was allowed to flow into the primary filtration process which in turn released its content into the secondary filtration process. The overflow from the secondary filtration process (10l) was allowed to flow into the final process (storage tank).

<u>d) Feed 4</u>: After 12h the feed tank was filled with another 40l of greywater which was allowed to flow after 0.25h rest time into the settling process. At this time, the settling, primary filtration and secondary filtration processes allowed greywater contained to flow respectively from one process to another releasing the same amount of greywater filled in the feed tank. This resulted in the storage tank filled at its full capacity (50l) and an overflow of 5l was released.

e) Feed 5: After 16h, the feed tank was filled with the last batch of greywater (40l). The same process occurred during which the amount fed was released in each respective process. This resulted in the overflowing of about 45l in the storage tank.

Following this feeding schedule, the total retention time was about 12h. The plant was operated from 8-00am and the last batch was filled at about 12am. However, this was done for control purposes since the 4th feed produced the final effluent. The full treatment cycle required 220l of greywater; as a precaution about 250l of greywater was collected daily for the duration of experiments.

The above feeding schedule was carried out daily. Since greywater used to feed the plant was collected from the same site, the starter greywater was left in the process and used for the next day of operation. This was done to accumulate the necessary biomass needed for testing the presence of gases.

3.6.5.2 Sampling and testing schedule

Samples of greywater were collected manually at the sampling point (situated at the exit of each process) as per feeding and sampling schedule described above. Sterilised glass bottles were used for microbiological parameters and normal plastic bottles for other parameters. Control samples in turn were collected daily as per sampling schedule presented in table 3-4. In total 14 samples were collected daily from the treatment plant as indicated in the table 3-2 and 3-4 and analysed in different laboratories. Results of both control and main analysis were compared for accuracy.

Table 3-4: Greywater sampling and testing schedule

Feed	Feeding time	Sampling time					
		Influent	Pre-treatment	S_1	S_2	S_3	S_4
1	08-00	8.00	8-15	x	x	x	x
2	12-00	12-00	x	12-15	14-00	x	x
3	16-00	16-00	16-15*	16-15*	x	17-00	x
4	20-00	20-00	x	x	20-15*	20-15	20-45
5	24-00	24-00	24-15*	24-15*	24-15*	24-15*	24-15*

* Control samples collected to control the accuracy of the main analyses

The first samples of greywater were collected prior to feeding the plant and after 0.25h following the feeding, while the remainder of samples S_1, S_2, S_3 and S_4 or final effluent were collected after 4, 8, 12 and 16h respectively.

Collected samples were labelled with a code indicating the source, sampling point number, time of sampling and parameters to be analysed. The temperature and pH were measured immediately and the remainder of samples were taken to the laboratory and analysed immediately or conserved when time was not allowing.

3.6.6 Analytical procedures

3.6.6.1 Data collection

Data needed for the purpose of this study were those of the quality of influent and effluent greywater. The quality parameters were selected based on their impact to both human health and environmental pollution perspectives. The collected data required included:

a) Physical parameters: temperature and TSS (total suspended solids)
b) Chemical parameters: pH, oil and grease (O&G), nutrients (nitrogen as total nitrogen, phosphorous as total phosphates); biodegradable organics (COD and BOD).
c) Microbiological parameters: micro-organism (e-coli and faecal coliform)

These data were collected on daily basis for the duration of experiments upon the completion of the treatment cycle.

3.6.6.2 Analytical procedures

Analytical procedures were done in accordance with the standard methods as per South African National Standard regulations and APHA (1998). Prior to analyses a printed form for the sampling report which included abbreviated sampling point designation, date, start and stop of sampling; time, name of the operator and analytical procedures applied, details of sampling method and comments.

Samples were analysed for quality parameters indicated previously. The temperature was taken directly after collection and prior to feeding the plant given its impact on the treatment process and overall analysis of other parameters. Samples collected were analysed immediately for faecal coliform and e-coli as well as pH. If the remainder of the sample could not be analysed immediately, the samples were kept at 4°C until further analysis for other parameters could be conducted.

Analyses were made following the standard methods as recommended by the South African National Standard (2007) SANS 5221: 2007 for microbiological analysis and Standard methods for the chemical analysis and Standard methods APHA (1998) (Greenberg et al., 1998) as indicated in table 3-5 below. Details analytical procedures for each parameters analysed are described in appendix A.

Table 3-5: Measurement method and analytical procedures

Parameter	**Measurement method**	**Analytical procedures**
pH	pH meter	Use of Fisher Model 805 pH meter
TSS		standard method 2540 D-solids APHA 1998
COD	Titration	Open reflux method, standard method 5210 B
BOD_5	Titration	Standard method 5210 B
O&G	Extraction	Extraction with trichloro-trifluoroethane
TN (NO_3/NO_2)	Colorimetric	Ultraviolet colorimetric screening method, standard method 4500.
TP	Colorimetric	Photometric method
FC	Test paper	Membrane filter method SANS 5221: 2007
e-coli	Test paper	Membrane filter method SANS 5221: 2007

a) pH

The pH was measured by change in potential of glass standard calomel electrodes in comparison with approved standard buffers of different pH values (4, 7, and 9).

Analytical procedures: The pH of grey water samples was determined by pH meter Fisher Model 805 with Crisson glass calomel electrode. The pH meter was first standardized by 3 standard buffer solutions of 4, 7 and 9 to verify the linear response of the electrode. The pH of water samples was determined by immersing the tip of the electrode in the samples and read the value indicated.

b) TSS

The standard method 2540 D solids (APHA, 1998) was used to measure he TSS. This method involves the vacuum filtration by Buchner funnel and flask. The 20ml sample was filtered on known masses of filter papers by vacuum filtration. The filtrate residue was dried at 103 to 105°C on an oven for 45min and weighed on an analytical balance. The TSS was then measured by using the equation TSS = Dried residue (mg/l) x 1000 / sample (ml).

c) COD

Open reflux method was used for the analyses of COD. The samples were refluxed for 2h in strong acidic solution with standard excess potassium dichromate solution. The un-reacted potassium dichromate was then titrated with ferrous ammonium sulphate to determine the amount of potassium dichromate solution reacted.

The following procedures were used to determine the COD:

- Reflux equipment was set up for six samples and another two for a quality control and a blank standard.
- A 5ml of each sample was placed in a 250ml conical flask that contained the following reagents; 0.5g Mercuric sulphate, 10ml of 0.0417M $K_2Cr_2O_7$, 25ml H_2SO_4 reagent.
- The QC flask contained 20ml of concentrated Potassium Hydrogen Phthalate and all the reagents that were added in the samples.
- The samples, blank and the QC flask were refluxed for 2h and the titrant results were used in the formula to calculate the COD concentration in the samples.
- After the reflux period samples were cooled and titrated with FeAS.

d) BOD_5

The Titration Standard method 5210 B consisted of adding a reagent drop in the greywater sample until the pH reaches 7.8±0.2 value, wait until the pH will stabilize, then read the value in mg/l from the conversion table (number of drops added correspond to the value).

e) NH_3

The method used to determine Ammonia is manual distillation method. The sample was first buffered at pH 9.5 with a borate buffer solution to reduce organic nitrogen compounds. After the distillation samples were titrated with 0.1N sulphuric acid. The procedures used were as follows:

- Mixed reagent was prepared by mixing ascorbic acid and combined solution of methylene blue and methyl red;
- 50ml of the mixed reagent was added with measuring cylinder into each of the six conical flasks and the conical flask was used to collect the distillate residue;
- A 5ml of each sample was placed in each of the round bottomed flask + 20ml NaOH and 3 drops of the phenolphthalein;
- The addition of 20ml NaOH was to bring up the pH of water samples 9.5;
- The distillate was collected (about 150-200ml) in the conical flask and titrated with 0.1N H_2SO_4.

f) Total Phosphate

The photometric method of analyses was used for the determination of phosphate as set out by Official Standard Methods of Analyses (1990). Ammonium molybdate and potassium antimonyl tartrate were reacted in acid solution with dilute solution of PO_4^{3-} to form Sb phosphomolybdate complex which was reduced to intensely blue complexes by ascorbic acid.

The method is selective for orthophosphate and for compounds that can be altered to orthophosphate. Procedures used were as follows:

- A stock solution of 1000ppm of phosphate solution was prepared by weighing 1g of KH_2PO_4 dissolved in distilled water and made up in 1l volumetric flask.
- A 100ppm was made by diluting the stock solution and a series of standard solutions of 0.5ppm, 1ppm, 1.5ppm and 2.00ppm were made from the 100ppm working standard in 100ml volumetric flasks.
- Samples were diluted 25 to 250 times based on the concentration of phosphate ions in greywater.
- 20ml of each sample was mixed to 3ml of combined reagent and added in the beakers; and the standards were treated the same way.
- Samples and standards had to stand for 10min before on the UV. The standards and samples absorbencies were measured at a single wavelength of 880nm.

g) Nitrate and Nitrite as TN

The method of determination of nitrates and nitrites in waste water is based on the reduction phosphomolybdic acid to phosphomolybdenum blue complex by sodium sulphide. The blue complex was oxidized by adding nitrite that causes the reduction of the intensity of the blue colour. The decrease in the absorbance of the blue colour was directly proportional to the nitrate and nitrite present. This change in the absorbance was monitored spectrophotometrically at the wavelength 814nm.

Analytical procedures:

In order to proceed with analyses, necessary reagents namely MoO_3 solution of 0.1M, KH_2PO_4 0.1M solution, Na_2S 0.01% (w/v) solution, 0.1M nitrate solution and 1000ppm stock solutions of nitrate and nitrite were prepared and then analysed as per following procedures:

- The series of standards of nitrate and nitrite had different working ranges and were prepared differently for the calibration curves knowing that the working range for nitrite is from 1.0000ppm, 1.5000ppm and 2.0000ppm whereas for nitrate is 0.5000ppm, 1.0000ppm and 1.5000ppm.
- The 2ml aliquots of samples and standards were mixed with 3ml of the complex in 10ml volume flasks and diluted with distilled water. The solutions were allowed to stand for 10min.
- Absorbencies were then measured against distilled water as a blank.
- The final reading provided the concentration of NO_3/NO_2

h) Faecal coliform and e-coli

The membrane filter method was used to determine the microbiological parameters of greywater. The method consisted of incubating the sample on m-tec for 2h at 37°C and then at 44°C for 22h. The faecal coliform count was done after incubation and was followed by in situ urease test and a final e-coli count. The bacterial colonies which are formed are then counted as bacterial count indicator value.

i) Sludge and gas

The volume of sludge produced was determined using a method called decantation which consisted of allowing influent greywater to rest for a designed HRT; at the end of the treatment process, the remaining greywater (mixed with settled solids) was allowed to stand for 24h. Afterwards it was collected and measured using a measure jug.

The gas produced was determined using a gas detector. The method consisted of inserting a gas pipe (above greywater level) into the sealed process. Following the decomposition of organic materials (in the bottom of the process), gases are emitted and collected into the gas pocket (which resembles a balloon). The gas pocket was fitted with a gas meter which indicates the level of gas in the process. This process was applied to detect methane and carbon dioxide.

3.7 Experimental work

Data needed to investigate the AnUBR were obtained through experimental work. These were carried out to determine the characteristics of influent greywater and that of effluent produced at each unit process. Since greywater used for the experiments was collected from selected case study sites (as indicated previously), it was decided to analyse greywater from each settlement separately. The experimental work was carried out into two phases, namely, preliminary and continuous experiments.

3.7.1 Preliminary experiments

The first phase of the experimental work consisted of running and monitoring the pilot plant for a short duration. The focus was firstly to analyse and determine the quality of influent greywater from each selected case study and assess its impact on the treatment process. Secondly to experiment the treatment processes designed and verify the working conditions.

Since the quality of greywater is variable from settlement to settlement, it was decided to determine the characteristics of greywater (as function of the specific site profile as indicated previously in section 3.6.3.1) and the quality of related effluent produced. The plant was run for 16h per day using influent greywater from each case study site separately. Prior to feeding the plant with greywater from another site, the plant was cleaned and disinfected in order to prevent cross contamination.

Based on results of the preliminary experiments, it was decided to select two sites that produce more polluted greywater as case study that should represent both sewered and un-sewered areas. Referring to the results of the preliminary experiments, it was found important to undertaken long continuous experiments in order to determine the performance of the AnUBR.

3.7.2 Continuous experiments

The continuous experiments consisted of monitoring the AnUBR on a daily basis for about 16h/d for 10 consecutive days using greywater from student's hostel and Doornbach only. Collected greywater was fed separately into the plant as per feeding schedule presented in table 3-3 and analyses were carried out as per sampling and testing schedule presented in table 3-4.

The long run time for continuous experiments was undertaken in order to understand the behaviour of each unit process and assess the performance of the AnUBR; given that the short run does not allow for sludge accumulation which is a major parameter in the detection of gases contained in greywater.

3.8 Analysis of results

The analysis of results was done in five stages:

- The first stage consisted of comparing results obtained (influent and effluent quality) to the available values found in the literature in order to discuss its validity;
- The second stage consisted of comparing results obtained (effluent quality) at each unit process to the values suggested in the literature (table 2-7) in order to determine the removal efficiency of each unit process;
- The third stage consisted of comparing the quality of the final effluent to that of influent from each process in order to establish the removal efficiency database;
- The fourth stage consisted of comparing the final effluent to the quality standards for discharging into water resources in order to verify the compliance to General Authorisation);
- The last stage consisted of assessing the potential of the AnUBR as a greywater treatment option for un-sewered settlements based on factors discussed previously.

3.9 Assessment of the performance of the AnUBR

The performance of a treatment plant is based on its capability to remove pollutants load contained in greywater and the quality of effluent produced. In this study, the performance of individual unit process was assessed by comparing the percentage of pollutant removed to available values found in the literature. The overall performance of the AnUBR was assessed by comparing the quality of influent greywater to the final effluent and the overall removal efficiency to available value found in the literature.

3.10 Evaluation of the treatment capabilities and performance of the AnUBR

The evaluation of the treatment capabilities was based on the ability of the AnUBR to produce effluent of certain standard that should be considered acceptable according to the specific regulations. This was achieved by comparing the effluent produced by the AnUBR to the quality standard applicable for discharging wastewater in general environment.

For the purpose of this study, the performance of the AnUBR was evaluated on the basis of the following criteria (discussed in the literature):

- Response to influent variations characteristics: the ability of the plant to treat greywater from different sources without causing operational deficiency;
- Removal efficiency: ability of removing pollutants to an acceptable standard. The removal efficiency was obtained by subtracting the concentration of influent to that of the effluent and dividing the value obtained by the concentration of influent.
- O&M requirements: operational and maintenance requirements of the plant.

The cost effectiveness was not selected amongst evaluation criteria due to the pilot scale of the plant used.

3.11 Prediction of the treatment capability of the AnUBR

The analysis of different greywater samples provided a database for each type of greywater used. Since the AnUBR was at pilot stage, the prediction of its performance was carried out by measuring the effluent quality obtained firstly against the available values found in the literature and secondly against the General Authorisations published by the DWAF (1999).

The treatment capabilities and performance of the AnUBR recommendations were made following the assessment of the compliance level of the treated effluent discharged. This was done by comparison of the effluent quality to the standards for discharging in water resources.

Recommendations regarding the typical application were made based on the specific requirements such as availability of a greywater collection, drainage and disposal facilities; solid-liquid separation practices and the context by which the AnUBR is used.

3.12 Conclusions

The AnUBR was built, commissioned and operated for the duration of experiments using greywater collected from case study sites. Collected greywater was fed separately in order to determine its quality based on the source of generation. For control purposes, greywater from sewered areas was used to feed the plant in order to verify and ensure that the AnUBR works appropriately.

The experimental apparatus used for analysis and analytical procedures were selected according to SANS requirements. The calibration of apparatus was conducted in order to ascertain the validity and the accuracy of the data collected during the operational period. Collected greywater was analysed for pH, TSS, TP, TN, COD, BOD_5, e-coli and FC. These parameters were selected according to its impacts on both human health and environmental pollution perspectives.

The pilot plant was designed and built based on existing design features taking into account the volume of greywater to be treated. The pilot plant consisted of four treatment processes namely pre-treatment, settling, primary and secondary filtration. Collected greywater was fed into the treatment system at a fixed flow rate corresponding to the designed retention time.

Results of analysis were used to compare the quality of influent greywater to the standards in order to predict the treatment capabilities and efficiency of the AnUBR and evaluate the treatment processes against the evaluation criteria.

Recommendations regarding the treatment capabilities, efficiency, performance and typical application were made after comparing the treated effluent to the standard.

Chapter 4: Results of experimental work

4.1 Introduction

This section of the study presents results of the experimental work conducted at the pilot AnUBR and comprises results of preliminary and continuous experiments. For easy and concurrent readability of this section, detailed results are presented in tabular and graphical forms in appendices B and C. Samples of laboratory report sheet are presented in appendix D.

4.2 Experimental work

4.2.1 Preliminary experiments

These experiments were carried out for a day using greywater from each of selected case study sites. Results presented in this section comprise the characteristics of influent greywater, the quality of effluent from each unit process, characteristics of effluent from the AnUBR, processes removal efficiencies, overall removal efficiency and sludge and gas production.

The characteristics of influent greywater were used to determine the quality of influent in order to compare its quality to the final effluent. Results obtained were used to inform on the operational requirements of the AnUBR. .

4.2.1.1 Characteristics of greywater from case study sites

a) Greywater from sewered areas

Sewered areas refer to areas served by a sewer network to which wastewater generated from households is connected. These include formal housing, residential, commercial and industrial compounds. The characteristics of greywater generated from case study sewered areas are summarised in table 4-1 below.

Table 4-1: Characteristics of mixed greywater from sewered areas

Parameter	Case study area		
	Household 1	Household 2	Student hostel
Temperature (ºC)	29.6	30.2	28.0
pH	6.2	7.1	7.2
TSS (mg/l)	107.6	245.6	145.6
TN (mg/l)	5.4	6.4	6.6
TP (mg/l)	13.2	16.85	16
COD (mg/l)	212	112	432
BOD_5 (mg/l)	55	67	122
O&G (mg/l)	82.2	112.6	42.7
e-coli (cfu/100ml)	4×10^3	18×10^3	48×10^3
Faecal coliform (cfu/100ml)	11×10^3	14×10^3	115×10^3

- *Household 1*

Greywater collected from household 1 was characterised by a temperature and pH values of 29.6ºC and 6.2 respectively. The level of TSS, TN and TP was found to be 107.6, 5.4 and 13.2mg/l respectively. The organic content was found to be 212mg/l for COD and 55mg/l of BOD_5. O&G concentration was found to be 82.2mg/l while that of micro-organism was found to be $4.0x10^3$ and $11x10^3$cfu/100 ml for e-coli and faecal coliform respectively.

- *Household 2*

The second household presented greywater with the following characteristics: The pH of 7.1 and the temperature of 30.2ºC were recorded; the concentration of TSS and O&G recorded was 245.6 and 112.6mg/l respectively. The nutrients concentration was 6.4mg/l for TN and 16.85mg/l for TP. The micro-organism content recorded was $18x10^3$ and $14x10^3$cfu/100 ml for e-coli and faecal coliform respectively.

- *Students' hostel*

Greywater collected at this particular site presented the following characteristics:
The temperature and pH value of 28.0ºC and 7.2 were recorded; the level of TN and TP were 6.6 and 16 mg/l respectively. The COD and BOD_5 level were 432 and 122mg/l respectively; while O&G, TSS, e-coli and faecal coliform level was found to be 42.7mg/l, 145.6mg/l, $48x10^3$ and $115x10^3$ cfu/100 ml respectively.

b) Greywater from un-sewered settlements

The average volume of water consumed by the residents of all case study sites in un-sewered settlements was estimated at 25l/c/d. From this volume resulted an average greywater production of 15l/c/d based on the assumption that 75% of water consumed ends up as greywater. However, apart from greywater generated directly from households, other portion generated from leaking standpipes was considered.

Un-sewered settlements refer to settlements not served by sewers or storm water networks. In the context of this research, it refers to informal settlements that are not served by a sewer and lacking disposal infrastructure. Greywater from selected un-sewered settlements presented the following characteristics summarised in table 4-2 below.

Table 4-2: Characteristics of mixed greywater from un-sewered settlements

Parameter	Settlement		
	Phola Park	**Wallacedene**	**Doornbach**
Temperature (ºC)	21.7	22.4	22.1
pH	7.4	7.1	7.8
TSS (mg/l)	2,345	1,876	1,229
TN (mg/l)	12.1	11.2	20.2
TP (mg/l)	132.5	121.6	113.1
COD (mg/l)	1,235	1,123	987
BOD_5 (mg/l)	467.8	461.3	72.1
O&G (mg/l)	478	435	686
e-coli (cfu/100 ml)	$68x10^6$	$51x10^6$	TNT*
Faecal coliform (cfu/100 ml)	$84x10^6$	$77x10^6$	TNT*

**TNT refers to value above or equal to 10^8cfu/100ml*

- *Phola Park Informal settlement*

The following values characterised greywater collected from Phola Park informal settlement. The temperature and pH were found to be 21.7ºC and 7.4 respectively; the concentration of solids recorded was 2,345 and 478mg/l for TSS and O&G respectively. The concentration of nutrients and organic compounds was found to be 12.1, 132.5, 1,235 and 467.8mg/l for TN, TP, COD and BOD_5 respectively. The concentration of micro-organism recorded was $68x10^6$ and $84x10^6$ cfu/100ml for both e-coli and faecal coliform.

- *Wallacedene Informal settlement*

Greywater from Wallacedene was characterised by a temperature and pH values of 22.4ºC and 7.1 respectively. The concentration of nutrients was found to be 1,876 and 11.2mg/l for TN and TP respectively while that of solids was 1,876 and 435mg/l for TSS and O&G respectively. The concentration of organic compounds and micro-organism was found to be 1,223 and 461.3mg/l for COD and BOD_5 and $51x10^6$ and $77x10^6$cfu/100ml for e-coli and faecal coliform.

- *Doornbach Informal settlement*

Greywater collected in Doornbach was characterised by a temperature of 22.1ºC for a pH value of 7.8. The nutrients and organic compounds concentration recorded was 20.2, 113.1, 987 and 72.1mg/l for TN, TP, COD and BOD_5 respectively. The concentration of solids averaged 1,229 and 686mg/l for TSS and O&G respectively and that of micro-organisms was too numerous to count (meaning above 10^8cfu/100ml) for e-coli and faecal coliform respectively.

4.2.1.2 Characteristics of greywater effluent from unit processes

Individual unit processes achieved a variable pollutant removal depending on the treatment process applied. Details of greywater characteristics are provided in appendix B.

a) Pre-treatment process

Effluent greywater from this process was characterised by a significant decrease of O&G and TSS. Other parameters decreased slightly as presented in table 4-3 below.

Table 4-3: Greywater effluent quality after pre-treatment

Parameter	***Sewered areas***			***Un-sewered settlements***		
	Household1	*Household2*	*Student host*	*Phola park*	*Wallacedene*	*Doornbach*
Temperature (ºC)	27.5	28.9	28.1	22.4	22.5	23.7
pH	7.3	7.3	7.1	7.2	7.4	7.5
TSS (mg/l)	93.8	119.5	134.8	1,289	1149	978.4
TN (mg/l)	4.9	5.9	4.9	7.0	3.2	11.12
TP (mg/l)	12.1	12.3	2.1	120.1	76.5	67.87
COD (mg/l)	187	107	321	1096	986.3	874.7
BOD_5 (mg/l)	45.50	62.82	114.42	396.3	413.1	47.5
O&G (mg/l)	18.2	20.5	3.8	76.5	17.8	18.6
e-coli (cfu/100ml)	3.8×10^3	17.5×10^3	42×10^3	5.6×10^5	8.7×10^5	8.2×10^5
FC (cfu/100 ml)	10.4×10^3	10.3×10^3	103.4×10^3	8.2×10^5	7.6×10^5	9.1×10^5

b) Settling process

The characteristics of greywater effluent from the settling process are presented in table 4-4 below. Results show a significant decrease of O&G and TSS, while the concentration of pollutants such as COD and BOD_5 decreased slightly.

Table 4-4: Greywater effluent quality after settling

Parameter	***Sewered areas***			***Un-sewered settlements***		
	Household1	*Household2*	*Student host*	*Phola park*	*Wallacedene*	*Doornbach*
Temperature (ºC)	28.1	29.7	29.1	22.8	24.7	23.6
pH	7.0	7.0	7.0	7.4	7.1	7.3
TSS (mg/l)	12.1	33.5	23.5	98	86.7	44.8
TN (mg/l)	3.4	3.3	4.4	6.8	2.1	9.6
TP (mg/l)	6.4	8.45	1.4	89.23	46.4	32.9
COD (mg/l)	135	89	195	456.7	321.8	133.42
BOD_5 (mg/l)	21.45	26.78	61.08	87.65	87.9	14.1
O&G (mg/l)	5.1	12.3	2.1	15.6	11.4	7.2
e-coli (cfu/100ml)	2.56×10^3	16×10^3	36.5×10^3	8.8×10^5	7.6×10^5	7.3×10^5
FC (cfu/100 ml)	8.3×10^3	9.5×10^3	98.7×10^3	7.7×10^5	7.2×10^5	8.7×10^5

c) Primary filtration process

The effluent from this process was characterised by a high decrease in concentration (when compared to the influent or effluent form previous processes). Nutrients and organic compounds concentration were found to be decreasing as well as micro-organisms.

Table 4-5: Greywater effluent quality after primary filtration

Parameter	***Sewered areas***			***Un-sewered settlements***		
	Household1	*Household2*	*Student host*	*Phola park*	*Wallacedene*	*Doornbach*
Temperature (ºC)	29.5	29.3	29.2	23.9	25.5	24.1
pH	7.1	7.15	7.1	7.3	7.22	7.4
TSS (mg/l)	7.3	11.1	12.4	23	32.2	33.2
TN (mg/l)	2.8	2.1	3.03	3.2	1.4	4.12
TP (mg/l)	3.1	6.01	1.0	54.2	21.3	11.6
COD (mg/l)	91	21	111	77.6	112.6	85.43
BOD_5 (mg/l)	12.83	14.53	25.62	39.65	44.3	13.8
O&G (mg/l)	2.2	9.9	1.9	8.1	2.4	5.1
e-coli (cfu/100ml)	219	1.8×10^3	1,789	12×10^3	24×10^3	38×10^3
FC (cfu/100 ml)	946	1.45×10^3	2,456	3×10^3	19×10^3	93,120

d) Secondary filtration

At this stage greywater characteristics had drastically improved; the concentration of pollutants was decreased significantly (as presented in table 4-6 below).

Table 4-6: Greywater effluent quality after secondary filtration

Parameter	***Sewered areas***			***Un-sewered settlements***		
	Household1	*Household2*	*Student host*	*Phola park*	*Wallacedene*	*Doornbach*
Temperature (ºC)	26.0	27.6	26.2	23.8	25.2	23.8
pH	7.2	6.9	7.2	7.1	7.24	7.3
TSS (mg/l)	5.2	7.5	6.8	18	28.3	20.9
TN (mg/l)	1.2	1.9	1.02	1.1	1.1	1.65
TP (mg/l)	2.85	2.90	0.75	12.3	10.4	8.13
COD (mg/l)	25	19	75	32.3	35.8	38.75
BOD_5 (mg/l)	5.17	6.69	13.1	17.2	19.3	7.6
O&G (mg/l)	0.90	4.2	1.1	2.3	1.8	2.7
e-coli (cfu/100ml)	90	430	234	1,343	2×10^3	4×10^3
FC (cfu/100 ml)	125	195	276	1,167	$3,3 \times 10^3$	1.98×10^3

4.2.1.3 Characteristics of effluent from the AnUBR

The last process acted as a storage tank in which treated effluent was stored prior to discharge. A low decrease in the concentration of pollutants was recorded (in table 4-7 below). The concentration of organic compounds and nutrients decreased slightly as well as that of micro-organisms and solids.

a) Greywater from sewered areas

The effluent greywater from each case study site was characterised by low concentration of pollutants. A temperature and pH increase in the final effluent was observed while the nutrient and organic compounds level decreased noticeably. The concentration of solids decreased significantly as well as that of the micro-organism. Detailed characteristics of effluent for each case study site are presented in appendix B section B.1.1.

b) Greywater from un-sewered settlements

Greywater from un-sewered settlements behaved in the same way as that from sewered areas. The temperature increased in all cases while the pH decreased. The concentration of nutrients and organic compounds decreased significantly as well as that of micro-organisms. Details of the characteristics of effluents are presented in appendix B section B.1.2.

Table 4-7: Greywater effluent from the AnUBR

Parameter	***Sewered areas***			***Un-sewered settlements***		
	Household1	*Household2*	*Student host*	*Phola park*	*Wallacedene*	*Doornbach*
Temperature (ºC)	25.8	27.2	26.0	23.5	25.9	23.7
pH	7.5	7.2	7.5	7.2	7.13	7.3
TSS (mg/l)	4.9	3.8	6.8	15	21.9	19.8
TN (mg/l)	1.2	1.9	0.90	1.1	0.8	1.4
TP (mg/l)	1.25	2.65	0.75	11.5	8.8	7.12
COD (mg/l)	22	18.2	42	28.8	26.2	31.4
BOD_5 (mg/l)	4.28	5.72	11.22	15.7	17.6	5.9
O&G (mg/l)	0.70	2.15	1.0	1.2	1.1	2.1
e-coli (cfu/100ml)	60	318	200	932	1,034	2145
FC (cfu/100 ml)	102	107	206	346	1,924	1,542

4.2.1.4 Processes removal efficiency

The pollutant removal efficiency at each unit process recorded was found to be variable from one process to another. The pre-treatment process showed a high removal efficiency of solids contents and low removal of micro-organisms; while the settling process showed a high removal of solids contents and nutrients. A significant removal of organic compounds, nutrients and micro-organism was observed at the filtration processes while the last process showed a low pollutants removal. For more details on the removal efficiency of individual unit process refer to appendix B section B.2.

a) Greywater from sewered areas

- *Influent greywater*

Influent greywater analysed has characteristics described in table 4-1. It was characterised by variable concentration of pollutant as described in section 4.2.1 above.

- *Effluent from the pre-treatment process*

The first process produced effluent with an average pollutant concentration lower than the influent. The concentration of solids (TSS and O&G) decreased significantly while that of nutrients was lower. The COD and BOD_5 decreased by about 20% averages. The e-coli and faecal coliform concentration showed a low decrease. Refer to appendix B (table B.7) for details.

- *Effluent from the settling process*

At this process, the AnUBR showed a high removal efficiency of TSS and O&G as presented in appendix B (table B.8). The level of TN and TP decreased of about 30 and 50% respectively while that COD and BOD_5 decreases of about 40 and 60% respectively. The micro-organism removal averaged 20 and 25% for e-coli and faecal coliform respectively.

- *Effluent from the primary filtration process*

Following this process, it was recorded that the level of pollutant for most parameters was decreasing except for the pH and temperature. The values recorded ranged from 39.67 to 66.87% for TSS and 9.53 to 56.86% for O&G. The nutrient removal averaged 17.65 to 36.37% for TN and 7.15 to 51.56% for TP. The micro-organism (e-coli and FC) removal averaged 88 to 96% for e-coli and 75 to 90% for faecal coliform as indicated in appendix B (table B.9).

- *Effluent from the secondary filtration process*

The second filtration process reduced the level of contaminants to certain levels as indicated in appendix B (table B.10). We recorded a removal of TSS and O&G ranging from 28 to 45: and 42 to 59% respectively; the nutrient removal was found to be ranging from 20 to 66% for TN and 8 to 51% for TP. The organic compounds removal averaged 20 to 72% for COD and 48 to 59% for BOD5 respectively. The micro-organism removal ranged from 13 to 86% for e-coli and 32 to 64% for faecal coliform.

- *Final effluent*

In the last process, the final effluent presented a concentration of pollutants lower than that recorded in other processes appendix B (table B.11). The removal of solids contents averaged 3 to 6% for TSS and 9 to 48% for O&G; the nutrient removal recorded ranged from 0 to 11% for TN and 0 to 56% for TP. We also found a variable organic compounds removal ranging from 4 to 44% for COD and 14 to 17% for respectively. A low removal of micro-organisms ranging from 5 to 14% for e-coli and 5 to 31% for faecal coliform was recorded.

b) Greywater from un-sewered settlements

- *Influent greywater*

Influent greywater analysed has characteristics described in table 4-4. The quality of greywater from un-sewered settlements was characterised by a variable concentration of pollutants as described above.

- *Effluent from the pre-treatment process*

Following the pre-treatment process, we recorded a variable removal of pollutant contents except for solids (TSS and O&G) that were significantly removed appendix B (table B.12). The average removal recorded averaged 20 to 45% for TSS and 84 to 97% for O&G. The nutrients removal averaged 42 to 71% for TN and 9 to 39% for TP; the COD and BOD_5 removal was found to average 11 to 12% and 10 to 34% respectively. The e-coli and faecal coliform removal averaged 9 to 28% for e-coli and 2 to 15% for faecal coliform.

