PERFORMANCE OF A HORIZONTAL ROUGHING FILTRATION SYSTEM FOR THE PRETREATMENT OF GREYWATER

Submitted in fulfilment for the requirements of the degree of Master of Engineering in the Department of Chemical Engineering in the Faculty of Engineering and the Built Environment at Durban University of Technology, KwaZulu-Natal, South Africa

Mtsweni Sphesihle

July 2016

Supervisors: Dr S. Rathilal Dr B.F. Bakare

DEDICATION

To my family, my parents Mr. and Mrs. Mavis and Koos Mtsweni for their moral support and continuous encouragement and to all who gave continuous assistance during my research and lastly, to the Most High - Jehovah God for the provision of life and strength during this research work.

DECLARATION

I, **Sphesihle Mtsweni**, declare that

(i) This research reported in this thesis except where otherwise indicated is my own original work.

(ii) This thesis has not been submitted for any degree or examination at any other University or academic institution.

(iii) This thesis does not contain other persons' data, pictures, graphs or other information, unless specifically acknowledged as being sourced from other persons.

(iv) This thesis does not contain other persons' writing, unless specifically acknowledged as being sourced from other researchers. Where other written sources have been quoted, then:

   a) Their words have been re-written but the general information attributed to them has been referenced;
   b) Where their exact words have been used, their writing has been placed inside quotation marks, and referenced.

(v) Where I have reproduced a publication of which I am an author, co-author or editor, I have indicated in detail which part of the publication was actually written by myself alone and have fully referenced such publications.

(vi) This thesis does not contain text, graphics or tables copied and pasted from the Internet, unless specifically acknowledged, and the source being detailed in the thesis and in the References sections

Signed: ....

As the candidate's Supervisors we have approved this thesis for submission

Dr B.F. Bakare	Dr S. Rathilal
....	....

ACKNOWLEDGEMENTS

I would really like to thank all the following people and practicing researchers for the support and contribution given to me during this research work in their respective and various roles.

My supervisors, Dr B.F. Bakare and Dr S. Rathilal from Mangosuthu University of Technology and Durban University of Technology for the roles they played in leading and making my research successful through sharing of useful research ideas and constructive criticism from the conceptual stages to the final stages of my research work which was almost on daily basis, the sacrifice through making time for consultations even during busy schedules was also a source of encouragement and was very helpful and remained meaningful to me. This also included positive research arguments which we use to have at times which was also indeed an eye opener and a strong drive to my research. Not least being able to interact at social level which was also needed most given the day to day research milestones to overcome and most of all their long lasting kindness.

My thanks also goes to Mr J. Bwapwa, the researcher, from Mangosuthu University of Technology for his moral support and sharing of useful research ideas around my experimental work and his ever willingness to give guidance during my experimental work. Also the oral and critical assessment discussions of my work from the beginning of my research was always helpful and informative. Not least being always availing himself for assistance and his optimism of the success of my research from early stages to the final stages of my research, indeed it was a source of inspiration to me.

My thanks also goes to the following researchers, Mr F. Mhlanga, Mr A.K. Tumba and O. Nkwonta in Mangosuthu University of Technology for sharing of useful and informative research ideas during the beginning of my research work and the guide in my experimental approach work from time to time.

Mr Khaya Pearlman Shabangu, my colleague and an industrial technician at Mangosuthu University of Technology for the support and sharing of technical ideas throughout my research almost on daily basis. I really like to also thank Mangosuthu University of Technology and Durban University of Technology research directorate for financial support given to me during the course of this research work.

Last but not least, my thanks extend to the following people: my mother, my father, my sisters-Nonhlanhla and Ntombi, my nephew-Thabiso and my niece-Nondumiso, family and friends for their moral support throughout this journey of my research.

PUBLICATIONS

1. BAKARE, B.F., **<u>MTSWENI, S</u>**. AND RATHILAL, S. (2015) A pilot study into public attitudes and perceptions towards greywater reuse in low cost housing development in Durban, South Africa. Accepted for publication, *Journal of water reuse and Desalination*. Available online 21 October 2015. 10.2166/wrd.2015.076.

ABSTRACT

A large fraction of the world's population, around 1.1 billion people, do not have access to acceptable sources of water. In South Africa there is a growing pressure on the available freshwater resources. New sources of freshwater supply are becoming increasingly scarce, expensive or politically controversial. This has led to large scale interest in the application of water reclamation and reuse of domestic, mining and industrial wastewater as an alternative water supply sources. This is becoming critical to sustain development and economic growth in the Southern African region. This research aims at providing both social and scientific information on the importance of greywater reuse and recycling as an alternate source to aid water demand management under South African conditions. The approach to this research work was divided into two main thrusts: the first was to gain an understanding of the public attitudes towards the idea of reusing greywater that is usually perceived as wastewater which pose health concerns. The second was to provide an understanding of typical greywater quality in a peri-urban community in Durban, South Africa as well as investigate the suitability of a horizontal roughing filtration system in reducing pollutant strength of contaminants found in greywater for non-potable reuse applications.

In order to achieve the central aim of this research study, the following objectives were considered:

- Investigation of public perception and attitudes towards the reuse of greywater.
- Determination of greywater quality in a peri-urban community in Durban South Africa.
- Investigation of the performance of a horizontal roughing filtration system for the treatment of greywater collected from a peri-urban community in Durban, South Africa.

It was important to have an understanding of public perception and attitudes towards the reuse of greywater because of the fact that the success of any reuse application depends on the acceptance of the public. The methodological approach for this aspect of the research work involved administering of structured questionnaires to residents within the community through field visits. The questionnaire addressed issues related to attitudes towards the reuse of greywater, perceived advantages related to the reuse of greywater and concerns related to

public health issues regarding the reuse of greywater. The successful implementation of any greywater treatment process depends largely on its characteristics in terms of the pollutant strength. The methodological approach for this aspect of the research work involved physico-chemical characterization of the greywater collected from different sources within the households in the peri-urban community. Greywater samples were collected from the kitchen, shower and laundry within each of the households. This aspect of the research work was undertaken to gain an understanding of greywater quality from different sources within and between households. In order to achieve the third objective of this research work, a pilot plant horizontal roughing filtration system was designed and fabricated for the treatment of greywater. The system consisted of three compartments containing different sizes of gravel that served as the filter media. This was done in order to investigate the effect of varying filter media size on the performance of the horizontal roughing filtration system in treating greywater. The system had an adjustable manual valve used in varying the filtration rate. The impact of varying filtration rate on the performance of the horizontal roughing filtration system in treating greywater was also investigated.

The main findings of this research were:

- From the survey conducted, the percentage of the public willing to accept the reuse of greywater within the community was far higher than the percentage opposing its reuse. Concerns have often been expressed by the public that the reuse of greywater could pose possible adverse effects to public health. However, in this pilot study it was found that a higher percentage of respondents (>60%) disagree that the reuse of greywater could negatively impact on public health compared to less than 20% of the respondents that agree. An interesting finding of this study was that a greater percentage of the respondents were willing to have a dual water distribution system installed in their current place of residence.
- The physico-chemical characterization of greywater from different sources within the households investigated indicated that, the quality of greywater varies considerably between all sources and from household to household. None of the households investigated produced the same quality of greywater. It was also found that greywater generated from the kitchen contains the most significant pollutants in terms of the physico-chemical parameters considered in this study compared to the other sources within the household.

- The pilot plant horizontal roughing filtration system demonstrated its suitability for the treatment of greywater for non-potable reuse applications. It was observed that 90% turbidity and 63% Chemical Oxygen Demand reduction was achieved over the entire duration of operation of the horizontal roughing filter. It was also observed that the removal efficiency was significantly higher in the compartment with the smallest filter media size and the removal efficiency was significantly higher at lower filtration rates.

It is therefore concluded from the investigation conducted in this research that the role of the public is a vital component in the development and implementation of any reuse system / application. It was found that there was a relatively high level of acceptance for the reuse of greywater among the respondents within the community where the study was conducted. The greywater characteristics results obtained from this investigation indicated the necessity of treatment prior to disposal in the environment. Also, a low BOD_5/COD ratio of 0.24, which is significantly lower than 0.5, is an indication that the greywater generated from the community cannot be easily treated using biological treatment processes and/or technologies. The pilot horizontal roughing filtration system used for the treatment of greywater in this study demonstrated its suitability for the treatment of greywater for non-potable reuse applications such as irrigation, toilet flushing and washing activities.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

AIDS	Acquired Immune Deficiency Syndrome
ANOVA	Analysis of variance
B	Boron
Black water	Wastewater from flush toilets
BOD	Biological Oxygen Demand
Cl	Chloride
COD	Chemical Oxygen Demand
DO	Dissolved Oxygen
Domestic sewage	Combination of greywater and black water that is discharged to sewer
DWAF	Department of Water Affairs and Forestry
EPA	Environmental Protection Agency
FAO	Food and Agricultural Organization of the United Nations
FCU	Faecal Coliform unit
Greywater	Wastewater that is produced from household processes (e.g. washing dishes, laundry and bathing) without input from toilets
HF	Horizontal Filter
HIV	Human Immunodeficiency Virus
HRF	Horizontal Roughing Filter
IDRC	International Development Research Centre

K	Potassium
L	litre
Mg	Magnesium
N	Nitrogen
Na	Sodium
NH_3	Ammonia
Non-sewered	Without on-site waterborne sanitation
NWA	National Water Act
P	Phosphorous
$PO4^{-3}$	Phosphate
RF	Roughing Filters
SA	South Africa
SS	Suspended Solids
TCU	Total Coliform unit
TKN	Total Kjeldahl Nitrogen
TSS	Total Suspended Solids
UPRS	Up-flow Roughing Filter
UN	United Nations
UPFRF	Up-flow Roughing Filter
US	United States
VS	Volatile Solids
WHO	World Health Organization
WRC	Water Research Council

XOC	Xenobiotic Organic Compound

CHAPTER 1

INTRODUCTION

1.0 BACKGROUND

In South Africa and around the world there is a growing pressure on the available freshwater resources. New sources of freshwater supply are becoming increasingly scarce, expensive or politically controversial. However, various efforts have been made and some underway to identify new means of meeting increasing water demands across the globe. Most importantly, researchers, scientists and government organizations are making efforts to reduce water demands by increasing the efficiency of water use and to expand the usefulness of alternative sources of water which were considered previously unusable. Among these alternative sources of water previously considered unusable is “greywater”.

Greywater is simply referred to as the wastewater generated from household uses like bathing, laundry and washing of dishes without input from toilets (Ludwig, 2006; Jefferson et al., 2004). Greywater is an immense resource that could find significant applications in regions of water scarcity. Greywater may contain many of the same contaminants as raw sewage but generally in lower concentrations. The advantage of greywater reuse either on-site or nearby is that it has the potential to reduce the demand for new water supply, reduce the energy and carbon footprint of water services and meet a wide range of social and economic needs (Carden et al., 2007a).

According to Finley et al. (2009), two-thirds of wastewater generated within households is greywater which is not directly considered for reuse or have proper existing infrastructures for reuse in the communities, whereas reuse of treated greywater can serve as a viable option in reducing fresh water demand (Finley et al., 2009). In South Africa alone, the surface water compared to ground water accounts for about 70% of the water used in both rural and urban communities (Carden et al., 2007a). The major challenge with surface water is the high level of pollution especially in towns and cities due to high exposure from polluted environments which makes it less favourable for reuse and consumption (Rodda et al., 2010).

Most of the developing countries are confronted with financial constraints and competitive demands to secure water resources (Ahsan, 1995). In South Africa, the idea of reusing greywater is slightly improving, however, there are still limitations on greywater regulations, greywater disposal, practices and safety precautions (Carden, et al., 2007a). As the availability of fresh water supply declines, a need for immediate action to address water challenges is becoming urgent in South Africa (Mofokeng, 2008). The reality is that the escalating levels of water demand compared to fresh water supply in South Africa and around the world remains a challenge.

Greywater treatment, recycling and reuse both on-site and at the household level, is a possible option available to minimize fresh water demands (Carden et al., 2006; Pidou et al., 2007). The goal of this research work is to provide appropriate information on the importance of greywater reuse and recycling to aid sustainable water demand management under South African conditions. In order to achieve this, it was important to take the following into consideration; (i) what would be the public attitudes and perception towards the idea of reusing greywater that is usually considered to pose health concerns. (ii) what are the typical characteristics of greywater generated from households as well as if pretreatment of a horizontal roughing filtration system will be sufficient enough in reducing the pollutant strength of contaminants formed in household greywater generated for non-potable reuse applications such as toilet flushing, garden irrigation and washing.

The development of greywater reuse schemes in South Africa have been generally slow compared to some developed countries. It is only of recent that some water authorities in South Africa have begun to shift their focus to identify various water reuse and recycling schemes. Thus, this research work focused on how greywater reuse and recycling can aid sustainable water demand management in South Africa.

1.1 DISSERTATION OBJECTIVES

In order to achieve the central aim of this research study, the following objectives were considered:

- To investigate public perception towards the reuse of treated greywater.
- To determine the greywater quality collected from low cost housing developments in a community in Durban, South Africa.
- To investigate the effects of varying the filtration rate on the effluent quality from the horizontal roughing filter.

- To investigate the effects of the grain size of filter media on the effluent quality from the roughing filter.

The approach of this work involved: (i) Administering survey questionnaires in the Umhlabeni informal settlement in order to investigate the public perception and attitudes towards greywater reuse. Survey responses obtained were analysed statistically and were presented in the form of tables and graphs. (ii) Collection of greywater from the community in order to investigate the pollutants found in the greywater. There were three greywater sources collected and investigated, viz. kitchen, laundry and bathing greywater sources. (iii) Experimental work for the investigation of the horizontal roughing filter performance where a roughing filter was designed and constructed and was operated to conduct experiments using the raw greywater collected in the Umhlabeni informal settlement. There were three filtration rates that were selected and used during the operation of the roughing filter.

1.2 JUSTIFICATION OF RESEARCH

Greywater from low cost communities in Durban are simply discarded. This is due to a lack of greywater treatment infrastructures to treat and recycle for reuse. In most informal settlements, greywater is normally disposed onto the ground by households which has an impact of increasing the pollution level in these settlements particularly in highly and densely populated communities. Such conditions may result in a poor environment and unwanted and unsafe health conditions for individuals in the community. As a result, a closer attention regarding the use and disposal of greywater generated mainly from household activities has the potential to save potable fresh water usage and the development of more greywater treatment systems aimed at overcoming water availability challenges at the household level. This study provides reliable data on greywater quality in the study area and endeavors to also investigate the performance of a treatment technology to treat greywater generated in the community to a standard that could be reused for non-potable applications. Domestic greywater reuse schemes may be a viable option for the future on the basis of this work for the community and at the household level. The research will also provide the context in terms of the information on the ability of horizontal roughing filtration in treating greywater from the study area. The study will also raise the consciousness and awareness of the community regarding greywater reuse.

1.3 DISSERTATION OUTLINE

The research and findings are presented in the following 4 chapters of the dissertation. **C**hapter 2 is the literature review of the key aspects related to greywater quality, greywater reuse applications, challenges of greywater reuse which looks at public acceptability and perceptions. **C**hapter 2 also covers aspects related to the various treatment options applicable to greywater. **C**hapter 3 focuses on the methodological approaches followed in this study. The chapter presents aspects related to the approach used to gain understanding into public attitudes and perceptions towards greywater reuse, the experimental and analytical work conducted for the characterisation of greywater samples collected from different sources within a number of households as well as the approach used for the operation of the horizontal roughing filter in treating greywater. The results of the research findings are presented and discussed in **C**hapter 4. The final conclusions and recommendations are presented in **C**hapter 5 where the dissertation objectives are addressed and the results of the research are evaluated. The schematic representation of the dissertation is provided in Figure 1.

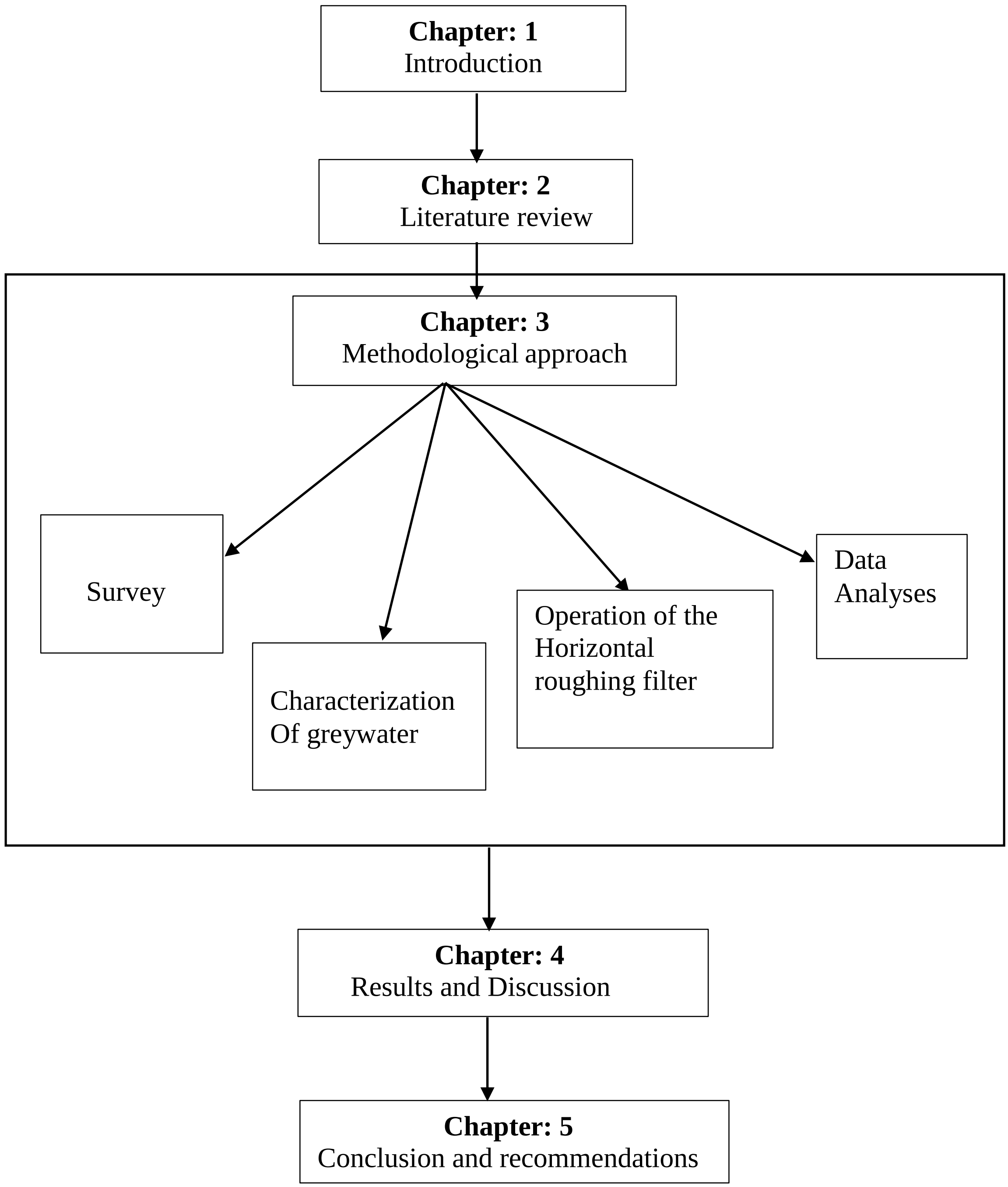

Figure 1: Schematic diagram of the dissertation outline

CHAPTER 2

LITERATURE REVIEW

This chapter defines the context of the problem through a review of literature related to this study. Literature review is presented in four main sections. In the first section, aspects related to greywater characteristics are discussed. The second section focuses on literature review related to greywater reuse applications. Literature review related to challenges of greywater reuse are presented in the third section. The fourth section focuses on the literature review related to different treatment options applicable to greywater. Finally, a summary section is presented which puts this chapter into context of the research problem.

2.1 GENERAL CHARACTERISTICS OF GREYWATER

Greywater approximately makes 60 - 70% of all domestic wastewater by volume in most parts of the developed countries (Finley et al., 2009; Friedler, 2004). According to Carden et al. (2006), it could be assumed that greywater accounts for virtually all water used in non-sewered areas except for that which is used for drinking purposes. Greywater may never be found free of contaminants (Almeida et al., 1999). Bulnes and Garduno (2009) indicates that kitchen and laundry greywater will always be found containing various physical, chemical and biological contaminants from the specific source in which the greywater was generated. Detergents, soaps, fabric softeners, dissolved matter, fats and oils and pathogens are typical examples and indicators of greywater pollution levels. A number of research studies have been conducted to characterize greywater at domestic level (Del Porto and Steinfeld, 2000; Eriksson et al., 2003; Eriksson et al., 2002; Ledin et al., 2001; Siegrist et al., 1976; Bodnar et al., 2014), however, the major challenge is that there is still minimal and limited research information available on typical characteristics of greywater in low income communities in the case of South Africa (Carden et al., 2006; Wegelin, 1996). The general characteristics of greywater from different sources within households are presented in Table 2.1.

Table 2.1: Physical and chemical parameters of greywater in Hungary (Bodnar et al., 2014)

Parameter	**Shower/ Bathtub (n=30)**	**Laundry (n=30)**	**Kitchen sink/ Dishwasher (n=30)**
	Mean±SD	Mean±SD	Mean±SD
pH	7.45±0.32	8.40±1.05	7.40±0.22
EC(µS cm-1)	544.35±44.78	1275.73±938.71	827.00±198.25
TDS (mg/l)	412.57±66.20	1232.14±507.41	1095.25±484.23
TS(mg/l)	470.32±142.71	1683.93±879.90	2205.25±905.43
TSS (mg/l)	67.79±64.58	181.2±80.79	840.63±743.15
Turbidity (NTU)	25.45±22.68	218.67±125.83	357.39±216.47
Alkalinity(mmol/l)	5.47±0.72	12.40±7.34	7.15±3.13
BOD_5 (mg/l)	111.85±73.84	635.64±336.22	827.14±198.25
DOC (mg/l)	39.57±19.38	265.82±125.64	335.13±155.16
MBAS (mg/l)	1.60±1.32	37.60±17.37	2.61±1.54

Physical, chemical and biological characteristics of greywater are more essential in accessing the quality of greywater. Hernandez et al. (2007) and Eriksson et al. (2007) indicated that the composition of greywater is a strong function of the source, detergents and the level of nutrients dissolved in the greywater. For instance, a COD value ranging between 13 - 550 mg/l can be expected in domestic greywater. Most of the COD in greywater originates from household chemicals such as detergents. These detergents will also give rise to the level of phosphates (PO_4) and sodium (Na) in the greywater. The total phosphorus concentration in greywater usually ranges between 4 - 14 mg/l (Eriksson et al., 2002). The level of total nitrogen (N) content in greywater is usually lower compared to domestic sewage due to low level of urine content and the total nitrogen concentration in greywater is around 0.6 -74 mg/l (Muanda, 2009).