- *Effluent from the settling process*

Analysis of effluent indicates variable removal efficiencies of pollutants. The solids contents removal averaged 52 to 98% for TSS and 36 to 79% for O&G; the nutrients removal was recorded in the average of 2 to 34% for TN and 25 to 51% for TP. The average organic compounds removal recorded ranged from 58 to 84% for COD and 70 to 78% for BOD_5; the micro-organism removal was found averaging 12 to 19% for e-coli and 8 to 16% for faecal coliform. Details are presented in appendix B (table B.13).

- *Effluent from the primary filtration process*

The removal efficiency recorded at this process shows a high removal of micro-organisms averaging 99% and for the remainder of pollutants, it was variable as indicated in appendix B (table B.14). The organic compounds removal averaged 35 to 83% for COD and 44 to 54% for BOD_5. The average removal of nutrients (TN and TP) was 33 to 57% and 54 to 64%; the solids removal averaged 48 to 75% for TSS and 48 to 78% for O&G respectively.

- *Effluent from the secondary filtration process*

A removal efficiency averaging 88 to 91% for e-coli and 61 to 97% for faecal coliform was recorded; the nutrient removal recorded averaged 21 to 65% for TN and 29 to 77% for TP. The removal of solids contents averaged 21 to 53% for TSS and 45 to 71% for O&G. The average COD and BOD_5 recorded ranged from 54 to 68% and 41 to 56% respectively while the micro-organism removal was recorded averaging 88 to 91% for e-coli and 61 to 97% for faecal coliform respectively. Refer to appendix B (table B.15 for details).

- *Final effluent (from the storage tank)*

The characteristics of the final effluent presented in appendix B (table B.16) give an indication of the quality of the effluent produced by the AnUBR. It was found that the concentration of pollutants was lower than that recorded in other processes. Most of the pollutant contents were reduced significantly to certain level. The solids removal recorded averaged 10 to 19% for TSS and 41 to 47% for O&G; while that of micro-organism averaged 30 to 48% for e-coli and 22 to 53% for faecal coliform. The nutrients and organic compounds removal recorded was found in the average of 0 to 27% and 6 to 15% for TN and TP; 18 to 28% and 8 to 10% for COD and BOD_5 respectively.

4.2.1.5 Overall removal efficiency

a) Greywater from sewered areas

Following the analyses, it was found that the influent greywater quality had changed after being treated in the AnUBR. There was observed a significant decrease in the level of pollutant content. The TSS level decreased from the initial 107.6 mg/l to 4.9 mg/l in the final effluent resulting in removal of 95%. The same high removal efficiency was observed for other pollutant in all case study sites as presented in table 4-8 below.

Table 4-8: Overall removal efficiency (sewered areas)

Parameter	Household 1			Household 2			Student hostel		
	Influent	Effluent	%	Influent	Effluent	%	Influent	Effluent	%
TSS (mg/l)	107.6	4.9	95	245.6	3.8	98	145.6	6.8	95
TN (mg/l)	5.4	1.2	77	6.4	1.9	70	6.6	0.90	86
TP (mg/l)	13.2	1.25	90	16.85	2.65	84	16	0.75	95
COD (mg/l)	212	22	89	112	18.2	84	432	42	90
BOD_5 (mg/l)	55	31	44	67	27	60	122	22	82
O&G (mg/l)	82.2	0.70	99	112.6	2.15	98	42.7	1.0	97
e-coli (cfu/100 ml)	$4x10^3$	180	95	$18x10^3$	400	98	$48x10^3$	200	99
FC (cfu/100ml)	$11x10^3$	432	96	$14x10^3$	670	95	$115x10^3$	764	99

b) Greywater from un-sewered settlements

The treatment of greywater from un-sewered settlements in the AnUBR shows a high pollutant removal as indicated in table 4-9 below. The concentration of pollutant decreased to up to 90% in all case study sites.

Table 4-9: Overall removal efficiency (un-sewered settlements)

Parameter	Phola Park			Wallacedene			Doornbach		
	Influent	Effluent	%	Influent	Effluent	%	Influent	Effluent	%
TSS (mg/l)	2,345	15	99	1,876	21.9	99	1,229	19.8	98
TN (mg/l)	12.1	1.1	90	11.2	0.8	90	20.2	1.4	93
TP (mg/l)	132.5	11.5	91	121.6	8.8	91	113.1	7.12	94
COD (mg/l)	1,235	32.8	97	1,123	31.2	97	987	68	93
BOD_5 (mg/l)	467.8	29.7	93	461.3	28.9	94	72.1	11.4	84
O&G (mg/l)	478	1.2	99	435	1.1	99	686	2.1	99
e-coli (cfu/100 ml)	$68x10^6$	932	99	$51x10^6$	1,034	99	TNT	1,102	99
FC (cfu/100ml)	$84x10^6$	846	98	$77x10^6$	1,524	99	TNT	1,342	98

4.2.1.6 Sludge and gas production

a) Sludge production

Since the AnUBR was operated for a day using greywater from each selected case study site separately, it was difficult to determine with accuracy the sludge volume produced. However, it was noticed a sludge build-up in the bottom of the processes. The odour emitted was comparable to that of rotten eggs.

b) Gas production

The level of gas depends on the VSS (volatile suspended solids) contents of wastewater (Franklin & Tchobanoglous, 2003). The concentration of VSS found was 93.6, 221.0 and 123.3mg/l for the household 1, 2 and students' hostel respectively and 2,227.8, 1,650.9 and 1093.8mg/l for Phola Park, Wallacedene and Doornbach informal settlements respectively.

Besides these results, the presence of NH_3 and CO_2 was observed and low methane production was detected. The NH_3 concentration was found to be averaging 0.4 and 7.4mg/l. Due to the low solid contents of greywater fed into the AnUBR and the short operating time, it was not possible to provide accurate results at this stage. It was therefore recommended to further the investigation by undertaking continuous experiments.

4.2.2 Continuous experiments

This section presents the results of experimental work undertaken at the AnUBR for 10 days using influent greywater from the students' hostel and Doornbach informal settlement respectively. Daily samples of influent and effluent from each process were collected and analysed for pH, TSS, O&G, COD, BOD_5, TN, TP, e-coli and Faecal coliform. Collected samples were also tested for NH_3, CH_4, and CO_2.

Results presented below comprise of characteristics of influent greywater from case study sites, characteristics of effluent greywater from each unit process, characteristics of final effluent and removal efficiency of each process. It also includes the overall removal efficiency, sludge and gas production, behaviour of unit process and operational requirements. The overall results are presented in appendix C.

4.2.2.1 Characteristics of influent greywater from case study sites

Table 4-10: Characteristics of influent greywater from case study sites

Parameters	**Case study site**	
	Student hostel	***Doornbach Informal settlement***
Temperature (ºC)	29.6	24.11
pH	7.12	7.39
TSS (mg/l)	117.72	2,246.6
TN (mg/l)	5.66	12.29
TP (mg/l)	12.27	116.46
COD (mg/l)	223.17	1,135.32
BOD_5 (mg/l)	98.0	383.6
O&G (mg/l)	52.22	475.29
e-coli (cfu/100 ml)	$8.87x10^4$	$2.17x10^7$
FC (cfu/100 ml)	$1.49x10^5$	$2.41x10^7$

a) *Temperature and pH*

The temperature of influent greywater was measured directly after collection and prior to feeding the plant. The temperature values recorded on greywater samples from the students' hostel and Doornbach informal settlement averaged 29.6 and 24.11ºC respectively.

The pH measurement was performed on samples drawn from influent greywater; values obtained were respectively 7.12 and 7.39 for the students' hostel and Doornbach.

b) *Solids contents (TSS and O&G)*

Table 4-10 shows values of TSS measured on the influent greywater. Results indicate a concentration of TSS averaging 117.72 and 2,246.6mg/l for greywater at the students' hostel and Doornbach informal settlement; while that of O&G was 52.2 and 475.29mg/l.

c) *Nutrients*

The average concentration of 5.66 and 12.27mg/l was recorded from the analysis of greywater collected at the students' hostel; the values of 12.29 and 116.46mg/l were recorded on samples from Doornbach.

d) Organic compounds

The average COD of influent greywater from the students' hostel and Doornbach were respectively 223.17 and 1,135mg/l. The average BOD_5 concentration of influent greywater found at the two study sites was 98.0 and 383.6mg/l.

e) Micro-organisms

The concentration of pathogen micro-organism detected in the influent greywater from the students' hostel and Doornbach was respectively $8.87x10^4$ and $2.17x10^7$cfu/100ml for e-coli and $2.41x10^5$ and $2.41x10^7$cfu/100ml.

4.2.2.2 Characteristics of effluent from unit processes

a) Pre-treatment process, settling and Primary filtration

The characteristics of effluent from the pre-treatment, settling and primary filtration are presented in table 4-11 below. It was A significant decrease of the concentration of major pollutants was observed while the temperature was fluctuating from 29 to 31ºC and 26 to 28ºC in both case study sites.

Table 4-11: Quality of greywater after pre-treatment, settling and primary filtration

Parameter	***Student's hostel***			***Doornbach***		
	Pre-treat.	*Settling*	*Filtration1*	*Pre-treat.*	*Settling*	*Filtration1*
Temperature (ºC)	29.5	30.9	31.3	26.9	27.6	28.2
pH	7.2	7.2	7.20	7.8	8.0	7.4
TSS (mg/l)	102.13	19.03	10.8	2021.45	80.27	36.2
TN (mg/l)	4.57	3.70	2.54	10.3	8.72	2.81
TP (mg/l)	10.28	8.05	1.81	103.13	89.4	38.71
COD (mg/l)	157.77	99.63	72.25	990.35	309.69	99.27
BOD_5 (mg/l)	85.92	57.5	25.6	347.12	71.41	34.91
O&G (mg/l)	9.26	3.83	2.43	42.72	17.05	10.42
e-coli (cfu/100ml)	$8.18x10^4$	$6.55x10^3$	886.37	$2.08x10^7$	$9.12x10^5$	$3.69x10^3$
FC (cfu/100 ml)	$1.37x10^5$	$1.01x10^3$	988.2	$2.17x10^7$	$2.96x10^6$	$5.05x10^3$

b) Secondary filtration and storage tank

The table 4-12 below presents the typical characteristics of greywater effluent from the second filtration and final effluent from the storage tank. As recorded, significant pollutants removal was achieved in both case study sites and the quality of effluent is much better than that from previous processes.

Table 4-12: Quality of greywater after secondary filtration and storage tank

Parameter	***Student hostel***		***Doornbach***	
	Filtration 2	*Storage tank*	*Filtration 2*	*Storage tank*
Temperature (ºC)	30.0	28.9	27.7	27.2
pH	7.2	7.2	7.2	7.1
TSS (mg/l)	6.29	5.12	19.74	12.82
TN (mg/l)	1.20	0.91	1.39	1.09
TP (mg/l)	1.25	0.93	11.23	7.47
COD (mg/l)	35.69	24.67	52.88	40.45
BOD_5 (mg/l)	11.14	8.59	19.51	16.0
O&G (mg/l)	1.52	1.15	3.15	1.72
e-coli (cfu/100ml)	345.5	213.3	$1.32x10^3$	$1.12x10^3$
FC (cfu/100 ml)	628.9	461.6	$1.89x10^3$	$1.5x10^3$

4.2.2.3 Characteristics of final effluent greywater from AnUBR

The qualities of greywater presented below are the average based on 10 days monitoring of the AnUBR using greywater from case study sites. The details results are presented in appendix C.

a) *Greywater from students' hostel*

The greywater collected from the students' hostel was analysed prior to feeding the AnUBR. Following the feeding and subsequent treatment through processes, there was observed a significant pollutant removal (presented in table 4-13 below).

The initial temperature of greywater recorded prior the feeding was 29.6ºC after a slight decrease at the settling process. It increased at the filtration processes to attain 30.9 and 31.3ºC then decreased to 28.9ºC. The pH in turn was initially 7.1 and fluctuated during the treatment process to a final value *of 7.2*.

The concentration of TSS decreased from the initial 117.2 to 5.12mg/l; the TN and TP decreased respectively from 5.66 and 12.27mg/l to 0.93 to 24.67mg/l. A similar decrease was recorded in the concentration of organic compounds which came from the initial 223.17 to 24.67mg/l for COD while that of BOD_5 decreased from 98.0 to 8.59mg/l.

The O&G concentration decreased from 52.22 to 1.15mg/l while the micro-organisms were reduced from the initial $8.87x10^4$ to 213.3cfu/100ml for e-coli and $1.49x10^5$ to 461.6cfu/100 ml for faecal coliform.

Table 4-13: Characteristics of greywater effluent (students' hostel)

Parameter						
	Influent	**Pre-treatment**	**P_1**	**P_2**	**P_3**	**P_4**
Temperature (ºC)	29.6	29.5	30.9	31.3	30.0	28.9
pH	7.1	7.2	7.2	7.20	7.2	7.2
TSS (mg/l)	117.72	102.13	19.03	10.8	6.29	5.12
TN (mg/l)	5.66	4.57	3.70	2.54	1.20	0.91
TP (mg/l)	12.27	10.28	8.05	1.81	1.25	0.93
COD (mg/l)	223.17	157.77	99.63	72.25	35.69	24.67
BOD_5 (mg/l)	98.0	85.92	57.5	25.6	11.14	8.59
O&G (mg/l)	52.22	9.26	3.83	2.43	1.52	1.15
e-coli (cfu/100ml)	8.87×10^4	8.18×10^4	6.55×10^3	886.37	345.5	213.3
FC (cfu/100ml)	1.49×10^5	1.37×10^5	1.01×10^3	988.2	628.9	461.6

b) Greywater from Doornbach

Greywater samples from the Doornbach informal settlement (table 4-14 below) are characterised by high concentration of pollutant. Similarly to the greywater samples from the students' hostel, significant decrease in pollutant concentration in all AnUBR processes was recorded.

The temperature of the influent and effluent greywater was 24.11ºC and 27.2ºC; the initial pH was 7.39 and the final was 7.1. The concentration of nutrients decreased from the initial 12.29 and 116.46mg/l of TN and TP respectively to 1.09 and 7.47 mg/l. The organic compounds concentration decreased from 1,135.32 to 40.45mg/l for COD and 383.6 to 16.0mg/l for BOD_5.

The O&G concentration was higher than that found on greywater samples from the students' hostel. After the treatment process, the concentration decreased from the initial 475.29 to 1.72mg/l. The concentration of micro-organism was higher compared to that obtained from the students' hostel's samples. The initial concentration of 2.17×10^7cfu/100ml decreased to 1.12×10^3 for e-coli and that of faecal coliform decreased from 2.41×10^7 to 1.5×10^3cfu/100ml.

Table 4-14: Characteristics of greywater effluent (Doornbach)

Parameter						
	Influent	**Pre-treatment**	**P_1**	**P_2**	**P_3**	**P_4**
Temperature (ºC)	24.11	26.9	27.6	28.2	27.7	27.2
pH	7.4	7.8	8.0	7.4	7.2	7.1
TSS (mg/l)	2,246.6	2021.45	80.27	36.2	19.74	12.82
TN (mg/l)	12.29	10.3	8.72	2.81	1.39	1.09
TP (mg/l)	116.46	103.13	89.4	38.71	11.23	7.47
COD (mg/l)	1,135.32	990.35	309.69	99.27	52.88	40.45
BOD_5 (mg/l)	383.6	347.12	71.41	34.91	19.51	16.0
O&G (mg/l)	475.29	42.72	17.05	10.42	3.15	1.72
e-coli (cfu/100ml)	2.17×10^7	2.08×10^7	9.12×10^5	3.69×10^3	1.32×10^3	1.12×10^3
FC (cfu/100ml)	2.41×10^7	2.17×10^7	2.96×10^6	5.05×10^3	1.89×10^3	1.5×10^3

4.2.2.4 Pollutant removal at individual unit process

The quality of greywater from individual unit process was analysed in order to determine the performance of each process. It was observed a decrease in the concentration of pollutants from one process to another. The pre-treatment process was able of removing significantly solids while the settling achieved a good removal of solids, organic compounds and at lesser extent nutrients and micro-organisms. The following results were recorded.

a) Pre-treatment

The pre-treatment process achieved a removal of 10 - 13% of TSS, 16-19% of TN; 11-16% of TP; 12-29% of COD; 9-12% of BOD_5; 82-91% of O&G; 5-8% of e-coli and 8-9% of faecal coliform on greywater samples from the students' hostel and Doornbach informal settlement respectively (table 4-15).

Table 4-15: Removal efficiency Influent – Pre-treatment process*

Parameter	**Student hostel**			**Doornbach Informal settlement**		
	Influent	Pre-treat.	% removal*	Influent	Pre-treat.	% removal*
Temperature (ºC)	29.6	29.5	-	24.11	26.9	-
pH	7.1	7.2	-	7.4	7.8	-
TSS (mg/l)	117.72	102.13	*13.25*	2246.6	2021.45	*10.02*
TN (mg/l)	5.66	4.57	*19.26*	12.29	10.3	*16.20*
TP (mg/l)	12.27	10.28	*16.22*	116.46	103.13	*11.45*
COD (mg/l)	223.17	157.77	*29.31*	1135.32	990.35	*12.77*
BOD_5 (mg/l)	98.0	85.92	*12.33*	383.6	347.12	*9.51*
O&G (mg/l)	52.22	9.26	*82.28*	475.29	42.72	*91.01*
e-coli (cfu/100ml)	$8.87x10^4$	$8.18x10^4$	*8.18*	$2.17x10^7$	$2.08x10^7$	*5.89*
FC (cfu/100ml)	$1.49x10^5$	$1.37x10^5$	*8.06*	$2.41x10^7$	$2.17x10^7$	*9.96*

** Based on average values*

b) Settling

Following the passage of greywater into this process, it was recorded in both case study sites a removal averaging 81-96% for TSS; 15% for TN, 13-21% for TP; 36-68% for COD; 33-79% for BOD_5; 58-60% for O&G; 12-19% e-coli and 9-11% faecal coliform. (Refer to table 4-16 below for details).

Table 4-16: Pre-treatment process – Settling*

Parameter	**Student hostel**			**Doornbach Informal settlement**		
	Pre-treat.	P_1	% removal*	Pre-treat.	P_1	% removal*
Temperature (ºC)	29.5	30.9	-	26.9	27.6	-
pH	7.23	7.21	-	7.8	8.0	-
TSS (mg/l)	102.13	19.03	*81.37*	2021.45	80.27	*96.03*
TN (mg/l)	4.57	3.70	*15.91*	10.3	8.72	*15.34*
TP (mg/l)	10.28	8.05	*21.70*	103.13	89.4	*13.31*
COD (mg/l)	157.77	99.63	*36.85*	990.35	309.69	*68.73*
BOD_5 (mg/l)	85.92	57.5	*33.08*	347.12	71.41	*79.43*
O&G (mg/l)	9.26	3.83	*58.64*	42.72	17.05	*60.09*
e-coli (cfu/100ml)	$8.18x10^4$	$6.55x10^4$	*19.92*	$2.08x10^7$	$1.82x10^7$	*12.5*
FC (cfu/100ml)	$1.37x10^5$	$1.21x10^5$	*11.68*	$2.17x10^7$	$1.96x10^7$	*9.68*

** Based on average values*

c) Primary filtration

Following the analysis on greywater samples from the students' hostel and the Doornbach informal settlement provided , the removal was recorded averaged 43-54% for TSS, 31-67% for TN, 50-77% for TP, 27-67% for COD, 51-55% for BOD_5, 36-38% for O&G, 86-99% e-coli and 90-99 for faecal coliform. Details are provided in table 4-17 below.

Table 4-17: Settling – Primary filtration*

Parameter	**Student hostel**			**Doornbach Informal settlement**		
	P_1	P_2	% removal*	P_1	P_2	% removal*
Temperature (ºC)	30.9	31.3	-	27.6	28.2	-
pH	7.21	7.20	-	8.0	7.4	-
TSS (mg/l)	19.03	10.8	*43.25*	80.27	36.2	*54.91*
TN (mg/l)	3.70	2.54	*31.35*	8.72	2.81	*67.78*
TP (mg/l)	8.05	1.81	*77.52*	89.4	38.71	*50.69*
COD (mg/l)	99.63	72.25	*27.49*	309.69	99.27	*67.95*
BOD_5 (mg/l)	57.5	25.6	*55.48*	71.41	34.91	*51.12*
O&G (mg/l)	3.83	2.43	*36.56*	17.05	10.42	*38.89*
e-coli (cfu/100 ml)	$6.55x10^3$	886.37	*86.47*	$9.12x10^5$	$3.69x10^3$	*99.60*
FC (cfu/100 ml)	$1.01x10^4$	988.2	*90.22*	$2.96x10^6$	$5.05x10^3$	*99.89*

** Based on average values*

d) Secondary filtration

A removal of 41-45% for TSS, up to 50% for TN, 30-70% for TP, 46-50% for COD, 44-56% for BOD_5, 37-69% for O&G, up to 60% for e-coli and 36-62% for faecal coliform was recorded. Details are provided in table 4-18 below.

Table 4-18: Primary filtration – Secondary filtration*

Parameter	**Student hostel**			**Doornbach Informal settlement**		
	P_2	P_3	% removal	P_2	P_3	% removal
Temperature (ºC)	31.3	30.0	-	28.2	27.7	-
pH	7.20	7.15	-	7.4	7.2	-
TSS (mg/l)	10.8	6.29	*41.76*	36.2	19.74	*45.47*
TN (mg/l)	2.54	1.20	*52.76*	2.81	1.39	*50.54*
TP (mg/l)	1.81	1.25	*30.94*	38.71	11.23	*70.99*
COD (mg/l)	72.25	35.69	*50.61*	99.27	52.88	*46.74*
BOD_5 (mg/l)	25.6	11.14	*56.49*	34.91	19.51	*44.12*
O&G (mg/l)	2.43	1.52	*37.45*	10.42	3.15	*69.77*
e-coli (cfu/100 ml)	886.37	345.5	*61.02*	$3.69x10^3$	$1.32x10^3$	*64.23*
FC (cfu/100 ml)	988.2	628.9	*36.36*	$5.05x10^3$	$1.89x10^3$	*62.58*

** Based on average greywater values*

e) Clear water storage tank

This process was used to collect treated effluent from the secondary filtration. A removal efficiency (presented in table 4-19 below) averaging 18-35% for TSS, 21-24% for TN, 25-33% for TP, 23-30% for COD, 17-22% for BOD_5, 24-45% for O&G, 15-38% for e-coli and 20-26% for faecal coliform was recorded.

Table 4-19: Removal efficiency Secondary filtration – Storage tank (effluent*)

Parameter	**Student hostel**			**Doornbach Informal settlement**		
	P_3	P_4	% removal	P_3	P_4	% removal
Temperature (ºC)	30.0	28.9	-	27.7	27.2	-
pH	7.15	7.2	-	7.2	7.1	-
TSS (mg/l)	6.29	5.12	*18.60*	19.74	12.82	*35.06*
TN (mg/l)	1.20	0.91	*24.17*	1.39	1.09	*21.59*
TP (mg/l)	1.25	0.93	*25.60*	11.23	7.47	*33.49*
COD (mg/l)	35.69	24.67	*30.88*	52.88	40.45	23.51
BOD_5 (mg/l)	11.14	8.59	*22.89*	19.51	16.0	*17.99*
O&G (mg/l)	1.52	1.15	*24.35*	3.15	1.72	*45.40*
e-coli (cfu/100 ml)	345.5	213.3	*38.27*	$1.32x10^3$	$1.12x10^3$	*15.16*
FC (cfu/100 ml)	628.9	461.6	*26.60*	$1.89x10^3$	$1.5x10^3$	*20.64*

** Based on average greywater values*

4.2.2.5 Overall removal efficiency

The analyses of influent and effluent greywater samples collected from the AnUBR processes shows the overall removal efficiency (referred in table 4-20) averaging 95 and 99% for TSS; 83 and 91% for TN, 92 and 93% for TP, 88 and 96% for COD, 91 and 95% for BOD_5, 97and 99% for O&G, and 99% for e-coli and faecal coliform respectively for the students' hostel and the Doornbach informal settlement.

Table 4-20: Overall removal efficiency

Parameter	**Student's hostel**			**Doornbach informal settlement**		
	Influent	Effluent	% removal*	Influent	Effluent	% removal*
Temperature (ºC)	29.6	28.9	-	24.11	27.2	-
pH	7.12	7.2	-	7.39	7.1	-
TSS (mg/l)	117.72	5.12	*95.67*	2,246.6	12.82	*99.43*
TN (mg/l)	5.66	0.91	*83.92*	12.29	1.09	*91.13*
TP (mg/l)	12.27	0.93	*92.42*	116.46	7.47	*93.60*
COD (mg/l)	223.17	24.67	*88.95*	1,135.32	40.45	96.44
BOD_5 (mg/l)	98.0	8.59	*91.24*	383.6	16.0	*95.83*
O&G (mg/l)	52.22	1.15	*97.80*	475.29	1.72	*99.64*
e-coli (cfu/100 ml)	8.87×10^4	213.3	*99.76*	2.17×10^7	1.12×10^3	*99.99*
FC (cfu/100 ml)	1.49×10^5	461.6	*99.70*	2.41×10^7	1.5×10^3	*99.99*

** Based on average values*

4.2.2.6 Sludge and gas production

a) Sludge production

The sludge volume was measured using the physical method that consists of measuring the amount of settled solids in the bottom of the reactor. The sludge produced has a variable volume based on the concentration of solids contents in each reactor. Following the analysis, the volume of sludge (excluding scum layer) was recorded (as shown in table 4-21 below).

Table 4-21: Volume of sludge produced

	Sludge volume (in l)	
	Student's hostel	***Doornbach IS***
Influent	Not measured	Not measured
Pre-treatment	3.00	8.40
P_1: Settling	1.20	5.30
P_2: Primary filtration	0.50	2.10
P_3: Secondary filtration	0.35	0.95
P_4: Clear water tank	0.02	Below detection limit

b) Gas production

An attempt was made to determine the level of gases generated from the decomposition of organic compounds. The following results (presented in table 4-22 and 4-23) were obtained.

Table 4-22: Level of gases produced (students' hostel)

Parameter	**Influent**	**Pre-treatment**	**P_1**	**P_2**	**P_3**	**P_4**
Temperature (ºC)	29.6	29.5	30.9	31.3	30.0	28.9
pH	7.12	7.23	7.21	7.20	7.15	7.2
NH_3 (mg/l)	0.7	0.9	0.4	0.15	0.02	0.01
CH_4 (m^3/kg COD)	x	0.09	0.03	BDL*	BDL	BDL*
CO_2 (%)	x	10	15	BDL	BDL	BDL

* BDL: below detection limit

Table 4-23: Level of gases produced (Doornbach)

Parameter	Influent	Pre-treatment	P_1	P_2	P_3	P_4
Temperature (ºC)	24.11	26.9	27.6	28.2	27.7	27.2
pH	7.39	7.8	8.0	7.4	7.2	7.1
NH_3 (mg/l)	11..2	12.1	6.1	2.0	0.9	0.4
CH_4 (m³/kg COD)	x	0.2	0.09	BDL*	BDL	BDL*
CO_2 (%)	x	15	20	BDL	BDL	BDL

* BDL: Below Detection Limit

4.2.3 Behaviour of unit processes

4.2.3.1 The pre-treatment process

Upon feeding the plant, it was observed turbulence which resulted in the flotation of FOG on the surface of greywater in the process and a foul odour (similar to rotten eggs) was emitted from the treatment process. After a short retention time, it accumulated FOG formed a scum layer that was removed periodically based on quantity trapped and when the geo-textile media was clogged.

4.2.3.2 Settling process

The organic matter retained at the bottom of the process undergoes anaerobic decomposition and it was observed a conversion of CO_2 and CH_4 gas (at low detection limit) as well as an odour emission. There was also observed a sludge accumulation in the process and reduction of the process volume which required to be removed.

4.2.3.3 Filtration processes

The main treatment process of the AnUBR was the filtration processes (which works as an attached growth process). It was observed a large amount of dissolved organic matter (that was not removed in first treatment processes) and non-settleable suspended organic matters. Once entering the process, these organic matters and micro-organisms were attached to the filter medium through the up-flow velocity that allows greywater to flow from one process to another; thus clogging filters and reducing the filtration rate.

4.2.3.4 Clear water storage tank

In this process, clean greywater (containing low pollutants contents) was stored. Certain levels of turbidity and odour were observed. In general effluent greywater was clear with lower suspended solids and O&G.

4.2.4 Operational requirements

The literature reviewed highlighted a number of problems related to the anaerobic treatment. During the investigation problems encountered while operating the AnUBR were related to the odour emission, cleaning or replacement of filters, sludge handling and variability in the removal efficiency.

4.2.4.1 Odour

As indicated previously, the odour emission was observed after 48h of treatment; the odour was emitted from the pre-treatment and settling process where solids (TSS and O&G) undergo anaerobic decomposition. In the primary and secondary filtration and the storage tank a reduction of odour was observed.

4.2.4.2 Cleaning and replacement of filter

The filter was cleaned after completing the treatment process as per monitoring schedule. The filter was cleaned by flushing high pressure water with a hosepipe. The strainer was cleaned in the same way at the end of each day or when the inlet pipe was clogged (which resulted in reducing the filtration rate). Filters were replaced every 5 days when the flow rate was lower than designed and when the concentration of TSS and O&G was found higher after the primary and secondary filtration. The filter was replaced by opening the process cover, then removing the filter by opening the down pipe and filter support.

4.2.4.3 Sludge handling

The sludge and scum produced was consistent after a certain period (of about a week). The sludge tended to reduce the volume of the process and needed to be removed in order to provide an optimal treatment. Problems occurred with the handling of removed sludge which has an undesirable smell added to a large volume of decomposed foodstuff. The scum layer formed on the top of the first process was skimmed prior to allowing greywater to flow into the settling process. The skimmed scum was collected and dumped into an inspection chamber alongside with removed sludge from different processes.

4.2.4.4 Variability in removal efficiency

The removal efficiency at individual unit processes was variable for some parameters. At the pre-treatment process it was found that the COD removal was about 29.31 and 12.77 % for the students' hostel and Doornbach. The settling process also recorded variable removal efficiency for both the students' hostel and Doornbach respectively: TP (21.7 and 13.31%), COD (36.85 and 68.73%), BOD_5 (33.08 and 79.43%).

The removal efficiency recorded at the primary filtration was 31.35 and 67.78% for TN; 77.52 and 50.69% for TP; 27.94 and 67.95% for COD and for TSS 43.25 and 54.91% for the students' hostel and Doornbach greywater respectively. The secondary filtration recorded only variable FC removal of about 36.36% for the students' hostel and 62.58% for Doornbach.

4.3 Conclusions

This section of the study presents the results of experimental works conducted to determine the quality of different greywater from residential locations selected to evaluate the AnUBR.

Results recorded showed that the quality of greywater varies according to the source from which it is generated. It was found that greywater from case study un-sewered settlements presented similar characteristics. In sewered areas it was observed that greywater was characterised by almost the same level of pollutants regardless of factors indicated previously as affecting its quality.

Results indicate that greywater from sewered areas has low concentrations of pollutants (compared to un-sewered settlements). The temperature was found to be higher in sewered areas than un-sewered settlements. In general, greywater was found to be more highly polluted in un-sewered settlements than sewered areas. Following the treatment processes, results show high removal efficiency for all pollutants; a significant decrease of pollutant load was observed after completion of the treatment phases. In all case study sites, a high removal efficiency of TSS, nutrients and organic compounds were observed while low removal of micro-organisms was observed in un-sewered settlements.

Chapter 5: Analysis and discussion of results

5.1 Introduction

This section of the study analyses and discusses results presented in the previous chapter with reference to the literature reviewed. The summary of the literature review related greywater quality, design of the AnUBR, monitoring process and evaluation criteria are discussed. The experimental methods and analytical procedures are discussed and most importantly the analyses of influent greywater in tables 4-1, 4-2 and 4-10, the behaviour of each unit process and the quality of effluent produced by the AnUBR as well as the performance of the unit processes, the AnUBR are discussed. Lastly, the treatment capabilities of the AnUBR, evaluation criteria, operational problems and typical application are also discussed.

Since published data on greywater quality from developing countries are very limited, results were often compared with literature data from other studies and the final effluent quality compared to the quality standards set by DWAF.

The comparison of the greywater from sewered areas to that of un-sewered settlements (considered as the most polluted) aims to show the extent of greywater pollution strength and the potential hazard it may cause. However, it should be considered that results obtained and discussions are based on a monitoring campaign of 16h/d treatment cycle in the AnUBR.

Following the objectives assigned to this study, results obtained provided a basis for discussion on the following points:

- Literature which includes greywater quality, design of the AnUBR, monitoring process and duration of experiments and evaluation criteria.
- Greywater used for experiments
- Experimental methods applied which include materials and apparatus, collection of samples, feeding method, monitoring process, monitored parameters and analytical procedures.
- Experimental work results
- Performance of the AnUBR

5.2 Literature

The available literature was reviewed with the main goal to identify some researchable areas related to the current study and to establish the need for investigation as well as to establish the conceptual framework which forms the foundation of the study.