Greywater temperature is normally reported to be 18 - 30 ^{o}C. These rather high greywater temperatures are associated with the use of warm water for personal hygiene and post potable water use activities (Wegelin, 1996). Biological oxygen demand (BOD), chemical oxygen demand (COD), nitrogen (N), phosphate (P), total dissolved solids (TSS), volatile solids (VS), turbidity and pH are some of the parameters that are often used to measure the quality of greywater (Eriksson et al, 2002). The pH of greywater is reported to be in the range of 7 - 8 (Jefferson et al., 2004) while Christova-Boal et al. (1996) reported a pH of 9.3 - 10 in laundry greywater.

Household chemical compounds normally used in kitchen wastewater and laundry and bathrooms can thus pollute useful greywater. Therefore analysis of greywater for heavy metals is essential if water is to be used for irrigation (Eriksson, et al., 2006). There are 900 xenobiotic organic compounds (XOC's) that have been identified to date by Eriksson et al. (2002) that can be contained in greywater as hazardous elements of heavy metals and toxic elements as a result of chemical compounds used in households (Eriksson et al., 2002). Table 2.2 summarizes typical greywater characteristics collected from different sources.

Table 2.2: Greywater characteristics collected from different sources (Li et al., 2009)

Parameter	**Bathroom**[a]	**Laundry**[a]	**Kitchen**[a]	**Mixed**[a]	**Wash basin**[b]
pH	6.4-8.1	7.1-10	5.9-7.4	6.3-8.1	6.64-7.41
TSS (mg/l)	7-505	68-465	134-1300	25-183	7-445
Turbidity (NTU)	44-375	50-444	298	29-375	7.41-127
COD (mg/l)	100-633	231-2950	26-2050	100-700	85-2423
BOD (mg/l)	50-300	48-472	536-1460	47-466	28-500
TN (mg/l)	3.6-19.4	1.1-40.3	11.4-74	1.7-34.3	
TP (mg/l)	0.11->48.8	ND->171	2.9->74	0.11-22.8	0.66-1.43[c]
Total coliforms (CFU/100 ml)	$10\text{-}2.4\times10^7$	$200.5\text{-}7\times10^5$	$>2.4\times10^8$	$56\text{-}8.03\times10^7$	2800-TNTC
Faecal coliforms (CFU/100 ml)	$0\text{-}3.4\times10^5$	$50\text{-}1.4\times10^3$		$0.1\text{-}1.5\times10^8$	100-TNTC

a: Li et al. (2009); b: Khatun et al. (2011); c: Phosphate (mg/l);
TNTC: Too numerous to count; CFU: Colony forming units.

2.2 GREYWATER REUSE APPLICATIONS

According to various researches conducted, the possible reuse applications for greywater at household levels include most commonly flushing of toilets, and/or garden irrigation (Eriksson et al., 2002; Jamrah et al., 2006; Ludwing, 1995; Nolde, 1999). These two reuse applications alone have the potential to significantly reduce domestic water consumption, since toilet flushing and outdoor watering can respectively represent 30-40% daily water needs (Carden et al., 2007b; Eriksson et al., 2002). The following section presents relevant literature related to greywater use in agriculture and its effect on soil and plants.

2.2.1 GREYWATER REUSE FOR IRRIGATION

Affluent areas have been using greywater for irrigation more often than peri-urban low-income communities and rural settlement communities (Mofokeng, 2008). In rural communities, greywater irrigation is also used even though at a lower scale compared to river water which is mainly used for crop irrigation (Carden et al., 2007a; Martinez et al., 2009). Carden et al. (2007b) reported that greywater irrigation in South Africa is used to a minimal scale mostly in the affluent areas. The irrigation is generally for garden watering and limited vegetable production in certain parts of the low-income communities, rural settlements and peri-urban communities.

Madungwe and Sakuringwa (2007) showed that garden irrigation and landscape irrigation are ranked high as modes of irrigation at domestic level as they are commonly used easily and successfully. However, in the reuse of greywater for irrigation, Roesner et al. (2006) emphasizes the focus on the health and environmental aspects as primary objectives in greywater use as this may have serious implications in soil quality, productivity and life. The short-term and long term soil effects may include accumulation of toxic chemicals, pathogens, high or low pH and salinity (ESCWA, 2003; Toze, 2005; Roesner et al., 2006).

2.2.2. EFFECTS ON SOIL AND PLANTS

One of the negative factors in using insufficient treated greywater is the contamination of plants and soil by pathogens (Roesner et al., 2006; Ottosson and Stenström, 2003; Christova-Boal et al., 1996). Nutrient rich greywater for irrigation may be good for the plants but may also cause eutrophication and oxygen depletion (Morel and Diener, 2006). According to Wegelin (1996), the use of greywater for the purpose of irrigation may thus contain nearly 15 times higher ammonia-nitrogen values compared to when discharged into rivers and streams. On the other hand, water used for irrigation must not contain more than 10 coliforms (faecal) counts/100 ml in greywater which is the recommended value for irrigation (Wegelin, 1996; Morel and Diener, 2006).

Armon et al. (1994) found some relations between plant pollution/contamination level and the quality of effluent water sprayed on test plots. Both plant and soil pollution have a negative effect at the level of the human beings. Human contact for example with the contaminated plants may cause sickness. Santamaria and Toranzos (2003) indicated that pathogens contained in greywater irrigated to soil is to be transported and spread all over depending on climate conditions, soil quality, temperature and pH conditions.

The use of insufficient treated greywater for irrigation must be avoided as this may have negative consequences in chemical properties and/or soil hydrophobic properties (Wiel-Shafran et al., 2006). Christova-Boal et al. (1996) warned about long-term effects against discharging metal-rich greywater in soil such as zinc, aluminum, high relative sodium content (SAR) values. This study indicated that the end-results including soil productivity level, soil alkalinity level and natural soil chemical imbalances will be the key and the major factor resulting in positive or negative effects on soil and plants depending on the rate of decomposition of chemical components, sorption, loading rates, soil types, leaching, and plant uptake (Christova-Boal et al., 1996; Muanda and Lagardien, 2008; Morel and Diener, 2006).

According to Al-Jayyousie (2003) and Carden et al. (2007b), the United States of America, Japan and Australia rank high in greywater research and reuse compared to European and Middle East countries who are also active in greywater research. South Africa is also at a growing phase in implementing regulations and guidelines and practices for greywater use. For the effects of irrigation, Roesner et al. (2006) indicated that greywater composition, the degradation rate of chemical components, sorption, loading rates, soil types, leaching, and plant uptake are important soil quality measures. Salinity, pH and organic compound levels are good indicators/measures of chemical soil quality. However more experimental researches still need to investigate the real effects of using greywater for irrigation on soil and plants.

2.3 CHALLENGES FOR GREYWATER REUSE

Limited human resources, financial constraints, wastewater treatment reliability, water treatment system energy demand, economic feasibility of the system, public perception and willingness, social and institutional acceptance level, water right issues and political environment and processes, sufficient and consistent codes and guidelines are some of the several challenges related to greywater reuse, success or failure around the globe (Khatun et al., 2011). In South Africa for instance, greywater reuse remains a challenge not because of unwillingness to the adaption of the idea of greywater reuse but due to potable water challenges, price and costs, greywater systems and level of greywater education, traditions and cultural aspects of the society with greywater reuse (Carden et al., 2007b).

2.3.1 PUBLIC PERCEPTION TOWARDS THE REUSE OF GREYWATER

To assess various attitudes of the public on greywater reuse, qualitative research studies are often used covering public attitude, perceptions, health aspects and challenges. In a research conducted by Dheyaa et al. (2013) in Baghdad, 575 households were selected and participated in a social survey, where 67% of the total participants agreed to the idea of greywater reuse and recycling as water scarcity is evident to all. The study also showed that for assessment of public acceptance of greywater reuse, 31% was totally against the idea. In one other particular previous research carried out in Baghdad, 71.8% of respondents thought that greywater reuse would pose health hazards while 28.2% thought that greywater reuse would not be economically feasible (Dheyaa, 2009).

Public perception of greywater reuse and installation is a major determinant for the success or failure of greywater reuse systems (Adewumi et al., 2010; Godfrey et al., 2005). Carden et al. (2007a), emphasizes public attitude and perceptions as important factors on greywater saving and success schemes or system installations. In the study conducted by Othman et al. (2012), the survey result revealed that 70.5% of the people surveyed fully agreed with the idea of greywater reuse in irrigation, while 13.6% of respondents totally disagreed with the idea of greywater reuse, and 15.9% people failed to decide their standing on greywater reuse for irrigation. In the same research, 93% of the people were unaware of the idea of greywater reuse and its potential importance while 73.2% of respondents expressed willingness to be educated with greywater treatment and reuse. In one other study conducted in Northern Sydney, Australia only 5% of all respondents were non-receptive to greywater reuse. However, 95% of all respondents were receptive to greywater reuse for garden watering (Brown and Davies, 2007).

However, public acceptance towards establishing water reuse projects has been a major challenge and it is in this view that recent studies now considers public acceptance and perceptions of water reuse as one of the key successes of any water reuse projects (Po et al., 2003). According to Po et al. (2005), several factors affects public attitudes towards any reuse schemes which can be issues related to perceived risks, political issues and degree of human contact. Human exposure to water reuse plays a major role towards public acceptance of any water reuse projects because the idea of reusing water in which they perceive to be unsafe or unhealthy is usually a challenge (Brown and Davies, 2007). According to Dolnicar et al. (2011), the willingness to reuse water which involves low human contact such as watering of gardens are generally acceptable by individuals compared to other uses with high chances of personal contact. The study conducted by Bruvold (1998) indicated that the acceptance of water reuse for non-potable uses that involved low human contact such as irrigation was high compared to uses with close human contact such as swimming and drinking. Hurlimann and Dolnicar (2010) found in a large scale study conducted in Australia that 92% of the respondents were willing to use recycled water for garden watering but only 36% were willing to use recycled water for drinking purposes. In one study in Northern Sydney, Australia, conducted by Brown and Davies (2007), 95% of respondents indicated that they were willing to make use of greywater for watering of gardens. Positive perceptions were directly the inverse of the level of physical contact with the water. The concerns raised as key reasons for the lack of acceptance of greywater reuse were about health, water pricing signals, and a belief that using recycled water represented a decrease in the standard of living. According to Brown (2007), health concerns can directly affect the attitude of most people with greywater reuse.

2.3.2 PUBLIC HEALTH CONCERNS

Pollution load in greywater normally include viruses, bacteria and inorganic and organic pathogens which makes greywater unsafe for simple reuse without further precautions (Okun, 2000; Carden et al., 2007b). In Barcelona Spain, Domenech and Saur (2010) indicated some factors that contributes immensely to the acceptance and public attitude of greywater reuse. Health concerns, operational costs and environmental factors were all identified. It was found in this study that the reuse of greywater was seen as relatively safe, within 84% of the respondents perceived health threats associated with the use of greywater to be low or very low.

According to Carden et al. (2007b) young people are the ones at high risk of being affected by pathogens found in greywater if they are exposed in raw and poor treated greywater compared to adults. For instance, in South Africa, Carden et al. (2007b) reported a number of health concerns mainly identified by residents in high density settlements. On-site disposal, stagnant greywater, greywater runoffs, water pools and smell, mosquitoes and flies are some of the serious health and environmental problems encountered in these areas. People at risk are mainly children as they tend to have more chances of contact with greywater during recreation. The risks are associated with weak immune systems, digestive and neurological systems which are still at developmental stages thus causing an impact when exposed to the use of unsafe greywater. However, adults too may be affected by the use of unsafe greywater especially those who have health challenges or poor immune systems due to health problems (Friedler, 2004; Murphy, 2006; WHO, 2006). Also in danger are patients who are suffering from health conditions such as human immune deficiency virus or acquired immune deficiency syndrome (HIV/AIDS), tuberculosis, chronic diseases and all other living people (Carden et al., 2007b). In Australia, western Sydney region, a research study with a total of 275 participants from various socio-economic backgrounds revealed that irrespective of age and gender, water quality is a priority while water availability without restriction is less important. These studies show that despite the general negative public attitude and perceptions in the concept of greywater reuse, public is slowly gaining an interest in water management and saving in almost all parts of the world (AWWA, 1992). In South Africa, there is still a need to investigate public acceptance towards the reuse of greywater and also create awareness towards the importance and underlying opportunities related to the reuse of large volumes of greywater generated in many low cost housing developments spread across the country.

2.4 GREYWATER TREATMENT OPTIONS

Different technologies are now developed and used for greywater treatment purposes. The selection of the specific technology depends on many factors such as operational scale, greywater quality, greywater use context, human capacity and financial resource availability, space availability, social acceptance, hygienic risks, public health aspects, environmental risks and assessments, system energy requirements and demand, feasibility of the system design, greywater reuse guidelines and standards of the country (Ramon, et al., 2004; Morel and Diener, 2006; Friedler, et al., 2006; Pidou, et al., 2007; Jefferson et al., 2004). Existing treatment technologies are:

- Natural treatment systems
- Biological processes
- Chemical processes
- Physical processes

The following sections describes a review of available literature related to these existing treatment technologies.

2.4.1. NATURAL TREATMENT SYSTEMS

One of the most natural treatment systems for wastewater treatment include land treatment, floating aquatic plants and constructed wetlands. These natural treatment systems are often combined with other pretreatment systems for the removal of the gross solids remaining in the wastewater (ESCWA, 2003).

Constructed wetlands are natural treatment systems consisting of approximately a meter deep pond or channel that uses wetland plants to treat wastewater (Kimwaga et al., 2004). These artificially constructed wetlands operate similar to natural wetlands systems that uses ecosystem processes. As water passes through the bed of constructed wetland medium, it becomes naturally treated while pollutants are removed through filtration (Godfrey et al., 2009). Physical, chemical and biological processes are also part of wetland treatment systems as pollutants will be transformed and consumed through biological action in constructed wetlands. Mixed operation aerobic, anoxic and anaerobic stages are part of the operation in the constructed wetlands. Constructed wetlands can treat greywater up to 4000 l/day (Godfrey et al., 2009).

Constructed wetlands comes in different forms and shapes such as horizontal flow constructed wetlands (HFCW), and vertical flow planted gravel filters (VFPGF) or vertical flow constructed wetlands (VFCW) (Kimwaga et al., 2004). Part of use which favors these natural treatment systems compared to other treatment systems is the efficiency and the good ability in the reduction and removing of contaminants in water despite high volumes of waste water to be handled (Ohio EPA, 2007). The use of HFCW can achieve a good removal efficiency of up to 90% and almost all pathogens in water (Godfrey et al., 2009). Industrially, constructed wetlands can handle/pretreat waste-water with a COD value of 500 mg/l (Morel and Diener, 2006). The use of constructed wetland technology is well recommended due to its relative ease of maintenance, capital costs and operating costs compared to conventional waste-water treatment systems involving activated sludge and aeration lagoons (Awaleh and Soubaneh, 2014).

Gross et al. (2007) conducted a study using recycled vertical flow constructed wetland for high strength greywater. The total suspended solids (TSS), biological oxygen demand (BOD_5), chemical oxygen demand (COD), total nitrogen (TN), total phosphorus (TP), anionic surfactants, boron and faecal coliform were all minimized from influent to effluent as shown in Table 2.3.

Table 2.3: Performance parameters of the constructed wetland (Gross et al., 2007)

Parameter	**Influent**	**Effluent**
TSS (mg/l)	158	3
BOD5 (mg/l)	466	0.7
COD (mg/l)	839	157
TN (mg/l)	34.3	10.8
TP (mg/l)	22.8	6.6
Faecal Coliform (CFU /100 ml)	$5 \times 10^7/100$	$2 \times 10^5/100$

For constructed wetland, land area required is about 5 m^2/capita, the flow rate required is 30 l/m^2d and the organic material is 8 g BOD/m^2d. A 0.5 - 1% slope of the impervious liner must also be maintained. Constructed wetlands can be coupled with a disinfection stage if greywater reuse is to be considered and a high efficiency may be expected (Morel and Diener, 2006).

Natural water treatment systems are slowly gaining acceptance worldwide in water treatment due to their high efficiency and low costs involved in maintenance and operation (Razmik, 2006). A table of pollutant removal efficiency of constructed wetlands is summarized below in Table 2.4.

Table 2.4: Pollutants removal efficiency for a constructed wetland (Razmik, 2006)

Parameter	**Influent**		**Effluent**		**Removal (%)**
	mg/l	**$g/(m^2 \cdot d)$**	**mg/l**	**$g/(m^2 \cdot d)$**	
Suspended solids	98.6	5.22	13.6	1.06	86
BOD_5	97.0	4.80	13.1	0.89	86
Total nitrogen	28.5	1.15	18.0	0.78	37
Total phosphorus	8.6	0.33	6.3	0.26	27

2.4.2 BIOLOGICAL TREATMENT SYSTEMS

Fixed film biological rotating drums, membrane bioreactors, biological aerated filters, activated sludge systems, pond stabilization and membrane treatment systems are all different types of biological treatment processes used in water and waste-water treatment (Nolde, 1999; Friedler et al., 2005; Eriksson et al., 2007). The main objective of biological processes is to remove dissolved matter in water and the organic matter present in water. During biological processes, microorganisms consume colloidal matter and dissolved organic matter into settleable matter and gases which are often removed later in sedimentation tanks. Organic content is measured as biological oxygen demand, total organic carbon, chemical oxygen demand and nutrients such as nitrogen and phosphorus. Biological processes are normally classified as aerobic processes, anoxic processes, anaerobic processes, combined processes and pond processes (ESCWA, 2003). These treatment technologies have a wide range of applications in waste-water treatment. However, some of these treatment technologies are at a developmental stage in terms of its applications in greywater treatment due to total costs involved in greywater applications (Al-Jayyousi, 2003).

Biological processes together with filtration can be combined to achieve non-potable greywater standard required for reuse. In a low strength greywater study conducted by Friedler et al. (2005), a combination of chemical treatment of rotatory biological contactor (RBC), sand filtration, and disinfection/chlorination was studied. Course solid removal through screening, sedimentation and sludge removal was part of this study. Performance parameters such as TSS, turbidity, COD, BOD and faecal coliforms were all reduced successfully from influent to the effluent with values of 43 - 16 mg/l, 33 - 1.9 NTU, 158 - 46 mg/l, 59 - 6.6 mg/l and 5.6 x 10^5/100 ml - 9.7 x 10^3/100 ml respectively (Friedler et al., 2005). The study indicated a significant performance improvement compared to single biological water treatment processes.

In one study conducted by Nolde (1999), 7-day biological oxygen demand (BOD_7) was minimized to a value not more than 5 mg/l from a high value of system influent of 250 - 50 mg/l biological influent. After ultra violet (UV) disinfection, a BOD value was decreased well within the greywater reuse standard. Eriksson et al. (2007) also studied three stage RBC, sedimentation, sand filtration and ultra violet performance in low strength greywater treatment.

The influent - effluent COD, BOD, TOC, NH_4-N and orthophosphate were reduced respectively from 142 - 25 mg/l, 93 - 6 mg/l, 72 - 13 mg/l 5.2 - 0.031 and 0.66 - 0.26 mg/l.

Hernandez et al. (2008) conducted a study on a high strength greywater using SBR. The sludge retention time was 378 days and reduced hydraulic time was 5.9 hours. The COD, TP, TN and ammonia were all reduced and the percentage removals achieved were 87%, 34%, 11%, and 45% from influent to effluent. 97% of anionic surfactants were also removed in this water treatment process through aerobic biodegradation.

2.4.3 CHEMICAL PROCESSES

The main categories for chemical processes include: coagulation and flocculation (chemical pre-treatment), photo-catalytic oxidation, ion exchange processes, granular activated carbon (adsorption processes) and chemical disinfection (Li et al., 2009). Chemical treatment systems in waste water treatment around the world are becoming highly important in achieving clean treated water for reuse with no impurities.

The removal of suspended solids through chemical treatment is often achieved by using a series of three stage operating units. The first unit is normally rapid mixing which allows the added chemicals to be completely dispersed and mixed throughout the waste-water for a period of time in a mixing basin (ESCWA, 2003). For the removal of impurities post coagulation and flocculation stages, water is allowed to settle in a clarifier and all impurities are then removed through clarification.

For greywater, chemical processes are well recommended and are able to reduce organic substances and turbidity very well compared to the physical processes (Li et al., 2009). However, chemical processes are slightly less efficient to meet the standards for non-potable reuse purposes for high strength greywater (Li et al., 2009). Chang et al. (2007) investigated the performance of flocculation processes for greywater treatment without combining other chemical processes. COD removal of 70% was achieved and 90% removal of anionic surfactants was achieved while it was identified that organic content was also removed well within the margin of greywater standard for reuse.

Optimum conditions for coagulation and flocculation are more important to achieve maximum reductions of turbidity and microbes in wastewater. Coagulant dose, pH, treated water quality and mixing conditions for flocculation must be monitored for optimum operating conditions (Ongerth, 1990). However, poor monitoring of these may result in poor treatment and less efficient removal of solids and microbes while microbial reductions above 90-99% can be achieved under optimum conditions. This includes all different classes of waterborne pathogens (WHO, 2002). However, less than 90% of microbe reduction can be achieved under sub-optimal conditions (Ongerth, 1990). In a study conducted by Lin et al. (2005) where electro-coagulation combination followed by disinfection with COD, BOD, turbidity and SS values were monitored the percentage reduction of effluent pollution of the respective parameters were 60%, 61%, 91%, and 86%, respectively.

A combined water treatment–physical, biological and chemical is more efficient and effective and can target most of the pollutants in wastewater with success. Thus chemical water treatment processes are well recommended for use compared to any other form of water treatment processes (Awaleh and Soubaneh, 2014). According to Awaleh and Soubaneh (2014), the treatment efficiency/ performance of this process is usually and mainly a function of retention time, temperature, pH, coagulant dose, treated water quality and mixing conditions for flocculation and tank design.

Ion exchange in water treatment is one of the useful chemical processes that has a good benefit for water treatment. Its primary use in water treatment is for softening hardness in water due to the presence of calcium and magnesium in water by using synthetic polymeric resins (Pentamwa, 2011). In other studies, the combined coagulation and ion exchange resin process for greywater treatment collected from the shower showed a success in reducing COD, BOD, turbidity, TN, and PO_4^{3-} from influent to effluent. The efficiency in percentage removals were 64%, 89%, 99%, 13% and 95% respectively (Pidou at al., 2008). Pidou et al. (2008) study is in support of other chemical processes studies such as that of Lin et al. (2005).

Adsorption is a process by which molecules of a dissolved compound collect on and adhere to the surface of an adsorbents solid surface (Awaleh and Soubaneh, 2014). Solids in wastewater may also be removed during the adsorption process. Granular activated carbon is the common adsorbent medium that is normally used to treat wastewater. Its use is recommended due to a high surface area to volume ratio (Olanrewaju and Ilemobade, 2015; Awaleh and Soubaneh, 2014). Adsorption using activated carbon is mainly used for the removal of toxic organic compounds, objectionable taste and odour found in water (Cleary, 2005). Granular or powdered activated carbon are used to treat community water especially in developing countries (Losleben, 2008). Furthermore, granular or pressed carbon black, can be used for point-of-use in household water treatment, combined coagulation, sand filtration and granular activated carbon for the treatment of low strength greywater indicated percentage reductions of COD, BOD, SS from influent to effluent of 92%, 95% and 86%, respectively, (AWWA, 1999; LeChevallier and McFeters, 1990; Soster-Turk et al., 2005).