5.2.1 Greywater quality

Morel & Diener (2006), Carden et al., (2007), Lindstrom (2000) and many other authors defined greywater as wastewater generated from household activities except toilets. Opinions were divided upon this definition; it emerges from the discussion that this definition was not applicable in un-sewered settlements contexts. Therefore, greywater should be defined in the context of which it is generated or according to its source of generation.

Looking at the last definition, it can be said that the quality of greywater varies in composition and strength based on the source of generation. An emphasis was made on the difference in the quality of greywater from sewered settlements to that of un-sewered settlements in developing countries.

The quality of greywater changes over time and space and may be polluted or not depending on a given time of the day. It may vary according to the source of generation, water availability, sanitation system, lifestyle and culture amongst many other factors. The level of service provision (in terms of water and sanitation) impacts on the quality of greywater; settlements where water is provided in yards show a high water consumption resulting in high daily greywater production compared to areas served by communal standpipes a certain distance from the household.

5.2.2 Greywater used for experiments

The quality of greywater varies from settlement to settlement based on factors such as lifestyle, water use and hygienic habits amongst others. Since one of the study's objectives was to characterise influent greywater, it was evident that the quality of influent greywater used to feed the plant had to be known. This was done in order to evaluate the removal efficiency based on the quality of greywater prior to and after the treatment.

Due to the absence of data on the application of the AnUBR in un-sewered settlements, it was decided to use greywater from sewered areas in order to verify the feasibility of the technology and reliability of data obtained from the literature for control purposes. However the focus of the study was to use greywater from un-sewered settlements; therefore results obtained were compared in order to ensure the working condition of the plant. The overall results obtained were compared to values found in the literature in order to evaluate the performance and recommend the typical application of the AnUBR.

5.2.2.1 Greywater from sewered areas

Sewered areas referred in this study are individual households and students' hostels that are connected to the existing sewerage. In these areas, greywater flow freely from the source of generation straight into the sewer through piped system.

Greywater generated from such areas is affected only by the household activities such as dishwashing products, detergents used and cultural habits (Morel & Diener, 2006). Other factors such as rainfall or solids waste management do not significantly affect the quality of greywater. However, discharge of faecally contaminated rinse water into the bath or washing basin may affect the quality. Following this argument, it was assumed that greywater collected in these areas was less polluted and supposedly contained less micro-organism than that collected from un-sewered informal settlements.

5.2.2.2 Greywater from un-sewered settlements

Un-sewered settlements refer to informal or formal areas without on-site water borne sanitation and settlements with dysfunctional or inadequate sewerage systems. In these settlements greywater was collected directly from the standpipes runoff, wash and rinse water from washing posts and ponds throughout the settlement. Collected greywater (regardless of its source) was filled into 25l drum and transported to the treatment plant.

Following the literature review, greywater in un-sewered settlements is affected by many factors; amongst these are rainfall, solid waste management and water and sanitation type (Carden et al., 2007). Given that greywater was collected during the rainy season and the vandalism of water supply standpipes, it was assumed that the quality was altered by the rainwater and runoff from leaking pipes.

Due to poor solids waste management, flow of greywater from standpipes, washing posts was allowed to flow through piles of solids waste thus resulting in highly polluted greywater. It was therefore assumed that greywater collected for the purpose of this study was highly contaminated and responded to the typical greywater quality from un-sewered informal settlements found in the literature.

5.2.3 Design of the AnUBR

The design of the AnUBR was based on existing design features described in the literature; this was used as a guideline. Following the study objectives, the AnUBR was designed based on the quantity of greywater to be treated. The main design parameters were the HRT and the volume of greywater to be treated. From these parameters, the flow rate was determined. Other features such as filter type and size, piping system (as shown figure 5-1 below) and flow meter were designed as recommended in the literature.

In addition to this, the literature suggested the use of sand filter, geo-textiles fabric or any other available materials. The filter material used should have a thickness of 0.5 to 15mm per layer in order to achieve a consistent filtration rate (Von Sperling & Chernicharo, 2005). The pre-treatment process should consist of any available technology whose main function is to trap FOG and prevent it entering the settling process.

Figure 5-1: Top view of the settling and filtrations processes

In this study, the design of the AnUBR was based on these and availability of materials. The design values presented in table 3-1 were selected based of the design guidelines suggested in the literature. The choice of geo-textiles layer as filter medium was attributed to its successful application in the protection of groundwater from infiltration. It was further chosen because its susceptibility of retaining small particles and forming biofilm layer that retain dissolved and organic matters and micro-organisms as well as ease with which it can be cleaned compared to sand.

Other design features (such as HRT, flow rate and filtration rate) were computed in function of the capacity of the process and volume of greywater to be treated.

5.2.4 Monitoring process and duration of experiments

The treatment process was monitored for the duration of the experiments. This was done conforming to the plant design requirements. The experiments were carried out over the same period in order to ensure that the plant is able to perform the treatment process under a range of conditions such as seasonal fluctuations or unforeseen circumstances. Due to the extent of the evaluation of the process performance, a daily monitoring programme (consisting of assessing the plant each and every hour) was carried out.

The monitoring process and duration of experiments were done in accordance with the literature which recommends assessing the plant regularly in order to ensure that processes are performing accordingly and depending on the extent of evaluation desired (Benett, 2002).

5.2.5 Criteria for evaluating small treatment plant performance

The literature reviewed indicated that the evaluation of small treatment plant performance is based on their removal efficiency and ability to produce effluent that complies with the standards either for irrigation or discharge. Following this statement, the AnUBR under investigation was evaluated on this basis with an emphasis on selected quality parameters known for their polluting effects on the environment and impacts on human health.

5.3 Experimental methods

5.3.1 Materials and apparatus

The equipment in the laboratory required calibration in order to record accurate results and data. For instance, equipment used for the purpose of this study was calibrated using relevant calibration procedures applicable to each of them. Materials and apparatus used were those found in the laboratory; each parameter was analysed using specific equipment as per analytical procedures requirements described in the previous chapter.

5.3.2 Collection of samples

Greywater samples were collected in selected informal un-sewered settlements described in chapter 3. The collection was done in the earlier hours of the morning in order to ensure that the quality of greywater was not diluted. This was done given that the quality of greywater may change over time and space (Morel & Diener, 2006). In all case study sites, the average water consumption was estimated to 25l/c/d and 250l/c/d for un-sewered and sewered areas respectively. The related greywater volume was estimated to 15l/c/d and 180l/c/d.

In un-sewered settlements, greywater was mixed with night soil (especially in the earlier hours of the day), hand-carried and discarded into open spaces, streets and at the standpipes. Samples comprising of mixed greywater were collected at different locations (such as ponding, standpipes and streams) within the settlements. In sewered areas, greywater was collected directly from the kitchen sink, bathtub, dish washer and washing machine. Collected greywater was stored into 25l container and transported immediately to the treatment plant.

5.3.3 Feeding method

The treatment plant under study was constructed far from a permanent source generating greywater. It was decided to collect greywater from selected settlements in order to feed the plant. Given the fluctuation of flow during day and night time and due to the fact that the system was designed to work on batch flow, the intermittent feeding mode was selected to feed the plant and allow the system to complete the treatment process as per designed HRT.

The intermittent feeding system was selected based on the plant treatment principles which consist of feeding per batch until the completion of the process before refilling. The feeding system was further selected in order to cope with flow and loading variations which are function of water use. The advantage of the batch feeding of reactors was that the material to be treated could be positively maintained within the reactor until the process is complete.

5.3.4 Monitoring process

The monitoring process was used to track the progress of the processes. In order to achieve this, collected greywater was directly transported to the treatment plant. Influent greywater samples were collected prior feeding the AnUBR and analysed for temperature and pH.

The monitoring process adopted for these experiments was in line with that suggested in the literature. This was design to take control of the overall treatment process on hourly and daily basis looking at parameters that may affect the treatment potential of the pilot plant.

5.3.5 Monitored parameters

Since greywater is generated from household activities, its characteristics and composition depend strongly on household habits. Parameters selected for the purpose of this study were based on their effects on human health and environmental pollution. Following on a study by Tchobanoglous & Franklin (2003), these parameters have detrimental effects on both human and environment and should be removed prior to reusing or discharging.

Hence, parameters selected were namely: pH, TSS, COD, BOD_5, O&G, e-coli and faecal coliform. Besides this, the temperature was selected amongst other parameter given its impact of the chemical reactions and the overall treatment process.

The analysis of TSS was carried out as part of chemical testing as it provided an indication of the propensity of the teated greywater to cause physical blockage of soil pores or irrigation systems if reused. COD and BOD_5 were analysed as it provide an indication of organic pollution that is detrimental to aquatic lives.

TP and TN were analysed as it provide a measure of nutrients conte of treated greywater. These parameters are required for plant growth but can cause detrimental effects to both plants and water bodies if present in excessive quantities; and it provide an indication of the propensity for biological regrowth in the treated water.

The faecal coliform was selected because it is considered as indicator organism commonly used in water quality monitoring (DWAF, 1996). The e-coli was analysed because it is considered to be a better measure of human faecal contamination. Other parameters were selected because of their importance as water quality indicators and their impact on human health and environment as described in table 2-2.

Knowing that greywater contains substances which may undergo decomposition during the treatment process, it was expected substantial amount of gas (common to anaerobic processes) to be generated; hence an attempt was made to monitor the presence of common gases such as CH_4, CO_2 and NH_3.

5.3.6 Analytical procedures

Upon completion of the treatment process, samples were collected after completing each treatment process as per sampling schedule. Once samples were collected, they were immediately taken to the laboratory for further analysis and where time was not allowing for immediate analysis, samples were kept in the fridge. Greywater samples were analysed for parameters indicated above using standard methods applicable in South Africa. These methods are specific to each selected parameter. Details of analytical procedures are provided in appendix A.

5.4 Experimental work results

5.4.1 Preliminary experiments

5.4.1.1 Characteristics of influent greywater

a) Influent greywater from sewered areas

In view of results presented in the previous chapter, the quality of greywater from sewered areas is characterised by a number of pollutants which have different level of concentration. Results obtained are compared to the values obtained from available literature (as presented in table 5-1 below).

Table 5-1: Results of experimental works vs. literature (sewered areas)

Parameter	Case study site			Theoretical values*
	Household 1	Household 2	Student's hostel	
Temperature (ºC)	29.6	30.2	28.0	15 – 35
pH	6.2	7.1	7.2	5.0 – 8.7
TSS (mg/l)	107.6	245.6	145.6	69.0 – 1,500
TN (mg/l)	5.4	6.4	6.6	20 – 45
TP (mg/l)	13.2	16.85	16	0.6 – 68
COD (mg/l)	212	112	432	530 – 3520
BOD_5 (mg/l)	55	67	122	275 – 2287
O&G (mg/l)	82.2	112.6	42.7	7 – 230
e-coli (cfu/100ml)	4 $x10^3$	18 $x10^3$	$48x10^3$	$1.0x10^7$
FC (cfu/100ml)	11 $x10^3$	14 $x10^3$	$115x10^3$	$1.0x10^7$

* Average values obtained from available literature

- Temperature and pH

Following the literature review, greywater generated from sewered areas has a warm temperature which may be attributed to the use of warm bath and/or warm water to carry out many household works such as dishwashing, laundry and cooking; the usual temperature of such greywater varies between 15 – 35ºC.

Results obtained showed that temperatures (of 28.0 to 30.2ºC) are situated in a suitable range based on Tchobanoglous & Crites (1991). The variation of temperature observed may be attributed to the type of activity that takes place in the house at the time of collection of greywater. Despite the variation, the temperature recorded was within the same range for all sites.

The pH of greywater is an indication of the acidity or alkalinity of the water; the pH value above 7 indicates alkalinity and below this value indicates acidity. The pH of greywater is often is the range of 5.0 – 8.7 as reported by (Rose et al., 1991) in the literature and may attain the value of 8.0-9.3 (USEPA, 2004. Results obtained in this study showed the pH value fluctuating between

6.2 and 7.2 which is in accordance with the values presented in the literature. The pH of greywater was found to be slightly acidic at household 1 and basic at student hostel and household 2. The fluctuation of the pH level may be attributed to cultural habit and the use of various chemical and detergents for personal hygiene and household activity.

- Solids contents (TSS and O&G)

The concentration of solids in greywater is expected to be lower compared to combined wastewater (Jefferson et al., 1999). Results obtained confirmed the statement showing the concentration of solids averaging 107.6 to 245.6mg/l is aligned with those indicated in the literature. This may be attributed to the common practice of preventing food leftover, fats and oil and other solids entering the greywater disposal system. The variability of solid contents may be attributable to the type of infrastructures available, life style, behaviour of household and awareness of the pollution.

Oil and grease in greywater originate from kitchen sinks and dishwashers where cooking grease, vegetable oil and food grease are used. The concentration of O&G however depends on the cooking and disposal habits of the household (Morel & Diener, 2006). Values (of 79.17mg/l) obtained are by far higher than that reported in the literature. This demonstrates that residents and householders may be using oil and other products in their day-to-day life which resulted in a high amount of O&G residue being discharged into greywater. The high O&G value may be attributed to the non-use of O&G traps in the kitchen sink and poor disposal of these residues. It may be attributable to the availability of infrastructure within the household.

- Nutrients

The average concentrations of nutrients measured was 6.13 and 15.35mg/l for TN and TP respectively and was in the closest range from one site to another. Compared to the literature, these values fall within the range. The low nutrients concentration may be attributed to the absence of faeces and urine which are the main contributor of nutrient in wastewater and the lesser use of phosphate containing products.

- Organic compounds

The COD concentration was variable from site to site; the average value of 252mg/l recorded was lower than that reported in the literature. The BOD_5 value was variable from house to house; the average value of 81.33mg/l was within the range values reported in the literature.

The low value of COD and BOD_5 (in comparison to un-sewered settlements) may be attributable to the lesser use of detergents, soaps, oil and fats. It was further attributed to the high water consumption averaging 150 to 250l/c/d since shower, bath, and tap in the house are used for various activities within the household. Thus, confirming Dallas's (2004) findings which revealed that low water consumption may result in higher COD and BOD concentration. However, the COD/BOD_5 ratio was found to be 3.0 indicating a moderate biodegradability of greywater (Al Jayyousi, 2003; Jefferson et al., 2004).

- Micro-organisms

The microbial characteristics were found to be slightly variable from the study areas. The average values of 2.4×10^4 and 4.7×10^4cfu/100ml (for e-coli and faecal coliform) were far lower than those found in the literature. Low values obtained indicate that greywater contained low pathogens which may be attributed to the low or absence of urine and excreta (Ledin et al., 2001).

However, in spite of the absence of urine and excreta, the level of faecal coliform and e-coli remained high. This may be explained by the fact that washing of children's nappies, washing of children after defecation or use of water for anal cleansing during bathing may be practiced.

b) Influent greywater from un-sewered settlements

The results of greywater quality from un-sewered settlements are compared to those found in the literature as presented in table 5-2 below.

Table 5-2: Results of experimental works vs. literature (un-sewered areas)

Parameter	**Case study site**			**Theoretical values***
	Phola Park	**Wallacedene**	**Doornbach**	
Temperature (ºC)	21.7	22.4	22.1	15 – 30
pH	7.4	7.1	7.8	3.3 – 10.9
TSS (mg/l)	2,345	1,876	1,229	29 – 3,450
TN (mg/l)	12.1	11.2	20.2	0.6 – 488.0
TP (mg/l)	132.5	121.6	113.1	0.7 – 769
COD (mg/l)	1,235	1,123	987	32 – 11451
BOD_5 (mg/l)	467.8	461.3	72.1	-
O&G (mg/l)	478	435	686	8 – 4650
e-coli (cfu/100 ml)	68×10^6	51×10^6	TNT	10^7 – TNT
FC (cfu/100 ml)	84×10^6	77×10^6	TNT	10^7 – TNT

* Average values obtained from available literature

- Temperature and pH

The temperature of greywater from un-sewered settlement falls within the theoretical ranges. Due to the lack of individual ablution facilities, communities use water (at normal temperature) for body washing; while warm water is used only during cooking. Due to fact that greywater generated from clothes washing may be used more than once prior to discharging (in most of the case study settlements), the temperature of greywater was expected to be low.

The low temperature recorded may be attributed to the lack of appropriate household appliances such as geyser, shower, washing machine or dishwasher. In most cases, a kettle is used to boil water for body or dish washing and temperature of such water may decrease significantly over time prior to discharging. The temperature recorded in all 3 case study sites remains closer perhaps due to the similarity of living style in these settlements.

The pH of greywater obtained in all case study settlements was within the range of typical values of 5.0 to 8.7 (Rose et al., 1991) and 8.0-9.3 (US EPA, 2004). The pH was fluctuating in some cases showing an increase and decrease. However, the final pH for all sites was alkaline; this may be attributed to the use of some detergents, soap and the presence of food particles containing O&G and fats in the influent greywater. The decomposition of these particles contributes to the raise in pH (Ledin et al., 2001).

- Solid contents (TSS and O&G)

The concentration of solids in greywater is expected to be lower than in wastewater (Jefferson et al., 1999). Results presented in the previous chapter show much higher solids in greywater with concentration averaging 1,816.67mg/l. In the reviewed literature, the concentration of solid contents in greywater range from 29 to 3,450mg/l.

The high solids content found in greywater from un-sewered settlements may be attributed to the lower flow and the practice of disposing food leftover, solid waste, unnecessary items into streams and washing-up wastewater as well as the presence of FOG in the effluents. The high concentration of solids may also result from the combination of colloids and surfactants (from detergents) that lead to stabilisation of solids due to sorption of the surfactant on the colloids surface, and as such reduce the settling of solids (Eriksson et al., 2002).

O&G present in greywater originating from kitchen sinks as discussed previously. In un-sewered settlement context communities do not have kitchens. Greywater generated from dishwashing and other household activities contains much higher O&G (from cooking oil, meat etc.); since there is absence of a sink in which a fat and oil trap may be placed. Hence, greywater from such a settlement may contain high levels of O&G.

The O&G concentration may be attributable to the habit of discarding kitchen, dish wash water and fatty from food leftover and the lack of household appliances such as kitchen sink.

- Organic compounds

COD and BOD are parameters used to measure the organic pollution in water. The COD and BOD_5 level was in the range reported in the literature. The COD and BOD_5 concentration of the influent greywater is probably attributed to the low water consumption (estimated to 25l/c/d in un-sewered areas) and the habit of discarding remaining food stuff.

The high concentration recorded may be attributed to the little amount of water used by households on a daily basis and products such as detergents, soaps, oils and fats. Low water consumption results in higher COD and BOD concentration (Dallas, et al., 2004).

The biodegradability of greywater has been evaluated from the COD/BOD_5 ratio. This ratio was found to be 3.34 indicating a moderately biodegradable greywater (Al Jayyousi, 2003; Jefferson et al., 2004) and may be attributed to the type of synthetic surfactants used in detergents and on the amount of O&G (588 mg/l) and fats present in greywater.

- Nutrients

The concentration of nutrients (TN and TP) of greywater was within the range of values reported in the literature. Since urine and faeces were not visible in greywater samples collected; it was assumed that greywater collected may be mixed with rainwater, water from leaking pipes and to some extent with night soil (containing urine mixed to faeces). The dilution factor may affect to some extent the quality of greywater (Murphy, 2006).

- Micro-organisms contents

Greywater contains less micro-organism in comparison to wastewater provided that urine and faeces are not mixed. Since greywater is wastewater generated from household activities except toilet, the faecal contamination is assumed to be minimal (Ottoson & Stenstrom, 2003). However, results obtained shows that greywater from un-sewered settlements contains high concentration of micro-organism averaging in some case 10^8cfu/100ml.

In areas where dry sanitation is used, the level of micro-organism was found to be high compared to settlements where pour flush toilets were provided. This may be attributed to the malfunctioning of dry sanitation systems resulting in unsafe discharge of night soil combined with greywater. The high concentration of micro-organism recorded may be attributed to the use of night soil as indicated previously, the discharge of animal faeces and solid waste into a greywater stream or pond. The values obtained were close to those reported in the literature, thus confirming that greywater generated from un-sewered settlements has the same characteristics as wastewater (Carden et al., 2007).

5.4.1.2 Analysis of greywater qualities

The average volume of greywater discharged by the residents of all case study sites un-sewered settlements is estimated at 15l/hh/d. This might be explained by the absence of household facilities such as kitchen sinks, washing machines and bathtubs. Households are generally served by one standpipe a certain distance apart from the house and the water is hand-carried to the place of use.

In view of the discussion presented in section 5.4.1.1 greywater from case study sites has concentration that falls within the range reported in the available literature. However, these values remain higher when compared to the standards in terms of general requirements for disposal, and such greywater should be considered polluted. Based on the analyses, it was found the following:

a) *Temperature and pH*

The temperature is a very important operation parameter in anaerobic treatment processes. As temperature increases, the rate of fermentation proceeds much faster and this results in more efficient operation and lower retention time requirements. The recorded temperature of greywater falls between the mesophillic range (25 to 35ºC) which is favourable for bacterial activities and chemical reactions (Tchobanoglous, 1991). This low temperature may not be susceptible to the treatment process and methane gas production. The rise of the temperature may be required to enhance the treatment process.

The pH is important in biological wastewater treatment because most micro-organisms grow best at pH values near neutrality (pH 7). The overall anaerobic processes occur at maximum rate in the pH range 6-8 below which the activity of the methane- forming bacteria drops rapidly so that at a pH of 5.5 they have by and large stopped their activity (Henze et al., 2002).

Typical pH of greywater was found in the range of 6.7 – 7.6 (Dixon et al., 1999); 5.0 – 7.0; (Rose et al., 1991) and 8.0- 9.3 (US EPA, 2004). Comparison with standard literature, the pH values obtained were close to that reported in the literature thus favourable for the anaerobic process to occur.

b) Solid contents (TSS and O&G)

Following Jefferson et al., (1999) study, the concentration of solids in greywater is expected to be lower than in combined wastewater. Results obtained confirmed this statement in sewered settlements case study areas. However, in un-sewered settlements results revealed much higher concentrations of solids in greywater with concentrations ranging from 1,229 to 2,345mg/l. In the reviewed literature, the concentration of solids in greywater (from the first world) range 69.0 to 1,420mg/l; and in un-sewered settlements this may range between 29.0 and 3,450mg/l.

The high solids concentration in un-sewered settlements may be attributed to the much lower flow, together with the common practice of disposing of food leftovers with kitchen and washing-up wastewaters and the presence of fat and oils in effluents. In sewered areas, the concentration of solids is lower and this may attributed to the good habits of separating solid from wastewater prior to discharge and the use of chemicals for cleaning plumbing devices (in order to prevent blockages that may occur from dumping of solids).

The O&G level was variable depending on its source. In sewered areas, the concentration was found to be in the range of those found in the literature. This may be attributed to the use of cooking oil, shampoo and other chemicals containing oil and grease. Most of O&G originates from dishwashing activities (in all cases study sites).

The low concentration of O&G (in sewered areas) may be attributed to the use of O&G traps in the kitchen sink and the use of dissolvent chemical to dilute fats prior to discharge into the sewer drain. In un-sewered settlements, the low concentration of O&G was attributed to the effect of sunlight that evaporates water leaving O&G exposed to the human traffic which assists solidification (filling the soil void).

c) Nutrients

Several studies demonstrated that urine and faeces contain higher level of nitrogen and phosphates. In sewered areas the separation of urine and faeces from domestic wastewater leads to the reduction of up to 90% of nitrogen and 80% of phosphates (Mara, 2003; Laber & Harbel, 1999); thus lowering the level of TN and TP. The concentration of TN and TP from all case study sites was within the range reported in the literature. However, in un-sewered settlements the concentration was significantly higher compared to sewered areas. This may be attributed to the disposal of night soil (containing human excreta) into greywater streams, pond or disposal points. Such greywater was expected to contain high level of TN and TP given that urine and faeces contain high level of these pollutants.

d) Organic compounds

The COD and BOD_5 are used as a measurement of primary pollution caused by the presence of organic matters. The more organic matter there is in greywater, the greater the amount of oxygen needed to decompose these pollutants is required (Lindstrom, 2000). In the absence of faeces, greywater is expected to contain lower levels of organic matter compared to ordinary wastewater (Eriksson et al., 2002; Ottosson, 2000).

Results obtained reveal the average COD and BOD_5 for greywater from sewered areas have been measured at 8.5 and 4.4mg/l respectively; resulting in a ratio of 1.93 indicating that greywater was easily biodegradable (Jefferson et al., 2000). In un-sewered settlements analysis revealed much higher levels of organic matter in greywater from un-sewered settlements.

The higher organic contents of greywater seems to be due to the low flow associated with the presence of large amounts of food particles as important sources of proteins, from kitchen wastewater and organic solids. The high level of organics may also result from the fact that greywater decomposes faster because of the nature of present organic matter more readily available to micro-organisms. The faster decomposition of organics in greywater may also be facilitated by the absence of urine which may lower the level of nitrogen compounds in the greywater and as such, the oxygen requirement for nitrification.

e) Micro-organism contents

Since night soil is mixed with greywater, the faecal contamination was expected to be high (as indicated in the results) compared to sewered settlements. In this study, greywater from un-sewered settlements was found to be significantly higher (too numerous to count). In un-sewered settlements, the high micro-organisms content may be attributed to the mixture of night soil with greywater caused by the lack of adequate sanitation system. In sewered areas, the presence of micro-organisms may be due to the washing of infant clothes contaminated by faeces, washing children and the use of water for anal cleansing; and at lesser extent kitchen greywater that may contain blood from washing of raw meat.

As results have shown, the greywater generated from un-sewered informal settlements was found to be physically, chemically and microbiologically polluted. It deserves more consideration and adequate treatment. The hand carrying of greywater for discharging in un-sewered settlements constitutes a direct exposure route to bacterial contamination since human contact with greywater is common on a daily basis. Greywater should be treated and disposed of in a way that avoids any risk of microbial contamination.

Results presented obtained confirm Murphy’s (2006) statement that said that the chemical quality of greywater is partly dependent on the chemical quality of water source. In view of these results, it was further confirmed that greywater quality depends very much on the quantity of water used for washing and food preparation, the source of generation, on the chemical used in the washing/bathing and whether or not it is re-used in the home prior to disposal (Alcock, 2002).

5.4.1.3 Characteristics of greywater effluent from unit processes

a) Pre-treatment and settling

These two processes are known as physical processes aimed at trapping suspended solids and coarse particles. From recorded results, it was found that these processes were capable of removing significantly O&G and TSS while other pollutants were removed to a lesser extent. As expected, the effluent produced has fewer solids than influent which may be attributed to the use of a strainer and the retention time in the settling reactor.

b) Primary and secondary filtration

These two processes were considered as main treatment; with reference to the literature reviewed, the effluent at this stage should have much fewer pollutants. In view of recorded results, the quality of effluent produced was characterised by a low concentration of pollutants which may be attributable to the action of filters.

c) Clear water storage tank

At this process, greywater from secondary filtration is stored for further treatment or for discharge. Results showed that no major change in the quality of greywater was observed. However, the literature suggests not storing such greywater for a longer period which may result in re-growth of pathogens indicator organisms.

The effluent quality was characterised by far lower concentration of pollutants than before; this may be attributed to the quality of treatment achieved in previous processes.

5.4.1.4 Characteristics of final effluent from AnUBR

Greywater from sewered and un-sewered areas was characterised by a level of pollutants indicated in table 4-1 and 4-2. The quality of this greywater was above the standard requirements for discharge into natural water resources, thus required treatment.

a) Greywater from sewered areas

Observation from the treatment process showed a significant decrease in the level of pollutants contained in greywater. The final effluent quality recorded shows the pH of the effluent averaged 7.3 which confirm the alkalinity of treated effluent. The temperature of the effluent averaged 25ºC which is not harmful to aquatic life. The solids concentration decreased significantly following the pre-treatment process, the settling time and the action of filters. It was also found that the level of organic compounds and nutrients were below the standards. The effluent produced by the AnUBR was thus meeting the standards requirements in terms of disposal.

b) Greywater from un-sewered settlements

The preliminary experiments carried out at the AnUBR using greywater from un-sewered settlements shows a high removal efficiency of pollutants contents of greywater. However, the concentration of micro-organisms was found to be above the standards requirements for disposal in the natural water resources or re-use since the value obtained were above 10^3 cfu/100ml. Given the quality of effluent produced, it was deemed necessary to undertake further experiments for accuracy.

5.4.1.5 Pollutant removal at individual unit process

Results presented in appendix B.2 indicates the removal efficiency recorded at each unit process. Effluent quality was used to determine the removal efficiency at each unit process upon completion of the treatment. In all case study sites (sewered and un-sewered). It was recorded variable removal of pollutants from one process to another. The pre-treatment process removed significant amount of solids as well as the settling process. Significant removal of nutrients, organic compounds and micro-organisms was observed at the filtration processes.

a) Pre-treatment and settling processes

A removal of solids varying from 7.4 to 51.34% for TSS and 42.11 to 91.1% for O&G was recorded at the pre-treatment process; while the settling process was able to remove up to 95% of TSS and O&G respectively. The high removal of solids in these processes may be attributed to the use of a strainer, the long retention time, the low flow rate and the low up-flow velocity which does not allow solid wash up to occur in the settling process specifically.

b) Filtration processes

Clearer greywater (in terms of solids contents) from the settling process was allowed to flow into the filtration process from bottom down following the designed flow rate. The flow was allowed to pass through the filter media which retain certain pollutants such as un-settleable solids (of diameter lesser that that of the filter pores) and micro-organisms.

Variable removal of nutrients, organic compounds and micro-organisms was achieved at this process; while the solids concentration was decreasing at similar level for all case study sites. According to the literature, the filtration processes remove up to 35-80% and 20-50% of nutrients, 50-80% of organic compounds and 50-95% of micro-organisms. The variability in the removal efficiency was found to be due to the short run of the process and other operational problems such as short-circuiting on the sides of the filtration processes and due to the fact that processes were not properly sealed. Results obtained are in line with values found in the available literature, thus proving the efficiency of the filter medium used.

c) Clear water storage tank

This process used to store effluent from other processes relies on the natural die off of micro-organisms caused by its exposure to sunlight. However, results obtained show a low removal of pollutants. This may be attributed to the shadow that covered the plant due to the fact that the last feed was filled in the evening and the final effluent was not affected by any sunlight.

5.4.1.6 Overall removal efficiency

Based on the overall results recorded, it was observed that the AnUBR was able to remove 95-99% of TSS and 97-98% of O&G contents of greywater. The removal of nutrients and organic compounds was found averaged 70-90% for TN, 84-95% for TP, 84-97% for COD and 44-94% for BOD_5 respectively. The micro-organisms removal averaged 95-99% in all case study sites. The high removal efficiency observed may be attributed to the design features of the AnUBR, the type of materials used and the strict monitoring of the processes and parameters. However, these results were based on 2 days monitoring process which did not take into account certain factors such as sludge accumulation and the decomposition of organic matters.

5.4.1.7 Sludge and gas production

The volume of sludge is a function of the quality of fed greywater. Referring to results obtained, it was found that greywater from sewered areas has less solid contents than that of un-sewered settlements. This was proven by the lower volume of sludge recorded at each process. The sludge volume was higher in P_1 and P_2 where solids, O&G and scum are removed; in other processes, it was observed low sludge volume which may attributed to the good performance of the pre-treatment and settling processes.

The concentration of ammonia was variable as shown in the results. The increase of NH_3 concentration observed confirmed Foxon et al., (2006) findings which states that the concentration of NH_3 increases over time. This increase may be attributed to the decomposition of organic matters found in greywater. The low detection of gases (CH_4 and CO_2) was observed as reported in the previous chapter.

The gas production increases with the increase in temperature; the standard level is attained with the temperature range of 35ºC and the optimum pH range of 6.4 to 7.25 (Foxon et al., 2006). The temperatures of greywater recorded in different processes were below the standard range as suggested by Foxon et al. (2006); the pH however was within the range. The short operating time of the AnUBR, inadequate sealing of processes and the short circuiting observed in the filtration processes may be the main cause of the low detection of gases.

5.4.1.8 Summary

The preliminary experiments were carried out to inform the operating problems and requirements of the AnUBR. Result recorded from all three case study sewered area sites un-sewered settlements shows that greywater has a level of contaminants within a certain range regardless of its sources and influential factors such life style, age distribution and culture amongst others. The values obtained are closer from one site to another and are within the range values reported in the literature. In un-sewered settlements case study sites, results obtained show the same trend (as in sewered sites).

The values found are closer from one settlement to another regardless of criteria (such as sanitation type, water availability and settlement density amongst others) used for their selection.

Results from the preliminary experiments show a high pollutants removal despite few operational problems encountered. The analyses conducted on greywater samples from both case study sewered and un-sewered sites show similarity in the quality of greywater regardless of the settlements profile.

Since greywater from both sewered and un-sewered settlements presents similarity (in terms of their respective quality), it was decided to select one case study site (per settlement type) representative of sewered and un-sewered settlement respectively. The selection criteria were based on greywater influent quality considering the site produced poor quality greywater. It was therefore decided to select the site that produced greywater of the worst quality (compared to others) as a case study site for continuous experiments.