2.4.4 PHYSICAL TREATMENT SYSTEMS

Physical treatment systems have an important and a significant impact in treatment of waste water for potable purposes. Their impact is generally associated with their good efficiency in treatment of wastewater with minimal cost of maintenance. Physical systems include sedimentation, flotation, membranes and granular media filtration.

There are a wide range of filtration systems which mainly differ in filter material size and for example, more complex filtration systems coupled with activated charcoal/ceramic available in the market today. According to Morel and Diener (1996), coarse filtration is one of the filtration processes used to remove solid content such as hair and food particles in greywater, for example in irrigation sites. In this filtration process, particles of a given size are retained by screens or filter media while allowing filtered water to pass through and only smaller particles filtered out in water. According Morel and Diener (1996), these filters highly reduce the solids present in water to the standard required to meet treatment steps but will not achieve removal of pollution load to the suitable level as some treatment processes can normally achieve (Del Porto and Steinfield, 2000).

The mesh sizes used are normally in the range of 0.03 - 0.16 mm. A good selection of mesh sizes required is important as a smaller size mesh may quickly clog while large mesh sizes may fail to reduce particles successfully. In greywater which normally contains non-biodegradable fibres from laundry water, care must be taken in the design and use of simple coarse filters since greywater normally contains these non-biodegradable fibres due to the fact that they are often too small to be filtered out by simple coarse filters or conventional filters. These non-biodegradable fibres may result in clogging of pipes and irrigation systems (Morel and Diener, 2006).

According to Morel and Diener (2006) coarse filters when used as primary treatment, is not recommended as they tend to create unmanageable filtration problems especially with the treatment efficiency as the treatment efficiency quickly drops if the filters are not well-maintained. The most common challenges are non-biodegradable particles and heavy loads of oil and grease with the potential of clogging coarse filters such as gravel and sand filters. Non-biodegradable filters such as microfibers however will not be retained during filtration and will eventually affect treatment steps. Therefore, good maintenance and washing of filter media is a common practice (Schulz and Okun, 1984; Wegelin, 1996).

Treated water meeting quality standards can be achieved through membrane technologies. In membrane filtration, a semipermeable membrane is employed as it serves as a form of barrier which separates water contaminants due to their pore sizes while permitting water to pass through thus subsequently treating water (ESCWA, 2003; Pirdou et al., 2008). Nano-filtration (NF), ultrafiltration (UF), microfiltration (MF) and reverse osmosis (RO) are all different types of membrane filtration technologies which have been employed in water and waste-water treatment. This filtration technology is generally recommended for use because of their simplicity, good operation and minimal chemicals required. However, fouling is the key factor in membrane filtration performance if treating high polluted water. A pretreatment step is often necessary to reduce the membrane fouling. Membrane filters can fairly remove suspended solids, organics and inorganics, depending on the specific design and purpose of membrane filter while combining different types of membranes can produce good performance (Pirdou et al., 2008).

According to Pirdou et al. (2008) membrane filtration can perform far better in removing suspended solids and dissolved solids compared to removing dissolved organics, however the design is the major variable to achieve this performance. In a study conducted by Sostar-Turk et al. (2005), a comparison of solids removal and dissolved organics of UF of 0.05 μm pore size coupled with RO was investigated using laundry greywater. It was observed that a BOD removal of 56% was achieved using the UF system while 98% was achieved using RO. Ramon et al. (2004) conducted a study using nano-filtration (NF) membrane with different molecular weight cut offs for the treatment of low strength greywater. A better performance was achieved with lower pore sizes and better organics removal and better COD removal respectively.

Gravel filtration has a long history of use in water treatment dating back to early 1800s. Scotland is one of the pioneers in the use of gravel filtration for the treatment of water before slow sand filtration (Cleary, 2005). Roughing filters were eventually converted to slow and rapid filters at the end of the last century. However, since 1960s, gravel filtration resurfaced specifically in developing countries due to less demand of use of chemicals and mechanical equipment but were primarily used in ground water recharge plants together with slow sand filters (Collins et al., 1994b; Cleary, 2005; Wegelin, 1996).

Roughing filters in water and waste-water treatment removes contaminants of the fine solids remaining after the sedimentation stage (Al-Bayati and Habeeb, 2009). According to Al-Bayati and Habeeb (2009), roughing filters perform well in the removal of physical pollution load in water. The good filter performances are associated with their ability to physically retain the solid content and a large filter surface area available which promotes sedimentation (Wegelin, 1996). Also, their ability to operate with relatively small filtration rates enhances adsorption of solids within the filter medium. For example, 60-90% of turbidity removal can be achieved using roughing filters while 60-90% coliform bacteria may be removed. According to Wegelin (1996), roughing filters can improve bacteriological water quality, colour and the amount of dissolved organic matter but to a very limited degree. Because of a greater surface area in roughing filter beds, particles deposited will increase mainly due to increased surface area by filter media inside the filter (Wegelin, 1996). A dome-shaped formation of particles will be formed inside the filter (Wegelin, 1996; Cleary, 2005). Particles continue accumulating inside the bed thus filling all pore spaces available to the bottom of the filter (Wegelin, 1996). A higher accumulation of solids will be evident at the bottom of the filter. The particle removal efficiency in roughing filters is a function of the nature of the solids to be removed, the filter design and water quality (Boller, 1993; Collins, 1994a; Wegelin, 1986).

Based on previous research studies, roughing filtration remains favourable in removing suspended solids, turbidity, coliform bacteria and microbes found in wastewater (Clarke et al., 1996; Collins, 1994a; Galvis, et al., 1998; Wegelin, 1986). For unreadily settling particulates, the use of roughing filtration can maximise the area available for the settling particulates with a higher treatment and removal performance. Roughing filters, compared to plain sedimentation, rank far ahead in terms of performance due to unlimited settling area available for the solids in roughing filters (Wegelin, 1996). Sedimentation, straining, interception, flocculation and absorption are the removal mechanisms in roughing filters which promotes their good performance compared to plain sedimentation methods. (ESCWA, 2003). Therefore roughing filtration characterise the cheapest alternative for water treatment compared to conventional and coagulation water treatment methods which have a greater cost involved (WHO, 2002).

FILTER THEORY AND DESIGN

With the increase in use of roughing filtration, application for conceptual filter theory described by Wegelin (1996) is now becoming more relevant and useful in the design of roughing filtration and in evaluating the performance of the horizontal roughing filtration. When a solid particle in the water passes through a gravel bed, there is a chance to escape the gravel particles or a chance to deposit onto the surface of the gravel. The probability of success of removal and failure is 1/3 and 2/3, respectively. This is the basis of the Wegelin's 1/3–2/3 theory. This theory has been used and/or practiced to formulate the models describing both the filter efficiency and removal efficiency of the horizontal roughing filtration system. According to the available filter theory and Fick's law based on Wegelin (1996), the filter efficiency can be expressed by the filter coefficient λ or,

$$\frac{dC}{dX} = -\lambda c \qquad (2.1)$$

Where C = Solid concentration,

X = Filter depth,

λ = Filter coefficient or coefficient of proportionality.

In the equation above, the concentration gradient is a function of the filter depth. The total length of the filter can be described as the number of parallel plates and act as a multistage reactor so the performance of the horizontal roughing filter can be ascertained on the basis of the results obtained from the small filter cells. The total suspended solid concentration after a length of Δx of the filter cell can be expressed as

$$C_{out} = \sum C_{inlet}\, e^{-\lambda i \Delta x} \qquad (2.2)$$

Where:

λ_i = Filter efficiency of each filter cell,

Δx = Length of experimental filter cell

C_{inlet} and C_{out}= Concentrations of particles in the inlet and outlet of the filter.

From the Eq. (3.1) it is to be stated that after evaluating the filter depth (length) and the filter coefficient and the SS (suspended solids) concentration, the performance efficiency of the filter can be predicted. According to Wegelin (1996), the effluent quantity for the n number of compartments is given by:

$$Ce = C_0 * E_1 * E_2 * E_3 * E_4 * \ldots\ldots\ldots\ldots E_n$$

C_0 = Concentration of the horizontal roughing filter influent,

Ce = Concentration of the horizontal roughing filter effluent

E_1, E_2, E_3, E_4............E_n = Filtration efficiency for the each compartment (1; 2 and 3 respectively). The basic expression for the above relationship is given by,

$$Ce = Coe^{-\lambda L} \qquad (2.3)$$

Where, λ = Coefficient of filtration

L = Length of the filter and the filter efficiency is given by,

$$E = Ce/C_0 = e^{-\lambda L} \qquad (2.4)$$

$$Ce = Co * E \qquad (2.5)$$

E_i = Filter efficiency for (i = 1; 2; 3...n) compartments. The values are obtained either from the table or graphical Nomo-gram developed by Wegelin.

DIFFERENT TYPES OF ROUGHING FILTERS

Cleary (2005) and Wegelin et al. (1991) list up-flow, down-flow and horizontal-flow roughing filters as different types of roughing filters commonly used in roughing filter technology to remove most of the contaminants found in wastewater. Barrett et al. (1991) indicates that the turbidity removal in roughing filters up to 90% can be realized using roughing filter technology alone. Wegelin (1996) shows that 50-90% of turbidity removal can be achieved using up-flow roughing filters (URF). Clarke et al. (1996) obtained a percentage removal of 60-75% using a three stage up-flow roughing filter with different filter medium particle sizes. These studies therefore point out to the good performance of roughing filters as physical mechanism to their qualitative abilities in pollutant removal. Therefore Wegelin et al. (1991) recommends a turbidity of 50-150 NTU to be handled by using up-flow roughing filters, 100 - 400 NTU and beyond using horizontal roughing filters.

HORIZONTAL ROUGHING FILTERS

Horizontal roughing filters usually have unlimited length compared to other different types of roughing filters because of its horizontal geometry which ideally will maximize the filter efficiency (Nkwonta, 2010). However, up-flow roughing filters tend to have a high efficiency in removal of solids compared to any other type of roughing filters, but can be more effective to handle turbidities less than 150 NTU (Wegelin, 1996). Figure 2.1 shows the horizontal and up-flow roughing filters.

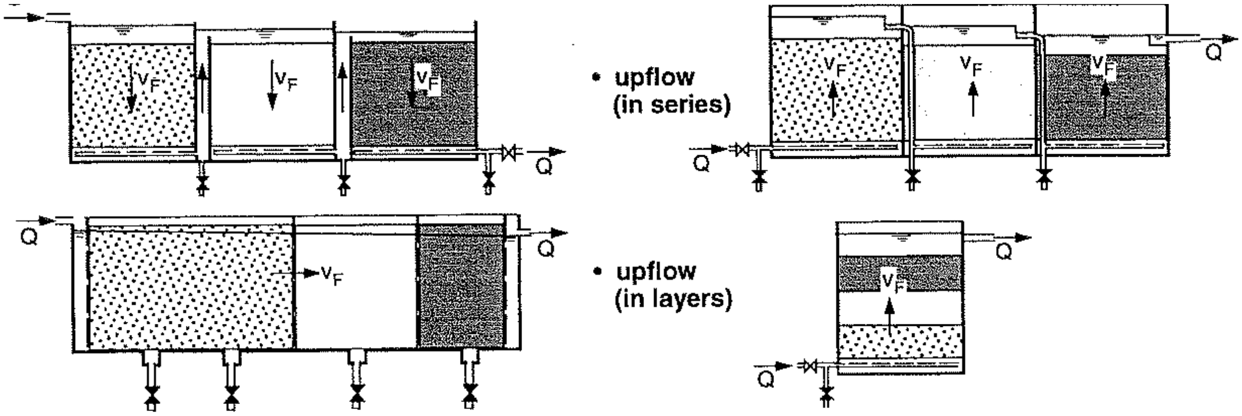

Figure 2.1: Types of roughing filters (Wegelin, 1996)

PRACTICAL EXPERIENCES WITH ROUGHING FILTERS

Galvis et al. (1996) conducted a comparison study of up-flow roughing filters and horizontal roughing filters using highly polluted lowland river water in Columbia. The river water turbidity, colour and faecal coliform were between 15 - 1880 NTU, 24 - 344 TCU and 7300 - 396000 FCU/100 ml respectively. In a horizontal roughing filter the percentage removal obtained for turbidity, suspended solids and faecal coliform were 66.7%, 93.8% and 95% respectively. For up-flow roughing filter: turbidity, suspended solids and faecal coliform were 80%, 97.9% and 99%. The up-flow roughing filter performed far better compared to the horizontal roughing filter. However, frequent cleaning in the up-flow roughing filter was necessary in achieving good filter performance. According to Boller (1993), roughing filters (RFs) may have a long filter run equivalent to a year due to their large storage capacity which allows more accumulation of solids into the filter compartments. Galvis et al. (1998) for instance recommends a hydraulic filter velocity of 0.4 - 0.8 m/h in a horizontal roughing filter for good filter performance.

In a study conducted in the Middle East, a pilot scale horizontal roughing filter was constructed for use in Al-Wehda water treatment plant which treats the raw water of Tigris River in Al-Karradah in Baghdad city. The horizontal roughing filter design characteristics were 5.5 m length x 1 m width x 1 m depth with inlet and outlet weirs of lengths 0.5 m and 0.5 m, respectively. The filter had three compartments of 2 m, 1.5 m and 1 m length, filled with three different sizes of gravel from the first to the last compartment, 15 mm, 10 mm and 5 mm, respectively. The filter was continuously operated for 24 hours for a period of 3 months of 2007. In the first stage, raw water free from any addition was treated using three different flow rates, 1.3, 1.1 and 0.9 m^3/h.

Turbidity, S.S, temperature, pH and bacteriological tests were performed. The mean removal efficiency of turbidity for 1.3, 1.1 and 0.9 m^3/h was found to be 92%, 94% and 95%, respectively while in the second stage raw water with alum addition was used and the filter was operated with a filtration rate of 1.3 m/h. A high performance in turbidity removal of 97% was achieved (Nkwonta, 2010).

In Northern region Ghana (NRG), a pilot horizontal roughing filter at Ghanasco dam in Tamale was used to treat highly turbid dugout water of 305 NTU. The pilot horizontal roughing filter was run for the period of 52 days to test a pilot horizontal roughing filter effectiveness in reducing turbidity from 305 to a value of 50 NTU or less which would have met a criteria for a use of slow sand filtration possible. In this pilot study, a 7 m length horizontal roughing filter with three compartments was used. The compartments were filled up with granite gravel, local gravel and broken pieces of ceramic arranged in order of decreasing size. At a performance level, granite gravel was found to be the best performing media by achieving an average of 46% removal of the influent turbidity and the effluent turbidity of 51 NTU was achieved which is slightly above the 50 NTU value required. The filter coefficient was 0.002/min. The granite gravel removal of 46% was twice as much turbidity removal than plain settling which can only be 25% (Nkwonta, 2010).

In another study conducted in South Africa, Mpumalanga province, a pilot horizontal roughing filter was designed for use by Nkwonta and Ochieng (2009) at Delmas coal. Gravel was used as the filter media. The objective of the pilot horizontal roughing filter was to investigate the ability of removing magnesium and iron in acid mine water. The horizontal roughing filter was designed according to Wegelin design criteria. The filtration rate of 1 m/h was used in the horizontal roughing filter. The filter removed magnesium and iron by 52% and 72%, respectively.

In India a pilot scale horizontal roughing filter was constructed in Jadavpur University in the Department of Water Resources Engineering. The study aimed to investigate the possibility of using a horizontal roughing filter to treat wastewater. A horizontal roughing filter with three compartments was designed. The compartments were filled with gravel medium of average sizes of 12.5 mm in the first compartment, 7.5 mm in the second compartment and 2.5 mm in the third compartment. A 0.75 m/h flow velocity was selected and maintained throughout the filter. The filter was operated for the period of 70 days during dry and rain seasons. The influent raw water used had a concentration of suspended solids in the range 40 -150 mg/l. The removal efficiency is summarized in Table 2.5.

Table 2.5: Filter removal efficiency (Nkwonta, 2010)

Effective size (mm)	**Filtration velocity (m/h)**	**Length of compartment (m)**	**E-value (%)**	**Total E-value**
5	0.75	0.45	21.3	0.026
10	0.75	0.45	19.6	
15	0.75	0.45	26.0	

Table 2.6 presents studies conducted on horizontal roughing filters by different researchers and the percentage removal of pollutants obtained. In the pilot study conducted by Pacini (2005), a percentage removal of 85% and 90% was obtained using a filtration velocity of 1.20 m/h for iron and manganese reduction. Jayalath (1994) however obtained 50% and 80% removal of coliforms and turbidity at a filtration rate of 1.5 m/h. In the other study conducted by Dome (2000), where a filtration velocity of 0.3 m/h was used and 95% and 90% for algae and turbidity removal, respectively in the waste water was achieved. The same percentage removal of algae and turbidity were also obtained in the study conducted by Ochieng et al. (2004) at a slightly reduced filtration velocity of 0.7 m/h, however, Mukhopadhay (2009) obtained a reduced percentage removal of 75% at the same filtration velocity of 0.75 m/h which is the same as that used in the study of Ochieng et al. (2004). Rabidra (2008), however obtained 95% removal for both turbidity and total suspended solids by maintaining 1 m/h filtration velocity.

Mahvi (2004) conducted the study using a filtration velocity of 1.5 m/h, which was slightly lower than that of Pacini (2005) and Dome (2000) and a removal of 90% was obtained. The percentage turbidity removal was even reduced drastically (63.4%) at increased filtration velocities, for example, Dastanaie (2007). Highest percentage removal was obtained from the filtration velocities below 1.5 m/h for colour and turbidity, and above 1.5 m/h for algae removal.

Table 2.6: Studies on HRF by different researchers (Affam and Adlan, 2013)

Filtration Rates (m/h)	Parameters	Percentage Removed (%)	Reference
1.2	Iron and Manganese	85 and 95	Pacini (2005)
0.3	Algae and turbidity	95 and 90	Dome (2000)
1.5	Turbidity	90	Mahvi (2004)
0.75	Turbidity and algae	90 and 95	Ochieng et al. (2004)
1.8	Turbidity, TSS and coliforms	63.4, 89 and 94	Dastanaie (2007)
1.5	Coliforms and Turbidity	50 and 80	Jayalath (1994)
1.0	TSS and Turbidity	95 and 95	Rabindra (2008)
0.75	Turbidity	75	Mukhopadhay (2009)

2.4.6 FACTORS AFFECTING REMOVAL IN ROUGHING FILTERS

THE FILTER MEDIA SIZE

Medium size used in roughing filters directly affect the removal efficiency of the filter. Screening as shown in Figure 2.2 is one of the processes that occurs during the operation of the roughing filter. This process occurs in roughing filters if the size of particle (dp) is larger than the pore size (d_o) of the gravel particle. Reduced media size can improve the roughing filter performance as it would encourage more resistance of solid pollutants in water thus trapping more solids in a filter, however, at an expense of reduced filter run time due to the clogging effect (Collins et al., 1994a). This is due to the reduction in pore area as the filter operates. Therefore, a good design and selection of filter medium size is necessary to achieve high removal of solid content in water (Collins et al., 1994b).

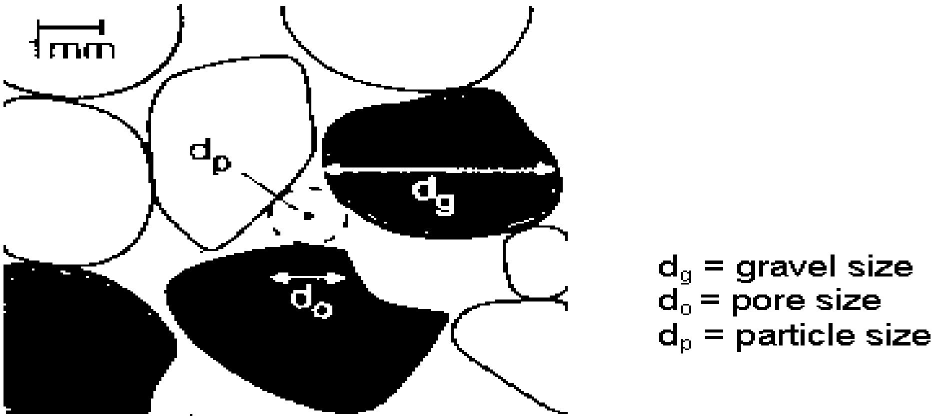

Figure 2.2: Screening (Wegelin, 1996)

Sedimentation is the other process for particle removal in water. It separates settleable solids through gravity (Figure 2.3 below). The solid particles settling in the filter takes into account mass density, size and shape of particles including viscosity and hydraulic conditions of water. These physical properties directly influence the sedimentation process. The solid particles settling will therefore accumulate on the gravel media thus increasing the occupied filter volume (Wegelin, 1996). This reduces the pore size and settling distance which the particles have to travel in order to accumulate on the gravel media.

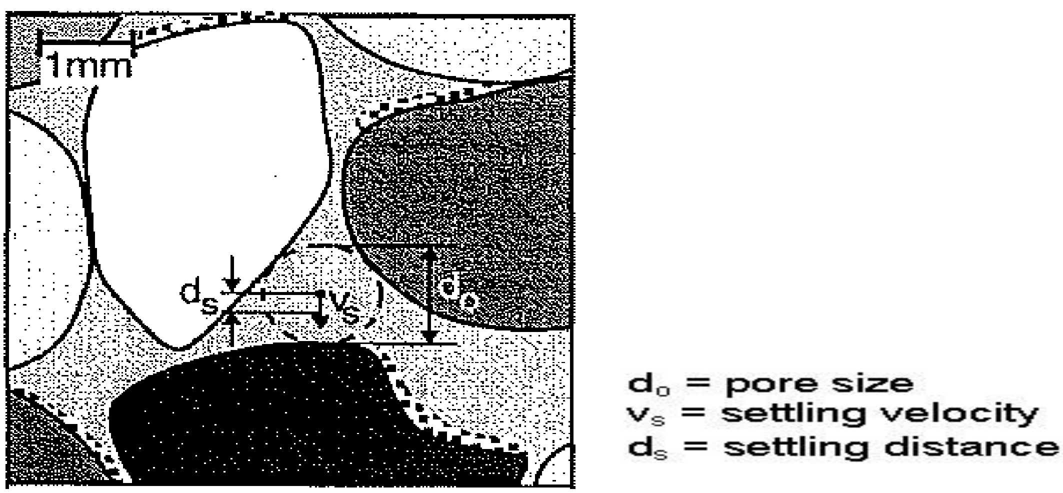

Figure 2.3: Sedimentation on filter media (Wegelin, 1996)

Interception is another process which enhances particle removal in roughing filters through gradual accumulation of solids in the filter as shown in Figure 2.4 below. During interception, there is a gradual reduction of pore size due to solid particles accumulating in the filter. For all particles greater than 1 µm, interception is more dominant and effective in roughing filters. Interception is the removal of solid particles in streamline flow due to contact with the filter medium. Therefore a higher efficiency can be expected with increased solid particles depositing in a filter bed medium according to Collins et al. (1994b).