Hence, the Doornbach informal settlement and the student's hostel (representing un-sewered settlements and sewered areas respectively) were selected as case study sites producing greywater of worst quality compared to others. It was decided to further the investigation by undertaking long run experiments using these 2 case studies sites.

In view of this analysis, it was decided to operate the AnUBR for a longer period, seal hermetically all processes, allow sludge accumulation and analyse accurately parameters according to the specific analytical procedures. Following these issues, it was deemed necessary to further the investigation by undertaking the major experimental works.

5.4.2 Continuous experiments

5.4.2.1 Characteristics of influent greywater from case study sites

Conversely to the preliminary experiments, greywater used for this phase of experiments was collected at 2 selected case study sites presented previously. The plant was operated for 10 days using greywater collected from each site separately. Collected greywater was analysed for parameters described previously and results obtained showed that the quality of greywater was variable from day-to-day. This variability of greywater may be attributed to the nature of activities taking place within the area, life style, chemicals used and availability of water and disposal infrastructures. Details of results are presented in appendix C.

a) Greywater from student's hostel

- *Temperature and pH*

The AnUBR was operated and fed with greywater collected at the students' hostel. Results show that the pH and temperature are fluctuating on daily basis with the values remaining in close range. This fluctuation may be due to the daily water use, type of soap and bath lotion used and the quality of water as well as the greywater collection method used. In general the pH and temperature recorded are consistent with the literature findings.

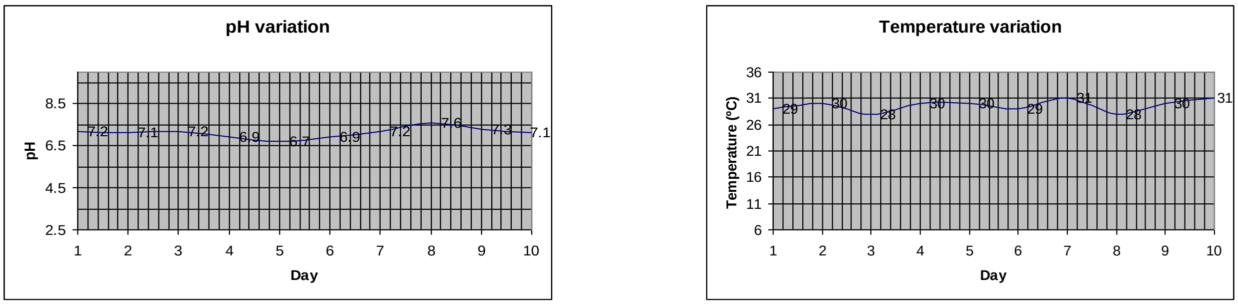


Figure 5-2: Daily variation of pH and temperature of influent greywater (Student's hostel)

- *TSS and O&G*

The concentration of solids was variable (as shown in figure 5-3). The high solids concentration was recorded on day 1 for TSS and day 9 for O&G. The concentration of solids is a factor of the household habits; where solids and O&G traps are used, the concentration is low. The fluctuation may be due to the infrequent use of traps, cooking and discharge of greywater containing foodstuffs.

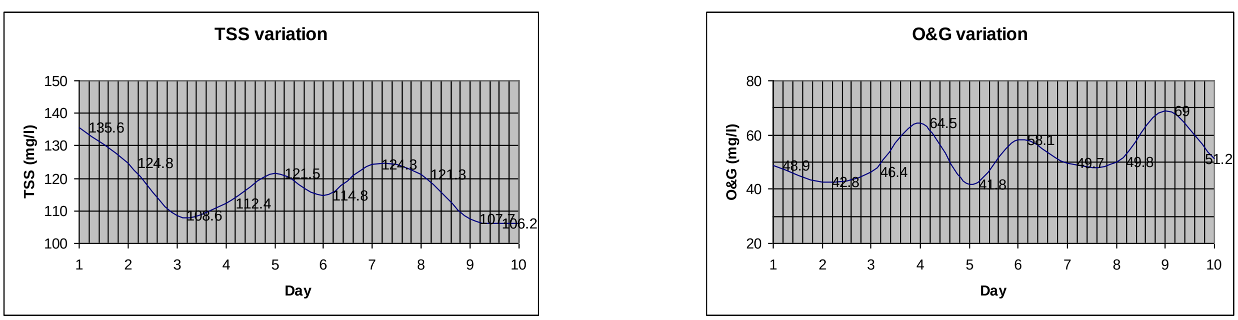


Figure 5-3: daily variation of solids concentrations (student's hostel)

- *TN and TP*

Nutrients (TN and TP) are important parameters given their fertilising value for plants, their relevance for natural treatment process and their potential negative impact on the aquatic environment (Del Porto & Steinfeld, 2000). Normally lower concentration of nutrients in greywater is expected due to the absence of urine and faeces.

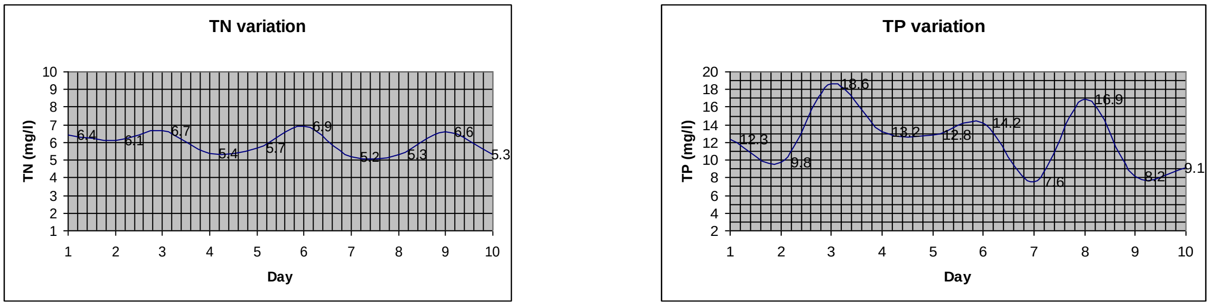


Figure 5-4: Daily variation of nutrients level (Student's hostel)

The greywater under study has a concentration of nutrients close to that found in the available literature (as shown in figure 5-4). The concentration of nutrients may be attributed to the use of ammonia containing cleansing household products; and the variability observed may be attributed to the residents' habits of using such cleansing products.

- *COD and BOD_5*

The COD and BOD_5 concentration are important parameters used to determine the performance of the wastewater treatment plant (Gaydon et al., 2006). The level of these pollutants (shown in figure 5-5) was found varying between 200 to 250mg/l for COD and 68 to 115mg/l for BOD_5. This fluctuation in the pollutant concentration may be attributed to the variability of life style and community behaviour amongst other such as cultural habits and use of chemicals.

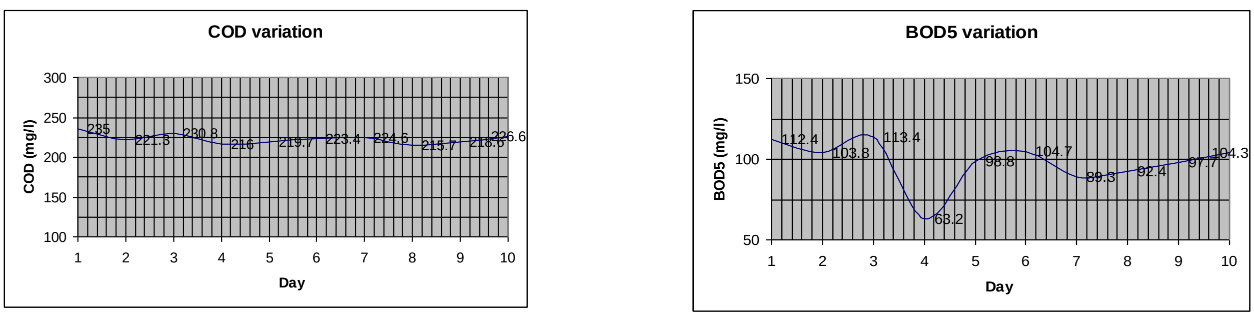


Figure 5-5: Daily variation of organic compounds (Student's hostel)

- *Micro-organisms*

The concentration of micro-organisms in greywater is supposedly low provided that faeces are not mixed in. However, results obtained (figure 5-6) confirm that greywater contains a concentration of these organisms which may be attributed to the use of water for anal cleansing during bathing or washing of raw meat in the kitchen sink since children are not living at the students' hostel.

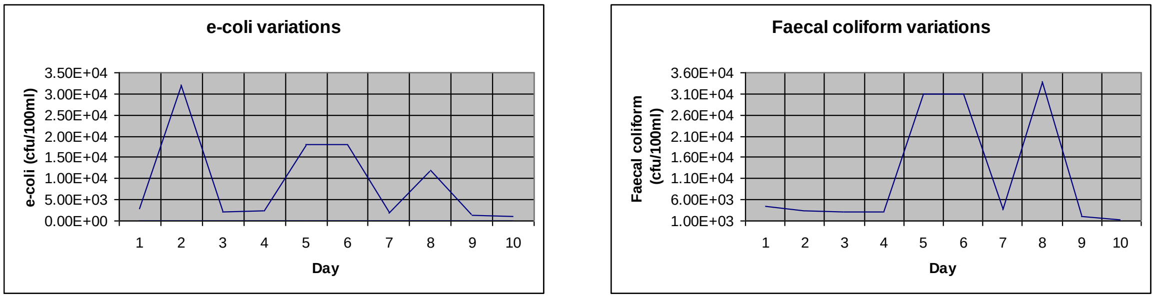


Figure 5-6: Daily variations of e-coli and Faecal coliform (Student's hostel)

b) Greywater from the Doornbach informal settlement

- *Temperature and pH*

The temperature of greywater was found to be varying between 23 and 28°C. Compared to the students' hostel influent greywater, the temperature was lower. This may be attributed to the habit of using tap water for bathing, house sweeping and laundry since warm water is used only for washing and cooking. Due to the lack of household infrastructures such as kitchen sink and bath warm water used for bathing flows from the point of generation to the lowest point in the area while that from cooking is discarded onto open spaces or behind shacks thus resulting in decrease in temperature. However, due to the exposure of greywater flow to the sunlight the temperature tended to rise above the ambient temperature.

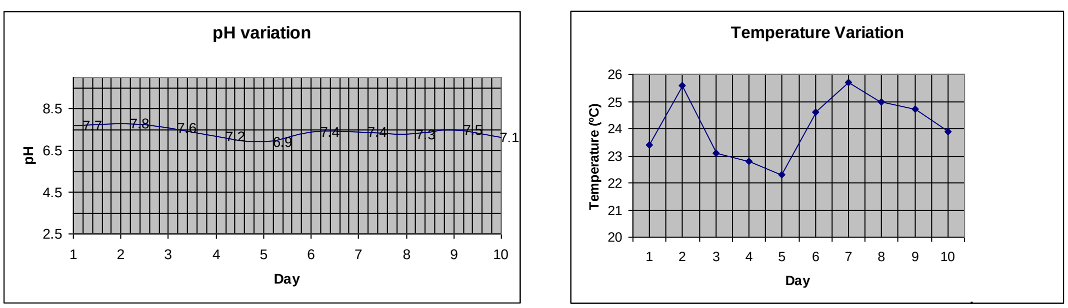
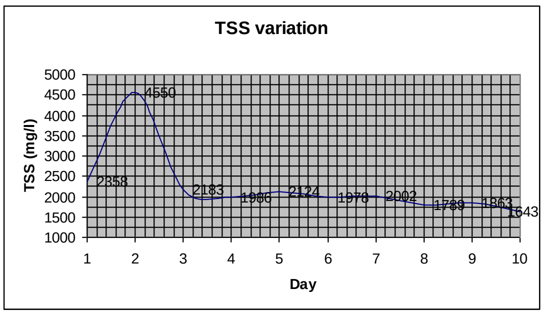


Figure 5-7: Daily variations of pH and temperature (Doornbach)

The pH of greywater recorded indicated that greywater generated was slightly alkaline. The pH value generally depends on the pH value of water supply and typical value of greywater pH is 8.0 to 9.3 (USEPA, 2004). The obtained value was in the range of values found in the literature and the alkalinity trends recorded may be attributed to the pH of water supply which is generally varies between 9.0 and 9.3 in South Africa and the large amount of food particles and oil found in greywater.

- *TSS and O&G*

The concentration of solids recorded was fluctuating daily (as shown in figure 5-8); the highest concentration was recorded on day 2 and the lowest on day 10. The high solid content recorded may be attributed to the habit of discarding food leftovers, solid waste and other waste in the greywater flow. It may be attributed as well to the lack of disposal infrastructure, separation of solids at source, the lower flow due to the lack of a permanent water source and the rainfall. The values obtained were in the range of those found in the literature.



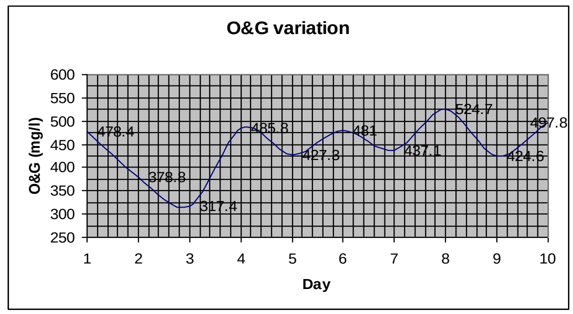


Figure 5-8: Daily variations of TSS and O&G (Doornbach)

O&G in greywater emanates from bath, kitchen sink and laundry. Since informal settlements are not provided with such infrastructures, these pollutants are present in greywater through discharge of kitchen greywater containing cooking oil, food leftovers; greywater from car wash, body washing and laundry. The high level of O&G recorded may be attributed to the habit of discharging kitchen greywater directly without separation and lack of appropriate disposal infrastructures.

- *Nutrients (TN and TP)*

The daily concentration of nitrogen was slightly fluctuating as shown in the figure 5-9 below. Values obtained are higher that found in the literature; this may be attributed to the unsafe disposal of night soil containing urine and faeces, animal excreta and intestines from animal slaughtering areas. The higher TN values may be attributed to the lower flow of effluents greywater (due to the lack of close source of water) and the long storage of greywater that allows conditions for the complete oxidation of the organic nitrogen in water.

The concentration of TP was found higher than that of TN and values were higher that those found in the literature. The presence of urine and the use of phosphate containing detergents and the lack of permanent water source close to users may be the main cause of the high concentration of phosphorus in greywater samples analysed.

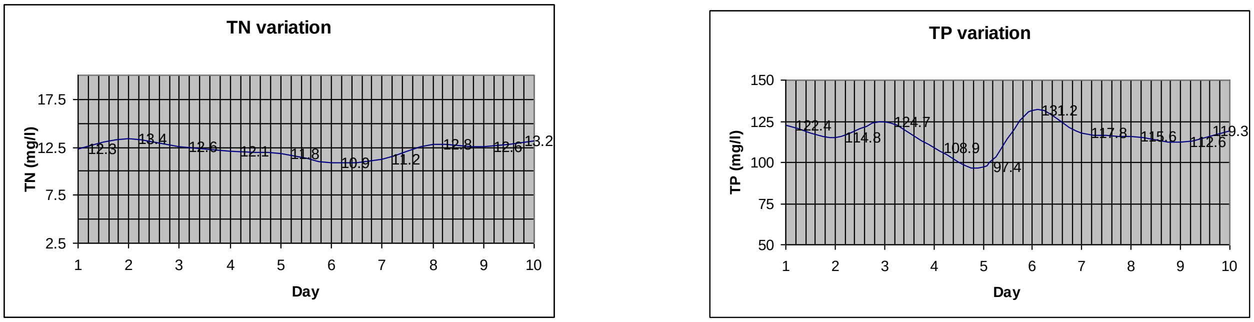


Figure 5-9: Daily variations of TN and TP (Doornbach)

- *Organic compounds (COD and BOD_5)*

The concentration of COD and BOD_5 (shown in figure 5-10) was found to be higher than suggested in the literature. This may be attributed to the low nutrients contents of greywater, the amount of water used, the use of detergents containing surfactants, soaps and the high amount of O&G contents. Where water consumption is low, the COD/BOD concentration is high (Morel & Diener, 2006).

The biodegradability of greywater is determined by its COD/BOD ratio and the nutrient availability which in turn is evaluated from the ratio of the BOD understood as the total amount of organic matter to be removed from wastewater by biological processes, by the amount of inorganic nitrogen (NH_4 and NO_3) and orthophosphates (PO_4) readily available in samples. The high concentration of organic matter in greywater contrasts with a deficiency of nutrients (nitrogen and phosphorus).

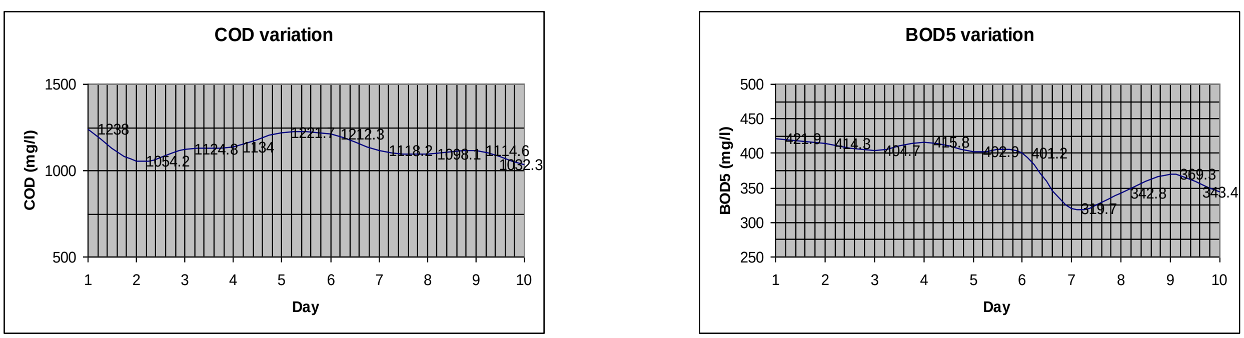


Figure 5-10: Daily variations of COD and BOD_5 (Doornbach)

- *Micro-organisms*

Pathogens indicator organisms were found in variable concentration (as shown in figure 5-11). The highest concentration was recorded on day 1 and 3 while the lowest was recorded on day 5 and 10. Following the literature, the concentration of these indicators is expected to be low provided that faeces as a source of pathogens are not part of greywater.

Results obtained indicate the contrary and show that greywater was highly polluted. The high concentration of micro-organism may be attributed to the lack of adequate sanitation service and disposal infrastructures for greywater. The discharge of night soil, soil waste containing food particles, blood and stomach waste from animal slaughtering areas amongst many others may be the main reasons for the high concentration of micro-organisms found in greywater.

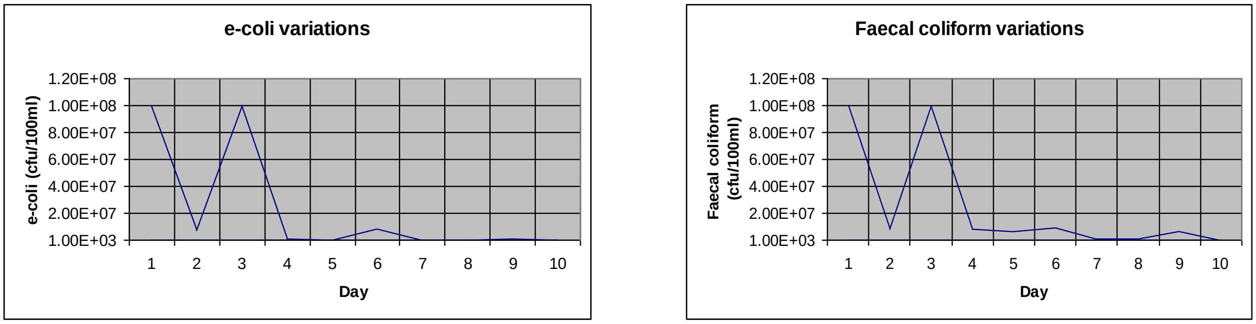


Figure 5-11: Daily variations of e-coli and Faecal coliform (Doornbach)

5.4.2.2 Characteristics of greywater effluent from individual unit processes

a) Pre-treatment, settling and primary filtration

The effluent from these processes was characterised by a low solid and nutrients content. In view of results presented in table 4-11, the quality of effluent recorded has fewer solids after pre-treatment and settling and fewer nutrients and organic compounds after the primary filtration.

The decrease of solids content may be attributed to the pre-treatment process; the decrease of organic contents concentration may be attributed to the decomposition of organic matters at the settling process and the micro-organisms and nutrients decrease may be attributed to the filtration process. In general, the quality of effluent was characterised by a low pollutants content attributed to the high pollutant removal observed at these processes.

b) Secondary filtration and clear water storage tank

Considered as final process, the secondary filtration aims at removing the remainder of pollutants from the previous processes while the storage tank was used to store effluent for further treatment or for discharge. Results presented in table 4-12 showed the effluent produced at the filtration process has a low concentration of pollutants (below the regulatory limit for discharge) except for micro-organism (in the Doornbach case study site).

At the storage tank, slight decrease in the concentration of pollutants was observed which may be attributed to the exposure of the process to ambient temperature and aeration.

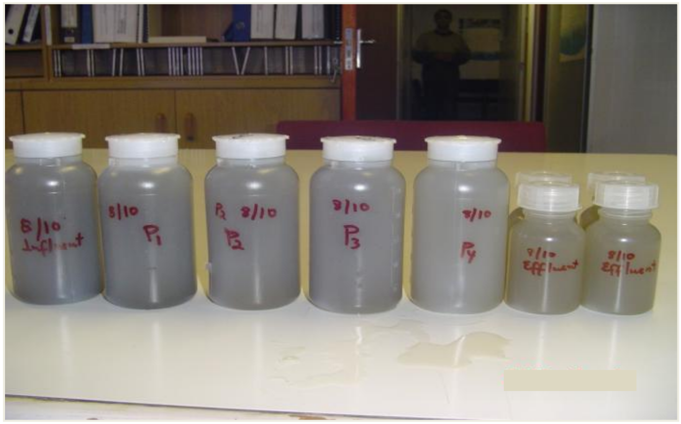


Figure 5-12: Quality of greywater effluent from processes

The effluent from these processes was characterised by low pollutants concentrations (as shown in figure 5-12) and the quality of greywater was found to be acceptable based on standard requirements for discharge. This may be attributed to the quality treatment procedures used.

5.4.2.3 Characteristics of final effluent greywater from the AnUBR

<u>a) Students' hostel</u>

The influent greywater from the students' hostel (presented in table 4-10) was characterised by variable concentration of pollutants as indicated previously. Throughout the treatment process, it was observed that the treated effluent from the students' hostel greywater has low concentration of pollutants (as presented in table 4-13), and is thus suitable for discharge into natural water resources or into the environment. The decrease of pollutants loads in the effluent may be attributed to the design of the AnUBR. The effluent qualities recorded were similar to those found in the literature, thus confirming the potential of the AnUBR as a reliable greywater treatment technology amongst many others.

<u>b) Doornbach informal settlement</u>

The characteristics of influent greywater (presented in table 4-10) from Doornbach was found to be highly polluted due to the high level of pollutant contents. Observation from the treatment process showed a significant decrease in the concentration of pollutant compared to the influent. At each stage of the treatment process an improvement of the quality of greywater was recorded (as can be seen in table 4-14).

Since the treatment process is anaerobic, the temperature was expected to rise during the treatment period and the pH was fluctuating between the pre-treatment and the second filtration process. The final temperature was 27.2ºC and pH was 7.1 indicating the alkalinity of greywater.

The concentration of nutrients decreased significantly. It is known that the removal of nutrients and organic compounds is difficult to achieve without biological processes. However, it was found that the use of geo-textile layers in the AnUBR plant (which worked according to the anaerobic suspended growth process) played an important role in the removal of nutrients and organic compounds contents of greywater. The high removal recorded may be attributable to the ability of the filter medium to form a biofilm layer that retained organic and dissolved matters as well as micro-organisms amongst other pollutants.

The concentration of O&G in the effluent was expected to be lower since greywater was pre-treated prior to feeding the plant. The concentration of micro-organisms was reduced to an acceptable level compared to the influent. However the quality of greywater effluent from the Doornbach remains questionable in terms of compliance for disposal despite the high removal of pollutants recorded.

Figure 5-13: Quality of influent and effluent before and after treatment

In general, the quality of effluent greywater compared to influent) was found much clearer (as shown in figure 5-13 above) and have lesser concentration of pollutants; thus showing the ability of the AnUBR to produce effluent of acceptable quality standards.

5.4.2.4 Pollutant removal at individual unit process

The removal efficiency of each unit process is discussed below in comparison with the literature values. For ease of reading, the comparison is made in tabular form (below) and graphical form (in appendix C).

a) Pre-treatment and settling processes

The pre-treatment process achieved a removal of up to 80% of O&G, 30% and up to 40% of TSS and TP respectively (as presented in table 5-3 below). Referring to the literature, the pre-treatment process of the four stages AnUBR can remove up to 90% of O&G and 10-20% of TSS. Results obtained are above the concentration values found in the literature. The high removal efficiency of these pollutants may be attributed to the HRT and the type of pre-treatment process which retained coarse and settleable particles.

Table 5-3: Pre-treatment and settling removal efficiency values vs. literature

Parameter	Pre-treatment			Settling		
	Exp. Values[1]	Exp. Values[2]	Literature	Exp. Values[1]	Exp. Values[2]	Literature
TSS (mg/l)	13.25	10.02	≤ 20	81.37	96.03	80 – 95
TN (mg/l)	19.26	16.20	10 – 20	15.91	15.34	≤20
TP (mg/l)	16.22	11.45	10 – 20	21.70	13.31	10 – 20
COD (mg/l)	29.31	12.77	10 – 20	36.85	68.73	50 – 80
BOD_5 (mg/l)	12.33	9.51	10 – 20	33.08	79.43	50 – 80
O&G (mg/l)	82.28	91.01	70 – 90	58.64	60.09	50 – 70
e-coli (cfu/100 ml)	8.18	5.89	0 – 10	19.92	12.5	0 – 20
FC (cfu/100 ml)	8.06	9.96	0 – 10	11.68	9.68	0 – 20

[1] Student's hostel, [2] Doornbach informal settlements

b) Filtration processes

The removal efficiency at these processes was higher than suggested values found in the literature. TSS and O&G showed higher removal efficiency of 43 and 54%, 36 and 38% respectively while the literature suggested 10-30% (as indicated in table 5-4 below). This may be attributed to the pre-treatment and settling processes in which coarse particles were retained and only un-settleable particles were allowed to flow into the filtration process.

The high removal may also be attributed to the filter materials used which allowed only particles of lesser size than the opening (or pores) to pass through and the retention of dissolved and organic matters on the filter matrix reducing the concentration of pollutants content.

In the second filtration process, we observed a high removal efficiency of TSS (41 and 45%) and O&G (37 and 69%) which was by far higher than that suggested in the literature (10-20%). This may be attributed to the quality of filter materials used following a good pre-treatment, settling and primary filtration. It may be attributed as well to the filter size which was smaller than that used in the previous process.

Table 5-4: Filtration processes removal efficiency values vs. literature

Parameter	Filtration 1			Filtration 2		
	Exp. Values[1]	Exp. Values[2]	Literature	Exp. Values[1]	Exp. Values[2]	Literature
TSS (mg/l)	43.25	54.91	10 – 30	41.76	45.47	10 – 20
TN (mg/l)	31.35	67.78	35 – 80	52.76	50.54	20 – 50
TP (mg/l)	77.52	50.69	35 – 80	30.94	70.99	20 – 50
COD (mg/l)	27.49	67.95	50 – 80	50.61	46.74	50 – 80
BOD_5 (mg/l)	55.48	51.12	50 – 80	56.49	44.12	50 – 80
O&G (mg/l)	36.56	38.89	10 – 30	37.45	69.77	10 – 20
e-coli (cfu/100 ml)	86.47	99.60	50 – 95	61.02	64.23	50 – 95
FC (cfu/100 ml)	90.22	99.89	50 – 95	56.60	62.58	50 – 95

[1] Student's hostel, [2] Doornbach informal settlements

c) Clear water storage tank

Since influent greywater undergoes a series of treatment processes, the effluent of the last process (presented in table 5-5 below) was expected to be of a high quality. It was indeed found that the removal efficiency was higher than suggested values from the literature except for micro-organisms. This may be attributed to the fact that the retention time of 2h allows small particles to settle in the last process and nutrients and organic compounds to volatilise and decompose through the effect of sunlight.

Table 5-5: Clear water storage tank removal efficiency vs. literature

Parameter	**Clear water storage tank**		
	Exp. Values[1] (%)	Exp. Values[2] (%)	Literature (%)
TSS (mg/l)	18.60	35.06	0 – 10
TN (mg/l)	24.17	21.59	0 – 10
TP (mg/l)	25.60	33.49	0 – 10
COD (mg/l)	30.88	23.51	0 – 10
BOD_5 (mg/l)	22.89	17.99	0 – 10
O&G (mg/l)	24.35	45.40	0 – 10
e-coli (cfu/100 ml)	38.27	15.16	20 – 50
FC (cfu/100 ml)	25.02	20.64	20 – 50

[1] Student's hostel, [2] Doornbach informal settlements

5.4.2.5 Overall removal efficiency

The AnUBR was developed for the removal of solids, nutrients, organic compounds and micro-organisms found in greywater. Following the literature, the AnUBR should achieve a removal efficiency indicated in table 2-11. However, depending on the characteristics of influent greywater and the treatment processes applied the removal efficiency may vary widely.

The overall removal efficiency of the AnUBR depends on the quality of greywater to be treated and the HRT as well as the pre-treatment process applied. The overall removal efficiency was obtained by comparing the concentration of influent to that of the final effluent.

Results recorded showed that the removal efficiency of the AnUBR averaged 90%. The highest removal rate recorded for O&G and TSS at the first and second processes while nutrients, organic compounds and micro-organisms were removed at a high rate in the first and second filtration processes.

a) Greywater from student' hostel

Following the experimental works results presented in the previous chapter, the AnUBR achieved high removal efficiency as indicated in table 4-20. The overall removal of 95.67, 83.92, 92.42, 88.95, 91.24, 97.80, 99.76 and 99.70% were recorded for TSS, TN, TP, COD, BOD_5, O&G, e-coli and FC respectively. These values are found to be higher than range values found in the literature.

The high removal efficiency recorded confirms values presented by Von Sperling & Chernicharo (2005) and Young (2001) which averaged 99% in some cases. These results are in agreement with Harrindra Corea (2001) who believed that the choice of good filter materials may impact on the quality of effluent, thus achieving high or low removal efficiency.

b) *Greywater from* Doornbach

The overall removal efficiency averaged 99.43 and 99.64% for solids (TSS and O&G); 91.13 and 93.60% for nutrients (TN and TP), 96.44 and 95.83 for organic compounds (COD and BOD_5) and lastly 99.99% for micro-organism (e-coli and FC). These values were higher those suggested in the literature and were aligned with those presented by Von Sperling & Chernicharo (2005) and Young (2001).

From results presented, it was observed that high removal efficiency was achieved on greywater samples from un-sewered settlements than that from sewered areas. However, the values are still within the range found in the literature which is evidence of the application of recommended analytical procedures.

Referring to the discussion above, it can be said that the physical treatments retain the active biomass and prevent the passage of solids into the filtration processes. This cause a decrease of COD/BOD_5 ratio which indicates that greywater was becoming more biodegradable (Jefferson et al., 2000). The high removal efficiency recorded in both case study sites may be attributed to the good quality of the pre-treatment methods and type of process used for treatment, filter media and design parameters such as HRT.

5.4.2.6 Sludge and gas production

Since greywater contains low solid contents, low sludge volume was expected. According to Franklin & Tchobanoglous (2003) anaerobic processes produce less sludge and require less nitrogen and phosphorus for biomass growth. In view of result obtained, the volume of sludge recorded is aligned with the literature thus confirming the anaerobic state of the treatment plant.

The gas produced was found below detection limit at certain processes and inexistent at others. The low volume of gas may be attributed to the low COD concentration and biomass production which in turn may be attributed to a short operating period during which the conversion of solids did not occur.

5.5 Performance of the AnUBR

The AnUBR as a secondary treatment depends highly on the pre-treatment process (Harridra Corea, 2001). Results presented in previous chapter indicate that greywater from un-sewered settlements had a high concentration of pollutants compared to that generated in sewered areas. After treatment, results showed that the AnUBR is capable of reducing the pollutants load up to 90%. The values obtained are close or similar to those reported in the literature; thus emphasising the performance of the AnUBR. A detailed evaluation of the performance of individual unit processes that constitute the AnUBR and the overall performance is discussed below.

5.5.1 Performance of unit processes

5.5.1.1 Pre-treatment

The pre-treatment process is important since it affects the overall treatment process. The aim of this process is to remove coarse solids, settleable suspended solids, O&G. and part of organic matters contained in greywater. The overall removal efficiency at this process was found to be variable depending on parameters. A high removal was O&G averaging 82 and 91% recorded in sewered and un-sewered settlements respectively was in the typical range of values suggested in the literature. The high removal efficiency of O&G may be attributed to the use of strainer to retain O&G and coarse solids contained in greywater (especially from un-sewered settlements).