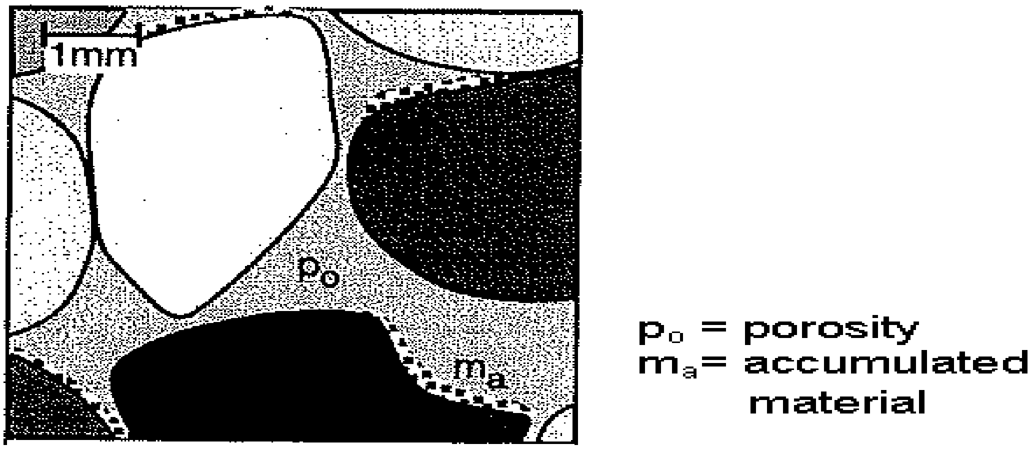

Figure 2.4: Interception effects (Wegelin, 1996)

Therefore, a higher efficiency can be expected with increased solid particles depositing in a filter bed. Diffusion on the other hand becomes dominant for particles less than 1µm and thus a higher efficiency will be evident with decreased solid particles in the filter bed according to Collins et al. (1994b). Sedimentation will become more dominant and effective within the roughing filter due to the presence of gravel media which reduces the settling distance of the solids (Wegelin, 1996).

FILTER FLOW RATE

Reduced flow rate according to Boller (1993) will allow more particles to settle in a filter bed as this will encourage more retention time by particles in the bed to settle and thus encouraging less turbulence and less particle shearing. However, a high capacity filter will be required in order to produce the required treated water effluent.

FILTER LENGTH

The length of the filter according to the Wegelin et al. (1986) affect filter performance in the removal of turbidity. The use of coarse gravel as a single medium in horizontal roughing filter will affect pressure drop and will require longer filter length. To reduce the filter length required, filter medium fractions of different sizes may have to be used. However, good grading of the filter medium and pressure drop across the filter, filter run duration will remain important. Wegelin (1996) stated that operating conditions of flow is important for a good filter performance and further showed filter removal efficiency as a function of flow where a high removal efficiency can be expected with decreased flow or Reynolds number. This can be seen in Figure 2.5 below.

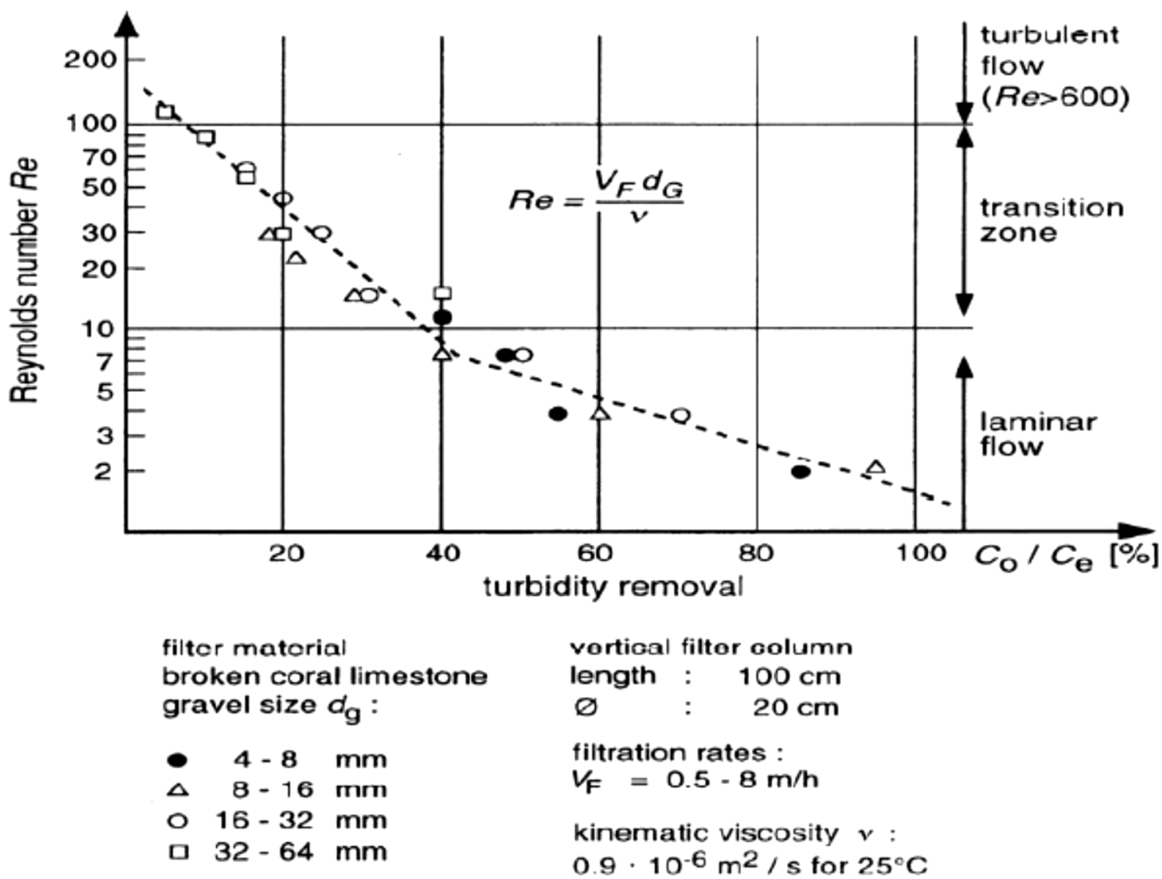

Figure 2.5: Roughing filter efficiency versus flow conditions (Wegelin, 1996)

FILTER DEPTH

Collins et al. (1994b) pointed out bed depth as a factor in the performance of a roughing filter as it will allow more particles to settle in a filter and reduce filter pores of the filter. Mineral particles are mainly affected and influenced by bed depth as the major variable, media size as the second variable and lastly the filtration rate in this order of importance. While organic particles are a function of filtration rate as the major variable, media size as the second variable and filter length in this order of importance. In one research study, Wegelin et al. (1986) discovered that the roughing filters perform far better in removing coarse particles compared to fine particles removal as the smaller particles tend to penetrate into the bed of the roughing filter shown in Figure 2.6 below.

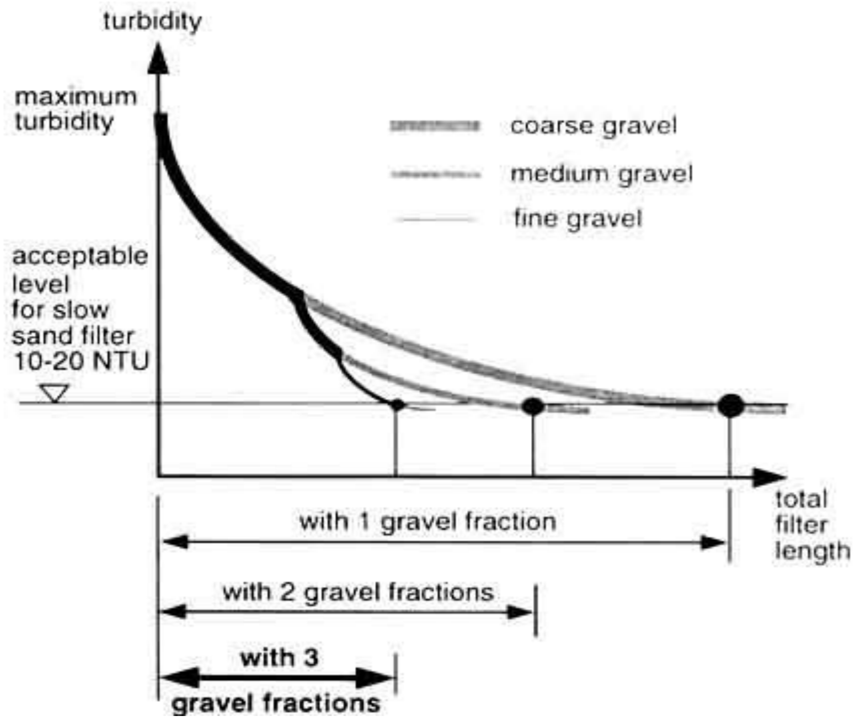

Figure 2.6: Turbidity reduction versus HRF length (Wegelin, 1996)

2.5 SUMMARY OF LITERATURE REVIEWED

A summary of the literature reviewed indicated that greywater accounts for two thirds of all domestic wastewater generated at household levels. With these high volumes generated, the treatment, reuse and recycling of greywater have the potential to reduce significantly the water demands within households.

Based on the literature reviewed, it is clear that any greywater reuse project is bound to fail if certain factors governing its implementation are not considered before the commencement of its implementation. Also, it is clear that any reuse system to be implemented depends not only on engineering and environmental feasibility but most importantly the acceptance of the public to the idea of greywater reuse. It has been also highlighted from the literature reviewed that greywater contains pollutants that could have adverse effects on the environment and public health if not treated before use and that the successful implementation of any greywater treatment process depends largely on its characteristics in terms of pollutant strength.

Also from the literature reviewed, various research studies have indicated that roughing filters have the ability of reducing the contaminants in greywater to a standard for non-potable reuses. Hence the current study investigates acceptance of the public towards the use of greywater, provides an understanding of the characteristics of greywater from low-cost housing developments and also evaluates the performance of the horizontal roughing filter in treating greywater under the South African context. The methodological approach to the study is presented on Chapter 3.

CHAPTER 3

METHODOLOGY

This chapter presents the methodological approach to this study. The chapter is presented in 4 main sections. The first section presents the approach used in gaining an understanding of public acceptability towards the reuse of greywater. The methodological approach used to determine the quality/characteristics of greywater is presented in section 2. The design, operation and the analyses conducted to determine the performance of the horizontal roughing filter in treating greywater is presented in section 3. Section 4, presents the approach and the analyses of data collected was performed.

3.1 METHODOLOGICAL APPROACH CONDUCTED TO DETERMINE PUBLIC ACCEPTANCE AND PERCEPTION TOWARDS GREYWATER REUSE

The study was approved by the Research Ethics Committee at the Faculty of Engineering of both Mangosuthu University of Technology and Durban University of Technology. The ethical guidelines and principles provided by both universities and the South African guidelines for Good Clinical Practice in Human Participants (Department of Health, 2000) were used in conducting the pilot study. The study was conducted in Umhlabeni informal settlement within Umlazi Township located in the South Western part of Durban (Figure 3.1). This area is a low income peri-urban settlement which comprises mainly informal dwellings and is densely populated. No problems were encountered during the administering of the questionnaire and people were willing to participate. All participants involved in the survey were informed of the objectives of the study in their home language (IsiZulu) and signed the informed consent. The survey was conducted anonymously using survey questionnaires - Appendix A. Based on the information provided by the community councilor from the 2014 demographic statistics, there were approximately 3500 dwellings in that community. In order to provide a statistical representation of the community, the determination of the number of households required to conduct this study was based on the statistical calculator for sample estimation presented by Christova-Boal et al. (1996). The calculation indicated that the required number of households for this study should be a minimum of 346. Data was collected by means of structured questionnaires during home visits to all randomly selected households. The questionnaire used were a modification of what was used in a previously conducted study by Adewumi et al. (2010). Data was obtained from owners of each dwelling with a response rate of 100%.

Figure 3.1: Study area – Umhlabeni informal settlement

The study area is a densely populated and covered with informal settlements with limited basic social needs such as drainage and waste management systems, schools and health services (Figure 3.2). The area was selected to obtain good representation and variation in the families and economic conditions which will all have an impact on greywater quality.

Figure 3.2: Greywater runoffs in the study area

3.2 METHODOLOGICAL APPROACH FOR THE CHARACTERISATION OF GREYWATER

This section outlines research undertaken in a low cost housing development, Umhlabeni informal settlement, the study area which was previously identified to conduct research on public attitude and perceptions towards greywater reuse. This section focuses on the methodological approach for the characterisation of greywater collected from different sources in the community. Greywater was collected from thirty households from the kitchen, shower and laundry activities in each household investigated. This was done to provide an understanding of the variability of greywater quality between households and from different sources in each household investigated. Collected greywater was transported to the laboratory at the Chemical Engineering Department at Mangosuthu University of Technology where analysis of the collected greywater was conducted. Analyses was performed immediately when possible however, if not, samples were stored in a cool room at 4 °C for not more than 24 hours before analyses was conducted. All analyses conducted were performed according to the standard methods for the characterisation of water and wastewater (APHA, 1998).

The parameters that were analyzed were: pH, electrical conductivity (EC), turbidity, chemical oxygen demand (COD), biological oxygen demand (BOD_5) and total dissolved solids (TDS). The quality parameters were selected based on their impact to both human health and environmental pollution effects. A brief description of each analysis conducted are presented below.

pH

The pH in all greywater samples collected was measured using pH meter Fisher Model 805. The pH meter was first standardized by 3 standard buffer solutions of 4, 7 and 9 to verify the linear response of the electrode after which the pH of greywater samples are determined. The pH scale ranged from 0 to 14, where 7 indicates a neutral solution, a value less than 7, an acidic solution and a value more than 7, indicates a basic solution. For greywater, the pH value normally ranges from 6.7-7.6 and can go as high as 9.3 to 10 depending largely on the greywater source, detergents used, social living and the level of affordability (Dixon et al., 1999; Christova-Boal et al., 1996).

CONDUCTIVITY

The conductivity test was carried out on greywater samples collected daily using multiline Orion Star A215 conductivity meter. Conductivity measures the amount of dissolved ions in greywater and indicates salinity level of all the ions, both negatively and positively charged, dissolved in greywater. In greywater, high conductivity values are related to phosphates and nitrates, detergents present in greywater, sodium based soaps and washing powders. Conductivity in greywater must be monitored as it can affect and become hazardous to plants and soil if greywater is to be reused for irrigation (Grattan, 2002).

TURBIDITY

Turbidity was measured in all greywater samples collected for analyses using TB 300 IR Turbidity meter. Turbidity measures the presence of particulate matter for inorganic and organics solids in greywater and is measured in terms of suspended solids in the water. Turbidity is associated with the accumulated solid matter in the greywater source collected for analyses. Water may be organic polluted or inorganic polluted or both depending on the nature of particulates found in the greywater. A high value of turbidity in greywater is related to the food particles, oil, colloids, hair and fibres present in greywater which leads to a high solid content in greywater.

CHEMICAL OXYGEN DEMAND (COD)

Chemical oxygen demand is the amount of oxygen required to oxidize the organic matter in the greywater sample by use of dichromate in an acid solution to convert it to carbon dioxide and water. The value of chemical oxygen demand is always higher than the value of biochemical oxygen demand because many organic substances present in greywater can be oxidized chemically rather than biologically. Therefore, chemical oxygen demand is used as a qualitative measure of the pollution of organic and inorganic content in greywater, and is determined by measuring the amount of oxygen content required to oxidize both organic and inorganic contamination in the wastewater samples.

The chemical oxygen demand test was carried out for greywater samples. All greywater samples collected for analyses were oxidized with a known excess amount of potassium dichromate ($K_2Cr_2O_7$). Following oxidation, the samples were then titrated with ferrous ammonium sulphate (FAS) to determine the amount of $K_2Cr_2O_7$ consumed which was then expressed in terms of its oxygen equivalence. A blank sample of the reagent was also tested and this was considered as a control for the entire experiment. The American Standard Method 5220 B and the open reflux procedure were followed, to determine the COD.

BIOLOGICAL OXYGEN DEMAND (BOD)

Biological oxygen demand refers to the content of oxygen that would be consumed by organic matter in one liter of greywater if all organics present in greywater were to be oxidized by bacteria and protozoa (Revelle and Revelle, 1988). The range of possible BOD readings can vary significantly. BOD_5 values in greywater may vary between 192 mg/l and 900 mg/l depending on the greywater source from the kitchen, laundry and bath (Burnat and Mahmoud, 2005).

To measure the level of BOD, samples were collected and using a dissolved oxygen test kit BOD (biochemical oxygen demand) was determined using the 5-day procedure (incubation at 20 °C) with OxiTop manometric equipment. The BOD level was immediately measured by comparing the dissolved oxygen level of the greywater sample taken immediately with the dissolved level of greywater sample that has been incubated in a dark location for five days. The difference between the two dissolved oxygen (DO) levels represents the amount of oxygen required for the decomposition of any organic material in the sample and is a good approximation of the BOD level in greywater. BOD was analyzed using Standard Method 5210 B for wastewater analysis.

TOTAL SOLIDS

Total solids was measured by drying greywater samples in crucibles in an oven at 103 - 105 ^{o}C and weighing the residue. The weight of the residue is the total solids present in the greywater sample. The residue is then ignited in the crucible in a muffle furnace at 550 ^{o}C and allowed to cool in a desiccator. The weight loss on ignition is the amount of volatile solids. These two parameters indicate approximately the amount of organic matter present in the solid fraction of the greywater samples collected. Measurement of total solids were performed on each of the collected samples according to standard methods (APHA, 2005).

3.3 METHODOLOGICAL APPROACH FOR THE DESIGN, OPERATION AND THE PERFORMANCE OF THE ROUGHING FILTER

This section outlines the experimental work undertaken to investigate the performance of a horizontal roughing filtration system treating greywater collected from the informal settlement (Umhlabeni informal settlement). It focuses on the detailed description of the horizontal roughing filter design and setting up of the treatment system, monitoring and experimental procedures conducted.

The horizontal roughing filter system was designed, constructed and installed at the Chemical engineering laboratory at the Mangosuthu University of Technology due to security concerns encountered in the informal settlement. The location was chosen for its suitability to allow strict controlled working conditions and for ease of cleaning and drainage of greywater effluent from the roughing filter including close proximity to the laboratory for experimental analyses.

The horizontal roughing filter system was constructed to investigate whether the concept chosen is technically a viable approach for greywater treatment. The horizontal roughing filter system was designed based on existing design features in accordance with available recommendations made in literature. Wegelin (1996) and Galvis et al. (1998) design guidelines, principles and concepts were followed or adapted for this research.

The components of the horizontal roughing filter system were ordered and built from the plastic product manufacturing company based in Pinetown Durban. The company was provided with needed operational principles and dimensions of a horizontal roughing filter consisting of three compartments with inlet and outlet baffles (Figure 3.3). Detailed dimensions of the horizontal roughing filter are summarized in Table 3.1 below. The main components of the horizontal roughing filter system are: horizontal roughing filter, feed tank, pump, drainage system, gravel media and piping and flow control which will be discussed in detail.

Figure 3.3: Horizontal roughing filter used for experiments

A vertical polyethylene plastic round feed water tank with a capacity of 1000 litres of 1110 mm diameter and 1300 mm height was designed for greywater collected from the community. The tank has the following standard fittings**:** a round outlet or opening of 50 mm diameter outlet from the tank placed 20 mm from the bottom which is used to connect the tank and pump suction side. Secondly, 480 mm lid/round man-hole with e-clips on top of the tank was used as a feed point of greywater into the tank.

The piping and valve material were made of rigid polyvinyl chloride (PVC) and Teflon tubing. The water sampling ports at the outlet baffle were made of PVC material. A 4 mm feeding pipe from the pump was connected and rose to an elevation of 1 m to the inlet baffle of the horizontal roughing filter where greywater was supplied. 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 plastic fittings were used to connect the pipes from the tank extending to the horizontal roughing filter. The influent greywater from the feed tank at constant hydraulic load/filtration rate (0.3-1.5 m/hr) throughout the filter was maintained using a centrifugal pump located at the bottom of the feed tank.

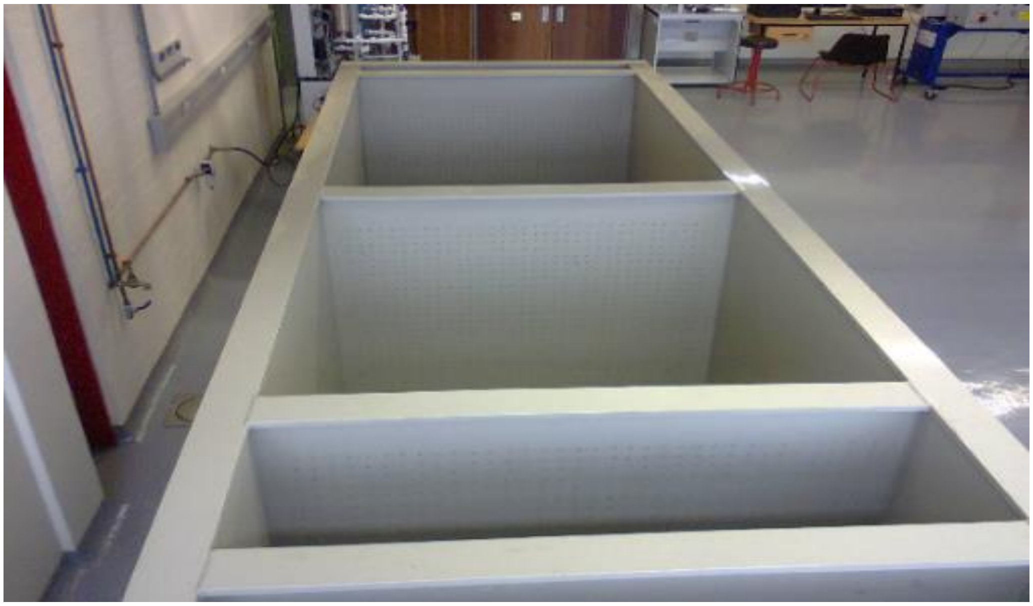

Figure 3.4 Three compartment horizontal roughing filter equipment

Quartzite gravel was selected and used as a filter media in the roughing filter. It was then placed in each of the three compartments (Figure 3.5 below) of the roughing filter starting from the coarse gravel size to the finer gravel size in the direction of water flow making the filter to operate in series. Metal made compartments externally covered with PVC material were filled with the following gravel sizes: 15 - 13.2 mm size gravel in 1st compartment; 13.2 - 9.5 mm in 2nd compartment and 9.5 - 6.7 mm in 3rd compartment. The filter media with different sizes were arranged such that the flow must follow the direction of decreasing media sizes (Boller, 1993; Mahvi et al., 2004). Each filter compartment is designed with the side drainage valve to allow drainage after experimental runs. The perforated PVC material partition was used to avoid gravel mixing in different compartments while allowing effluent to trickle at the minimum flow velocity.

Figure 3.5: Filling of gravel in a roughing filter

The roughing filter was operated for three months and greywater collected from the community was charged into the feed tank through the 480 mm lid on top of the feed tank. Collected greywater was fed directly into the plant which was operated under a temperature range of 21 to 24 °C in the laboratory.

The following operational parameters were considered:

- Raw water quality: the quality of greywater was characterized/analyzed prior to the stage of feeding the horizontal roughing filter.
- A predetermined filtration rate for each batch in the range of 0.3 - 1 m/h was selected using the flow control valve for the required smooth flow of raw greywater into the horizontal roughing filter. Three filtration rates were selected in the operation of a horizontal roughing filter.

The operating mode of the horizontal roughing filter system was based on the batch feeding mode. After filling the feed tank with 420 litres required for the single batch operation, a predetermine filtration rate between 0.3 - 1 m/h had to be selected. The feeding method consisted of manually filling the feed tank with influent greywater in each batch of operation. Afterward the roughing filter system operation begun until the full pretreatment process was completed. The process was operated and was allowed to perform pretreatment as per designed retention time in the roughing filter. The treatment was done per batch and effluent produced allowed to flow out from the outlet baffle. Greywater was collected in the community of the study area throughout this research and was transported from the community to the laboratory for experimental work.

Figure 3.6: Greywater samples collected from the community

The horizontal roughing filter system was normally operated once per day and sometimes twice per day. Prior to feeding with greywater, the feed tank was cleaned using fresh water to ensure that there was no cross contamination from incoming greywater. The feed tank was filled with greywater directly after cleaning. Water samples were collected from the filter bed using sample bottles at predetermined intervals. The samples were collected in each compartment of the sampling ports of the horizontal roughing filter and subsequently at the outlet of the horizontal roughing filter during its operation. Figure 3.7 shows the influent and effluent greywater streams and sample points.

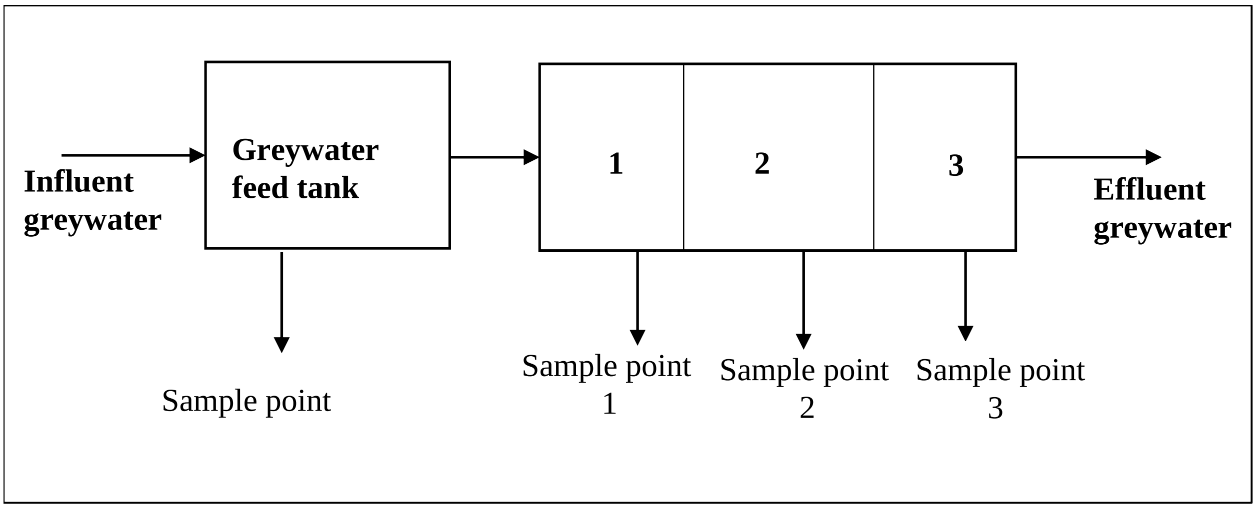

Figure 3.7: Influent and effluent greywater streams and sample points

Table 3.1 summarises of the recommended and the design parameters used in this study.

Table 3.1: Horizontal roughing filter design parameters

Design parameter		**Recommended literature value**	**Design parameter value**
Gravel media	Compartment 1(mm)	20 - 12[a]	15 - 12.2
	Compartment 2(mm)	12 - 8[a]	12.2 - 9.5
	Compartment 3(mm)	8 - 4[a]	8 - 6.7
Gravel type		(granite. quartz, local)[a]	Quartzite
Filter depth (m)		0.2 - 0.3[b]	0.3
Area of the filter (m^2)			1
Hydraulic velocity (m/hr)		0.3 - 1.5	0.3, 0.5, 1.0
Uniformity coefficient		< 2[a]	
Filter length (m)	Compartment 1 (m)		1.5
	Compartment 2 (m)		1
	Compartment 3 (m)		0.5
Filter width (m)		1 - 2.3[a]	1
Filter material			Steel and PVC (internals)

[a]Wegelin (1996); [b]Galvis et al. (1998)

3.4 DATA ANALYSIS

The responses for the survey questionnaires were collected and manually analyzed for the correlation, distribution and statistical inference examination in relation to greywater reuse. Data was analyzed to compute descriptive statistics mainly averages, standard deviations, correlations and frequency distribution. The type of data collected was ranked in ordered of responses from the participants which consisted a five scale ordinal level: strongly disagree, disagree, not sure, agree, strongly agree. Responses were grouped in an ordinal scale and analyzed to provide insight on the community attitude, perception, and concerns towards the reuse.

The test of significance of each age group was performed in all 3 sections of the survey questionnaire (Q1-Q5, Q6-Q8 & Q9-Q10) which was performed using MS excel 2013 and Real-Statistics software package available in Excel. The structural setup of the questionnaires consisted of 10 questions which were to be responded by all participants, questionnaire form were: (Q1-5) - Attitude towards greywater reuse, (Q6-8) - health concerns on greywater and (Q9-10) - perceived advantage on greywater reuse. The survey questionnaire is given in Appendix A.

Descriptive statistics was used for the analyses of data collected. To analyze, describe and represent the collected data, results were presented in tables and graphs as actual counts and equivalent percentages. To examine the relationships in the data from variability, correlation and distributions, statistical inferences were made by cross-tabulating the data. Each analysis of samples was carried out in replicate and averages, standard deviation, variation and relative standard deviation for the actual and credible representation of the analyses was done. Statistical tools in Microsoft packages were used to generate random sampling and sample sizes.

For influent and effluent greywater samples, paired-sample t-test was used for two dependant groups (influent and effluent greywater) to confirm/understand the difference in means before and after treatment using the roughing filter. Percentage removal was also calculated for each parameter analysed. This was done in order to monitor the efficiency of a roughing filter and stabilisation of pollutants in greywater.

CHAPTER 4

RESULTS AND DISCUSSION

The research findings are presented in this chapter. The chapter is subdivided into 3 main sections presenting the findings from the studies conducted on public attitudes and perceptions towards the reuse of greywater collected from different households from different sources and the performance of the horizontal roughing filter. The raw data obtained from the studies are presented in the appendix D.

4.1 RESULTS FOR PUBLIC PERCEPTION TOWARDS THE REUSE OF GREYWATER

This section presents the results of a survey conducted in the community on public perception towards greywater reuse, perceived advantages related to the reuse of greywater and concerns related to public health issues regarding the reuse of greywater. A total number of 346 questionnaires were administered and respondents were aged from less than 19 to over 60 years. Of the respondents, 55% were female and 45% male.

Table 4.1 presents the demographic characteristics of the 346 respondents that participated in the study. As summarized in the table, there was a larger number of female than male respondents and most of the respondents were between the ages of 20 and 29 years (40% of the respondents).

Table 4.1: Demographic characteristics of the respondents

Age	**Percentage**
Under 19	7
20-29	40
30-39	22
40-49	19
50-59	9
Over 60	3
Gender	**Percentage**
Male	45
Female	55

In order to ascertain the attitudes of respondents towards the reuse of greywater for specific applications as identified to be appropriate for the community in which the study was conducted, respondents attitudes were assessed by asking five questions on how comfortable and willing respondents are to use greywater for the identified applications within the community. Responses available for selection were ‘strongly disagree, disagree, not sure, agree, and strongly agree’. The results are shown in Table 4.2. As can be seen, there was a higher percentage (>70%) of respondents that were willing to reuse greywater for either toilet flushing or for garden purposes. This result indicates that people residing in the community where the study was conducted do not have any issues related to the reuse of greywater for the identified application found appropriate for the community. It is also interesting to see from this study that a greater percentage of respondents (approximately 71%) are willing to use greywater from other buildings for the identified applications (toilet flushing/garden purpose). A positive attribute of this study is that 65% of respondents are willing to use greywater not because there is a drought or water scarcity and 80% of the respondents were also willing to have a dual water distribution system installed where they reside.

Table 4.2: Percentage of respondents willing to use greywater for the identified reuse applications

	Strongly disagree	**Disagree**	**Not sure**	**Agree**	**Strongly agree**
Q1: I am willing to use greywater for toilet flushing	6.1	10.1	8.1	28.3	47.4
Q2: I am willing to use greywater for garden purpose	5.8	12.5	11.6	32.5	37.7
Q3: I am willing to use greywater from other buildings for toilet flushing or for garden purposes	9.9	7.8	11.6	34.9	35.8
Q4: I am only prepared to use greywater for either of the identified applications only during drought or water scarcity	19.9	4.7	9.8	36.7	28.9
Q5: I am willing to have a dual water distribution system installed in where I currently reside	4.9	4.9	10.1	31.8	48.3

The main factors identified to being associated with higher levels of public acceptance of greywater reuse were age and gender. Chi-square tests were undertaken to assess whether there was a significant association in agreement with the respondents attitudes towards the reuse of greywater between different age groups and gender. The result indicated that there was a significant association ($p<0.05$) for all the questions posed. The influence of respondent age and gender on their attitudes towards the reuse of greywater is presented in Figure 4.1 and Figure 4.2, respectively. As can be visually seen in Figure 4.1, the percentage of respondents within the age bracket of 20 - 29 years showed greater willingness towards the reuse of greywater compared to the other age group considered in this study. Statistical analysis performed using univariate analysis of variance with a Post-hoc Scheffe test to compare the mean values of response in terms of attitudes that are in agreement with the reuse of greywater for the different age groups indicated that there was a significant difference ($p = 0.03$) between the age bracket of 20 - 29 years and the other age groups considered in this study. This could be attributed to the fact that this age group is well informed, educated, or have a better knowledge or understanding of the importance of water reclamation and reuse, thus they are keen to see changes in the current practice within their community.

It was also observed that the female respondents showed more willingness towards the reuse of greywater as presented in Figure 4.2. Statistical analysis using the t-test method was conducted to establish if there is any significant differences in responses in terms of gender between the female and male respondent in this study. It was found that there was significant difference ($p<0.05$) between the female and male response.

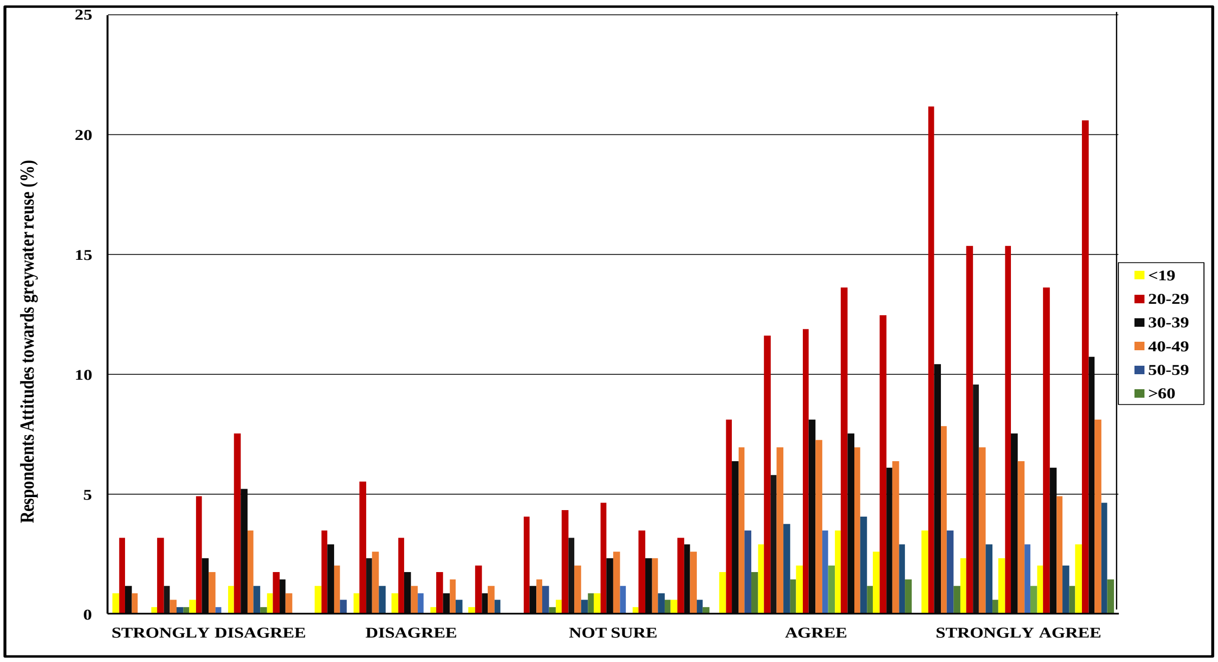

Figure 4.1: Influence of respondent age on attitudes towards greywater reuse

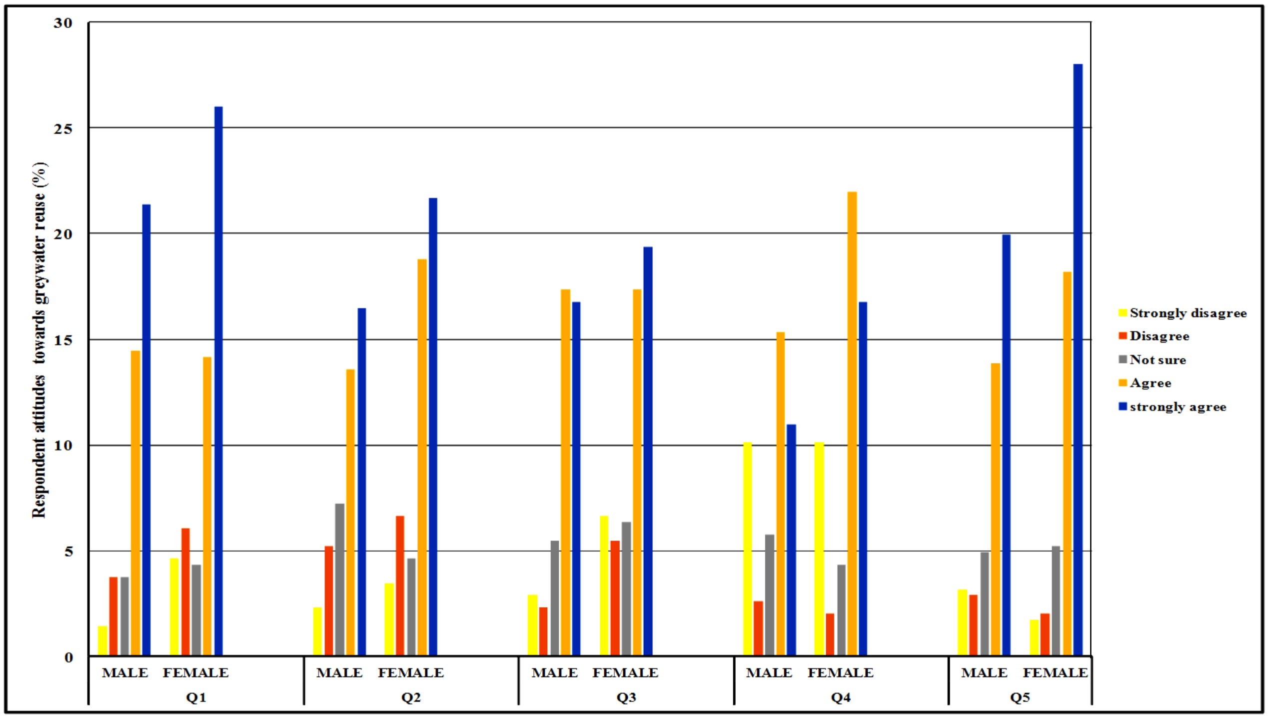

Figure 4.2: Influence of respondent gender on attitudes towards greywater reuse

Another important factor that influences public acceptance towards the reuse of greywater is often related to public health issues from using the water. Respondents were asked three main questions to access their concerns on health implications associated with the reuse of greywater. Also responses available for selection were 'strongly disagree, disagree, not sure, agree, and strongly agree'. This was done because health concerns associated with the reuse of greywater has often been one of the major factors that have affected public willingness to accept the reuse of greywater for various applications. Table 4.3 shows the percentage of respondents which have concerns on the health impacts associated with the reuse of greywater.

Contrary to what was expected, this study has indicated that public concerns related to health implications associated with the reuse of greywater for the identified applications were minimal. It was found that a higher percentage of respondents (> 60%) disagree that the reuse of greywater could negatively impact on public health compared to less than 20% of the respondents that agree that the reuse of greywater can negatively impact public health.

Table 4.3: Percentage of respondent's concerns on health implications associated with the reuse of greywater

	Strongly disagre	**Disagree**	**Not sure**	**Agree**	**Strongly agree**
Q1: Can the use of greywater for toilet flushing impact negatively on public health	38.5	25.8	16.9	14.4	4.4
Q2: Can the use of greywater for garden purpose impact negatively on public health	42.2	27.7	15	10.2	4.9
Q3: Is using greywater for toilet flushing or for garden purpose disgusting	45.2	24.9	10.1	9.8	10

Chi-square tests were also undertaken to assess whether there was a significant association in agreement with the respondent's concerns on health implications associated with the reuse of greywater between different age groups and gender. The result indicated that there was a significant association ($p<0.05$) for all the questions posed. The influence of respondent age and gender on concerns related to health issues associated with the reuse of greywater is presented in Figure 4.3 and Figure 4.4 respectively. As it can also be visually seen in Figure 4.3, respondents within the ages of 20 to 29 years showed a greater percentage in disagreement for the fact that the reuse of greywater for the identified applications in this study could have adverse effects on public health.

Statistical analysis performed using univariate analysis of variance with a Post-hoc Scheffe test to compare the mean values of responses in terms of public health concerns that are in disagreement that the reuse of greywater could pose adverse effects on public health for the different age groups for every single statement, indicated that there was a significant difference ($p<0.05$) between the age bracket of 20 - 29 years and the other age groups considered in this study. It was also observed that the female respondents are in more disagreement that the reuse of greywater could pose adverse effects to public health compared to the male as presented in Figure 4.4. Statistical analysis using the t-test method was conducted to establish if the differences were significant in responses in terms of gender between the female and male respondent in this study. It was found that there was a significant difference ($p<0.05$) between the female and male respondent. The overall assessment of this aspect of the study indicates that a greater percentage of the respondents do not agree that the reuse of greywater could have any adverse effects on public health. This is a good indication of public awareness and willingness to accept the reuse of greywater within the community.

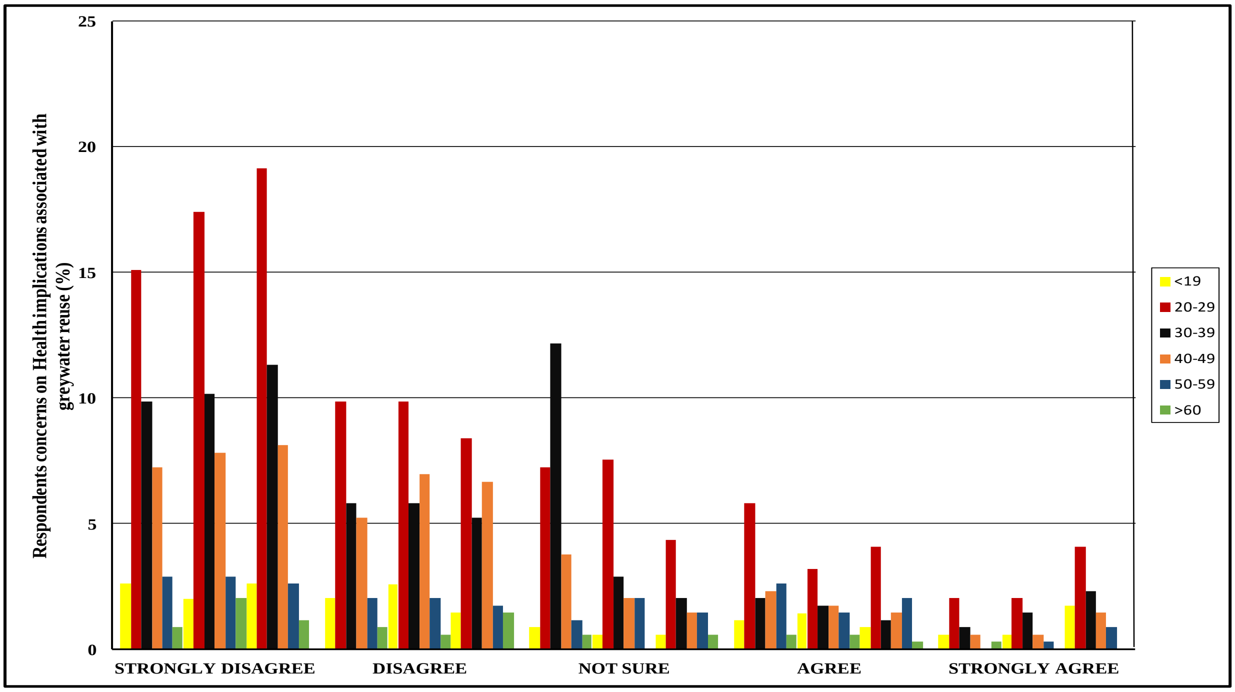

Figure 4.3: Respondents concerns on health implications in relation to age

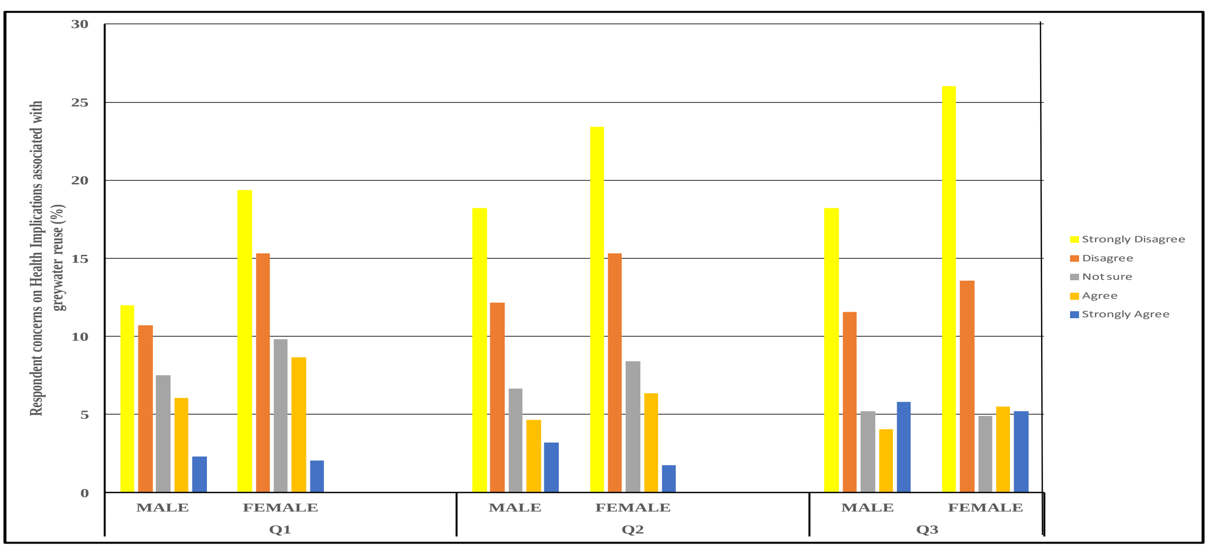

Figure 4.4: Respondents concerns on health implications in relation to gender

Two questions were posed to the respondents which were aimed at determining whether the respondents had any perceived advantage of greywater reuse for the identified application in this study. It was found that a greater percentage of the respondents (>75%) agreed that the reuse of greywater for the identified applications considered in this study will have a positive impact on the environment and will help in saving freshwater as well as reducing large volumes of wastewater discharged into wastewater treatment works which could be reused. The findings are shown in Table 4.4.