Since the pre-treatment process is a physical treatment, it can only achieve a high removal rate of O&G (which form scum accumulated on the top of the process) and solids particles bigger than the pores size of the strainer. A low nutrient, organic compounds and micro-organism removal rate was observed. This may be due to the fact that the physical process can only remove solids matter contained in wastewater while other may be removed by chemical or through biological processes. Following the literature, the physical treatment can achieve low removal averaging 0 - 20% of nutrients, 10 – 20% of organic compounds and 0 – 10% of micro-organisms. Values obtained indicate the performance of the pre-treatment process used and the efficiency of the strainer in trapping particles.

5.5.1.2 Settling

The settling process is a physical treatment which aims to remove non settleable solids and some organic matters in greywater. Following the pre-treatment process, greywater flowing into the settling process has lesser concentration of O&G and high levels of non-settleable solids that were not removed at the first treatment process.

The literature studied suggests that the settling process should be able to remove 80-90% of TSS, ≤20 % TN and 10-20% of TP, 50 to 80% of COD and BOD_5, 50 to 70% of O&G and 10-20% of micro-organisms. Results obtained indicate that the settling process of the AnUBR under study achieved a pollutant removal similar to that found in existing literature (as shown in table 5-6 below). The settling showed high removal efficiency for TSS above the suggested values from the literature. This may be attributed to the quality of effluent from the previous process, the up-flow velocity and retention time that allowed effluent to rest and solids to settle.

Table 5-6: Pre-treatment process – Settling*

Parameter	***Student's Hostel***			***Doornbach informal settlement***			***Literature (%Removal)***
	Pre-treat.	*P_1*	*% removal*	*Pre-treat.*	*P_1*	*% removal*	
Temperature (ºC)	29.5	30.9	-	26.9	27.6	-	-
pH	7.23	7.21	-	7.8	8.0	-	-
TSS (mg/l)	102.13	19.03	*81.37*	2021.45	80.27	*96.03*	*≤20*
TN (mg/l)	4.57	3.70	*15.91*	10.3	8.72	*15.34*	*10-20*
TP (mg/l)	10.28	8.05	*21.70*	103.13	89.4	*13.31*	*10-20*
COD (mg/l)	157.77	99.63	*36.85*	990.35	309.69	*68.73*	*10-20*
BOD_5 (mg/l)	85.92	57.5	*33.08*	347.12	71.41	*79.43*	*10-20*
O&G (mg/l)	9.26	3.83	*58.64*	42.72	17.05	*60.09*	*70-90*
e-coli (cfu/100 ml)	$8.18x10^4$	$6.55x10^4$	*19.92*	$2.08x10^7$	$1.82x10^7$	*12.5*	*0-10*
FC (cfu/100 ml)	$1.37x10^5$	$1.21x10^5$	*11.68*	$2.17x10^7$	$1.96x10^7$	*9.68*	*0-10*

** Based on average greywater values*

5.5.1.3 Primary filtration

During this process, a slight increase was observed in the temperature which favours the anaerobic decomposition of organic compounds. For instance, the primary filtration whose aim is to trap non-settleable materials and micro-organism's food achieved significant removal efficiency. Referring to the literature, the primary filtration is able to remove 10 to 30% of TSS; 35 to 85% of TN and TP; 50 to 80% of COD and BOD_5; 10 to 20% of O&G and 50 to 95% of pathogens indicator organisms.

Results recorded (in table 5-7) shows that the process can achieve significant removal efficiency higher than that reported in the literature. The high removal of TSS may be attributed to the AOS of the geo-textile layers used which was by far smaller than the size of particles. It was also found that the TN and TP removal was by far higher than the suggested range in the literature. Generally, anaerobic processes achieve low nutrients removal varying from 10 to 30% (Morel & Diener, 2006). The high removal efficiency observed may be attributed to the performance of pre-treatment and settling processes.

Table 5-7: Settling – Primary filtration*

Parameter	***Student's Hostel***			***Doornbach informal settlement***			***Literature (%Removal)***
	P_1	*P_2*	*% removal*	*P_1*	*P_2*	*% removal*	
Temperature (ºC)	30.9	31.3	-	27.6	28.2	-	-
pH	7.21	7.20	-	8.0	7.4	-	-
TSS (mg/l)	19.03	10.8	*43.25*	80.27	36.2	*54.91*	*80-95*
TN (mg/l)	3.70	2.54	*31.35*	8.72	2.81	*67.78*	*≤20*
TP (mg/l)	8.05	1.81	*77.52*	89.4	38.71	*50.69*	*10-20*
COD (mg/l)	99.63	72.25	*27.49*	309.69	99.27	*67.95*	*50-80*
BOD_5 (mg/l)	57.5	25.6	*55.48*	71.41	34.91	*51.12*	*50-80*
O&G (mg/l)	3.83	2.43	*36.56*	17.05	10.42	*38.89*	*50-70*
e-coli (cfu/100 ml)	$6.55x10^3$	886.37	*86.47*	$1.82x10^7$	$3.69x10^3$	*99.60*	*10-20*
FC (cfu/100 ml)	$1.21x10^5$	988.2	*90.22*	$1.96x10^7$	$5.05x10^3$	*99.89*	*10-20*

** Based on average greywater values*

5.5.1.4 Secondary filtration

The secondary filtration was designed to remove the remainder of pollutant that was not removed at the previous processes. This process was fitted with a filter medium consisting of a single layer geo-textile fabric. It was observed a high removal of pollutants as indicated in the table 5-8 below. According to the literature, the second filtration is expected to remove 10 to 20% of TSS, 20 to 50 % of TN and TP, 50 -80% of COD and BOD_5, 10-20% of O&G and 50 - 95% micro-organisms.

Results obtained are in agreement with the range values found in the literature. This may be attributed to the type strength of previous treatment processes and use of geo-textile layers as filter media.

Table 5-8: Primary filtration – Secondary filtration*

Parameter	***Student's Hostel***			***Doornbach informal settlement***		
	P_2	*P_3*	*% removal*	*P_2*	*P_3*	*% removal*
Temperature (ºC)	31.3	30.0	-	28.2	27.7	-
pH	7.20	7.15	-	7.4	7.2	-
TSS (mg/l)	10.8	6.29	*41.76*	36.2	19.74	*45.47*
TN (mg/l)	2.54	1.20	*52.76*	2.81	1.39	*50.54*
TP (mg/l)	1.81	1.25	*30.94*	38.71	11.23	*70.99*
COD (mg/l)	72.25	35.69	*50.61*	99.27	52.88	*46.74*
BOD_5 (mg/l)	25.6	11.14	*56.49*	34.91	19.51	*44.12*
O&G (mg/l)	2.43	1.52	*37.45*	10.42	3.15	*69.77*
e-coli (cfu/100 ml)	886.37	345.5	*61.02*	3.69×10^3	1.32×10^3	*64.23*
FC (cfu/100 ml)	988.2	428.9	*56.60*	5.05×10^3	1.89×10^3	*62.58*

** Based on average greywater values*

5.5.1.5 Clear water storage tank

The storage tank was exposed to the sunlight with the intention of destroying the remainder micro-organism by UV light. The process showed little effect and the concentration of most pollutants for the parameters analysed showed a slight decrease (as shown in table 5-9 below).

In light of literature, the process achieved good removal efficiency; the storage tank (often exposed to sunlight) should be able to achieve a removal efficiency of 0-10% of solids contents, nutrients and organic compounds and 10-20% of micro-organisms. However, the use of chemical at this final process may significantly enhance the performance.

Table 5-9: Removal efficiency Secondary filtration – Storage tank (effluent*)

Parameter	***Student's Hostel***			***Doornbach informal settlement***		
	P_3	*P_4*	*% removal*	*P_3*	*P_4*	*% removal*
Temperature (ºC)	30.0	28.9	-	27.7	27.2	-
pH	7.15	7.2	-	7.2	7.1	-
TSS (mg/l)	6.29	5.12	*18.60*	19.74	12.82	*35.06*
TN (mg/l)	1.20	0.91	*24.17*	1.39	1.09	*21.59*
TP (mg/l)	1.25	0.93	*25.60*	11.23	7.47	*33.49*
COD (mg/l)	35.69	24.67	*30.88*	52.88	40.45	23.51
BOD_5 (mg/l)	11.14	8.59	*22.89*	19.51	16.0	*17.99*
O&G (mg/l)	1.52	1.15	*24.35*	3.15	1.72	*45.40*
e-coli (cfu/100 ml)	345.5	213.3	*38.27*	1.32×10^3	1.12×10^3	*15.16*
FC (cfu/100 ml)	428.9	321.6	*25.02*	1.89×10^3	1.5×10^3	*20.64*

Depending on the quality parameters analysed, the overall performance of the AnUBR was found in the average of 90 to 99%. As indicated in table 4-15, the AnUBR achieved a solid removal about 99%, 91% of TN, 93% of TP, 95 and 96% of COD and BOD respectively and 99.99% of micro-organisms.

These values were higher than the theoretical performance values found in the literature which suggested that the AnUBR should be able to remove 85-90% of solids (TSS and O&G); 50-80% of organic compounds (COD and BOD_5); 80-90% of micro-organisms (e-coli and FC); 10-50% of TN and 15-60% of TP. Comparing these values, it can be said that experiments conducted provided good results confirming the performance of the AnUBR as alternative technology for the treatment of greywater.

5.5.2 Behaviour of unit process

5.5.2.1 Pre-treatment and settling

The pre-treatment process is a physical process by which light components such as FOG and other constituents heavier than water are removed. The O&G trap was used for this purpose and showed a high O&G removal efficiency. In this process, solids were allowed to settle in the bottom while FOG form a scum layer on the top. The scum layer has to be removed periodically after completing the treatment process in order to prevent odour and bad smell that may occur.

The settling process is a physical process (similar to the O&G trap used in the pre-treatment process) that aims to remove coarse solids and other heavy constituents found in greywater. Substances denser than water were allowed to settle in the bottom of the tank, while fats, O&G float to form scum layer. The organic matters at the bottom of the tank undergo anaerobic decomposition and were converted into more stable compounds and gases.

After removing up to 70% of O&G and 30% of solids in the first process, greywater entering this process has a concentration of solids less that the influent greywater. Solids that didn't settle in the first process (due to short HRT) were allowed to settle. It was observed a high removal of solids (up to 90%) and formation of small thin scum layer in the top while a sludge layer of about 15mm was formed at the bottom of the process.

At this stage of the treatment, the biochemical reactions occur on the accumulated sludge due to anaerobic decomposition of organic matters. The process was able to remove up to 80% of COD and BOD_5 contained in greywater. Sludge accumulated in the bottom of the process undergoes anaerobic decomposition which reduces the amount of oxygen needed to oxidise organic matters found in greywater, thus lowering the concentration of COD and BOD_5.

These first two processes are considered as physical processes which can achieve their removal through liquid-solid separation from which solids settle and light material float under specific retention time. This process enhances the performance of the plant and improves the quality of effluent in terms of TSS and O&G. During these processes solids contents (TSS and O&G) were significantly removed through decantation and floatation processes during which solids were allowed to rest for a designed HRT while light particles, O&G were floating forming scum layers.

Other pollutants were removed upon contact with the atmosphere through evaporation or decomposition that occurred during the retention time. Their removal was lower since the HRT was too short to complete such organic decomposition. After these processes, organic matter present in greywater took form of dissolved and suspended organic that should not be easily removed

5.5.2.2 Primary and secondary filtration

The main treatment process is the anaerobic filtration that aims at removing non-settleable and dissolved solids, organic matters, nutrient loads and pathogenic organisms (Von Sperling & Chernicharo, 2005). This process comprises a reactor equipped with a dual filter and single filter which provide surface for bacteria to settle. During this process greywater flows through the filter (from bottom to top) and comes into contact with biomass on the filter and is subjected to anaerobic degradation.

Following this process, these pollutants are removed through close contact with anaerobic bacteria attached to the filter. Micro-organism concentration is reduced after the removal of microbial food thus leaving micro-organism under the state of starvation which speeds the natural die-off. During this process, it was observed (following results obtained) that the level of nutrients, organic compounds and micro-organism was reduced significantly.

5.5.2.3 Clear water storage tank

The final process as indicated previously is a clear water storage tank. In this process, greywater is allowed to stay for a period no longer than 24h due to the fact that the level of micro-organism could increase significantly if greywater is stored for a period exceeding 24h (Al-Jayyousi, 2003). However, greywater should be allowed to stay for a period that will create a natural die-off of the remainder of micro-organism by UV produced by sunlight.

5.5.3 Treatment capabilities of the AnUBR

The AnUBR is efficient in reducing pollutants load in greywater. Following several studies undertaken in sewered areas of developed countries, results show high removal of TSS, organic compounds and micro-organisms. However, nutrient removal was found to be varying between 15 to 70% depending on cases. These results were confirmed following the experimental works undertaken at the AnUBR using greywater generated from sewered areas. These results are summarised in the table 4-1.

In general, it was found that the AnUBR treatment capabilities are based on the different stages of the treatment cycle. The pre-treatment process is capable of reducing solids (TSS and O&G) significantly to a level averaging 90 to 99%. While the concentration of other parameters decrease at low rate.

The settling process in turn is able to reduce the concentration of solids at a level averaging 95 to 99%. Nutrients are also removed at this stage and during this process, the decomposition of organic matters results in significant reduction of COD and BOD_5 level.

The primary filtration (considered as the main treatment process) is capable of reducing significantly the nutrient, organic compounds and micro-organisms concentration. The secondary filtration treats greywater from previous process by removing the remainder of pollutants concentration and the last process acts a storage tank that may be used for further treatment if required.

Based on results presented and discussed above, it was found that the AnUBR achieved high removal efficiency of suspended solids, organic compounds and micro-organisms compared to values found in the literature (presented in table 2-12). It was found that the AnUBR is capable of treating greywater from both sewered and un-sewered settlements (considered as the most polluted) to an acceptable level.

5.5.4 Evaluation of the treatment capabilities and performance of the AnUBR

The purpose of evaluating the AnUBR is to assess its performance (as the treatment capabilities), establish a database of the technology (based on data collected) firstly and the outcomes at the end (based on the study's objectives). The type of wastewater and its characteristics are important in the evaluation and design of the anaerobic process (Franklin & Tchobanoglous, 2003). In order to evaluate the performance of the AnUBR the following factors were considered; these are namely the characteristics of influent greywater used, the pollutant removal efficiency, and O&M requirements (as indicated in section 3.10).

5.5.4.1 Characteristics of influent greywater

Results presented in table 4-15 show that the quality of influent greywater from both case study sites has a variable concentration of pollutants and was generally found polluted regardless of its source.

From the experimental work, it was found that the AnUBR has capabilities to treat greywater from sewered and un-sewered settlements without causing breaking down of the plant. Since the system was able to handle greywater from un-sewered settlements (considered the most polluted), it was assumed that it could accommodate any type of greywater. However, due to the high solid contents of greywater from un-sewered settlement, a pre-treatment process was required to prevent unforeseen filter clogging, to ensure the viability of the treatment process and prevent operational breakdown and to monitor the variability of influent greywater.

From this perspective, the quality of greywater to be fed into the plant and most importantly the pre-treatment process are pre-requisite factors to be investigated if the AnUBR has to be used in un-sewered settlements. The AnUBR is capable of treating only greywater containing lower solids contents or pre-treated greywater.

5.5.4.2 Pollutants removal efficiency

The removal efficiency is one of the main performance indicators used to evaluate the performance and reliability of a treatment process. Following the treatment of the two types of greywater a high removal efficiency of pollutants was observed regardless of the source of greywater. The results demonstrated that the AnUBR is an efficient treatment system for greywater treatment as the average removal efficiency recorded for TSS, COD, BOD_5, TN, TP, O&G, e-coli and FC averaging 95 - 99%, 90 – 97%, 44 – 80%, 70 – 90%, 80 – 90%, 90 – 98% and 99% respectively were achieved. The physical process achieved a removal of up to 90% of TSS and O&G while the biological process achieved a removal of up to 80% and 90% for organic compounds, nutrients and micro-organisms respectively.

The high removal rate achieved indicates the potential of applying the AnUBR in the treatment of greywater. Moreover, the results demonstrated that the high pollutants removal efficiency was obtained at HRT that is between the designed ranges (12-36h) and the average greywater temperature of 20ºC (knowing that the temperature of greywater ranges between 18 and 38ºC) (Eriksson et al., 2002).

About 16h were required to complete the full treatment cycle and achieve this removal efficiency. Consequently, installing of the AnUBR in an individual household, at a block of flats or in a un-sewered settlement is found to be a suitable option.

The values reported in table 5-10 (below) show a high pollutants removal rate except for micro-organisms which was below the recommended limit. In sewered areas, the removal of micro-organisms was satisfactory and meets the standard regulation. It can be said that the low removal recorded in un-sewered settlements may be attributed to the quality of greywater which was closer to that of black water. Hence, the AnUBR is capable of removing pollutants only in greywater that is not mixed with night soil.

Referring to this performance, it can be said that the AnUBR processes were capable of treating greywater at an acceptable level as per quality standard as per by the general authorisation for discharging into water resources applicable to South Africa.

5.5.4.3 O&M requirements

During the operating period, it was found that the AnUBR has low operational and maintenance requirements. The main O&M works were the filter cleaning and change, scum and sludge removal. These operations were carried out after a certain period of time and do not need skilled operators (but may need some plumbing knowledge) or sophisticated equipment. Therefore, the AnUBR has low O&M requirements compared to other localised greywater treatment technologies.

Following this analysis, it can be said that the AnUBR achieves a high pollutant removal efficiency which may be attributed to the process design and type of filter used. It can accommodate any type of greywater provided a pre-treatment process is used and only if influent greywater is not contaminated by night soil. The AnUBR has low O&M requirement and easy to operate and maintain.

5.5.5 ***Operational requirements***

5.5.5.1Odour

Following the literature reviewed odour emission was expected due to the fact that anaerobic decomposition of organic matter occurred in the settling process. The odour was emitted due to the fact that the process was not as tightly sealed as it should be. The odour emitted resembled rotten eggs which may be attributed to the presence of ammonia.

5.5.5.2 Cleaning and replacement of filter

The plant was cleaned 10 days upon the completion of the treatment process using greywater from the first case study site. This was done to prevent cross contamination that could impact on the quality of greywater from the second case study site.

The cleaning was done by opening the piping system and removing the filter. This process was found to be difficult due to the pilot scale of the process used for the research. However, this needs to be investigated further in order to find a suitable way of placing devices in such a way as to allow cleaning.

Clogging is a result of deposition of and/or growth of organic materials of geo-textiles; it occurs when the void and the particle size are similar (Young, 2001). The replacement of filter was done during the second phase of the experiment using greywater from the Doornbach informal settlement. After 5 days of operation the filter clogged and required a cleaning which was done using pressure water. Prior to that filters were replaced upon the completion of the first treatment phase.

5.5.5.3 Sludge handling

Since greywater produces a certain amount of sludge, it was decided following the completion of the treatment process to discharge the sludge produced into the closer inspection chamber. There was no sludge handling problem since the greywater produced low sludge volume.

5.5.5.4 Variance of removal efficiency

Generally several abnormalities were observed in the removal efficiency. Variable removal efficiency was noted for similar parameters (in both case study sites) as reported in the previous chapter. At the pre-treatment process this may be attributed to the quality of influent greywater which was highly polluted; at the settling process the variability in removal efficiency may be attributed to the operational problem and clogging of strainer.

At the first and second filtration processes the variability in removal efficiency recorded may be attributed to the short-circuiting observed along the sidewalls where the filter was not properly fitted; as result greywater inflow passing through the sidewalls was not adequately filtered thus resulting in poor quality. The low removal observed may be attributed as well to the quality of effluent from the previous process which impacted on the filter run. The problem was then fixed by putting in a new filter which resulted in high removal efficiency.

The variability of the removal efficiency may be attributed to the quality of influent greywater and the state of processes (strainer and filters media) at the end of the first experimental phase. It was noticed that when the filters are new, they work at their maximum efficiency, thereafter their filtration capabilities start decreasing. The variability in the removal efficiency may be attributed to the filter cleaning methods which may result in the decrease of quality.

5.6 Potential of applying AnUBR in greywater treatment

5.6.1 Comparison of effluents quality against standards

Given that overall removal efficiency of up to 90% was achieved, effluent produced by the AnUBR was of an acceptable quality (as shown in table 5.10 below). However, due to high micro-organisms contents of the effluent greywater, it seems that the filtration processes alone were not capable of achieving complete removal of pathogenic micro-organisms to required standards.

The incomplete removal of pathogenic micro-organism may be attributed to the short-circuiting on the sidewall of the plant which allowed un-treated greywater to flow in the next process. In a situation where the sand filter was used, the AnUBR was capable of completely removing the micro-organism (Harrindra Corea, 2001) despite the high level of pre-treatment required.

Table 5-10: AnUBR effluent quality vs. standards

Parameter	Effluent quality*		Standard limit	
	Student's hostel	**Doornbach**	**General**	**Special**
Temperature (ºC)	28.9	27.2	-	-
pH	7.2	7.1	5.5 – 9.5	5.5 – 7.5
TSS (mg/l)	5.12	12.82	< 25	< 10
TN (mg/l)	0.91	1.09	< 15	< 1.5
TP (mg/l)	0.93	7.47	< 10	< 1
COD (mg/l)	24.67	40.45	< 75	< 30
BOD_5 (mg/l)	8.59	16.0	Not specified	Not specified
O&G (mg/l)	1.15	1.72	2.5	0
e-coli (cfu/100 ml)	213.0	**1.12×10^3**	< 1000	0
FC (cfu/100 ml)	462.0	**1.5×10^3**	< 1000	0

* Average values

In view of the results above, the quality of effluent produced by the AnUBR complies with the effluent standard limit for discharge except for the micro-organisms. The pH of treated effluent was in the suitable range of both general and special limit. The TSS comply with the general limit and was above the special limit meaning that such greywater should not be used for irrigation for example. The level of TN was compliant and that of TP was found closer to the general limit and by far above the specific limit; further investigations are required to find out the real capability of the AnUBR on removing TP.

The level of COD in the effluent was compliant with the standard and that of BOD_5 was not specified in the current standard applicable in South Africa. The O&G level was compliant with the general limit but not with the specific while the pathogens indicator organisms' concentration was above both limits.

The quality of effluent produced by the AnUBR may be attributed to the treatment process used and the design features of the plant. Compared to the standard, the quality was found to be acceptable provided further treatment occurs.

5.6.2 Typical application of the AnUBR

The literature showed that the AnUBR was suitable for treatment of greywater generated from households in sewered areas of developed and developing countries. The high quality of effluent produced made the technology popular amongst many others. However, the technology was not yet tested in un-sewered informal settlements of developing countries.

Results presented in the tables 4-10 to 4-14 give an indication of the treatment capabilities of the AnUBR and provide an overview of effluent quality against standards. From a compliance point of view, results show that influent greywater generated in informal un-sewered settlements was characterised by a high level of pollutant (especially micro-organism) and was found polluted, thus constituting a health hazard.

The AnUBR was capable of achieving 90% removal of pollutants content of greywater. Despite this being the case, the level of e-coli and faecal coliform was above the regulatory limit. The AnUBR achieved high removal efficiency of pollutant content of greywater but failed to comply with the standards with regard to the pathogenic micro-organisms.

From regulatory control perspectives TSS and BOD are universally used as effluent standard by which the performance of wastewater treatment plants is judged (Franklin & Tchobanoglous, 2003). Given that 95 and 80% removal of these 2 pollutants was achieved, it can be assumed that the AnUBR holds promise in the treatment of greywater regardless of its source.

Based on the overall removal efficiency, it was found that the AnUBR is suitable for treatment of greywater produced in sewered areas as claimed by other authors. However, it can be applicable to un-sewered settlements context only if influent greywater is not mixed with night soil and /or solid waste and an adequate collection system is provided otherwise additional treatment process may be required to achieve the total removal of pathogenic organisms.

In view of the analysis, from compliance perspectives the AnUBR is suitable for reducing the pollutants contents of greywater to a certain extent but further treatment such as disinfection may be required to ensure the total killing of pathogenic organisms in order to comply with standards.

Chapter 6: Conclusions and Recommendations

6.1 Conclusions

This study continues previous work on the potential of localised greywater treatment technologies (by Harrindra Corea) which concluded that the current state of the environment (especially in developing countries) needs to be given special care. The study further concluded that the economic situation in these countries does not allow the use of first world technologies such as conventional wastewater treatment plant; therefore localised treatment technologies are seen as alternatives to solving the current problem caused by unsafe discharge of effluent.

The use of low cost on-site treatment systems was found suitable for low income areas in developing and offer the prospect of reducing pressure on centralised treatment system. Amongst these, the AnUBR was selected as an emerging technology due to the ease with which it can be implemented, absence of energy and chemical consumption, high pollutants removal efficiency and low operating cost amongst other advantages.

The performance and typical application of the AnUBR as alternative greywater treatment technology have been revealed through the literature review and the pilot plant investigation. Results obtained revealed that the AnUBR is capable of treating greywater to a quality that meet the standards requirements for discharge in natural water resources. Results of this study provide the first basis for testing the AnUBR in the context of South African un-sewered settlements which may serve for replicability. The conclusions drawn from this investigation include:

6.1.1 The quality of influent greywater from case study sites

Greywater quality is very much dependent on the source and would normally be returned to a water source such as river as part of a treated municipal wastewater returns flow, so that it can be used by downstream users.

The quality of greywater from both sewered and un-sewered areas was characterised by high pollutants content and was found to be polluted. However, the extent of pollution was site specific and the highest polluted influent was that from un-sewered settlements. The high pollution was attributable to the lack of disposal infrastructure and hygienic habits of communities. This greywater was not suitable for discharge without specific treatment.

In order to comply with the required quality standards for discharge, suitable treatment process and good monitoring process are required. Influent greywater to be treated in the AnUBR should be free of solid waste, night soil or any other matters than greywater.

It was therefore concluded that greywater from un-sewered settlements was treatable by the AnUBR with respect to physical, chemical and microbiological quality discussed in previous chapters. Prior to the main treatment process, a pre-treatment stage may be required in order to remove coarse particles.

6.1.2 The quality of effluent produced by the AnUBR pilot plant

The effluent greywater from the AnUBR was found to be below the standards limits for discharge. Effluent produced was characterised by a decrease in the concentration of pollutants from one process to another. The quality of effluent after the pre-treatment process was characterised by low O&M and TSS and after the settling process it was recorded low TSS, TN, TP, COD and BOD_5. After the primary and secondary filtration, effluent produced has low concentration of solids, nutrients and organic compounds; at these processes, the micro-organisms decreased significantly.

The physical and chemical quality of effluent produced was acceptable in general while the microbiological quality was slightly above the standards requirements for discharge in natural water resources and reuse.

6.1.3 The performance and treatment capabilities of the AnUBR

As a treatment technology, the AnUBR has shown its ability in treating greywater from both case study sites to certain extent. Greywater from sewered areas was treated satisfactorily; effluent produced was of acceptable quality standard as per general regulations for discharge into natural water resources.

In the case of un-sewered settlements, greywater was treated satisfactorily as well except for micro-organisms that were slightly above the regulatory limits. However, the performance of the AnUBR was satisfactory when influent greywater was not mixed with night soil. In the case of un-sewered settlements, the quality of greywater influent was found to be highly polluted and can be treated to a certain extent which may require a post treatment in order to improve the quality of effluent and to comply with regulations for discharge or irrigation.

Referring to results obtained it was finally concluded that:

- The AnUBR achieves a high removal of O&G, TSS and organics compounds of about 95, 99 and 80% respectively;
- The AnUBR shows a medium to high nutrients removal of about 30 to 80% for TN and TP;
- The treatment of greywater in AnUBR shows an overall removal efficiency of pollutants of 85%; however, the concentration of micro-organism observed in the final effluent was above the regulatory limits which indicated the need for a post treatment prior to discharging or reusing.
- The sludge volume was low and produce a low biomass as found in most of anaerobic processes;
- It was found difficult to obtain accurate measurement of gas production rates from the plant due to the low COD level and biomass concentration which mainly was affected by the short experimental period. However, the level of CH_4, NH_3 and CO_2 was very low.

6.1.4 Typical application of the AnUBR in un-sewered settlement context

It was concluded that the AnUBR is able to treat greywater to physical and chemical acceptable quality and to some extent reduce the concentration of micro-organisms. Based on results obtained and the good overall removal efficiency, it can be concluded that the AnUBR is suitable technology for treatment of greywater in sewered areas. In un-sewred settlements the AnUBR may be applied provided a post treatment for achieving the removal of remaining micro-organisms and ensure that the quality of effluent is not harmful to the environment.

Despite this issue, the AnUBR can be used as an alternative to classic septic tank or sewage treatment plant in high density areas where these technologies may be difficult to implement due to lack of spaces. The AnUBR as greywater treatment system can be applicable in un-sewered settlements only if adequate drainage and collection of influent greywater is provided and regular separation of solids from greywater is practiced.

6.2 Recommendations

The AnUBR is viewed as a promising technology for the treatment of greywater. Based on results obtained further investigation on the variance of treatment efficiency is recommended. The following recommendations were drawn up for using the AnUBR in un-sewered settlements and possible future investigations based on experience with the pilot plant and the critical literature review:

- To achieve a good performance, the AnUBR need an adequate pre-treatment process; the quality of greywater treated should be free of solids waste and night soil contents;
- The AnUBR should be operated for long period for anaerobic steady state and if gas production is expected;
- The monitoring process is required to ensure that processes are working optimally;
- The filter media should be cleaned whenever the flow rate decrease; filter should be replaced when the filtration rate decrease and the quality of effluent is not complying with the standards;
- The implementation of the AnUBR in un-sewered settlements context should take into account number of issues such as drainage and collection of influent, solids content of influent greywater and filter materials used.

➢ **Recommendations for future research**

It emerges from the study number of issues that need to investigate further:

- With regard to the operation of the AnUBR, odours emitted are objectionable and need to be reduced. There is a need to investigate odour reduction measures to be applied when operating an AnUBR.
- The final effluent from the AnUBR has a high turbidity which should be regarded as a problem in terms of discharge into the natural water resources. The way of reducing turbidity in greywater effluent from the AnuBR should be investigated.
- To prevent health risks and environmental pollution the microbiological quality of effluent greywater should be further investigated in order to recommend a post treatment option;
- The AnUBR as any other anaerobic treatment process was expected to produce gases; a long operation of the plant should be considered in order to investigate the anaerobic steady state of the plant and the potential gas production and sludge quality.
- The typical application of the AnUBR should take into account certain issues such as drainage and collection, solids separation and filters quality. These issues should be investigated in order to provide a good understanding of the plant operation.
- The variance of the treatment efficiency should be investigated in order to establish the causes and remedial actions.

References

Al Beiruti, S., 2007. Domestic greywater treatment system, the inter-islamic network on water, resources development and management journal, Jubieha-Amman, Jordan.

Al-Jayyousi, O., 2003. Greywater reuse: towards sustainable water management. Desalinisation, volume 156,181-192.

Alcock, P., 2002. The possible use of greywater at low-income households for agricultural and non-agricultural purposes: a South African overview. Pietermaritzburg, South Africa.

Anda, M.; Ho, G.; and Mathew, K. 1997. *Graywater Reuse: Some Options for Western Australia*. Perth and Bridgetown, Western Australia: Permaculture Association of Western Australia and authors. Retrieved 25 May 2008, from <http://www.rosneath.com.au/ipc6/ch08/anda/>.

APHA (American Public Health association), 1998. Standards methods for the examination of water and wastewater, 20th edition. American Water Works Association and Water Environmental Federation, Washington, DC.

Baruth, E., 2002. Water treatment plant design. Springfield water and sewers, Springfield, Massachussets. Mc - Graw Hill, 4th edition.

Bennett, R., 2002. *Monitoring Graywater Use: Three Case Studies in California*. Santa Barbara, CA: Oasis Design. Retrieved 29 May 2008, from <http://www.oasisdesign.net/faq/SBebmudGWstudy.htm>.

Berktay, A., 2008. Biogas production and utilisation potential of wastewater treatment sludge. Energy sources part A: Recovery utilisation and environmental effects. Istanbul, Turkey.

Bino, M.J., 2003. *Graywater Treatment and Reuse, Tufileh, Jordan*. Ottawa: International Development Research Center. Retrieved 29 May 2008, from <http://network.idrc.ca/ev.php?URL>.

Bino, M.J., 2004. Greywater reuse for sustainable water demand management, International water demand management conference, Amman, Jordan.

Brikké, F., Bredero, M., De Veer, T., and Smet, J. 1997. Linking Technology Choice with Operation and Maintenance for low-cost water supply and sanitation. IRC (International Water Research centre), The Hague, Netherlands.

Burnat, J.M.Y. & Mahmoud, N., 2005. Evaluation of on-site grey wastewater treatment plants performance in Bilien and Biet-Diko villages/Palestine, Environmental protection committee (EPC).

Carden, K., Armitage, N., Sichone, O. and Rivet, U., 2007. Understanding the use and disposal of greywater in the non-sewered areas of South Africa. WRC project K5/1524/1/07, Water Research Commission, Pretoria, South Africa.