Table 4.4: Percentage of respondents with perceived advantages towards greywater reuse

	Strongly disagree	**Disagree**	**Not sure**	**Agree**	**Strongly agree**
Q1: I believe that greywater reuse for toilet flushing and garden purpose will positively impact on the environment	5.5	4	10.7	34.4	45.4
Q2: Greywater reuse for toilet flushing and garden purpose help save our limited fresh water usage	5.5	2.9	9.5	30.6	51.5

It was found that there was significant association in agreement with the respondent's perceived advantages for the reuse of greywater between different age groups and gender in the community in which this study was conducted using the Chi-square test ($p<0.05$). Statistical analysis conducted using univariate analysis of variance with a Post-hoc Scheffe test to compare the mean values of responses in relation to their perceived advantages towards the reuse of greywater for the different age groups, showed that the respondents within the age brackets of 20 - 29 years demonstrated a higher percentage compared to the other age bracket considered in this study (presented in Figure 4.5). This finding is consistent with the other aspect of this study and therefore supports the facts that this particular age group (20 - 29 years) are well informed, educated, or have a better knowledge/understanding of the importance of water reclamation and reuse, and are keen to see changes in the current practice within their community.

It was also observed that the female respondents had a higher perception that the reuse of greywater could have an advantage in reducing water demand within the community and will have a positive impact on the environment compared to the male as presented in Figure 4.6. Statistical analysis to compare means using the t-test method was conducted to establish if the differences were significant in responses in terms of gender between the female and male respondents in this study. It was found that there was significant difference ($p<0.05$) between the female and male respondents.

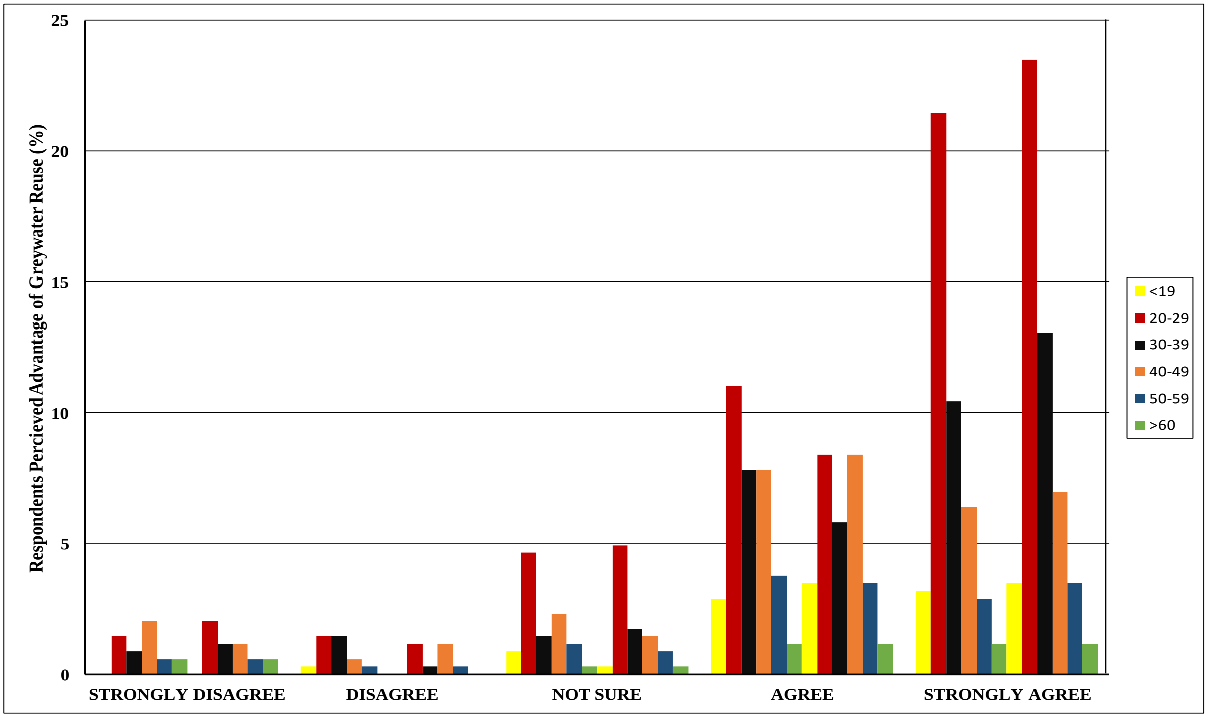

Figure 4.5: Respondents perceived advantage of greywater reuse in relation to age

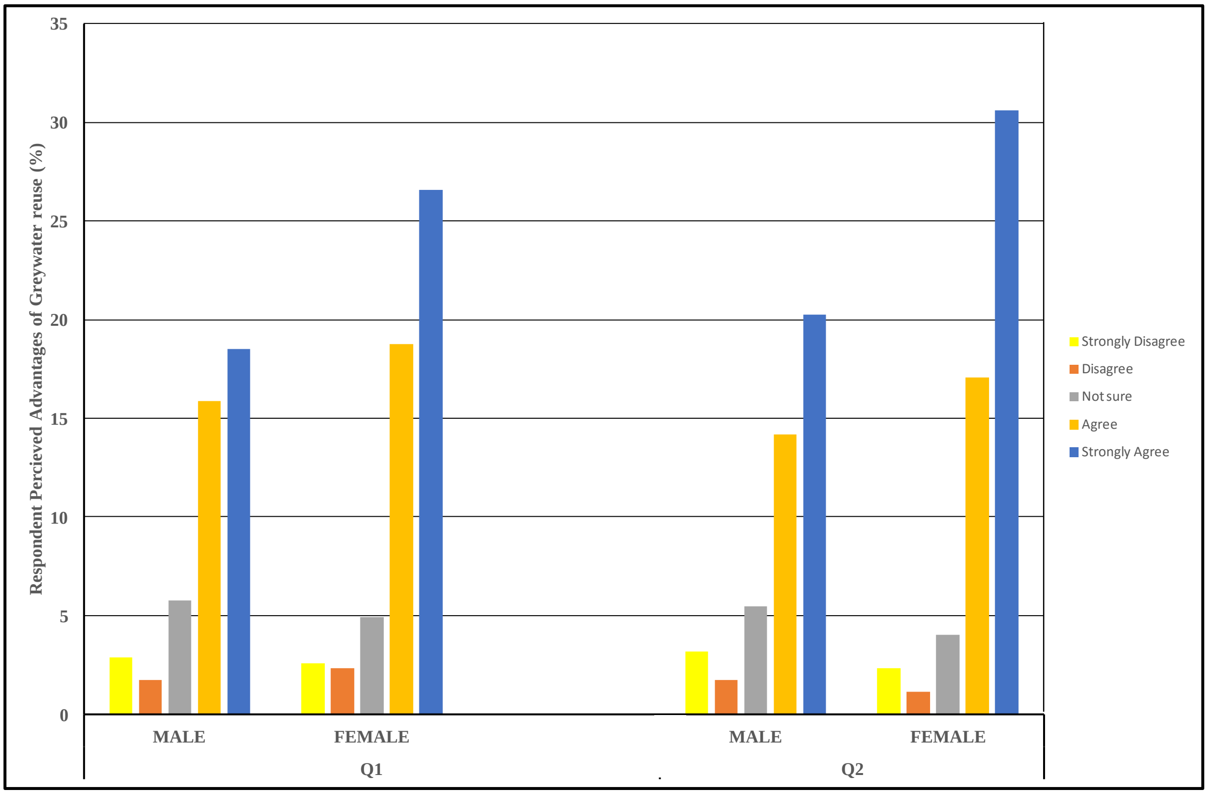

Figure 4.6: Respondents perceived advantage of greywater reuse in relation to gender

4.2 CHARACTERISTICS OF GREYWATER FROM DIFFERENT SOURCES IN THE UMHLABENI INFORMAL SETTLEMENT

This section presents the results of the analysis carried out on greywater collected from the characterization of different sources in households within the community where investigation was conducted. The experiments were carried out for a period of a month in order to investigate the general quality of greywater from different sources within the selected case study site (Umhlabeni informal settlement). Results presented in this section comprise the characteristics of raw greywater from the kitchen, shower and laundry greywater sources.

Results obtained were used to inform the design and the operational requirements of the horizontal roughing filter equipment. The greywater collected in different households in the community was characterized to determine the following parameters: turbidity, pH, conductivity, biological oxygen demand (BOD_5), chemical oxygen demand (COD) and the total solids (TS) present.

TURBIDITY

Figure 4.7 presents turbidity results obtained in greywater sources collected. The turbidity analyses were conducted for the following three greywater sources, laundry, bath and kitchen and for each greywater source analyzed, the sample size was 30. The analyses of turbidity showed that the greywater from the laundry recorded the highest value of 206 NTU followed by the greywater from the kitchen which recorded a value of 176 NTU and the lowest value was 120 NTU which was obtained from bathing greywater source.

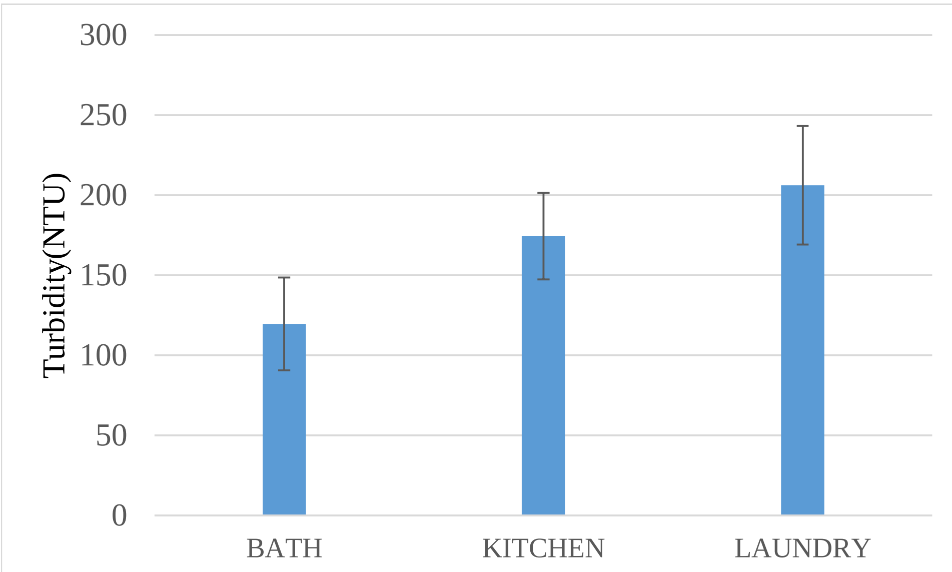

Figure 4.7: Turbidity for greywater sources in Umhlabeni informal settlement
(Bars represent mean values ± 1 standard deviation, n = 30 per source)

The statistical analyses of turbidity using one-way analysis of variance (ANOVA) was conducted to investigate the significant difference in the turbidity of greywater from the laundry, bath and kitchen activities. The statistical analysis results showed that there was a significance difference in turbidity for greywater sources ($p<0.05$). The reasons behind the observed variation in greywater sources on turbidity values are that greywater contains lots of suspended particles resulting from washing activities (for example laundry) and that different households contribute with a different extent and level on greywater pollutant loads. From Figure 4.7, greywater sources collected from bath and laundry fall in the similar range of results with the studies conducted by Li et al. (2009) and Khatun et al. (2011) which were found in the range of 44 - 375 NTU and 50 - 444 NTU, respectively. The greywater source from the kitchen was also in agreement with results from the studies conducted by Li et al. (2009) and Khatun et al. (2011) in Table 2.2 in Chapter 2. Based on the presented results, the greywater sources (except kitchen greywater which is not recommended for reuse due to a wide range and level of pollutants always present in it) can be generally considered for reuse in irrigation when precautions according to greywater standards of South Africa are met (Carden et al., 2007a).

pH

Figure 4.8 presents pH found in greywater from the laundry, bath and kitchen sources. The average pH obtained for laundry, bath and kitchen sources were 9.68; 9.34 and 6.44, respectively.

Figure 4.8: pH for greywater sources in Umhlabeni informal settlement
(Bars represent mean values ± 1 standard deviation, n = 30 per source)

Kitchen source (pH = 6.44) recorded the lowest average pH compared to the laundry and bathing greywater sources which recorded the highest average pH values, way above kitchen greywater sources. The analysis of variance test was conducted to compare the average pH for laundry, kitchen and bathing greywater sources. From the statistical test conducted, a significant difference on the average pH of greywater sources indicated that there was a significant difference amongst these greywater sources ($p = 0.001$). This shows that the way of living of people in the informal settlement is generally different and the laundry, bath and kitchen greywater sources in Umhlabeni informal settlement are totally different and people tend to use a wide range of chemical detergents which results and contributes differently on pollutant loads in each greywater source in the community. A low pH value in kitchen greywater (pH = 6.44) may be due to acidic content used in kitchen washing activities and this is normally associated with basic chemicals used for bathing and laundry activities as well as the high decomposition of greywater. This also includes the nature of food used seasonally in the low income community which has the impact to decrease the pH level of greywater. From these results, it is therefore widely accepted that kitchen greywater is one of the most contaminated type of greywater due to significant amounts of surfactants. Also, based on the environmental factors and sources, the concentration level of pollutant loads may sometimes vary widely from one area to another based on available and existing local conditions, lifestyle and customs which is in agreement with the study of Ledin et al. (2001).

The pH values found in this study are consistent with others reported in the literature by Friedler (2004) and Li et al. (2009). These results are also in agreement with the study conducted by Li et al. (2009) presented in Table 2.2 in Chapter 2 in which the range of laundry was 7.1 - 10 and kitchen was 5.9 - 7.4. Only bathroom greywater source deviates from the studies conducted by the above researchers. These greywater sources meets the South African standard of greywater reuse for irrigation, though precautions must always be considered if any greywater source has to be reused.

CONDUCTIVITY

Figure 4.9 presents results of the average conductivity of greywater collected from household activities from three different sources, laundry, bath and kitchen greywater. The conductivity of 195 µS/cm for laundry water, 180 µS/cm for bath, 665 µS/cm for kitchen were obtained. The value of conductivity seem to be far lower in bathing source, followed by laundry source while kitchen source recorded a far higher value and exceeding the other two greywater sources as it can be seen in Figure 4.9.

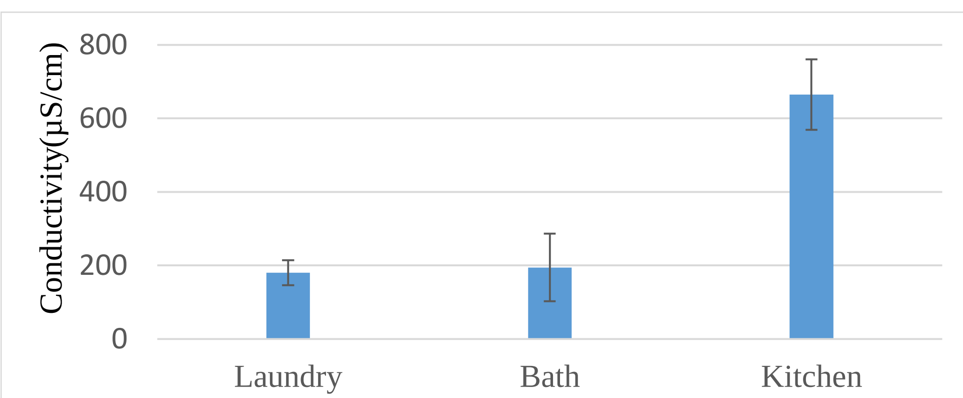

Figure 4.9: Conductivity of greywater sources in Umhlabeni informal settlement
(Bars represent mean values ± 1 standard deviation, n = 30 per source)

The statistical analysis using ANOVA was conducted to investigate if there was a significant difference in these greywater sources using conductivity. The analysis showed that there was a significant difference ($p<0.05$) in the average conductivity when laundry, bath and kitchen greywater sources were compared. Higher conductivity variation determined in greywater sources were due to the quality of water collected in these households which varies widely in the area from one household to the other. This also includes differences in the number of inhabitants of each household and greywater quality and differences in concentrations of major pollutants contained in each greywater source such as chemical oxygen demand, total suspended solids, ammonical nitrogen and phosphates. Therefore conductivity values are related to the different living habits of the persons involved in the informal settlement.

The conductivity in greywater has been found to be in the range of 30 to 150 mS/m and sometimes can be as high as 270 mS/m based on the studies conducted by DWAF (1996) and Morel and Diener (2006). In this present study, conductivity results obtained for all greywater sources from laundry, bath and kitchen sources are in agreement of the general greywater conductivity values in literature based on the study conducted by DWAF (1996) and Morel and Diener (2006). Carden et al.'s (2007a) study identified a conductivity up to 28 mS/m as low range conductivity and conductivity up to 366 mS/m as average conductivity and conductivity up to 1763 mS/m as a high conductivity range. In this present study, conductivity results obtained for greywater sources from laundry and bath fall in the low range region while kitchen source falls in the high range region. From these greywater sources, a use of kitchen water is not recommended as it may have detrimental effects on plants and soil if it is used without further treatment.

CHEMICAL OXYGEN DEMAND (COD)

Figure 4.10 presents average COD results on each greywater source collected from laundry, bath and kitchen sources. The laundry, bath and kitchen values obtained were 1528 mg/l, 1426 mg/l, and 2041 mg/l, respectively. The kitchen source recorded 2041 mg/l, the highest average COD values than both laundry and bathing source. The laundry and bathing sources make the lowest average COD values compared to kitchen greywater source but generally containing high COD values.

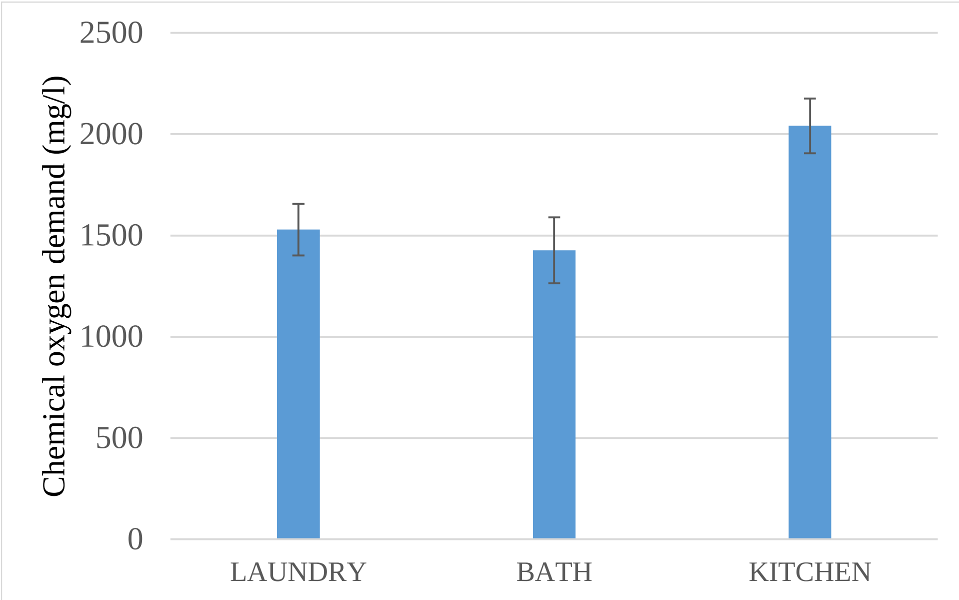

Figure 4.10: COD from greywater sources in Umhlabeni informal settlement
(Bars represent mean values ± 1 standard deviation, n = 30 per source)

Results obtained in Figure 4.10 were compared statistically using ANOVA. A p-value lower than 0.05 was obtained for this statistical analysis. These results confirm that the mean values of COD for laundry, bath and kitchen sources are chemically polluted differently from each other. In the studies conducted by Li et al. (2009) and Khatun et al. (2011), the results obtained for bathing, laundry and kitchen sources were in the range of 26 - 2050 mg/l, 100 - 633 mg/l and 231 - 2950 mg/l, respectively. From Figure 4.10, greywater from the kitchen has a similar range of results with that of the study conducted by Li et al. (2009) and Khatun et al. (2011). Laundry and bath showed slight deviation from the study results showing chemical contamination of more organic pollutants. These results are in agreement with the studies conducted by authors such as Carden et al. (2007) for the selected informal settlements in South Africa and the studies conducted by Al-Jayyousi (2003), Khong (2009) and Jefferson et al. (2004).

BIOLOGICAL OXYGEN DEMAND (BOD)

Figure 4.11 presents average BOD results for greywater sources collected from the laundry, bath and kitchen. The BOD values from the laundry, bath and kitchen activities obtained were 414 mg/l, 185 mg/l and 605 mg/l, respectively.

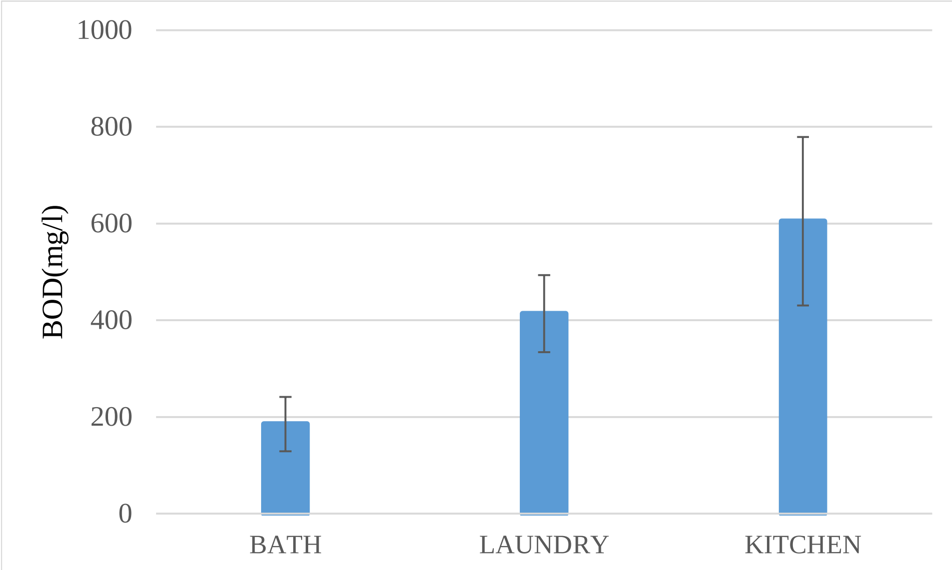

Figure 4.11: BOD_5 greywater sources in Umhlabeni informal settlement
(Bars represent mean values ± 1 standard deviation , n = 30 per source)

The greywater from kitchen source recorded the highest average BOD value of 605 mg/l and the lowest was the greywater source from the bath with 185 mg/l. Laundry and bath greywater sources, respectively makes the lowest average BOD values compared to the kitchen greywater sources. In terms of organic pollutants, the bathing greywater seemed to be less polluted in organic pollutants than kitchen and laundry greywater with a BOD value way below the two other greywater sources. Kitchen greywater seemed to be the most polluted greywater than the other sources while laundry greywater recorded a BOD value between bath and kitchen ranging the second highest in the value of BOD.