Casanova, LM., Gerba, CP., and Karpiscak, M. Chemical and microbiological characterisation of household greywater. Journal Envirn. Sci. Health, A 36 (4), 395 – 401.

Centre for the Study of the Built Environment (CSBE), 2003. Graywater Reuse in Other Countries and its Applicability to Jordan. www.csbe.org/graywater/report/graywater_reuse_other_countries. [17 April 2008].

Chernicharo, C.A and Machado, R.M.G., 1998. Feasibility of the UASB/AF system for domestic sewage treatment in developing countries. Water Science Technology, vol. 38, No 8-9, 325-332.

Christopher, B.R. and Fischer, G.R., 1992. Geo-textiles filtration principles, practices and problems. Journal of geo-textiles and geo-membranes. Vol.11, No 4-6.

Christova Boal, D., Eden, R.E. and McFarlane, S., 1996. An investigation into greywater reuse for urban residential properties. Desalisation, 106 (1-3): 391 – 397.

City of Cape Town, 2004. Minutes of workshop on greywater in informal settlements. Upgrading of informal settlements project, Cape Town.

City of Cape Town, 2005. Guidelines for the management of greywater in informal area of Western Cape – draft version, Cape Town, South Africa.

Costner, 1990. Greywater treatment methods. Wat.Sc.Tech; vol.2-32 No43.

Crites, R. & Tchobanoglous, G. (1998). Small and decentralised wastewater management systems. Water Resources and Environmental Engineering, 1. WCB/Mcgraw Hill, Boston, USA.

Dague, R. R.; Habben, C. E.; Pidaparti, S. R.; 1992. Initial Studies on the Anaerobic Sequencing Batch Reactor; Wat. Sci. Tech; Vo. 1-26; No. 9-11; pp. 2429-2432.

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

Dallas, S., Scheffe, B. and Ho, G., 2004. Reedbeds for greywater – Case study in Santa Elena-Monteverde, Costa Rica, Central America. Ecological Engineering 23(1): 55-56.

Dallas, S., 2001. Literature review and greywater characteristics, chapter two. Unpublished PhD thesis, Murdoch University, Perth, Australia.

Dama, P., 2002. Pilot scale study of an anaerobic baffled reactor for the treatment of domestic wastewater in Monteverde, Costa Rica, Central America. Water Science and Technology, 46: 263-270.

Davies, T.R., (2008), the importance of chemical analysis to optimum operation of watercare plants. Proceeding of the 2008 WISA Western Cape Annual conference, Cape Town, 05 March 2008.

Del Porto, D. & Steinfeld, C.,1999. The composting toilet system book, 1. The center for ecological pollution prevention, concord, pp 234.

Del Porto, D. & Steinfeld, C.,2000. What about greywater, the composting toilet system book. Massachusetts, The center for ecological pollution prevention (CEPP), Concord, Massachusetts, pp. 167 – 193.

Department of Water Affairs and Forestry (DWAF), 1996. South African Water Quality Guidelines, Vol. 4 Agricultural use: Irrigation 2nd edition. Department of Water Affairs and Forestry, Pretoria.

Department of Water Affairs and Forestry (DWAF), 1998. Quality of domestic water supplies. Volume 1-Assessment guide. WRC report no TT 101/98. Water Research Commission, Pretoria, South Africa.

Department of Water Affairs and Forestry (DWAF), 1999. General authorisations in terms of section 39 of the National Water Act. Government gazette 20 526 No 1191, Government printer, Pretoria, South Africa.

Department of Water Affairs and Forestry (DWAF), 2001a. Managing the water quality effects of settlements: The National strategy. Government printer, Pretoria, South Africa.

Department of Water Affairs and Forestry (DWAF), 2001b. Managing the water quality effects of settlements: Legal considerations for managing pollution from settlements. Government printer, Pretoria, South Africa

Department of Water Affairs and Forestry (DWAF), 2001c. Managing the water quality effects of settlements: Planning to avoid pollution problems. Government printer, Pretoria, South Africa.

Department of Water Affairs and Forestry (DWAF), 2005. Greywater in informal settlement areas in Western Cape: a management framework drawn from lessons learnt by three municipalities. DWAF project no 271/2004. Pretoria, South Africa.

Department of Water Affairs and Forestry (DWAF), 2007. Best practice guidelines H4: Water treatment. Government printer, Pretoria, South Africa.

Dixon, A. M., Butler, D. And Fewkes, A., 1999. Guidelines for greywater re-use: Health issues. Journal of the chartered Institution of Water and Environmental Management, 13 (5): 322-326.

Elmitwalli, T.A., 2006. Anaerobic biodegradability and treatment of greywater in upflow anaerobic sludge blanket reactor. Proceeding of 7th IWA conference, March 2006, Mexico.

Eriksson, E., Auffarth, K., Henze, M., and Ledin, A., 2002. Characteristics of grey wastewater. Urban water journal (4 March 2002), 85-104.

Faruqui, N. & Al-Jayyousi, O., 2002. Greywater reuse in urban agriculture for poverty alleviation - A case study in Jordan. Water international, 27(3): 387-394.

Foxon, K.M & Buckely, C. 2007. Guidelines for the implementation of anaerobic baffled reactors for on-site or decentralised sanitation. Pollution Research Group, University of Kwazulu Natal, Durban.

Foxon, KM; Buckley CA; Brouckaert CJ; Dama P; Mtembu DZ; Rodda N; Smith M; Pillay S; Arjun N; Lalbahadur, T., 2006. The evaluation of the anaerobic baffled reactor for sanitation in dense peri-urban settlements (ABR). WRC report No 1248/1/06, Water Research Commission, Pretoria.

Friedler, E. 2004. Quality of individual domestic greywater streams and its implication for on-site treatment and reuse possibilities. Environmental Technology, 25(9): 997-1008.

Gaydon, P., Mcnab, N., Mulder, G., Pillay, I., Sahibdeen, M., Thompson, P., 2007. Evaluation of sewage treatment package plants for rural, peri-urban and community use. WRC project no 1539/1/06. Water Research Commission, Pretoria, South Africa.

Ghaniyari-Benis, S., 2009. Anaerobic treatment of synthetic medium-strength wastewater using a multistage biofilm reactor. Journal of Biosource technology (3) 2009.

Ghougassian, B., 2003. *Graywater Treatment and Reuse in West Bekaa, Lebanon*. Ottawa: The International Development Research Center. Retrieved 04 June 2008, from <http://network.idrc.ca/ev.php?URL>.

Gourc, JP. And Faure, YH, 1990. Filter criteria for geo-textiles, proceedings of the 4th international conference on geo-textiles, the Hague, Netherlands, vol.4.

Gross, A., 2005. Environmental impact and health risks associated with greywater irrigation: a case study. Water Science and Technology, 52(8): 161-169.

Gross, A., Wiel-Shafran, A., Bondarenko, N., and Ronen, Z., 2006. Reliability of small commercial greywater treatment systems – a case study, protection and restoration of the environment VIII, Chania, Crete, Greece.

Gustafson, D.M., Anderson, J.L. and Christopherson, S.H., 2002. Innovative on-site treatment systems, University of Minnesota.

Haddad, N. and Kai, L. (2007). Tanoura, deceived by politicians, saved by greywater, environmental link journal, vol. 3: 91. Beirut, Lebanon.

Hanna, K.M., Kellam, J.L. & Boardman, G.D., 1994. On-site anaerobic package treatment systems. Wat. Res. Vol. 29. no 11, 2530-2450.

Harindra Corea, E.J., 2001. Appropriate disposal of sewage in urban and suburban Sri lanka. Unpublished PhD thesis, The University of Leeds, Leeds. 270 pp.

Henze, M., Harremoës, P., la Cour Jansen, J. & Arvin, E. 2002. Wastewater Treatment: Biological and Chemical Processes, 3rd revised edition. Berlin: Springer.

Hulsman, A. & Swartz, CD., 1993. Development of an improved compact package plant for small community wastewater treatment. Water Science Technologies vol. 28 no 10, 283-288.

Idris, A., Azmin, W., Soom, M. and Al-Mamun, A., 2005. The importance of sullage (greywater) treatment in the restoration and conservation of urban streams. International Journal of River Basin Management Vol. 3, 223-227.

International Development Research Centre (IRDC), 2006. Greywater treatment and reuse for peri-urban horticulture (West bank, Palestine). Palestinian Agriculture Relief Committee, IDRC, Jerusalem, http://www.irdc.ca/en/ev-6338-201-1-DO_TOPIC.html

INWRDAM (Inter-Islamic Network on Water Resources Development and Management), 2003. Greywater treatment and reuse, Tfileh, Jordan. 100880, Jefferson, B., Laine, A., Parsons, S., Stephenson, T., and Judd, S., 1999. Technologies for domestic wastewater recycling. Urban water 1, pp 285 – 292.

Jefferson, B. Judd, S. & Diaper, C., (2001): Treatment methods for greywater. In: Lens P, Zeeman G & Lettinga G (eds.): Decentralised Sanitation and Reuse: Concepts, systems and implementation. IWA Publishing. London, UK; pp.334-353.

Jefferson, B.,Palmer, A., Jeffrey, P., Stuetz, R., Judd, S. (2004). Greywater characterisation and its impact on the selection of technologies for urban reuse. Water science technology 50 (2), 157-164).

Jeppeson, B. and Solley, D., 1994. Domestic greywater reuse overseas practice and its applicability to Australia, Research report no 73, Urban Water Research Association of Australia, Melbourne.

Ji, G.D., 2009. Anaerobic baffled reactor (ABR) for treating heavy oil produced water with high concentration of salt and poor nutrients. Journal of Bioresource 2 (2009).

Kadlec, R.H. & Knight, R.L., 1996. Treatment wetlands. Lewis Publishers, Boca Raton, Florida.

Källerfelt, C. & Nordberg, A., 2004. Evaluation of local greywater treatment in South Africa – Greywater characteristics, water use and user acceptance. Msc. Diploma thesis, Department of Analytical and Marine Chemistry, Chalmers University of Technology, Göteborg, Sweden.

Kerry, K.D. and Brady, J., 1997. Small wastewater system operation and maintenance, California State University, Office of Water Programs, Sacramento.

Kobayashi, H.A., Strenstrom, M.K. and Mah, R.A., 1983. Treatment of low strength domestic wastewater using the anaerobic filter. Water research journal, 38 (3): 681-687.

Koottatep, T., Panuvatvanich, A. And Morel, A., 2006. Wastewater Effluent Polishing Systems of Anaerobic Baffled Reactor Treating black water from households. 7th specialized conference on small water and wastewater systems, March 7-10, Mexico City, Mexico.

Laber & Haberl, 1999. Teilstrombehandlung häuslicher Abwässer mit dem Schwerpunkt der Grauwasserbehandlung in Pflanzenkläranlagen (Treatment of separate streams of domestic wastewater with a special focus on greywater treatment using constructed wetlands); Report, IWGA-SIG, BOKU, Vienna [*in German*].

Laine, A.T. (2001). Technologies for greywater recycling in buildings. Unpublished PhD Thesis, Cranfield University. UK

Lazarova, V. (2001). Role of water reuse in enhancing integrated water management in Europe. Final report to EU project CatchWater, V.Lazarova (ed.) ONDEO, Paris, France.

Ledin A, Eriksson E & Henze M (2001): Aspects of groundwater recharge using grey wastewater. In: Lens P, Zeeman G & Lettinga G (eds.): Decentralised Sanitation and Reuse: Concepts, systems and implementation. IWA Publishing. London, UK; pp.354-370.

Lindstrom, C., 2000. Greywater information on web. http://www.greywater.com [19 May 2008].

Little, V. 2001. *Graywater Guidelines*. Tucson: Water Conservation Alliance of Southern Arizona (Water CASA).

Machdar I., Harada H., Ohashi A., Sekiguchi Y., Okui H. and Ueki K. (1997) A novel and cost-effective sewage treatment system consisting of UASB pre-treatment and aerobic post-treatment units for developing countries. *Water Science & Technology,* Vol. 36, 189-197.

Malan, WM., 2002. Guidelines for the evaluation of wastewater purification plants. Western Cape provincial Administration, Cape Town.

Mara, D., 2003. Domestic wastewater treatment in developing countries, 1. Earthscan, London, 293 pp.

Marais, P., 2007. Investigation into the possible re-use of treated effluent in the Cape Winelands region. Water and Wastewater Engineering, Cape Town.

Martin, C., 2005. Ecological sanitation greywater demonstration project at Hui Singh garden Kuching, Sarawak, Malaysia, Urban Environmental Management System (UEMS) Project Natural Resources and Environmental Board (NREB)< Sarawak.

McLachlan, C., 2004. Guidelines for the management of greywater in informal areas of the Western Cape. Department of Water Affairs and Forestry, project no 271/2004. Pretoria, South Africa.

Mohammed, A., 2003. Graywater Treatment and Reuse for Peri-Urban Horticulture (West Bank)*, Palestine*. Future of urban agriculture in Gaza: Regional workshop, Gaza, Palestine.

Morel & Diener, 2006. Greywater management in low and middle-income countries: review of different treatment systems for households and neighbourhoods. Sandec report; no 16/06). Dubendorf, Switzerland.

Muanda, C. & Lagardien, A., 2008. Investigating greywater disposal options in an informal settlements.Paper presented at Water Institution of Southern Africa, biennial conference, Sun City, South Africa.

Muanda, C. 2007. Investigating greywater generation and disposal options in the Doornbach informal settlement. Unpublished BTech thesis. Cape Peninsula University of Technology, Cape Town.

Mufid, A. (2007). Greywater treatment and reuse: the Anaerobic upflow batch reactor system, Journal of wastewater engineering, vol.2: 56.

Murphy, K., 2006. A scoping study to evaluate the fitness-for-use of greywater in urban and peri-urban agriculture. A water Research Commission project. Pretoria.

Musvoto, E. & Ramphao, M. 2007. Characterisation of wastewater from low-income/high density residential areas. WRC report No 1449/1/07, Water Research Commission, Pretoria.

Mwiinga, G. 1998. The potential for the use of roughing – slow sand filtration systems in Zambia. Unpublished MSc thesis. University of Zambia, Lusaka. Zambia.

Mwiinga, G. 2008. Interview with the author on 07 August 2008, Cape Town.

National Water Demand Management Center (NWDMC), 2000. *A study of Domestic Greywater Recycling*. Bristol: Environment Agency. England.

Nyakutsika, N., 1993. On-site sullage treatment. Proceedings of the 19th WEDC conference-low cost sanitation. Accra, Ghana.

OPS/CEPIS, 2002. Integrated Systems for the Treatment and Recycling of Waste Water in Latin America: Reality and Potential.

Otterpohl, R., Braun, U. and Oldenburg, M., 2003. Innovative technologies for decentralized water, wastewater and biowaste management in urban and peri-urban areas. *Wat. Sci. Technol.* 48 (2003) (11/12), pp. 23–32.

Otterpohl, R., Grottker, M. and Lange, J., 1997. Sustainable water and waste management in urban areas. Water Science Technology, 35(9): 121-123.

Otterpohl, R., Albold, A., and Oldenburg, M., 1999. Source control in urban sanitation and waste management: ten systems with reuse of resources. Water Sci. Technol. 39 (1999) (5), pp 153 – 160.

Ottoson, J. and Stenstrom, T.A., 2003. Faecal contamination of greywater and associated microbial risks. Water research, 37(3): 645-655.

Page, M. 2008. Interview with the author on 01 April 2008, Cape Town.

Papadopoulos, A. Parisssopoulos, G., Papadopoulos, F. and Krteris, F., 2001. Variations of COB/BOD_5 ratio at different units of wastewater stabilisation pond pilot treatment facility. Proceeding of 7th conference on environmental science and technology. September 2001, Ermoupolis, Greece.

Rand water, 2008. Greywater: the Cinderella of low income townships, rand water year book, pp 35-36.

Republic of South Africa (RSA), 1997. Water Services Act (WSA), Act no 108 of 1997. Government printer, Pretoria, South Africa.

Republic of South Africa (RSA), 1996. The Constitution, Act no 108 of 1996. Government printer, Pretoria, South Africa.

Republic of South Africa (RSA), 1998a. National Water Act (NWA), Act no 36 of 1998. Government printer, Pretoria, South Africa.

Republic of South Africa (RSA), 1998b. National Environment Management Act (NEMA), Act no 107 of 1998. Government printer, Pretoria, South Africa.

Republic of South Africa (RSA), 2000. Municipal Systems Act (MSA), Act no 32 of 2000. Government printer, Pretoria, South Africa.

Republic of South Africa (RSA), 2003. National Health Act (NHA), Act no 61 of 2003. Government printer, Pretoria, South Africa.

Ridderstolpe, P., 2004. Introduction to greywater management, Stockholm Environment Institute, Stockholm.

Rittman, B., Love, N. & Siegrist, H. 2008. Making wastewater a sustainable resource. Magazine of the International Water Association, April 2008: 22-23.

Rose, J.B., Sun, G., Gerba, C.P. and Sinclair, N.A., 1991. Microbial quality and persistence of enteric pathogens in greywater from various household sources. Water Research, 25. 37 – 42.

Sall, O., 2006. Physical, chemical and biological characteristics of stored greywater from unsewered suburban Dakar in Senegal. Urban water journal Vol. 3 no 3 (2006) pp 153-164.

Sanders, T., Ward, R., Loftis, J., Steele, T., Adrian, D. and Yevjevich, V., 1987. Design of network for monitoring water quality. Water resources publications, 2nd edition, Colorado, USA.
SANS (South African National Standard), 2007. Chemical and Microbiological analysis of water – General test methods. Pretoria, South Africa

Sasse, L., 1998. Decentralised wastewater treatment in developing countries. BORDA, Bremen, 160 pp.

Shrestha, R.R, Harbel, R., Laber, J., Mandhar, R. and Mader, J., 2001 Application of constructed wetlands for wastewater treatment in Nepal. Water Science Technology, 44(11-12): 381-386.

Stephenson, D., Kisembo, C. & Owusu-Asante, Y., 2006. Drainage in rural and peri-urban townships. WRC report K5/1440. Water Research Commission, Pretoria, South Africa.

Stoodley, A.E., 1989. Operational experiences with package filter sewage treatment plants. Journal, IWEM, 3 December. 583-587.

Surendran, S. & Wheatley, A.D. (1998). Greywater reclamation for non-potable reuse. Journal Ciwem, 12, 406-413.

Tchobanoglous, G. & Franklin, L.B., 2003. Wastewater Engineering: treatment and reuse. 4th ed. Metcalf & Eddy, Inc. Irwin, McGraw-Hill, New York, USA.

Tchobanoglous, G., 1991. Wastewater Engineering, Treatment and Disposal, and Reuse. 1st ed. Metcalf & Eddy Inc., Irwin, McGraw-Hill, New York, USA.

US EPA (United State Environmental Protection Agenecy), 1992. Wastewater treatment/disposal for small communities, US Environmental Protection Agency, Washington DC.

US EPA (United State Environmental Protection Agenecy), 2004. Vegetated submerged beds and other high-specific surface anaerobic reactors. Fact sheet no 5, Washington DC.

Van Wyk, R. & Muanda, C., 2006. Resource manual for sampling and testing greywater. Unpublished report to Community Water Supply and Sanitation Unit. Cape Peninsula University of Technology, Bellville.

Voigtländer, G. & Kulle, E.P., 1994. An improved small sewage treatment plant for biological purification of wastewater. Water and Science Technology, vol. 29 no 12, 23-29.

Von Sperling, H. & Chernicharo, C.A.L., 2005. Biological wastewater treatment in warm climate regions, IWA publishing, London, 835 pp.

Werner, C., 2003. An ecosan source book for the preparation and implementation of ecological sanitation projects. GTZ (Deutche Gesellschaft für Technische Zusammenarbeit), 2009. Symposium on ecological sanitation. www.gtz.de/ecosan, GmbH, Eschborn.

Winblad, U. & Simpson – Herbert, M., eds, 2004. Ecological sanitation, revised edition. Stockholm Environmental Institute, Stockholm, Sweden.

Wood, A., Uchronska, W. and Valashiya, G., 2001. Greywater management in dense informal settlements in South Africa, WRC report No 767/1/01, Water Research Commission, Pretoria.

World Health Organization (WHO), 2006. Guidelines for the safe use of wastewater, excreta and greywater. Volume 2. Wastewater use in agriculture. Geneva, Switzerland, World Health Organization. www.who.int/water_sanitation_health/wastewater/gsuweg2/en/index.html

Young, J.C.,1991. Factors affecting the design and performance of up-flow anaerobic filters. Water Science and Technology, 24 (8): 133-15.

Appendices

Appendix A: Analytical procedures

A.1 Total Suspended Solids

a) Apparatus

Basic apparatus required are: glass bottles (1,000 ml), Imhoff cone (1,000 ml), filter (glass fibre), oven and evaporating dish.

b) Procedures

The operational efficiency of various treatment units is defined by solids removal. TSS is a material left in a dish after evaporation of a sample of wastewater and subsequent drying in an oven. A measured volume of sample was placed in an evaporating dish, made of porcelain. Water is evaporated from the dish on a steam bath or in drying oven at approximately 2ºC below boiling to prevent splattering. The evaporated samples are dried for at least an hour in an oven at 103 to 105˚C and cooled in a desiccator to a constant weight. The milligrams of total residue are equal to the difference between the cooled weight of the dish and the original weight of the empty dish. Concentration of total residue is calculated using equation: TSS = Dried residue (mg/l) x 1000 / sample (ml).

A.2 Total Nitrogen

a) Apparatus

The following apparatus are used for the analysis of total nitrogen: UV-VIS Spectrometer Cells: 1x1cm glass cells, water as a blank @ 25^{O}C, λ = 814.0 nm, volumetric flask (10ml, 25ml, 100ml) , beakers (25ml-100ml) and pipettes (5,10,20ml).

b) Procedures

The method used to analyse the TN is called “Ultraviolet Spectrometric Screening Method”. The method consists of adding 1 ml of HCl acid solution to 50 ml clear and filtered sample and mixed thoroughly. The preparation of the standard curve is done preparing nitrate’s calibration standards in the range 0 to 7 mg of nitrate by diluting to 50 ml the following volumes of intermediate nitrate solution. The spectrometric measurement was done by reading absorbance or transmittance against redistilled water set at zero absorbance or 100% transmittance. A wavelength of 220 nm was used to determine to obtain nitrate reading and another of 275 nm was used to determine the interference due to dissolved organic matter.

A.3 Total Phosphates

a) Apparatus

To analyse the concentration of TP, the following apparatus are required: UV-VIS Spectrometer Cells: 1x1cm glass cells, water as a blank @ 25^{O}C, λ = 880nm, volumetric flask (10 ml, 25ml, and 100ml), beakers (25-100ml) and pipette (5, 10 and 20ml).

b) Procedures

The Molybdenum blue spectrophotometric method was chosen because of its high sensitivity to phosphorus and less interferences present with better stability.

- 2ml sample was added to 100ml water and made to the mark. From that 25ml sample was placed in a beaker and 4ml combined reagents was added.
- The standards were treated the same way, as 25ml of Potassium stock was added and made to mark in 100ml. From that varying volumes as per standard concentration were made and 4ml combined reagent was added.
- Blanks were 25ml of water and 4ml of combined reagent.
- All these solution were allowed to standard for 10minutes before start measure and were measured within 30minutes. A blue colour was observed and the strength of the colour depended on the concentration of the standards and sample used.

A.4 COD

a) Apparatus

- *Reflux apparatus,* consisting of 500 or 250-ml Erlenmeyer flasks with ground-glass 24/40 neck and 300mm jacket Liebig, West, or equivalent condenser with 24/40 ground-glass joint, and a hot plate having sufficient power to produce at least 1.4 W/cm^2 of heating surface, or equivalent. A blender and pipettes (class A and wide-bore) are required

b) Reagents

- *Standard potassium dichromate solution,* 0.04167*M*: Dissolve 12.259 g $K_2Cr_2O_7$, primary standard grade, previously dried at 150°C for 2 h, in distilled water and dilute to 1000 ml. This reagent undergoes a six-electron reduction reaction; the equivalent concentration is 6 X 0.04167*M* or 0.2500*N.*
- *Sulfuric acid reagent:* Add Ag_2SO_4, reagent or technical grade, crystals or powder, to concentration H_2SO_4 at the rate of 5.5 g Ag_2SO_4 /kg H_2 SO_4. Let stand 1 to 2 d to dissolve. Mix.

- *Ferroin indicator solution:* Dissolve 1.485 g 1,10-phenanthroline monohydrate and 695 mg $FeSO_4 \cdot 7H_2O$ in distilled water and dilute to 100 ml. This indicator solution may be purchased already prepared.*
- *Standard ferrous ammonium sulfate (FAS)* titrant, approximately 0.25*M*: Dissolve 98 g $Fe(NH_4)_2(SO_4)_2 \cdot 6H_2O$ in distilled water. Add 20 ml concentration H_2SO_4, cool, and dilute to 1000ml. Standardize this solution daily against standard $K_2Cr_2O_7$ solution as follows:
  - Dilute 25.00 ml standard $K_2Cr_2O_7$ to about 100 ml. Add 30 ml concentration H_2SO_4 and cool.
  - Titrate with FAS titrant using 0.10 to 0.15 ml (2 to 3 drops) ferroin indicator.

$$\text{- Molarity of FAS solution} = \frac{\text{Volume } 0.04167M\ K_2Cr_2O_7 \text{ Solution titrated, ml}}{\text{Volume FAS used in titration, ml}} \times 0.2500$$

- *Mercuric sulfate,* $HgSO_4$, crystals or powder.
- *Sulfamic acid:* Required only if the interference of nitrites is to be eliminated (see 5220A.2 above).
- *Potassium hydrogen phthalate (KHP) standard,* $HOOCC_6H_4COOK$: Lightly crush and then dry KHP to constant weight at 110°C. Dissolve 425 mg in distilled water and dilute to 1000ml. KHP has a theoretical COD[1] of 1.176mg O_2/mg and this solution has a theoretical COD of 500µg O_2/ml. This solution is stable when refrigerated, but not indefinitely. Be alert to development of visible biological growth. If practical, prepare and transfer solution under sterile conditions. Weekly preparation usually is satisfactory.

c) Procedures

The chemical oxygen demand (COD) is used as a measure of the oxygen equivalent of the organic matter content of a sample that is susceptible to oxidation by a strong chemical oxidant. The method used to determine the COD is the open reflux method.

The open reflux method used to measure the COD concentration is described as follows:

Treatment of samples with COD of >50mg O_2/l: Blend sample if necessary and pipette 50.00ml into a 500ml refluxing flask. For samples with a COD of >900mg O_2/l, use a smaller portion diluted to 50ml. Add 1g $HgSO_4$, several glass beads, and very slowly add 5.0ml sulfuric acid reagent, with mixing to dissolve $HgSO_4$. Cool while mixing to avoid possible loss of volatile materials. Add 25ml 0.04167*M* $K_2Cr_2O_7$ solution and mix.

Attach flask to condenser and turn on cooling water. Add remaining sulfuric acid reagent (70 ml) through open end of condenser. Continue swirling and mixing while adding sulfuric acid reagent. Caution: Mix reflux mixture thoroughly before applying heat to prevent local heating of flask bottom and a possible blowout of flask contents.

Cover open end of condenser with a small beaker to prevent foreign material from entering refluxing mixture and reflux for 2h. Cool and wash down condenser with distilled water. Disconnect reflux condenser and dilute mixture to about twice its volume with distilled water. Cool to room temperature and titrate excess $K_2Cr_2O_7$ with FAS, using 0.10 to 0.15ml (2 to 3 drops) ferroin indicator. Although the quantity of ferroin indicator is not critical, use the same volume for all titrations.

Take as the end point of the titration the first sharp color change from blue-green to reddish brown that persists for 1min or longer. Duplicate determinations should agree within 5% of their average. Samples with suspended solids or components that are slow to oxidize may require additional determinations. The blue-green may reappear. In the same manner, reflux and titrate a blank containing the reagents and a volume of distilled water equal to that of sample.

Determination of standard solution: Evaluate the technique and quality of reagents by conducting the test on a standard potassium hydrogen phthalate solution.

The COD concentration was then computed using the equation below:

$$\text{COD as mg } O_2/\text{l} = \frac{(A - B) \text{ X } M \text{ X } 8000}{\text{ml sample}}$$

Where:

A = ml FAS used for blank,

B = ml FAS used for sample,

M = molarity of FAS, and

8000 = milliequivalent weight of oxygen X 1000ml/l.

Notes: the **screening method** may be used as well for analysisng COD:

The analytical procedures consist of adding measured quantities of standard potassium dichromate, sulphuric acid reagent containing silver sulphate, and a measured volume of sample into flask. After attaching a condenser on top, this mixture is refluxed (vaporized and condensed) for 2h. The oxidation of organic matter converts dichromate to trivalent chromium.

After cooling, washing down the condenser, and diluting the mixture with distilled water, the excess dichromate remaining in the mixture is measured by titration with standardized ferrous ammonium sulphate. A blank sample of distilled water carried through the same COD testing procedure as the greywater sample. The purpose of testing a blank is to compensate for any error that can result because of the presence of extraneous organic matter in the reagents.

A.5 BOD$_5$

The biological oxygen demand (BOD) determination is an empirical test in which standardised laboratory procedures are used to determine the relative oxygen requirements of wastewater, effluent and polluted waters. The test measures the oxygen utilised during a specific incubation period for the biochemical degradation of organic material and the oxygen used to oxidise inorganic material such as sulphides and ferrous iron.

a) Apparatus

Apparatus and reagents used are: glass stoppered BOD test bottles (300ml), distilled water and DO probe (equipped with stirring device).

b) Procedures

The 5 – day BOD test method consists of filling with sample, to overflowing, an airtight bottle of the specified size and incubating it at the specific temperature for 5 days. Dissolved oxygen is measured initially and after incubation, and the BOD is computed from the difference between initial and final dissolve oxygen (DO). Because the initial DO is determined immediately after the dilution is made, all oxygen uptake, including that occurring during the first 15 minutes, is included in the BOD measurement.

The analytical procedures used to determine BOD$_5$ consist of following steps:

- Preparation of dilution water
- Dilution of water check
- Glucose-glutamic acid check
- Seeding
- Sample pre-treatment
- Dilution technique
- Determination of initial DO
- Incubation
- Determination of the final DO.

Measured wastewater, diluted with prepared water, is placed in 300ml BOD bottles. The dilution water, containing phosphate buffer (pH 7.2), magnesium sulphate, calcium chloride and ferric chloride is saturated with dissolved oxygen. A plastic or foil cup is placed over the flared mouth of the BOD bottle during incubation to reduce evaporation of the water seal. The primary reaction was the metabolism of the organic matter and uptake of dissolved oxygen by bacteria; the secondary reaction resulted from the oxygen used by the protozoa-consuming bacteria.

Depletion of dissolved oxygen in the test bottle is directly related to the amount of degradable organic matter. The BOD of the sample is calculated using equation: BOD = $D_1 – D_2$ /P where D_1 is the initial DO of the diluted wastewater sample about 15 min after preparation (mg/l) and D_2 final DO of the diluted wastewater sample after incubation for five days (mg/l); P decimal fraction of the wastewater sample used (ml of wastewater sample/mm volume of the BOD bottle). Example: wastewater portion: 2ml---DO_i 8.3 incubation period 0 day --- DO_f nil.

A.6 O&G

a) Apparatus

The analysis of O&G requires the following apparatus: extraction apparatus, soxhlet, vacuum pump or other source of vacuum, extraction thimble, paper, analytical balance - weight to 0.01g, 250 or 300ml bottom Erlenmeyer flask, distilling head, claisen or equivalent, grease-free cotton or glass wool and beaker 150 ml.

b) Reagents: hydrochloric acid, ACS, concentrated, magnesium sulfate monohydrate reagent grade. Prepare by spreading a thin layer of the $MgSO_4.H_2O$ on a watch glass or dish, then place in an oven (150°C) overnight. Freon-113 (distill if necessary) and grease-free cotton or glass wool.

c) Procedures

The quantity of O&G contained in greywater was determined by extraction of the greywater sample with trichloro-trifluoroethane which make O&G are soluble. The measurement consists of the following steps:

- In a 150 ml beaker, weigh a sample of wet sludge, 20+/- 0.5 g of which the dry-solids content is known. Acidify to pH 2.0 with concentrated HCl (generally, 0.3ml of concentrated HCl is sufficient).
- Add 25g $MgSO_4.H_2O$. Stir to a smooth paste and spread on the sides of the beaker to facilitate subsequent removal. Allow to stand until solidified, 15 to 30 minutes.
- Remove the solids and grind in a porcelain mortar. Add the powder to a paper extraction thimble. Wipe the beaker and mortar with small pieces of filter paper moistened with freon and add to the thimble.