Results obtained in Figure 4.11 were compared statistically using ANOVA. From statistical test analyses, the laundry, bath and kitchen sources were found to be significantly different from each other. This shows that these sources are biologically polluted differently from each other as they come from different sources in the community.

Greywater from the kitchen source has the highest value of BOD_5 which may be due to organic matter from food particles. The BOD_5 of kitchen source depends directly on how much and how dirty the dishes were and how many food remains were left in the greywater and may be due to very little water used for household washing activities than organic particles present in the kitchen source, thereby the high concentration of organic content (Kaguongo, 2010).

In the studies conducted by Burnat and Mahmoud (2005) average BOD results in greywater were as high as 590 mg/l and exceeded 2,000 mg/l in isolated cases. In another study conducted by Leo et al. (2009), the BOD_5 values in greywater varied between 192 mg/l and 900 mg/l. The BOD_5 result for the kitchen greywater source is comparable and is in range of this study. From Figure 4.11, the greywater source from the kitchen, laundry and bath are also in agreement with the study results conducted by Li et al. (2009) in Table 2.2 in Chapter 2 and by Carden et al. (2007a) results for the selected informal settlement in South Africa.

TOTAL SOLIDS

Figure 4.12 below presents the results of total solids in greywater from the three different sources, greywater from the bath, laundry and kitchen. The total solids average values obtained were, 111 mg/l, for the laundry, 73 mg/l, for the bathing source and 489 mg/l, for the kitchen source. From the results, it can be seen that greywater from the kitchen contained the highest total solids than both laundry and bathing sources. The laundry ranked the second following kitchen source while bathing source recorded the lowest value of total solids present.

Figure 4.12: Total solids from greywater sources from Umhlabeni informal settlement
(Bars represent mean ± 1 SD, n = 30 per source)

The findings of the study conducted by Bodnar et al. (2014) as presented in Chapter 2 Table 2.2 in Hungary are almost similar to the result of the present study conducted at Umhlabeni informal settlement as can be seen in Table 4.6 below with all physical and chemical parameters for characterization of greywater from different sources being summarized and presented in Table 4.6.

These results presented by Bodnar et al. (2014) are comparable and fall in the similar range with the present study results summarized in Table 4.5.

The three different sources were significantly different from each other from the statistical test of ANOVA ($p<0.05$). The kitchen greywater is clearly the most contaminated greywater source, the higher content of solids in kitchen water is associated with the presence of food particles, soil and dissolved particles from washing activities and dissolved salts. The laundry and the bathing greywater has a fairly low value of total solids compared to kitchen sources which has a high amount of solids present. These findings are supported by the study conducted by Abedin and Rakib (2013). Therefore, body care products, detergents, bleaches, paints, traces of urine, dissolved elements from old plumbing and piping systems are amongst the major factors that has the potential to affect greywater quality (Boyjoo et al., 2013; Ghaitidak and Yadav, 2013). These results obtained are in agreement with existing literature studies conducted on greywater sources (Morel and Diener, 2006).

Table 4.5, 4.6 and 4.7 present the coefficient of variation of greywater from the three different sources in the community.

Table 4.5: Coefficient of variation for greywater from laundry

Parameter	Mean	Standard deviation	Coefficient of variation (%)
pH	9.68	0.14	1.45
Conductivity(µS/cm)	195	47	24.10
COD (mg/l)	1528	65	4.25
BOD (mg/l)	413	24	5.81
Turbidity (NTU)	206	19	9.22
TDS(mg/l)	111	31	27.93

Table 4.6: Coefficient of variation for greywater from bathing

Parameter	mean	Standard deviation	Coefficient of variation (%)
pH	9.34	0.13	1.39
Conductivity(μS/cm)	180	17	9.44
COD (mg/l)	1426	83	5.82
BOD (mg/l)	185	34	18.38
Turbidity (NTU)	120	15	12.50
TDS(mg/l)	73	15	20.55

Table 4.7: Coefficient of variation for greywater from kitchen

Parameter	Mean	Standard deviation	Coefficient of variation (%)
pH	6.44	0.003	0.05
Conductivity(μS/cm)	665	49	7.37
COD (mg/l)	2040	68	3.33
BOD (mg/l)	604	74	12.25
Turbidity (NTU)	174	14	8.05
TDS(mg/l)	489	53	10.84

Tables 4.5, 4.6 and 4.7 show that the highest coefficient of variation for greywater from laundry, bathing and kitchen were 28%, 21% and 12% respectively while the least coefficient of variation were 1.45%, 1.39% and 0.05% respectively. This is an indication that most influent parameters have coefficient of variation that are less than 10% meaning that the raw greywater samples were well collected and consistent in quality (Westgard et al.,1998).

4.3. RESULTS FOR THE PERFORMANCE OF THE HORIZONTAL ROUGHING FILTER

The first part of this section will present experimental results for the effect of filtration rate on the performance of the horizontal roughing filter system. The second part will present experimental results on the effect of grain or gravel size on the performance of the horizontal roughing filter system. The performance will be based on the following parameters: turbidity, pH, conductivity, chemical oxygen demand (COD) and total solids (TS) present in greywater.

4.3.1 EFFECT OF FILTRATION RATE ON THE PERFORMANCE OF THE HORIZONTAL ROUGHING FILTER

TURBIDITY

Figure 4.13 presents the results for the turbidity removal in the roughing filter for the filtration rates of 0.3 m/h, 0.5 m/h and 1 m/h. The removal was found to be 90% for 0.3 m/h, 85% for 0.5 m/h and 73% for 1 m/h.

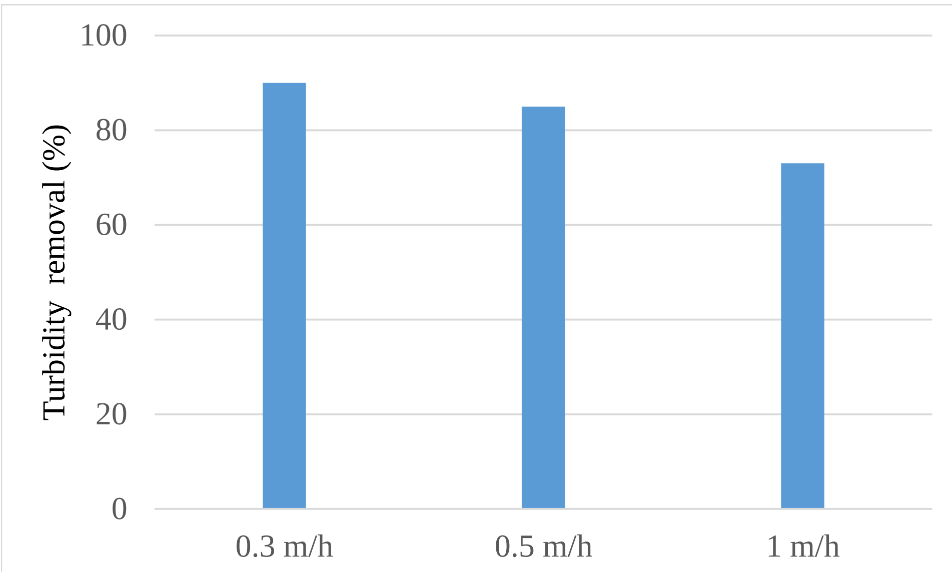

Figure 4.13: Turbidity removal of the HRF at varying flow rates

The highest removal was achieved at a filtration rate of 0.3 m/h which is the lowest filtration rate used. At 0.3 m/h, the average influent turbidity of greywater was 329 NTU and the average effluent turbidity of the effluent greywater from the roughing filter was 27 NTU. The lowest turbidity removal however occurred at the highest filtration rate of 1 m/h with an average greywater influent turbidity of 266 NTU and the average effluent value of 65 NTU. The turbidity removal of 85% was achieved with the filtration rate of 0.5 m/h and the average greywater influent turbidity was 311 NTU and the effluent greywater turbidity was 46 NTU.

A statistical test using ANOVA was conducted to compare the average values of turbidity removal for the filtration rates of 0.3 m/h, 0.5 m/h and 1 m/h. From the statistical analysis test, a significant difference ($p<0.05$) was obtained for each filtration rate of turbidity removal which indicates that the filter performed differently for each filtration rate. The observed reduction in turbidity was mainly dependent on the selected operating filtration rate during the operation of the roughing filter which affected the residence time of the influent greywater within the filter equipment passing in each of the three filter compartments therefore having a direct impact on turbidity removal as greywater passed through in each filter compartment. These results indicate that the HRF operation will tend to favour the higher turbidity removal when lower filtration rate is selected and will remove turbidity more effectively than any other higher filtration rate selected for the operation of the roughing filter. Such results obtained show that the HRF is capable of reasonably reducing turbidity despite the wide range of turbidity handled in the filter system and the influent greywater fluctuations that were evident in each filtration rate. The filtration rate of 0.3 m/h also meets the standard turbidity reduction required for slow sand filtration which must be below 50 NTU. These results are in agreement with the studies conducted by Nkwonta and Ochieng (2009) and Muhammad et al. (1996).

Turbidity removal can be achieved to the extent of 70-90% and even in some cases up to 98% but depending upon the qualitative raw greywater characteristics even reducing the high turbidity, for instance 329 NTU at 0.3 m/h to < 50 NTU thus making slow sand filtration a viable option and should be less than 50 NTU based on the studies conducted by Galvis et al. (1993) and Wegelin (1996). The effluent greywater pretreated at 0.3 m/h can be used for irrigation as turbidity removal meets the general standard for greywater reuse in South Africa which were conducted by Carden et al. (2007).

pH

Figure 4.14 presents results for the average pH of three greywater effluents from the horizontal roughing filter. The highest pH obtained was 7.39 for the filtration rate of 0.3 m/h and the low values of pH obtained were 7.26 and 7.24 for the filtration rates of 0.5 m/h and 1 m/h, respectively. For all greywater influents, the pH values recorded were lower than the values of all effluents obtained in the HRF. For influents, the average values of pH were 7.03 for 0.3 m/h, 6.81 for 0.5 m/h and 6.81 for 1 m/h.

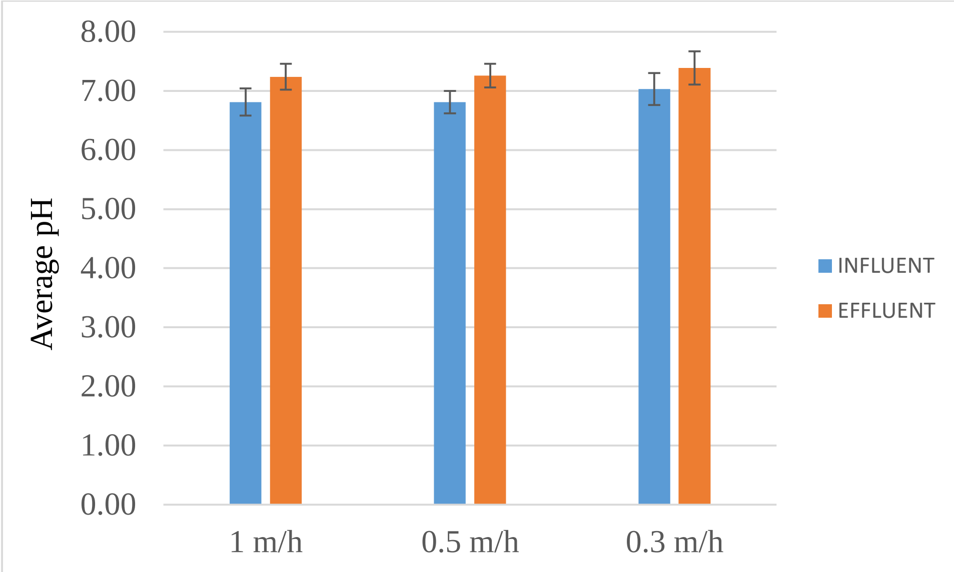

Figure 4.14: pH for the influent-effluent greywater

The comparison of the effluent pH values at the selected filtration rates were analyzed statistically using ANOVA and the p-value was found to be 0.59. This shows that there was no significant difference statistically in the pH for varying filtration rates. These results are associated with the buffing capacity of the HRF due to types and level of substances in greywater. The greywater source and domestic activities amongst many other factors. For all effluents from the roughing filter, the pH value is within the specified range for effluents discharged into the environment according to the South African standard (DWAF, 1999). The greywater effluents also met the standard for reuse in soil and plants in which a pH of greywater should be 6.5 - 8.4 (USEPA, 2004).

CONDUCTIVITY

Figure 4.15 presents average conductivity values for the performance of the roughing filter for the filtration rates of 0.3 m/h, 0.5 m/h and 1 m/h. The conductivity observed for the effluent at 0.3 m/h, 0.5 m/h and 1 m/h were 342 µS/cm, 722 µS/cm and 940 µS/cm respectively, while greywater influents for each respective filtration rates were 1557 µS/cm, 1838 µS/cm and 1923 µS/cm. It can be observed that the minimum conductivity was achieved at 0.3 m/h. The lowest average conductivity was achieved at 1 m/h, the highest filtration rate.

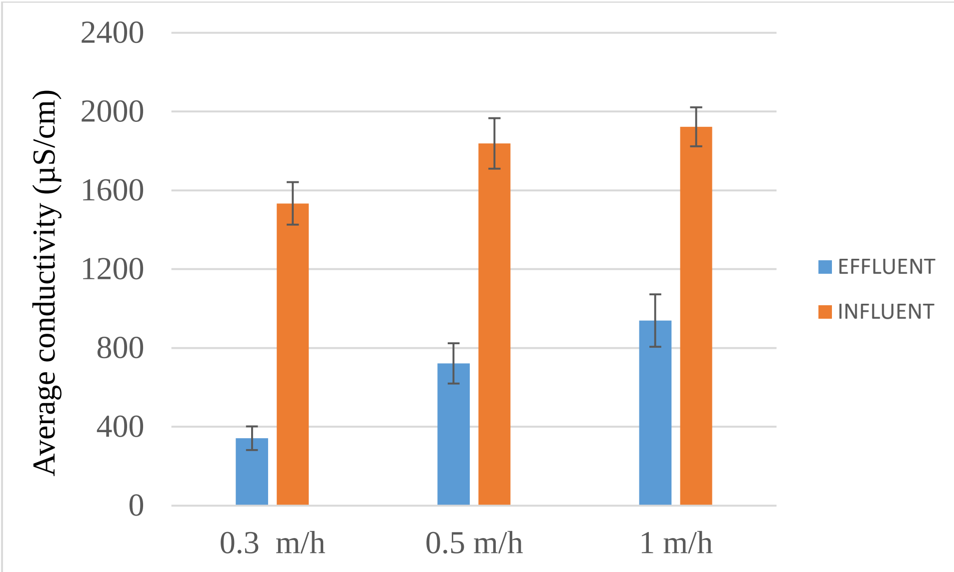

Figure 4.15: Conductivity for influent-effluent greywater

ANOVA test was conducted to compare average effluent conductivity. From the statistical test results, a significant difference for average conductivity values was observed which indicated that there was a significant difference of the effluent greywater results obtained from the roughing filter for each filtration rate ($p<0.05$). Results show that the roughing filter is capable of handling and reducing a wide range of solids present in greywater resulting in reduced average conductivity values.

A good performance of roughing filter in the reduction of conductivity encourages a good deposition of solids within the roughing filter, and it can be seen that a low filtration rate favored a high removal in conductivity whereas a high filtration rate favored a low removal of conductivity. Based on the study conducted by Carden et al. (2007a), the conductivity parameter is an important factor for greywater in irrigation. As shown in Figure 4.15, the HRF had an impact in removing conductivity of greywater in all filtration rates and the major impact was observed at 0.3 m/h filtration rate.

COD

Figure 4.16 presents results for the removal of chemical oxygen demand for the filtration rates of 0.3 m/h, 0.5 m/h and 1 m/h. From the graph, the removals of COD for 0.3 m/h, 0.5 m/h and 1 m/h filtration rates were 63%; 57 and 46, respectively. The highest removal of COD was achieved using the lowest operating filtration rate of 0.3 m/h (63%). The average influent values of COD at 0.3 m/h, 0.5 m/h and 1 m/h were 1977 mg/l, 2630 mg/l and 2370 mg/l, respectively.

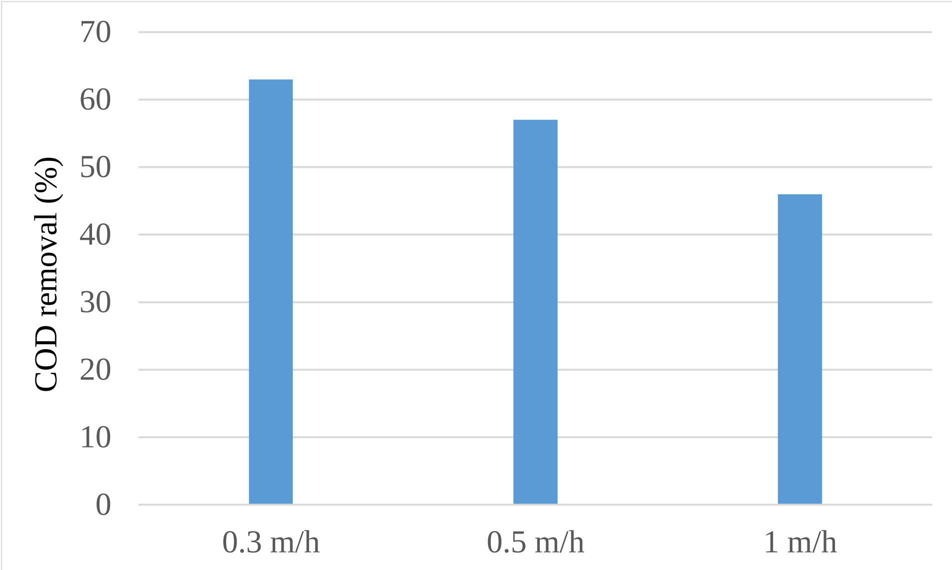

Figure 4.16: COD removal in each filter compartment of a roughing filter

The ANOVA statistical test was conducted to investigate if there was underlying statistical difference in each percentage removal of chemical oxygen demand. From the statistical analysis, the p-value was found to be less than 0.05 indicating a significant difference in the percentage removal of chemical oxygen demand. These findings are attributed to the effect of filtration rate in the removal of the organics. The low filtration rate tends to allow more removal of organic content/matter and phathogens than higher filtration rates. These results obtained are almost similar to the Wegelin (1996) guidelines and operating principles for a horizontal roughing filter.

TOTAL SOLIDS

Figure 4.17 presents the results for the total solids removal in the roughing filter for the filtration rates of 0.3 m/h, 0.5 m/h and 1 m/h. The removal was found to be 91% for 0.3 m/h, 76% for 0.5 m/h and 53% for 1 m/h. The highest removal was achieved at a filtration rate of 0.3 m/h. It can be seen that the total solids removal is generally decreasing along the filter in each filtration rate.

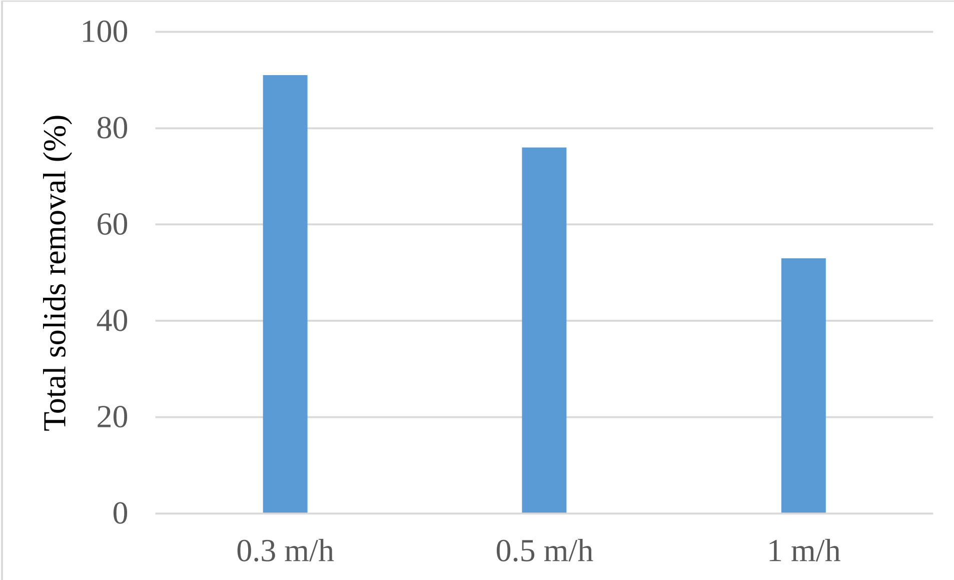

Figure 4.17: Total solids removal in relation to varying filtration rate in HRF

A statistical test using ANOVA was conducted and showed significant difference ($p<0.05$). A low filtration rate is recommended for a good removal of total solids in the roughing filter (Boller, 1993) and as a result solids attached to the filter media will be retained and settle out in the roughing filter due to a smooth flow of greywater under low filtration rate thus maintaining laminar flow conditions favoring good total solids removal (Cleary, 2005).

4.3.2 EFFECT OF GRAIN SIZE/FILTER MEDIA ON THE PERFORMANCE OF THE HORIZONTAL ROUGHING FILTER

The performance is based on the following parameters: turbidity, pH, conductivity, chemical oxygen demand (COD) and the total solids.

TURBIDITY

Figure 4.18 presents turbidity removal results obtained in compartment 1 with 15 - 13.2 mm gravel media fractions, compartment 2 with 13.2 - 9.5 mm gravel media fractions and compartment 3 with 9.5 - 6.7 mm gravel media fractions prior to the effluent leaving the outlet baffle as presented in Table 3.1. The highest removal achieved in compartment 1 was 15% for 0.3 m/h followed by 13% for 0.5 m/h and 7% for 1 m/h. For compartment 2, the highest turbidity removal was 17% for 0.3 m/h followed by 14% at 0.5 m/h and 11% at 1 m/h. For compartment 3 at the filtration rate of 0.3 m/h, 0.5 m/h and 1 m/h, the values of turbidity removal achieved were 87%, 80% and 65%, respectively. The highest turbidity removal was observed in compartment 3 in all filtration rates, 0.3-1 m/h.