- Fill the thimble with glass wool or cotton. Extract in a soxhlet apparatus, using freon, at a rate of 20 cycles/hour for four hours.
- If any turbidity of suspended matter is present in the extraction flask, remove by filtering through grease-free cotton or glass wool. Rinse flask and cotton with freon.
- Distill the solvent from the extraction flask in water at 70°C. Place the flask on a warm steam bath for 15 minutes and draw air through the flask by means of an applied vacuum for the final one minute.
- Cool in a dessicator for exactly 0.5h and weigh.
- Calculate oil and grease on a dry weight basis.
- The O&G was then computed by using the equation below:

$$\% \text{ Oil and grease} = \frac{\text{weight residue (g)} \times 100}{\text{Weight of wet solids (g)} \times \% \text{ dry solids}}$$

A.7 Faecal coliform and e-coli

a) Apparatus

The following apparatus are used: autoclave, weighing scale, filter plates and microscope counter.

b) Procedures

The method used is the colony forming count which consisted of the following parts:

Part 1:-Preparation of the Growth medium

- Weigh 31g of Nutrient Agar
- Pour it in 1 litre Schott bottle
- Add distilled or demineralised water
- Shake well to dissolve Nutrient Agar
- Autoclave at 121°C for 0.25h (the pressure should be high before autoclave)
- Cool Agar to 45 - 50°C

Part 2: - Spreading, incubating and count

- Total heterotrophic counts were done in triplicate on Nutrient agar (NA) (Merck, Biolab Diagnostics) plates after serial dilutions (10^{-1} - 10^{-5}) of sample suspensions were performed.
- Plates were incubated for 3-4 days at 37ºC.

Thereafter, the number of visible cells [colony forming units (CFU)] were counted and recorded.

A.8 Ammonia

a) Apparatus: simple distillation, titration to purple-blue, burette, condenser, Kjeldahl flask, delivery tube as an Outlet tips, Erlenmeyer flask and beakers

b) Procedures

- A borosilicate glass 800ml Kjeldahl flask was attached to a vertical condenser to an outlet tip that was submerged below the surface of receiving acid solution.
- 250ml of sample was placed into an 800L Kjeldahl flask. The pH was adjusted to 9.5 using sodium hydroxide and 50ml of indicator boric acid solution was added to 500ml Erlenmeyer flask.
- The Kjeldahl flask was then placed on distillation apparatus and the tip was below the surface of the indicating boric acid. Distillate was distilled at rate of 6 to 10 ml/l.
- About 200ml of distillate was collected and titrated with ammonia in distillate with standard 0.10N sulphuric acid to a purple-blue endpoint.

Appendix B: Preliminary experiments

B.1 Characteristics of effluent greywater

B.1.1 Greywater from sewered areas

Table B.1: Greywater from household 1

Parameter						
	Influent	**Pre-treatment**	**P_1**	**P_2**	**P_3**	**P_4**
Temperature (ºC)	29.6	27.5	28.1	29.5	26.0	25.8
pH	6.2	7.3	7.0	7.1	7.2	7.5
TSS (mg/l)	107.6	93.8	12.1	7.3	5.2	4.9
TN (mg/l)	5.4	4.9	3.4	2.8	1.2	1.2
TP (mg/l)	13.2	12.1	6.4	3.1	2.85	1.25
COD (mg/l)	212	187	135	91	25	22
BOD_5 (mg/l)	55	45.50	21.45	12.83	5.17	4.28
O&G (mg/l)	82.2	18.2	5.1	2.2	0.90	0.70
e-coli (cfu/100 ml)	4.0×10^3	3.8×10^3	2.56×10^3	219	90	60
FC (cfu/100 ml)	11×10^3	10.4×10^3	8.3×10^3	946	125	102

Table B.2: Greywater from household 2

Parameter						
	Influent	**Pre-treatment**	**P_1**	**P_2**	**P_3**	**P_4**
Temperature (ºC)	30.2	28.9	29.7	29.3	27.6	27.2
pH	7.1	7.3	7.0	7.15	6.9	7.2
TSS (mg/l)	245.6	119.5	33.5	11.1	7.5	3.8
TN (mg/l)	6.4	5.9	3.3	2.1	1.9	1.9
TP (mg/l)	16.85	12.3	8.45	6.01	2.90	2.65
COD (mg/l)	112	107	89	21	19	18.2
BOD_5 (mg/l)	67	62.82	26.78	14.53	6.69	5.72
O&G (mg/l)	112.6	20.5	12.3	9.9	4.2	2.15
e-coli (cfu/100 ml)	18×10^3	17.5×10^3	16×10^3	1.8×10^3	430	318
FC (cfu/100 ml)	14×10^3	10.3×10^3	9.5×10^3	1.45×10^3	195	107

Table B.3: Greywater from student hostel

Parameter						
	Influent	**Pre-treatment**	**P_1**	**P_2**	**P_3**	**P_4**
Temperature (ºC)	28.0	28.1	29.1	29.2	26.2	26.0
pH	7.2	7.1	7.0	7.1	7.2	7.5
TSS (mg/l)	145.6	134.8	23.5	12.4	6.8	6.8
TN (mg/l)	6.6	4.9	4.4	3.03	1.02	0.90
TP (mg/l)	16	2.1	1.4	1.0	0.75	0.75
COD (mg/l)	432	321	195	111	75	42
BOD_5 (mg/l)	122	114.42	61.08	25.62	13.1	11.22
O&G (mg/l)	42.7	3.8	2.1	1.9	1.1	1.0
e-coli (cfu/100 ml)	48×10^3	42×10^3	36.5×10^3	1,789	234	200
FC (cfu/100 ml)	115×10^3	103.4×10^3	98.7×10^3	2,456	276	206

B.1.2 Greywater from un-sewered settlements

Table B.4: Greywater from Phola park informal settlement

Parameter						
	Influent	**Pre-treatment**	**P_1**	**P_2**	**P_3**	**P_4**
Temperature (ºC)	21.7	22.4	22.8	23.9	23.8	23.5
pH	7.4	7.2	7.4	7.3	7.1	7.2
TSS (mg/l)	2,345	1,289	98	23	18	15
TN (mg/l)	12.1	7.0	6.8	3.2	1.1	1.1
TP (mg/l)	132.5	120.1	89.23	54.2	12.3	11.5
COD (mg/l)	1,235	1096	456.7	77.6	32.3	28.8
BOD_5 (mg/l)	467.8	396.3	87.65	39.65	17.2	15.7
O&G (mg/l)	478	76.5	15.6	8.1	2.3	1.2
e-coli (cfu/100 ml)	TNT	$5.6x10^5$	$8.8x10^5$	$12\ x10^3$	1,343	932
FC (cfu/100 ml)	TNT	$8.2\ x10^5$	$7.7x10^5$	$3x10^3$	1,167	346

Table B.5: Greywater from Wallacedene informal settlement

Parameter						
	Influent	**Pre-treatment**	**P_1**	**P_2**	**P_3**	**P_4**
Temperature (ºC)	22.4	22.5	24.7	25.5	25.2	25.9
pH	7.1	7.4	7.1	7.22	7.24	7.13
TSS (mg/l)	1,876	1149	86.7	32.2	28.3	21.9
TN (mg/l)	11.2	3.2	2.1	1.4	1.1	0.8
TP (mg/l)	121.6	76.5	46.4	21.3	10.4	8.8
COD (mg/l)	1,123	986.3	321.8	112.6	35.8	26.2
BOD_5 (mg/l)	461.3	413.1	87.9	44.3	19.3	17.6
O&G (mg/l)	435	17.8	11.4	2.4	1.8	1.1
e-coli (cfu/100 ml)	TNT	$8.7x10^5$	$7.6x10^5$	$24x10^3$	$2x10^3$	1,034
FC (cfu/100 ml)	TNT	$7.6x10^5$	$7.2\ x10^5$	$19x10^3$	$3,3\ x10^3$	1,924

Table B.6: Greywater from the Doornbach informal settlement

Parameter						
	Influent	**Pre-treatment**	**P_1**	**P_2**	**P_3**	**P_4**
Temperature (ºC)	22.1	23.7	23.6	24.1	23.8	23.7
pH	7.8	7.5	7.3	7.4	7.3	7.3
TSS (mg/l)	1,229	978.4	44.8	33.2	20.9	19.8
TN (mg/l)	20.2	11.12	9.6	4.12	1.65	1.4
TP (mg/l)	113.1	67.87	32.9	11.6	8.13	7.12
COD (mg/l)	987	874.7	133.42	85.43	38.75	31.4
BOD_5 (mg/l)	72.1	47.5	14.1	13.8	7.6	5.9
O&G (mg/l)	686	18.6	7.2	5.1	2.7	2.1
e-coli (cfu/100 ml)	$56x10^4$	$8.2x10^5$	$7.3x10^5$	$38x10^3$	$4x10^3$	2145
FC (cfu/100 ml)	$> 1x10^5$	$9.1x10^5$	$8.7x10^5$	93,120	$1.98\ x10^3$	1,542

B2: Pollutant removal at individual unit process

B.2.1 Sewered areas

Table B.7: Pollutant removal at the Pre-treatment process

Parameter	Household 1			Household 2			Student hostel		
	Influent	Pre-treat	%	Influent	Pre-treat	%	Influent	Pre-treat	%
TSS (mg/l)	107.6	93.8	12.83	245.6	119.5	51.34	145.6	134.8	7.4
TN (mg/l)	5.4	4.9	9.3	6.4	5.9	7.8	6.6	4.9	25.75
TP (mg/l)	13.2	12.1	8.3	16.85	12.3	27.0	16	2.1	86.88
COD (mg/l)	212	187	11.8	112	107	4.46	432	321	25.7
BOD_5 (mg/l)	55	45.5	17.28	67	62.82	6.24	122	114.47	6.17
O&G (mg/l)	82.2	18.2	77.86	112.6	20.5	81.8	42.7	3.8	91.1
e-coli (cfu/100 ml)	$4x10^3$	3,800	5.0	$18x10^3$	17,500	2.78	$48x10^3$	$42\ x10^3$	12.5
FC (cfu/100ml)	$11x10^3$	10,400	5.45	$14x10^3$	10,300	26.43	115,000	103.400	10.44

Table B.8: Pollutant removal at the settling process

Parameter	Household 1			Household 2			Student hostel		
	Pre-treat	P_1	%	Pre-treat	P_1	%	Pre-treat	P_1	%
TSS (mg/l)	107.6	12.1	95.5	245.6	33.5	86.36	145.6	23.5	83.86
TN (mg/l)	5.4	3.4	37.04	6.4	3.3	48.44	6.6	4.4	33.3
TP (mg/l)	13.2	6.4	51.5	16.85	8.45	49.85	16	1.4	91.25
COD (mg/l)	212	135	36.3	112	89	20.54	432	195	54.86
BOD_5 (mg/l)	55	21.54	60.84	67	26.78	60.03	122	61.08	49.93
O&G (mg/l)	82.2	5.1	93.8	112.6	12.3	89.08	42.7	2.1	95.08
e-coli (cfu/100 ml)	$4x10^3$	2,560	36	$18x10^3$	16,000	11.1	$48x10^3$	36,500	23.96
FC (cfu/100ml)	$11x10^3$	$8,3\ x10^3$	24.55	14,000	9,500	32.14	$115x10^3$	98,700	14.18

Table B.9: Pollutant removal at the primary filtration process

Parameter	Household 1			Household 2			Student hostel		
	P_1	P_2	%	P_1	P_2	%	P_1	P_2	%
TSS (mg/l)	12.1	7.3	39.67	33.5	11.1	66.87	23.5	12.4	47.24
TN (mg/l)	3.4	2.8	17.65	3.3	2.1	36.37	4.4	3.03	31.14
TP (mg/l)	6.4	3.1	51.56	8.45	6.01	28.89	1.4	1.0	7.15
COD (mg/l)	135	91	32.59	89.0	21	76.40	195	111	43.08
BOD_5 (mg/l)	21.54	12.83	40.44	26.78	14.53	45.75	61.08	25.62	58.06
O&G (mg/l)	5.1	2.2	56.86	12.3	9.9	19.52	2.1	1.9	9.53
e-coli (cfu/100 ml)	2,560	219	91.45	16,000	1,800	88.75	36,500	1,789	95.10
FC (cfu/100ml)	8,300	946	88.60	9,500	1,450	84.74	9870	2,456	75.12

Table B.10: Pollutant removal at the secondary filtration process

Parameter	Household 1			Household 2			Student hostel		
	P_2	P_3	%	P_2	P_3	%	P_2	P_3	%
TSS (mg/l)	7.3	5.2	28.77	11.1	7.5	32.43	12.4	6.8	45.16
TN (mg/l)	2.8	1.2	57.15	2.1	1.9	20.0	3.03	1.02	66.34
TP (mg/l)	3.1	2.85	8.06	6.01	2.90	51.75	1.0	0.75	25.0
COD (mg/l)	91	25	72.53	21	19	20.0	111	75	32.43
BOD_5 (mg/l)	12.83	5.17	59.71	14.53	6.69	53.96	25.62	13.1	48.87
O&G (mg/l)	2.2	0.90	59.10	9.9	4.2	57.58	1.9	1.1	42.11
e-coli (cfu/100 ml)	219	190	13.24	1,800	430	76.11	1,789	234	86.92
FC (cfu/100ml)	946	455	51.9	1,450	985	32.07	2,456	876	64.33

Table B.11: Pollutant removal at the storage tank

Parameter	Household 1			Household 2			Student hostel		
	P_3	P_4	%	P_3	P_4	%	P_3	P_4	%
TSS (mg/l)	5.2	4.9	5.77	7.5	3.8	49.33	6.8	6.8	0
TN (mg/l)	1.2	1.2	0	1.9	1.9	0	1.02	0.90	11.77
TP (mg/l)	2.85	1.25	56.14	2.90	2.65	8.62	0.75	0.75	0
COD (mg/l)	25	22	12.0	19	18.2	4.21	75	42	44.0
BOD_5 (mg/l)	5.17	4.28	17.22	6.69	5.72	14.5	13.1	11.22	14.35
O&G (mg/l)	0.90	0.70	22.22	4.2	2.15	48.81	1.1	1.0	9.09
e-coli (cfu/100 ml)	190	180	5.26	430	400	6.98	234	200	14.53
FC (cfu/100ml)	455	432	5.05	985	670	31.98	876	764	12.79

B.2.2 Un-sewered settlements

Table B.12: Pollutant removal at the pre-treatment process

Parameter	Phola Park			Wallacedene			Doornbach		
	Influent	Pre-treat	%	Influent	Pre-treat	%	Influent	Pre-treat	%
TSS (mg/l)	2,345	1,289	45.03	1,876	1149	38.75	1,229	978.4	20.39
TN (mg/l)	12.1	7.0	42.15	11.2	3.2	71.43	20.2	11.12	44.95
TP (mg/l)	132.5	120.1	9.36	121.6	76.5	37.09	113.1	67.87	39.99
COD (mg/l)	1,235	1,096	11.26	1,123	986.3	12.17	987	874.7	11.38
BOD_5 (mg/l)	467.8	396.3	15.28	461.3	413.1	10.45	72.1	47.5	34.12
O&G (mg/l)	478	76.5	84.0	435	17.8	95.91	686	18.6	97.29
e-coli (cfu/100 ml)	$68x10^6$	$56x10^6$	17.65	$51x10^6$	$46x10^6$	9.8	TNT	$72x10^6$	28.0
FC (cfu/100ml)	$84x10^6$	$82 x10^6$	2.4	$77x10^6$	$74x10^6$	3.9	TNT	$85 x 10^6$	15.0

Table B.13: Pollutant removal at the settling process

Parameter	Phola Park			Wallacedene			Doornbach		
	Pre-treat	P_1	%	Pre-treat	P_1	%	Pre-treat	P_1	%
TSS (mg/l)	1,289	98	93.4	1149	86.7	92.5	978.4	44.8	52.2
TN (mg/l)	7.0	6.8	2.9	3.2	2.1	34.4	11.12	9.6	13.7
TP (mg/l)	120.1	89.23	25.7	76.5	46.4	39.4	67.87	32.9	51.5
COD (mg/l)	1,096	456.7	58.3	986.3	321.8	67.4	874.7	133.42	84.8
BOD_5 (mg/l)	396.3	87.65	77.9	413.1	87.9	78.7	47.5	14.1	70.3
O&G (mg/l)	76.5	15.6	79.6	17.8	11.4	36.0	18.6	7.2	61.3
e-coli (cfu/100 ml)	$56x10^6$	$45x10^6$	19.7	$46x10^6$	$38x10^6$	17.4	$72x10^6$	$63x10^6$	12.5
FC (cfu/100ml)	$82\ x10^6$	$70x10^6$	14.6	$74x10^6$	$62x10^6$	16.3	$85\ x\ 10^6$	$78x10^6$	8.2

Table B.14: Pollutant removal at the first filtration process

Parameter	Phola Park			Wallacedene			Doornbach		
	P_1	P_2	%	P_1	P_2	%	P_1	P_2	%
TSS (mg/l)	98	23	75.53	86.7	32.2	62.86	44.8	23.2	48.22
TN (mg/l)	6.8	3.2	52.94	2.1	1.4	33.3	9.6	4.12	57.08
TP (mg/l)	89.23	54.2	39.26	46.4	21.3	54.09	32.9	11.6	64.48
COD (mg/l)	456.7	77.6	83.0	321.8	112.6	65.0	133.42	85.43	35.97
BOD_5 (mg/l)	87.65	39.65	54.76	87.9	44.3	49.6	14.1	7.8	44.68
O&G (mg/l)	15.6	8.1	48.08	11.4	2.4	78.95	7.2	3.1	56.94
e-coli (cfu/100 ml)	$45x10^6$	$12x10^3$	99.97	$38x10^6$	$24x10^3$	99.9	$63x10^6$	$38x10^3$	99.9
FC (cfu/100ml)	$70x10^6$	$3x10^3$	99.99	$62x10^6$	$19x10^3$	99.9	$78x10^6$	93,120	99.8

Table B.15: Pollutant removal at the second filtration process

Parameter	Phola Park			Wallacedene			Doornbach		
	P_2	P_3	%	P_2	P_3	%	P_2	P_3	%
TSS (mg/l)	23	18	21.74	32.2	28.3	12.11	23.2	10.9	53.02
TN (mg/l)	3.2	1.1	65.63	1.4	1.1	21.43	4.12	1.65	59.95
TP (mg/l)	54.2	12.3	77.31	21.3	10.4	51.18	11.6	8.13	29.92
COD (mg/l)	77.6	32.3	58.38	112.6	35.8	68.21	85.43	38.75	54.64
BOD_5 (mg/l)	39.65	17.2	56.62	44.3	19.3	56.43	7.8	4.6	41.03
O&G (mg/l)	8.1	2.3	71.6	2.4	1.2	50.0	3.1	1.7	45.16
e-coli (cfu/100 ml)	$12\ x10^3$	1,343	88.8	$24x10^3$	$2x10^3$	91.67	$38x10^3$	$4x10^3$	89.47
FC (cfu/100ml)	$3x10^3$	1,167	61.1	$19x10^3$	3,300	82.63	93,120	1,980	97.88

Table B.16: Pollutant removal at storage tank

Parameter	Phola Park			Wallacedene			Doornbach		
	P_3	P_4	%	P_3	P_4	%	P_3	P_4	%
TSS (mg/l)	18	15	16.7	28.3	21.9	22.62	10.9	8.8	19.27
TN (mg/l)	1.1	1.1	0	1.1	0.8	27.28	1.65	1.4	15.15
TP (mg/l)	12.3	11.5	6.5	10.4	8.8	15.38	8.13	7.12	12.42
COD (mg/l)	32.3	28.8	10.84	35.8	26.2	26.82	38.75	31.4	18.97
BOD_5 (mg/l)	17.2	15.7	8.7	19.3	17.6	8.8	4.6	4.1	10.87
O&G (mg/l)	2.3	1.2	47.83	1.2	0.7	41.67	1.7	0.9	47.06
e-coli (cfu/100 ml)	1,343	932	30.6	$2x10^3$	1,034	48.3	$4x10^3$	2145	46.38
FC (cfu/100ml)	1,167	846	27.5	3,300	1,524	53.82	1,980	1,542	22.12

B.3 Overall removal efficiency and performance of AnUBR

B.3.1: Greywater effluent quality from sewered areas

Table B.17: Greywater from household 1

Parameter							**% Removal**
	Influent	**Pre-treatment**	**P_1**	**P_2**	**P_3**	**P_4**	
Temperature (ºC)	26.1	27.5	28.1	29.5	26.0	25.8	-
pH	6.2	7.3	7.0	7.1	7.2	7.5	-
TSS (mg/l)	107.6	93.8	12.1	7.3	5.2	4.9	95
TN (mg/l)	5.4	4.9	3.4	2.8	1.2	1.2	77
TP (mg/l)	13.2	12.1	6.4	3.1	2.85	1.25	90
COD (mg/l)	212	187	135	91	25	22	89
BOD_5 (mg/l)	55	45.5	21.54	12.83	5.17	4.28	92
O&G (mg/l)	82.2	18.2	5.1	2.2	0.90	0.70	99
e-coli (cfu/100 ml)	$4 x10^3$	3,800	$2,56 x10^3$	219	190	180	95
FC (cfu/100 ml)	$11 x10^3$	10,400	$8,3 x10^3$	946	455	432	96

Table B.18: Greywater from household 2

Parameter							**% Removal**
	Influent	**Pre-treatment**	**P_1**	**P_2**	**P_3**	**P_4**	
Temperature (ºC)	27.7	28.9	29.7	29.3	27.6	27.2	-
pH	7.1	7.3	7.0	7.15	6.9	7.2	-
TSS (mg/l)	245.6	119.5	33.5	11.1	7.5	3.8	98
TN (mg/l)	6.4	5.9	3.3	2.1	1.9	1.9	70
TP (mg/l)	16.85	12.3	8.45	6.01	2.90	2.65	84
COD (mg/l)	112	107	89	21	19	18.2	84
BOD_5 (mg/l)	67	62.82	26.78	14.53	6.69	5.72	92
O&G (mg/l)	112.6	20.5	12.3	9.9	4.2	2.15	98
e-coli (cfu/100 ml)	$18 x10^3$	$17,5 x10^3$	$16 x10^3$	$1,8 x10^3$	430	400	98
FC (cfu/100 ml)	$14 x10^3$	$10,3 x10^3$	$9,5 x10^3$	$1,45 x10^3$	985	670	95

Table B.19: Greywater from student's hostel

Parameter	Influent	Pre-treatment	P_1	P_2	P_3	P_4	% Removal
Temperature (ºC)	26.7	28.1	29.1	29.2	26.2	26.0	-
pH	7.2	7.1	7.0	7.1	7.2	7.5	-
TSS (mg/l)	145.6	134.8	23.5	12.4	6.8	6.8	95
TN (mg/l)	6.6	4.9	4.4	3.03	1.02	0.90	86
TP (mg/l)	16	2.1	1.4	1.0	0.75	0.75	95
COD (mg/l)	432	321	195	111	75	42	90
BOD_5 (mg/l)	122	114.47	61.08	25.62	13.1	11.22	90
O&G (mg/l)	42.7	3.8	2.1	1.9	1.1	1.0	97
e-coli (cfu/100 ml)	48×10^3	42×10^3	36.5×10^3	1,789	234	200	99
FC (cfu/100 ml)	115×10^3	103.4×10^3	98.7×10^3	2,456	876	764	99

B.3.2: Greywater effluent quality from un-sewered areas

Table B.20: Greywater from Phola park informal settlement

Parameter	Influent	Pre-treatment	P_1	P_2	P_3	P_4	% Removal
Temperature (ºC)	21.7	22.4	22.8	23.9	23.8	23.5	-
pH	7.4	7.2	7.4	7.3	7.1	7.2	-
TSS (mg/l)	2,345	1,289	98	23	18	15	99
TN (mg/l)	12.1	7.0	6.8	3.2	1.1	1.1	90
TP (mg/l)	132.5	120.1	89.23	54.2	12.3	11.5	91
COD (mg/l)	1,235	1096	456.7	77.6	32.3	28.8	98
BOD_5 (mg/l)	467.8	396.3	87.65	39.65	17.2	15.7	97
O&G (mg/l)	478	76.5	15.6	8.1	2.3	1.2	99
e-coli (cfu/100 ml)	TNT	56×10^4	80×10^3	12×10^3	1,343	932	99
FC (cfu/100 ml)	TNT	82×10^3	21×10^3	3×10^3	1,167	846	98

Table B.21: Greywater from Wallacedene informal settlement

Parameter	Influent	Pre-treatment	P_1	P_2	P_3	P_4	% Removal
Temperature (ºC)	22.4	22.5	24.7	25.5	25.2	25.9	-
pH	7.1	7.4	7.1	7.22	7.24	7.13	-
TSS (mg/l)	1,876	1149	86.7	32.2	28.3	21.9	99
TN (mg/l)	11.2	3.2	2.1	1.4	1.1	0.8	90
TP (mg/l)	121.6	76.5	46.4	21.3	10.4	8.8	91
COD (mg/l)	1,123	986.3	321.8	112.6	35.8	26.2	98
BOD_5 mg/l)	461.3	413.1	87.9	44.3	19.3	17.6	96
O&G (mg/l)	435	17.8	11.4	2.4	1.8	1.1	99
e-coli (cfu/100 ml)	TNT	6×10^5	18×10^4	24×10^3	2×10^3	1,034	99
FC (cfu/100 ml)	TNT	56×10^4	82×10^3	19×10^3	9,300	1,524	99

Table B.22: Greywater from the Doornbach informal settlement

Parameter							% Removal
	Influent	Pre-treatment	P_1	P_2	P_3	P_4	
Temperature (ºC)	22.1	23.7	23.6	24.1	23.8	23.7	-
pH	7.8	7.5	7.3	7.4	7.3	7.3	-
TSS (mg/l)	1,229	978.4	44.8	33.2	20.9	19.8	98
TN (mg/l)	20.2	11.12	9.6	4.12	1.65	1.4	93
TP (mg/l)	113.1	67.87	32.9	11.6	8.13	7.12	94
COD (mg/l)	987	874.7	133.42	85.43	38.75	31.4	97
BOD_5 (mg/l)	72.1	47.5	14.1	13.8	7.6	5.9	92
O&G (mg/l)	686	18.6	7.2	5.1	2.7	2.1	99
e-coli (cfu/100 ml)	$56x10^4$	$12x10^4$	$63x10^3$	$38x10^3$	$9x10^3$	1,102	99
FC (cfu/100 ml)	$> 1x10^5$	10×10^3	$151,3 \times 10^3$	93,120	1,980	1,342	98

Appendix C: Continuous experiments

C.1 Characteristics of raw greywater

C.1.1 Greywater from Student's hostel (sewered areas)

Table C.1: Characteristics of influent greywater (Student's Hostel)

Parameter	Student's Hostel				
	Day 1	Day 2	Day 3	Day 4	Day 5
Temperature (ºC)	29	30	28	30	30
pH	7.2	7.1	7.2	6.9	6.7
TSS (mg/l)	135.6	124.8	108.6	112.4	121.5
TN (mg/l)	6.4	6.1	6.7	5.4	5.7
TP (mg/l)	12.3	9.8	18.6	13.2	12.8
COD (mg/l)	235	221.3	230.8	216	219.7
BOD_5 (mg/l)	112.4	103.8	113.4	63.2	98.8
O&G (mg/l)	48.9	42.8	46.4	64.5	41.8
e-coli (cfu/100 ml)	$3x10^3$	$3.2x10^4$	$2.2x10^3$	$2.3x10^3$	$1.8x10^4$
FC (cfu/100 ml)	$4.5x10^3$	$3.5x10^4$	$3.1x10^3$	$3.2x10^3$	$3.1x10^4$

Table C.2: Characteristics of influent greywater (student's hostel)

Parameter	Student's Hostel				
	Day 6	Day 7	Day 8	Day 9	Day 10
Temperature (ºC)	29	31	28	30	31
pH	6.9	7.2	7.6	7.3	7.1
TSS (mg/l)	114.8	124.3	121.3	107.7	106.2
TN (mg/l)	6.9	5.2	5.3	6.6	5.3
TP (mg/l)	14.2	7.6	16.9	8.2	9.1
COD (mg/l)	223.4	224.6	215.7	218.6	226.6
BOD_5 (mg/l)	104.7	89.3	92.4	97.7	104.3
O&G (mg/l)	58.1	49.7	49.8	69.0	51.2
e-coli (cfu/100 ml)	$1.8x10^4$	$1.8x10^3$	$1.2x10^4$	$1.3x10^3$	$1.1x10^3$
FC (cfu/100 ml)	$3.1x10^4$	$3.6x10^3$	$3.4x10^4$	$2.1x10^3$	$1.2x10^3$

C.1.2 Greywater from Doornbach informal settlement

Table C.3: Characteristics of influent greywater

Parameter	Doornbach Informal settlement				
	Day 1	Day 2	Day 3	Day 4	Day 5
Temperature (ºC)	23.4	25.6	23.1	22.8	22.3
pH	7.7	7.8	7.6	7.2	6.9
TSS (mg/l)	2358	4540	2183	1986	2124
TN (mg/l)	12.3	13.4	12.6	12.1	11.8
TP (mg/l)	122.4	114.8	124.7	108.9	97.4
COD (mg/l)	1238	1054.2	1124.8	1134	1221.7
BOD_5 (mg/l)	421.9	414.3	404.7	415.8	402.9
O&G (mg/l)	478.4	378.8	317.4	485.8	427.3
e-coli (cfu/100 ml)	TNT*	$7x10^6$	TNT	$7.4x10^5$	$8.1x10^4$
FC (cfu/100 ml)	TNT	$8x10^6$	TNT	$8.2x10^6$	$6.4x10^6$

* TNT: values ≥ 10^8 cfu/100 ml)

Table C.4: Characteristics of influent greywater (Doornbach)

Parameter	Doornbach Informal settlement				
	Day 6	Day 7	Day 8	Day 9	Day 10
Temperature (ºC)	24.6	25.7	25.0	24.7	23.9
pH	7.4	7.4	7.3	7.5	7.1
TSS (mg/l)	1978	2002	1789	1863	1643
TN (mg/l)	10.9	11.2	12.8	12.6	13.2
TP (mg/l)	131.2	117.8	115.6	112.6	119.3
COD (mg/l)	1212.3	1118.2	1098.1	1114.6	1032.3
BOD_5 (mg/l)	401.2	319.7	342.8	369.3	343.4
O&G (mg/l)	481	437.1	524.7	424.6	497.8
e-coli (cfu/100 ml)	$7.8x10^6$	$4.2x10^4$	$3.8x10^5$	$7.2x10^5$	$6.1x10^4$
FC (cfu/100 ml)	$9.2x10^6$	$8.5x10^5$	$8.1x10^5$	$6.5x10^6$	$3.2x10^5$

C.2 Characteristics of effluent at the AnUBR

C.2.1 Greywater from Student's hostel

Table C.5: Greywater treatment in AnUBR day 1

Parameter	Day 1					
	Influent	Pre-treatment	P_1	P_2	P_3	P_4
Temperature (ºC)	29	30.2	32.1	30.4	28.6	26.3
pH	7.2	7.4	7.2	7.1	7.2	7.3
TSS (mg/l)	135.6	126.4	19.8	12.1	6.3	6.2
TN (mg/l)	6.4	4.27	3.6	2.3	0.9	0.63
TP (mg/l)	12.3	10.25	8.6	1.1	0.75	0.60
COD (mg/l)	235	124	89.3	72.4	41.8	31.4
BOD_5 (mg/l)	112.4	102.7	61.4	23.3	11.25	8.37
O&G (mg/l)	48.9	4.25	2.1	1.9	1.21	0.98
e-coli (cfu/100 ml)	$9.3 x10^4$	$8.9x10^4$	$1.3x10^3$	988	184	172
FC (cfu/100 ml)	$1.35x10^5$	$1.35x10^5$	$2.3x10^4$	1575	376	289

Table C.6: Greywater treatment in AnUBR day 2

Parameter	Day 2					
	Influent	Pre-treatment	P_1	P_2	P_3	P_4
Temperature (ºC)	30	30.4	32.2	31.1	29.5	27.3
pH	7.1	7.4	7.5	7.3	7.1	6.9
TSS (mg/l)	124.8	115.7	21.8	13.7	5.9	5.2
TN (mg/l)	6.1	3.98	3.4	2.1	1.1	0.8
TP (mg/l)	9.8	8.84	7.1	1.12	0.88	0.55
COD (mg/l)	221.3	138	92.7	76.4	36.8	29.8
BOD_5 (mg/l)	103.8	96.4	58.6	21.3	9.75	6.15
O&G (mg/l)	42.8	6.5	4.5	3.1	2.4	1.8
e-coli (cfu/100 ml)	$8.1 x10^4$	$6.7x10^4$	$2.5x10^4$	$1.4x10^3$	980	275
FC (cfu/100 ml)	$1.3 x10^5$	$1.25 x10^5$	$2.9x10^4$	$1.8x10^3$	1120	415

Table C.7: Greywater treatment in AnUBR day 3

Parameter	Day 3					
	Influent	**Pre-treatment**	**P_1**	**P_2**	**P_3**	**P_4**
Temperature (ºC)	28.5	30.1	31.4	29.9	28.7	26.8
pH	7.2	7.5	7.4	7.3	7.2	7.0
TSS (mg/l)	108.6	98.9	19.7	11.2	6.1	4.8
TN (mg/l)	6.7	4.75	3.8	2.0	1.3	0.9
TP (mg/l)	18.6	16.65	12.4	3.7	1.95	0.9
COD (mg/l)	230.8	121.7	6.4	3.7	1.95	1.1
BOD_5 (mg/l)	113.4	98.5	61.7	23.8	10.3	7.2
O&G (mg/l)	46.4	8.4	4.3	2.8	2.1	1.8
e-coli (cfu/100 ml)	10×10^4	9.9×10^4	1.6×10^3	1.1×10^3	245	200
FC (cfu/100 ml)	1.6×10^5	1.45×10^5	2.4×10^3	1.2×10^3	540	500

Table C.8: Greywater treatment in AnUBR day 4

Parameter	Day 4					
	Influent	**Pre-treatment**	**P_1**	**P_2**	**P_3**	**P_4**
Temperature (ºC)	30	29.1	31.8	31.4	29.8	29.4
pH	6.9	7.2	7.4	7.2	7.1	7.2
TSS (mg/l)	112.4	96.8	18.7	12.6	9.8	7.6
TN (mg/l)	5.4	3.85	2.7	1.8	1.2	0.9
TP (mg/l)	13.2	10.7	8.3	3.1	1.85	1.25
COD (mg/l)	216	139.9	92.4	71.8	31.4	19.6
BOD_5 (mg/l)	63.2	41.3	4.2	2.4	1.9	1.4
O&G (mg/l)	64.5	9.7	4.2	2.4	1.9	1.4
e-coli (cfu/100 ml)	9.2×10^4	8.5×10^4	1.9×10^3	1.2×10^3	512	430
FC (cfu/100 ml)	1.20×10^5	1.10×10^5	2.6×10^3	1.5×10^3	866	760

Table C.9: Greywater treatment in AnUBR day 5

Parameter	Day 5					
	Influent	**Pre-treatment**	**P_1**	**P_2**	**P_3**	**P_4**
Temperature (ºC)	30.1	29.8	31.1	32.2	30.1	29.6
pH	6.7	6..9	6.1	7.3	7.1	7.3
TSS (mg/l)	121.5	102.3	24.5	12.1	7.3	6.2
TN (mg/l)	5.7	4.84	4.1	3.2	1.24	0.98
TP (mg/l)	12.8	9.75	6.95	1.21	0.96	0.60
COD (mg/l)	219.7	124.3	63.6	49.7	33.1	21.3
BOD_5 (mg/l)	98.8	83.4	45.1	20.3	11.2	9.8
O&G (mg/l)	41.8	4.2	2.3	1.8	1.2	0.8
e-coli (cfu/100 ml)	7.9×10^4	6.9×10^4	1.2×10^4	1.1×10^3	446	214
FC (cfu/100 ml)	1.60×10^5	1.45×10^5	2.3×10^4	1.6×10^3	620	448

Table C.10: Greywater treatment in AnUBR day 6

Parameter	Day 6					
	Influent	Pre-treatment	P_1	P_2	P_3	P_4
Temperature (ºC)	29.6	28.4	29.9	31.2	30.6	30.2
pH	6.9	7.1	7.2	7.0	6.9	7.1
TSS (mg/l)	114.8	97.3	19.8	11.3	6.9	4.3
TN (mg/l)	6.9	5.78	4.3	3.1	1.14	0.92
TP (mg/l)	14.2	10.65	7.98	1.12	0.87	0.75
COD (mg/l)	223.4	187.4	78.3	51.2	29.8	18.6
BOD_5 (mg/l)	104.7	91.8	44.8	21.2	9.7	6.3
O&G (mg/l)	58.1	10.2	5.4	2.3	1.8	1.1
e-coli (cfu/100 ml)	$9.7x10^4$	$9.7x10^4$	$1.1x10^4$	$1.2x10^3$	376	312
FC (cfu/100 ml)	$1.3 x10^5$	$1.20 x10^5$	$1.8x10^4$	$1.7x10^3$	869	674

Table C.11: Greywater treatment in AnUBR day 7

Parameter	Day 7					
	Influent	Pre-treatment	P_1	P_2	P_3	P_4
Temperature (ºC)	31	29.6	30.4	31.4	30.6	30.1
pH	7.2	7.4	7.4	7.2	7.0	7.2
TSS (mg/l)	124.3	99.8	20.1	10.4	5.8	3.9
TN (mg/l)	5.2	4.89	3.6	2.9	1.35	0.85
TP (mg/l)	7.6	6.1	4.85	1.10	0.90	0.72
COD (mg/l)	224.6	166.4	72.3	49.6	26.1	13.4
BOD_5 (mg/l)	89.3	75.5	36.4	16.3	7.2	4.2
O&G (mg/l)	49.7	10.1	3.8	1.7	1.1	0.8
e-coli (cfu/100 ml)	$8.9x10^4$	$8.3x10^4$	$1.3x10^3$	776	210	130
FC (cfu/100 ml)	$2.0 x10^5$	$1.85 x10^5$	$1.9x10^3$	1120	250	200

Table C.12: Greywater treatment in AnUBR day 8

Parameter						
	Influent	Pre-treatment	P_1	P_2	P_3	P_4
Temperature (ºC)	28.6	28.2	29.9	31.2	30.9	29.6
pH	7.6	7.4	7.1	7.3	7.4	7.4
TSS (mg/l)	121.3	102.8	22.6	11.2	5.7	4.9
TN (mg/l)	5.3	4.12	3.6	2.9	1.0	0.9
TP (mg/l)	16.9	14.3	11.4	1.0	0.70	0.68
COD (mg/l)	215.7	187	132	90	23	21
BOD_5 (mg/l)	92.4	86.3	78.2	32.3	9.2	7.1
O&G (mg/l)	49.8	9.5	4.3	2.2	0.98	0.80
e-coli (cfu/100 ml)	$8.6x10^4$	$8.2x10^4$	$9.5x10^3$	548	185	160
FC (cfu/100 ml)	$1.80 x10^5$	$1.65 x10^5$	$2.1x10^4$	$1.2x10^3$	987	760

Table C.13: Greywater treatment in AnUBR day 9

Parameter	Day 9					
	Influent	**Pre-treatment**	**P_1**	**P_2**	**P_3**	**P_4**
Temperature (ºC)	30	29.6	30.3	32.0	30.3	29.8
pH	7.3	7.1	7.0	7.2	7.2	7.3
TSS (mg/l)	107.7	91.6	12.1	7.2	4.9	4.3
TN (mg/l)	6.6	4.90	4.4	3.1	1.1	0.9
TP (mg/l)	8.2	7.1	6.3	2.4	1.8	1.6
COD (mg/l)	218.6	192	141	93	62	36
BOD_5 (mg/l)	97.7	89.6	80.1	40.3	18.6	17.2
O&G (mg/l)	69.0	17.6	7.4	3.2	1.4	1.1
e-coli (cfu/100 ml)	$8.5x10^4$	$7.5x10^4$	$1x10^3$	321	219	150
FC (cfu/100 ml)	$1.40\ x10^5$	$1.30\ x10^5$	1.4	842	512	435

Table C.14: Greywater treatment in AnUBR day 10

Parameter	Day 10					
	Influent	**Pre-treatment**	**P_1**	**P_2**	**P_3**	**P_4**
Temperature (ºC)	31	29.6	30.1	32.0	31.3	29.9
pH	7.1	6.9	6.8	7.1	7.3	7.3
TSS (mg/l)	106.2	89.7	11.2	6.2	4.2	3.8
TN (mg/l)	5.3	4.27	3.1	2.0	1.7	1.5
TP (mg/l)	9.1	8.4	6.6	2.2	1.8	1.4
COD (mg/l)	226.6	197	146	96	38	34.2
BOD_5 (mg/l)	104.3	93.7	83.3	39.7	17.8	14.5
O&G (mg/l)	51.2	12.1	6.8	2.9	1.1	0.90
e-coli (cfu/100 ml)	$8.5x10^4$	$7.2x10^4$	920	230	98	90
FC (cfu/100 ml)	$1.20\ x10^5$	$1.10\ x10^5$	$1x10^3$	720	149	135

C.2.2 Greywater from Doornbach

Table C.15: Greywater treatment in AnUBR day 1

Parameter	Day 1					
	Influent	**Pre-treatment**	**P_1**	**P_2**	**P_3**	**P_4**
Temperature (ºC)	23.4	22.6	23.7	24.2	23.6	23.2
pH	7.7	7.3	7.5	7.2	7.0	7.2
TSS (mg/l)	2358	2116.5	78.5	21.2	15.7	9.6
TN (mg/l)	12.3	9.63	8.5	2.9	1.24	1.14
TP (mg/l)	122.4	110.6	96.8	48.4	11.3	8.7
COD (mg/l)	1238	1012	396.8	82.4	32.8	26.7
BOD_5 (mg/l)	421.9	376.3	81.25	36.13	16.21	13.82
O&G (mg/l)	478.4	74.2	15.2	7.9	3.2	1.7
e-coli (cfu/100 ml)	TNT*	$3.5x10^7$	$11x10^3$	1785	987	618
FC (cfu/100 ml)	TNT	$1.98x10^7$	$15x10^3$	2718	1326	956

Table C.16: Greywater treatment in AnUBR day 2

Parameter	Day 2					
	Influent	**Pre-treatment**	**P_1**	**P_2**	**P_3**	**P_4**
Temperature (ºC)	25.6	24.4	25.8	26.2	24.1	23.8
pH	7.8	7.5	7.7	7.8	7.3	7.1
TSS (mg/l)	4540	4063	188.5	96.5	36.8	21.4
TN (mg/l)	13.4	10.80	9.2	2.6	1.2	0.95
TP (mg/l)	114.8	106.3	93.3	39.8	13.2	9.6
COD (mg/l)	1054.2	986.7	289.4	71.6	31.4	24.2
BOD_5 (mg/l)	414.3	378.3	76.2	32.3	15.15	11.25
O&G (mg/l)	378.8	66.5	13.8	6.1	2.4	1.9
e-coli (cfu/100 ml)	$2.17x10^7$	$1.12x10^7$	$3.7x10^4$	$1.8x10^3$	$1.2x10^3$	$1.1x10^3$
FC (cfu/100 ml)	$2.41x10^7$	$1.97x10^7$	$7.4x10^4$	$2.6x10^3$	$1.5x10^3$	$1.3x10^3$

Table C.17: Greywater treatment in AnUBR day 3

Parameter	Day 3					
	Influent	**Pre-treatment**	**P_1**	**P_2**	**P_3**	**P_4**
Temperature (ºC)	23.1	23.9	24.3	24.7	24.1	23.8
pH	7.6	7.1	7.4	7.6	7.1	6.9
TSS (mg/l)	2183	1811	54.6	23.8	11.3	9.6
TN (mg/l)	12.6	10.70	9.12	1.75	1.21	1.10
TP (mg/l)	124.7	102.8	91.8	17.24	9.86	7.15
COD (mg/l)	1124.8	997.1	186.5	102.3	42.8	35.4
BOD_5 (mg/l)	404.7	368.2	74.8	38.1	21.2	17.5
O&G (mg/l)	317.4	23.7	12.8	5.4	3.0	2.3
e-coli (cfu/100 ml)	TNT	$5.3x10^7$	$7.2x10^5$	$2.5x10^3$	$1.3x10^3$	$1.2x10^3$
FC (cfu/100 ml)	TNT	$1.95x10^7$	$9.1x10^5$	$3.3x10^3$	$2.0x10^3$	$1.8x10^3$

Table C.18: Greywater treatment in AnUBR day 4

Parameter	Day 4					
	Influent	**Pre-treatment**	**P_1**	**P_2**	**P_3**	**P_4**
Temperature (ºC)	22.8	23.4	23.8	24.3	23.9	23.6
pH	7.2	6.9	7.1	7.4	7.2	7.2
TSS (mg/l)	1986	1903	92.8	41.5	24.3	18.7
TN (mg/l)	12.1	10.01	9.4	4.5	1.4	1.3
TP (mg/l)	108.9	91.5	81.6	39.8	11.2	8.7
COD (mg/l)	1134	981.6	322.4	114.8	76.2	54.3
BOD_5 (mg/l)	415.8	392.1	76.5	38.0	19.8	12.7
O&G (mg/l)	485.8	32.8	17.5	13.6	3.1	1.42
e-coli (cfu/100 ml)	TNT	$5.3x10^7$	$6.8x10^5$	$3.3x10^3$	$1.3x10^3$	986
FC (cfu/100 ml)	TNT	$2.66x10^7$	$7.2x10^6$	$4.3x10^3$	$1.9x10^3$	$1.5x10^3$

Table C.19: Greywater treatment in AnUBR day 5

Parameter	Day 5					
	Influent	Pre-treatment	P_1	P_2	P_3	P_4
Temperature (ºC)	22.3	22.5	23.6	24.2	23.8	23.6
pH	6.9	6.7	6.9	7.1	7.0	6.9
TSS (mg/l)	2124	1940	78.8	21.4	16.5	13.4
TN (mg/l)	11.8	10.30	8.9	4.2	1.3	1.2
TP (mg/l)	97.4	86.7	71.7	36.4	10.1	6.8
COD (mg/l)	1221.7	1054.2	492.8	88.3	61.2	52.8
BOD_5 (mg/l)	402.9	376.3	69.1	39.4	22.2	20.5
O&G (mg/l)	427.3	36.4	17.8	14.3	2.9	1.65
e-coli (cfu/100 ml)	TNT	$1.98x10^7$	$7.0x10^4$	$1.4x10^3$	891	761
FC (cfu/100 ml)	TNT	$2.50x10^7$	$5.8x10^6$	$1.7x10^3$	$1.4x10^3$	$1.25x10^3$

Table C.20: Greywater treatment in AnUBR day 6

Parameter	Day 6					
	Influent	Pre-treatment	P_1	P_2	P_3	P_4
Temperature (ºC)	24.6	24.9	24.9	25.3	25.4	24.8
pH	7.4	7.2	7.3	7.2	7.1	7.2
TSS (mg/l)	1978	1742	59.6	19.5	13.6	9.8
TN (mg/l)	10.9	8.60	7.2	3.9	1.1	0.9
TP (mg/l)	131.2	109.8	92.8	44.5	12.4	7.4
COD (mg/l)	1212.3	1025.8	443.8	98.1	59.6	45.3
BOD_5 (mg/l)	401.2	369.7	64.2	33.3	21.2	18.2
O&G (mg/l)	481	38.3	18.8	13.2	3.7	1.73
e-coli (cfu/100 ml)	TNT	$1.70x10^7$	$6.1x10^6$	$5.4x10^3$	$1.8x10^3$	$1.28x10^3$
FC (cfu/100 ml)	TNT	$2.8x10^7$	$8.8x10^6$	$9.2x10^3$	$2.3x10^3$	$1.56x10^3$

Table C.21: Greywater treatment in AnUBR day 7

Parameter	Day 7					
	Influent	Pre-treatment	P_1	P_2	P_3	P_4
Temperature (ºC)	25.7	25.3	25.7	26.2	26.4	26.1
pH	7.4	7.1	7.3	7.5	7.3	7.3
TSS (mg/l)	2002	1883	85.6	43.2	29.3	18.6
TN (mg/l)	11.2	9.70	7.3	1.8	1.4	1.21
TP (mg/l)	117.8	108.7	95.6	42.1	10.4	8.6
COD (mg/l)	1118.2	1082.2	158.1	94.3	56.8	43.2
BOD_5 (mg/l)	319.7	281.4	49.7	21.2	13.3	10.9
O&G (mg/l)	437.1	32.2	15.8	9.41	4.38	1.85
e-coli (cfu/100 ml)	TNT	$1.94x10^7$	$3.1x10^4$	$4.2x10^3$	$1.4x10^3$	$1.31x10^3$
FC (cfu/100 ml)	TNT	$1.98x10^7$	$6.9x10^4$	$5.4x10^3$	$2.1x10^3$	$1.9x10^3$

Table C.22: Greywater treatment in AnUBR day 8

Parameter	Day 8					
	Influent	Pre-treatment	P_1	P_2	P_3	P_4
Temperature (ºC)	25.0	24.8	25.2	25.7	25.4	25.1
pH	7.3	7.0	6.8	7.2	7.4	7.3
TSS (mg/l)	1789	1639	52.8	42.1	26.4	22.4
TN (mg/l)	12.8	10.60	8.4	2.8	1.7	1.5
TP (mg/l)	115.6	112.6	102.5	39.9	11.8	9.2
COD (mg/l)	1098.1	919.3	146.1	92.3	51.3	38.7
BOD_5 (mg/l)	342.8	302.4	76.7	37.3	24.5	20.1
O&G (mg/l)	524.7	38.6	18.7	9.75	2.15	1.67
e-coli (cfu/100 ml)	TNT	1.22×10^7	2.9×10^5	3.8×10^3	1.6×10^3	1.5×10^3
FC (cfu/100 ml)	TNT	1.97×10^7	7.0×10^5	4.2×10^3	2.6×10^3	2.1×10^3

Table C.23: Greywater treatment in AnUBR day 9

Parameter	Day 9					
	Influent	Pre-treatment	P_1	P_2	P_3	P_4
Temperature (ºC)	24.7	24.3	24.5	25.2	25.3	25.0
pH	7.5	7.3	7.4	7.4	7.2	7.2
TSS (mg/l)	1863	1619	41.8	20.19	12.7	8.12
TN (mg/l)	12.6	11.20	9.9	2.0	1.5	1.3
TP (mg/l)	112.6	99.4	78.6	40.2	9.9	8.1
COD (mg/l)	1114.6	912.2	342.4	118.9	54.9	34.3
BOD_5 (mg/l)	369.3	317.4	81.3	39.8	20.9	18.6
O&G (mg/l)	424.6	41.7	19.9	8.7	2.3	1.36
e-coli (cfu/100 ml)	TNT	1.9×10^7	6.2×10^5	5.6×10^3	1.4×10^3	1.3×10^3
FC (cfu/100 ml)	TNT	2.51×10^7	5.7×10^6	7.2×10^3	2.2×10^3	1.7×10^3

Table C.24: Greywater treatment in AnUBR day 10

Parameter	Day 10					
	Influent	Pre-treatment	P_1	P_2	P_3	P_4
Temperature (ºC)	23.9	23.6	23.8	24.3	24.6	24.2
pH	7.1	6.9	7.2	7.3	7.3	7.1
TSS (mg/l)	1643	1408	69.7	32.3	10.8	6.14
TN (mg/l)	13.2	11.40	9.2	3.4	1.8	1.4
TP (mg/l)	119.3	102.9	89.3	38.7	12.1	7.6
COD (mg/l)	1032.3	932.4	318.6	129.7	61.8	49.6
BOD_5 (mg/l)	343.4	309.1	64.3	33.5	20.6	16.4
O&G (mg/l)	497.8	42.8	20.2	15.8	4.3	1.54
e-coli (cfu/100 ml)	TNT	1.96×10^7	5.6×10^4	7.1×10^3	1.25×10^3	1.1×10^3
FC (cfu/100 ml)	TNT	1.93×10^7	2.7×10^5	9.8×10^3	1.53×10^3	1.3×10^3

C.3 Pollutant removal at individual unit process

C.3.1 Greywater from student's hostel

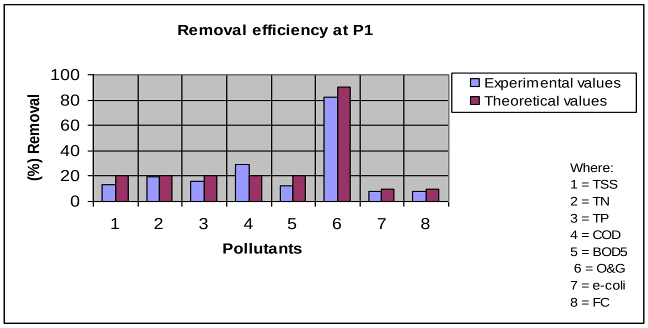


Figure C.1: Pollutant removal at P_1 vs. Theoretical values

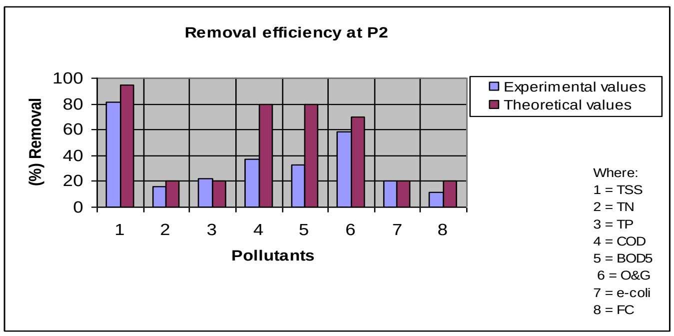


Figure C.2: Pollutant removal at P_2 vs. Theoretical values

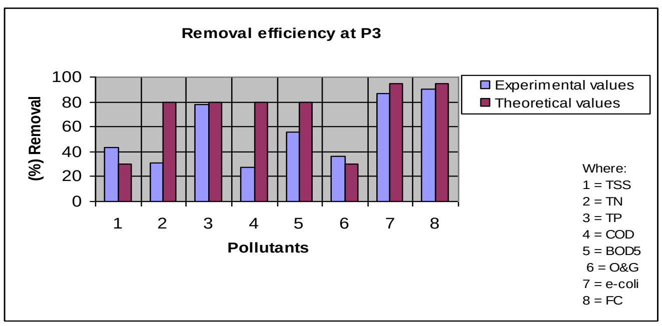


Figure C.3: Pollutant removal at P_3 Vs Theoretical values

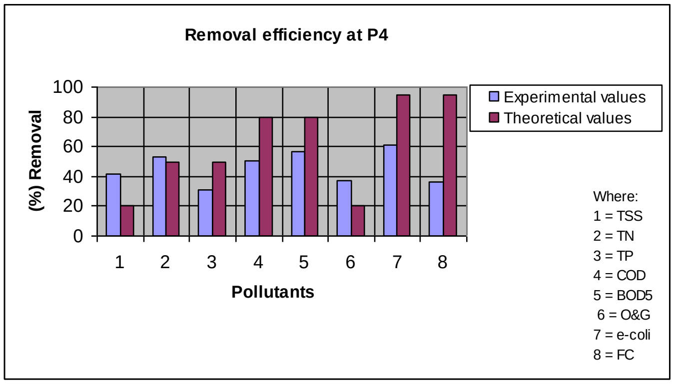


Figure C.4: Pollutant removal at P_4 Vs Theoretical values

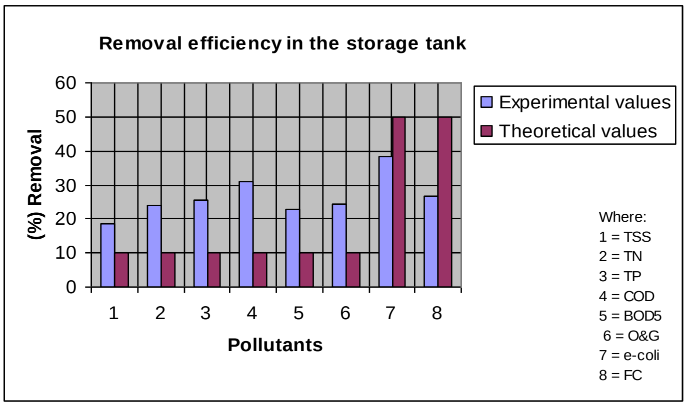


Figure C.5: Pollutant removal at the storage tank vs. Theoretical values

C.3.2 Greywater from the Doornbach informal settlement

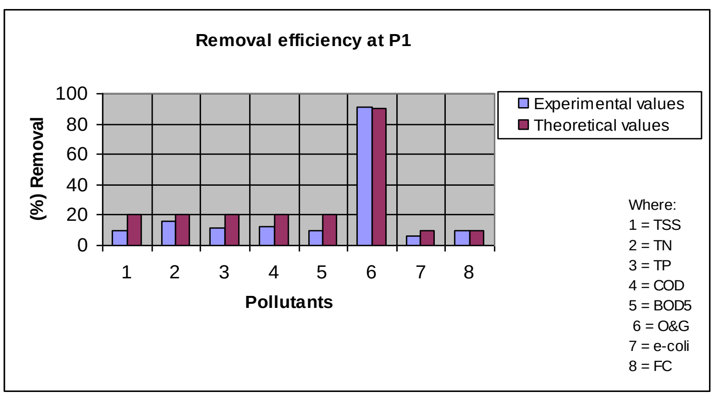


Figure C.6: Pollutant removal at P_1 vs. Theoretical values

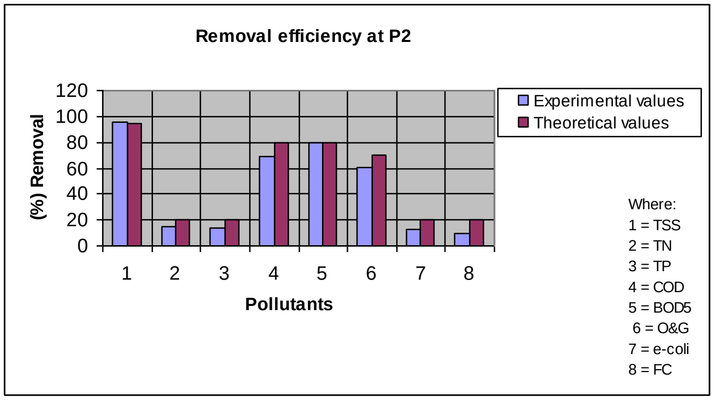


Figure C.7: Pollutant removal at P_2 vs. Theoretical values

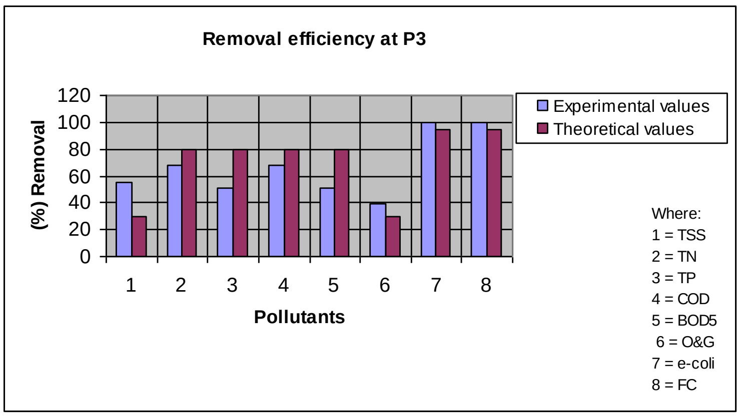


Figure C.8: Pollutant removal at P_3 vs. Theoretical values

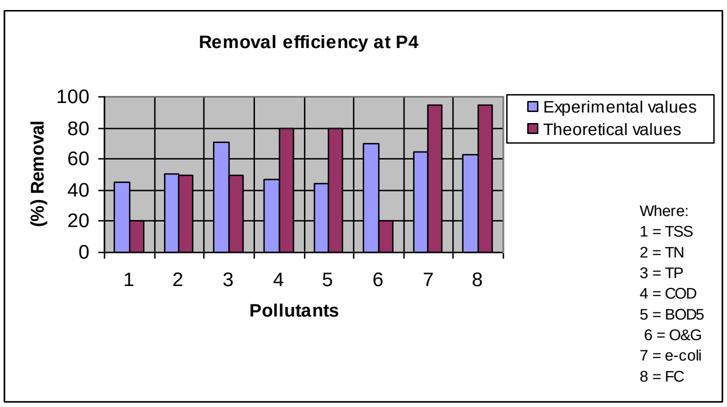


Figure C.9: Pollutant removal at P_4 vs. Theoretical values

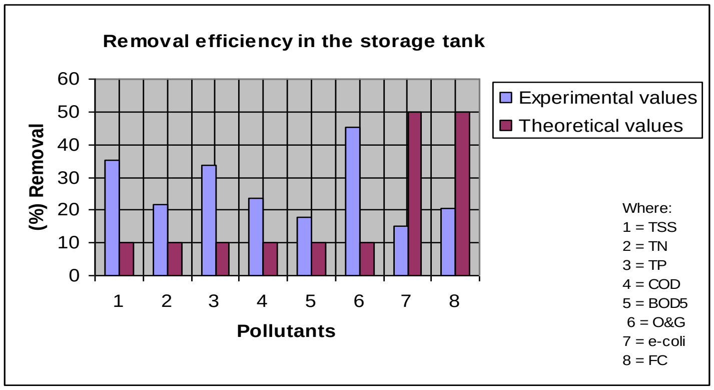


Figure C.10: Pollutant removal at the storage tank vs. Theoretical values

C.4: Overall pollutant removal efficiency from processes

Table C.25: Overall removal in greywater from student's hostel

Parameter	*Unit process removal efficiency (in %)*				
	Pre-treatment	*P_1*	*P_2*	*P_3*	P_4
TSS (mg/l)	13.25	81.37	43.25	41.76	18.60
TN (mg/l)	19.26	15.91	31.35	52.76	24.17
TP (mg/l)	16.22	21.70	77.52	30.94	25.60
COD (mg/l)	29.31	36.85	27.49	50.61	30.88
BOD_5 (mg/l)	12.33	33.08	55.48	56.49	22.89
O&G (mg/l)	82.28	58.64	36.56	37.45	24.35
e-coli (cfu/100 ml)	8.18	19.92	86.47	61.02	38.27
FC (cfu/100 ml)	8.06	11.68	90.22	56.60	25.02
Overall removal	**23.61**	**34.89**	**56.04**	**48.45**	**26.22**

Table C.26: Overall removal efficiency in greywater from Doornbach

Parameter	*Unit process removal efficiency (in %)*				
	Pre-treatment	P_1	P_2	P_3	P_4
TSS (mg/l)	10.02	96.03	54.91	45.47	35.06
TN (mg/l)	16.20	15.34	67.78	50.54	21.59
TP (mg/l)	11.45	13.31	50.69	70.99	33.49
COD (mg/l)	12.77	68.73	67.95	46.74	23.51
BOD_5 (mg/l)	9.51	79.43	51.12	44.12	17.99
O&G (mg/l)	91.01	60.09	38.89	69.77	45.40
e-coli (cfu/100 ml)	5.89	12.5	99.60	64.23	15.16
FC (cfu/100 ml)	9.96	9.68	99.89	62.58	20.64
Overall removal	**20.87**	**44.39**	**66.35**	**56.81**	**26.61**

Appendix D: Laboratory analysis reports

Day 1: Doornbach informal settlement

Cape Peninsula University of Technology

Greywater Quality parameters analysis results

Date: 06/10/2008

Sampled by: NCEDIWE AND MABUWA (15 GREWATER)

At: CWSS PLANT / CPUT BELLVILLE

Parameter	Sampling point					
	Influent	Process 1	Process 2	Process 3	Process 4	Effluent
T (° C)	23,4	22,6	23,7	24,2	23,6	23,2
pH	7,7	7,3	7,5	7,2	7,0	7,2
TSS (mg/l)	2358	2116,5	78,5	21,2	15,7	9,6
NO_3/NO_2 (mg/l) as TN	12,3	9,63	8,5	2,9	1,24	1,14
PO_4 (mg/l) as TP	122,4	110,6	96,8	48,4	11,3	8,7
COD (mg/l)	1238	1012	396,8	82,4	32,8	26,7
BOD_5 (mg/l)	421,9	376,3	81,25	36,13	16,21	13,82
O&G (mg/l)	478,4	74,2	15,2	7,9	3,2	4,7
e-coli (cfu/100ml)	TNT	$3,5 \times 10^7$	11×10^3	1785	987	618
FC (cfu/100ml)	TNT	$1,98 \times 10^7$	15×10^3	2718	1326	956

Analysed at FOOD TECH **by:** NCEDIWE & CLOETE

Indicate the sampling procedures used for each parameter:

....

....

Signature: [signature]

Controlled by: Dr M. Thamae

Day 1: Student's hostel

Cape Peninsula
University of Technology

Greywater Quality parameters analysis results

Date: 18/12/2008

Sampled by: OBADIA & NCEDIWE (HOSTEL GREYWATER)

At: CWSS PLANT /BELLVILLE

Parameter	Sampling point					
	Influent	Process 1	Process 2	Process 3	Process 4	Effluent
T (° C)	29	30,2	32,1	30,4	28,6	26,3
pH	7,2	7,4	7,2	7,1	7,2	7,3
TSS (mg/l)	135,6	126,4	19,8	12,1	6,3	6,2
NO_3/NO_2 (mg/l) as TN	6,4	4,27	3,6	2,3	0,9	0,63
PO_4 (mg/l) as TP	12,3	10,25	8,6	1,1	0,75	0,60
COD (mg/l)	235	124	89,3	72,4	41,8	31,4
BOD_5 (mg/l)	112,4	102,7	61,4	23,3	11,25	8,37
O&G (mg/l)	48,9	4,25	2,1	1,9	1,21	0,98
e-coli (cfu/100ml)	$9,3 \times 10^4$	$8,9 \times 10^4$	$1,3 \times 10^3$	988	194	172
FC (cfu/100ml)	135×10^5	$1,35 \times 10^5$	$2,3 \times 10^4$	1575	376	289

Analysed at ANALCHEM LAB **by:** MABUWA & SHAIDA

Indicate the sampling procedures used for each parameter:

....

....

Signature: [signature]

Controlled by: Dr M. Thamae