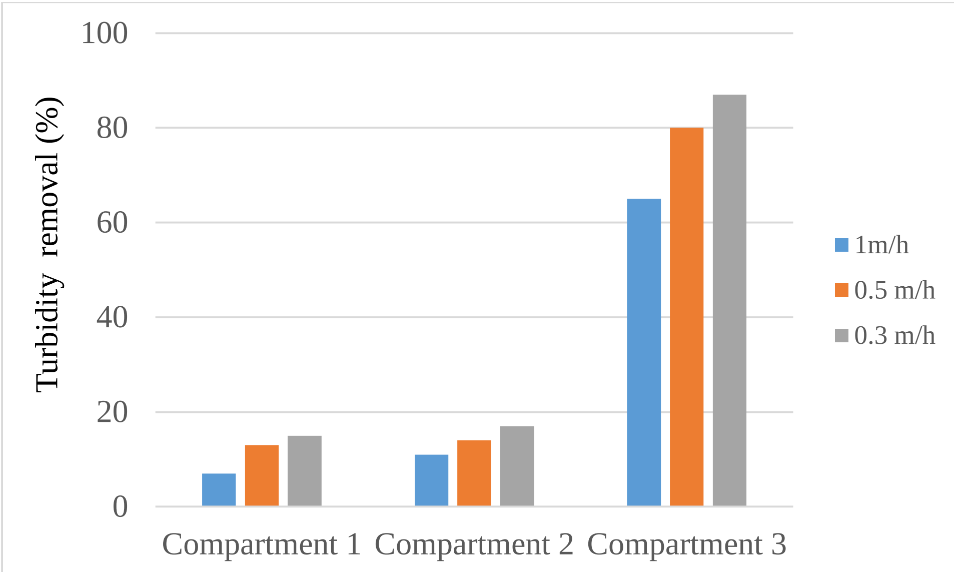

Figure 4.18: Turbidity removal in different gravel media sizes

ANOVA test indicated that there was a significant difference within the roughing filter compartments and gravel media fractions had a significant impact on turbidity removal obtained in each compartment of the roughing filter. The p-value obtained was found to be less than 0.05 showing that each filter media has the effect in average turbidity reduction. These results are due to the specific surface area and particle size arrangement for gravel media in each filter compartment which increases adsorption capacity while the solids entering the filter along the length of the roughing filter becomes separated due to the decline in the hole diameter spaces within the particles thus increasing the filtration process. Smaller filter media sizes have larger adsorption area and tends to perform better in treatment processes based on the studies conducted by Losleben (2008) and Wegelin (1996). The turbidity removal achieved in this study is in agreement with the study conducted by Wegelin (1996). The turbidity removal improved drastically for the reduced gravel size in compartment 3.

A high surface area achieved with small size gravel which reduced pore space available for solids to pass through the gravel media, therefore retaining more solids in the filter bed while filtered water passed through the filter (Cleary, 2005; Boller, 2003; Wegelin, 2006). The reduced removal is due to reduced smooth flow conditions as the flow rate increased resulting in settled and filtered solids drifting and penetrating through the filter compartments therefore reducing the efficiency of the filtration process as the retention time in a horizontal roughing filter was suddenly reduced by operating with increased filtration rate. This result implies that size of the filter media affects the performance of the roughing filter because of the large interstitial spaces within the particle matrix (Adlan et al., 2008).

pH

Figure 4.19 shows results on average pH for the same gravel media fractions within compartment 1, compartment 2 and compartment 3.

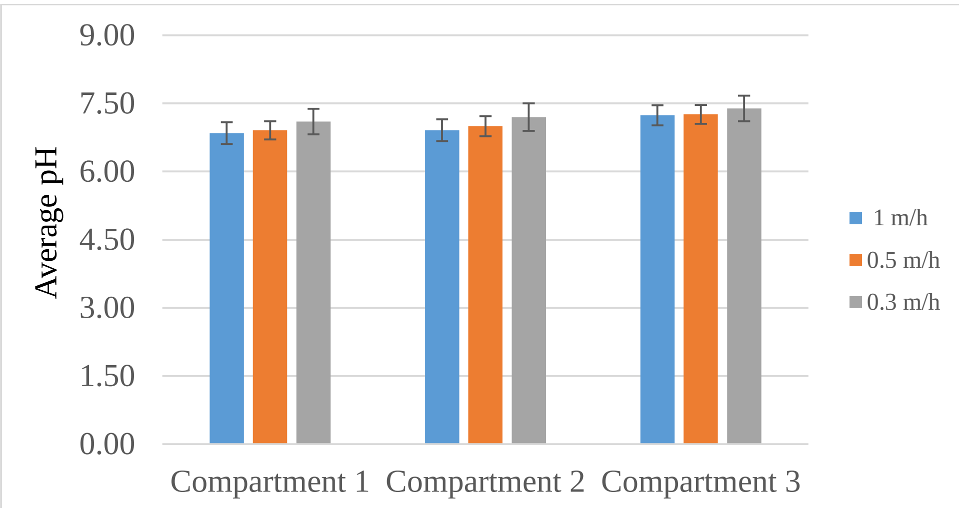

Figure 4.19: pH versus gravel size in each filter compartment of a roughing filter
(Bars represent 95% confidence interval around the mean)

In compartment 1, the average values of pH achieved were 7.10, 6.91 and 6.85 for the filtration rates of 0.3, 0.5 and 1 m/h, respectively. In compartment 2, the average pH recorded was 7.20, 7.05 and 6.91 for the filtration rates of 0.3, 0.5 and 1 m/h. In compartment 3, the average pH values achieved were 7.39, 7.26 and 7.24 for the same filtration rates of 0.3, 0.5 and 1 m/h. The pH generally improved in compartment 3 while pH overall showed minimal improvement within the roughing filter compartments.

The ANOVA test showed that there was insignificant difference on the values of pH ($p>0.05$). From this result, the average values of pH for greywater effluent improved along compartment 1, compartment 2 and compartment 3 within the horizontal roughing filter from the influent greywater in all filtration rates used during the operation of the roughing filter.

CONDUCTIVITY

Figure 4.20 presents average conductivity results obtained. A high reduction of conductivity was obtained in compartment 3 for all filtration rates compared to compartment 1 and compartment 2.

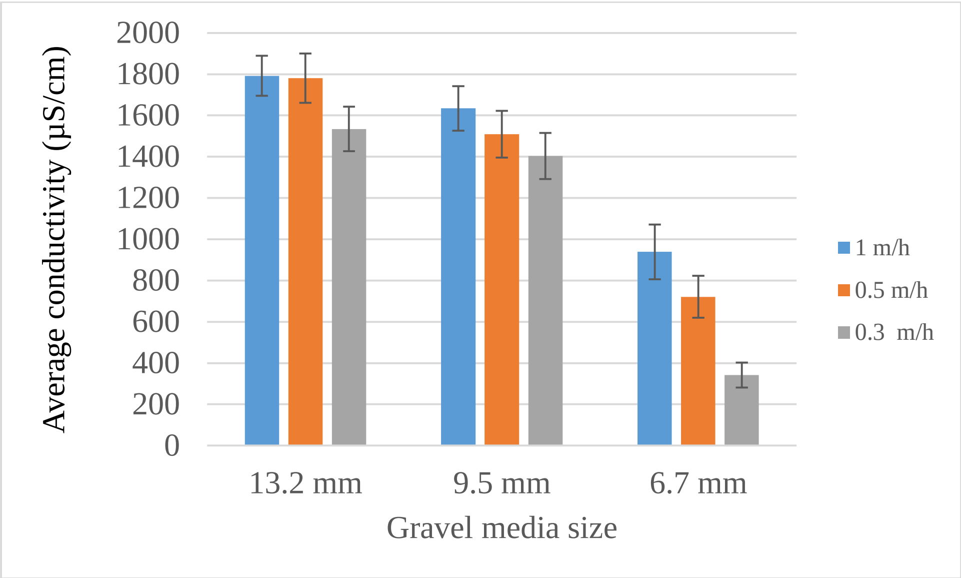

Figure 4.20: Average conductivity removal in each filter compartment
(Bars represent 95% confidence interval around the mean)

The conductivity values obtained for compartment 3 were 342 µS/cm, 722 µS/cm and 940 µS/cm for the filtration rate of 0.3 m/h, 0.5 m/h and 1 m/h, respectively. A low reduction was achieved in compartment 1 and the average conductivity values achieved were 1524 µS/cm for 0.3 m/h, 1781 µS/cm for 0.5 m/h and 1792 µS/cm for 1 m/h. Compartment 3 with the smallest gravel size achieved the highest reduction of conductivity for all filtration rates.

The ANOVA tests showed that there was a significant difference in the conductivity reduction achieved in each compartment (p = 0.01). As it can be observed in Figure 4.20 the conductivity removal improved in the direction of fine gravel size in compartment 3 (9.5 - 6.7 mm gravel size) for all filtration rates. This is due to the increased gravel media size surface area from compartment 1 to compartment 3 and the increase in the accumulation of solids content in the roughing filter compartments.

COD

Figure 4.21 presents chemical oxygen demand removal results.

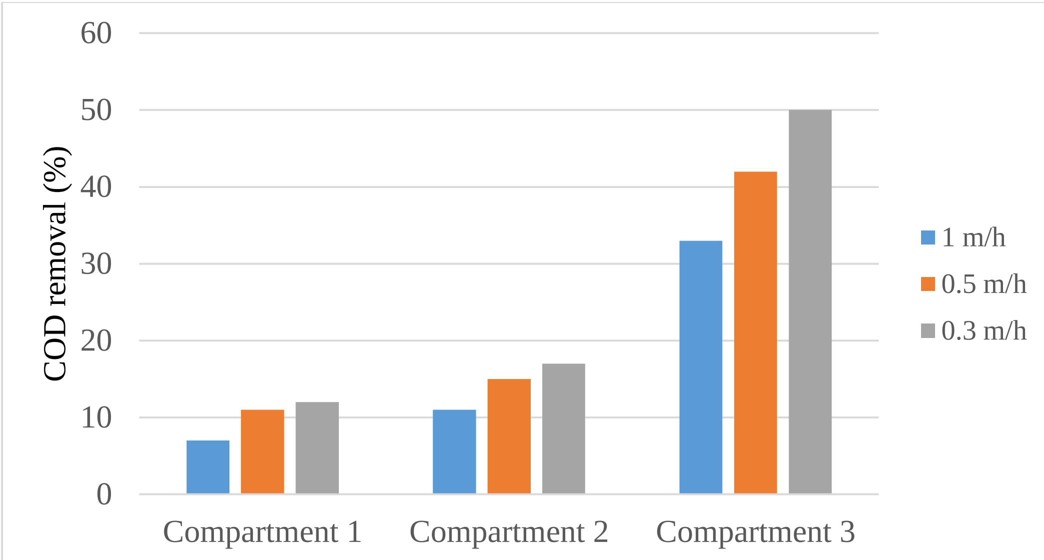

Figure 4.21: COD in the horizontal roughing filter compartments

In compartment 1, the highest COD removal was found to be 12% at a filtration rate of 0.3 m/h followed by 10% at a filtration rate of 0.5 m/h and the lowest COD removal was 7% at a filtration rate of 1 m/h. The highest COD removal was achieved in compartment 3 while the lowest COD removal was achieved in compartment 1. The statistical results showed that there was a significant difference on COD removal in each compartment of the roughing filter. The p-values obtained were found to be less than 0.05.

One study conducted by Ibrahim et al. (2013) showed the percentage removal of COD at a filtration rate of 0.3 m/h using a 3 to 6 mm size of filter media, the optimum percentage COD removal was found to be 27.0 %. With a 6 to 12 mm size of filter media, the optimum percentage COD removal was found to be 23.8 %, whereas with a 12 to 20 mm size of filter media, the optimum percentage COD removal was found to be 12.3%.

TOTAL SOLIDS

Figure 4.22 presents average total solids removal results.

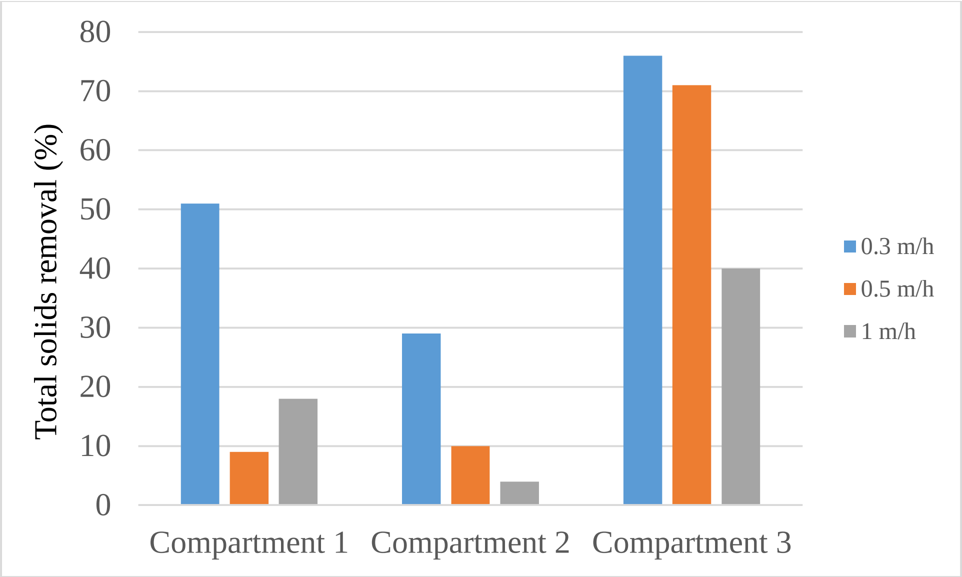

Figure 4.22: Total solids removal in each compartment of the HRF

A high reduction of conductivity was obtained in compartment 3 for all filtration rates. The total solids removals for compartment 3 were 76%, 71% and 40% for the filtration rate of 0.3 m/h, 0.5 m/h and 1 m/h, respectively. Compartment 3 with the smallest gravel size achieved the highest reduction of conductivity for all filtration rates. ANOVA tests showed that there was a significant difference in total solids reduction achieved in each compartment in the horizontal roughing filter ($p<0.05$).

A high removal in the compartment 3 is due to increased solid particles depositing in a filter bed medium which encourages more resistance in solid pollutants thus trapping more solids in the filter due to the reduction in pore area as the filter operates (Collins et al., 1994b and Collins et al., 1994b) and a low removal in the compartment 2 observed is as a result of high deposition of solids in compartment 1. In compartment 2, the reduced proportion of solids in greywater gave rise to reduced filtration after the high removal in compartment 1. The type and the proportion of solids present in greywater and the gravel media size had a major effect in the removal of solids for the specified filtration rates.

4.3.3 OVERALL PERFORMANCE OF THE HORIZONTAL ROUGHING FILTER

This section presents experimental results on the overall performance of the horizontal roughing filter system and the performance will be based on the following parameters that were measured: turbidity, pH, conductivity, total solids, chemical oxygen demand (COD), volatile solids and ash in greywater.

Tables 4.8 to 4.10 summarize experimental results of the HRF system at filtration rates of 0.3 m/h, 0.5 and 1m/h. From the tables, the pretreatment process showed a high removal efficiency on turbidity and moderate removal of conductivity while the settling process showed a high removal of solids. A significant removal of organic substances or COD nutrients and micro-organisms was observed at the filtration processes while the last process showed a low pollutants removal, for a filtration rate of 0.3 m/h. The overall percentage removal of turbidity was 90% at 0.3 m/h, 85% at 0.5 m/h and 73% at 1m/h.

Results presented below comprise of characteristics of influent greywater from the community, characteristics of influent through the roughing filter compartments and effluent greywater from each compartment, characteristics of final effluent and removal efficiency of each compartment. It also includes the overall removal efficiency, behavior of the roughing filter and operational requirements.

Table 4.8: Filter performance at a filtration rate of 0.3 (m/h)

Average Parameter		COMPARTMENT				Removal %
	Influent	1	2	3	Effluent	
Turbidity(NTU)	329	256	219	191	27	90
TS(mg/l)	2424	1190	847	555	207	91
COND(µS/cm)	1557	1534	1404	1086	342	
pH	7.03	7.10	7.20	7.25	7.39	
COD(mg/l)	1977	1739	1446	1190	726	63

Table 4.9: Filter performance at a filtration rate of 0.5 (m/h)

Average Parameter		COMPARTMENT				Removal %
	Influent	1	2	3	Effluent	
Turbidity(NTU)	311	302	255	234	46	85
TS(mg/l)	1299	1179	1067	747	306	76
COND(µS/cm)	1838	1781	1509	1204	722	
pH	6.81	6.91	7.05	7.16	7.26	
COD(mg/l)	2630	2355	1978	1476	1138	57

Table 4.10: Filter performance at a filtration rate of 1.0 (m/h)

Average Parameter		COMPARTMENT				Removal %
	Influent	1	2	3	Effluent	
Turbidity(NTU)	266	249	223	183	65	73
TS(mg/l)	1173	966	928	839	552	53
COND(µS/cm)	1923	1792	1635	1330	940	
pH	6.81	6.85	6.91	7.04	7.24	
COD(mg/l)	2370	2195	1955	1678	1291	46

Removal efficiency was found to be higher when a smaller size of filter media was used. By contrast, the use of a large size of filter media decreased removal efficiencies. Consequently, the performance of the horizontal roughing filter using limestone medium effectively reduced COD by up to 63% at a low filtration rate while at a high filtration rate the removal was less than 63%. Statistically, by using one-way analyses of variance, the results indicated an overall significant difference in all parameters that were measured for this present study except pH which was not statistically significant. Thus, the results of this study indicate that roughing filtration by using gravel media is a feasible technique for the improvement of greywater.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

The main focus of this research was to provide an understanding regarding the potential of greywater reuse and recycling for non-potable purposes under South African conditions. More precisely, the research aimed to provide both social and scientific information on the importance of greywater reuse and recycling. This is considered an alternative source to aid water demand and management under South African conditions where water is a scarce resource. The outcome of this research has therefore demonstrated and highlighted the possibilities of greywater recycling and reuse for non-potable purposes as an important strategy for water demand and management in regions of water scarcity as the case experienced in South Africa.

The research work conducted was undertaken to achieve the following objectives;

- To investigate public perceptions and attitudes towards the reuse of greywater
- To determine the quality of greywater generated from a peri-urban community in Durban, South Africa
- To investigate the performance of a horizontal roughing filtration system in treating greywater generated from a peri-urban community in Durban, South Africa

5.1 CONCLUSIONS

PUBLIC PERCEPTIONS AND ATTITUDES TOWARDS GREYWATER REUSE AND RECYCLING

The first objective of this research work was to investigate public perceptions and attitudes towards the reuse of greywater. This investigation was undertaken because the success of any reuse and recycling system depends not only on the engineering design and environmental feasibility but also on the acceptance and support of the general public. In this particular study, it was found that it is very important to access the attitudes, heath concerns and perceptions of individuals within a community towards the reuse and recycling of greywater. It was observed that the role of the public is a vital component in the development and implementation of any greywater reuse system/application. The major factor affecting the public attitudes and perception towards the reuse of greywater was found to be the need for reuse and their level of education. The results obtained from this investigation, reinforces the findings from previous research that the willingness to reuse greywater which involves low human contact is generally acceptable by individuals compared to the uses with high chances of personal contact since the greywater reuse options identified in this investigation were for toilet flushing and for garden purposes.

The findings from the survey conducted showed that the percentage of the public willing to accept the reuse of greywater within the community was far higher than the percentage opposing its reuse. Concerns have often been expressed by the public that the reuse of greywater could pose possible adverse effects to public health. However, in this investigation it was found that a higher percentage of respondents (>60%) disagree that the reuse of greywater could negatively impact on public health. An interesting finding of this study was that a greater percentage of the respondents were willing to have a dual water distribution system installed in their current place of residence. Therefore the following conclusions were made from this particular investigation:

- There is a relatively high level of acceptance for the reuse and recycling of greywater among the respondents within the community where this investigation was conducted. The relatively high level of support for the reuse of greywater is a key issue for the success of this water saving strategy. This therefore suggests that the implementation and development of greywater reuse concepts within the community will gain support and this could be a viable option for maximizing the use of freshwater.
- Although the majority of the people residing in the community are receptive to the concept of reusing and recycling large volumes of greywater generated for the identified applications (toilet flushing and for gardening purposes), more awareness programmes on the benefits of greywater reuse will be required so that the people residing in the community will have the proper knowledge that greywater reuse and other alternate sources of water will soon become a necessity in South Africa.

GREYWATER QUALITY GENERATED FROM A PERI-URBAN COMMUNITY IN DURBAN, SOUTH AFRICA

To successfully implement any greywater treatment system and/or technology, will depend largely on the characteristics of the greywater in terms of the pollutants strength. The results obtained from the characterization of greywater generated from randomly selected households within a peri-urban community indicated that greywater contains pollutants that could have adverse effects on the environment and public health if not treated before reuse. It was observed that the quality of greywater generated from the selected households exceed the maximum permissible standard for direct irrigation based on comparison between the results obtained from the parameters analyzed in this study and the standard presented by the Department of Water Affairs and Forestry guidelines (DWAF, 1999). It was also observed that the characteristics of greywater from different sources (kitchen, shower and laundry) within the households varied. There was a significant difference statistically in all the parameters analyzed between the characteristics of greywater from the kitchen compared with the greywater from the shower and laundry. The quality of greywater samples collected from the kitchen was found to be highly polluted compared to the other two sources of greywater collected from households.

Therefore, concluding from this particular study, the greywater characteristics results obtained from this investigation indicated the necessity of treatment prior to disposal to the environment. Also with a low BOD_5/COD ratio of 0.24 (which is significantly lower than 0.5) is an indication that the greywater generated from the community where this investigation was conducted cannot be easily treatable using biological treatment processes and/or technologies.

PERFORMANCE OF A HORIZONTAL ROUGHING FILTRATION SYSTEM IN TREATING GREYWATER GENERATED

The aim of this particular research work was to investigate and measure the performance of a horizontal roughing filtration system in treating greywater generated from a peri-urban community. This was done through the approach of investigating and studying two major variables that have the major impact in the performance of the rouging filter. The experimental approach was therefore divided into two objectives and these were;

- To investigate the effect of filtration rate of greywater in the performance of the horizontal roughing filter. The three filtration rates were 0.3 m/h, 0.5 m/h and 1 m/h.
- To investigate the effect of gravel media fractions in the performance of the horizontal roughing filter. The HRF compartments were charged with one of the three gravel media fractions (coarse, medium and fine) that were selected and used in the roughing filter in the direction of greywater effluent.

To assess the performance of the HRF, the required tests were carried out. These tests were turbidity, total dissolved solids, pH and chemical oxygen demand (COD), conductivity and the total solids. For the first objective, the turbidity removal were found to be 90% for 0.3 m/h, 85% at 0.5 m/h and 73% at 1 m/h. The average influent values of COD were found to be a 63% for the filtration rate of 0.3 m/h which was the smallest filtration rate used in the operation of the horizontal roughing filter, 57% for 0.5 m/h and 46% for 1 m/h. A high performance of HRF was also obtained for conductivity and total solids at filtration rate of 0.3 m/h. The conductivity reduction was 1534 - 342 µS/cm for the influent to the effluent. The highest total solids removal was 91% for the filtration rate of 0.3 m/h. The HRF showed a high removal efficiency in most of the physical parameters such as turbidity, conductivity and total solids contents within the roughing filter for the low filtration rate.

The observed reduction in turbidity was mainly dependent on the selected operating filtration rate during the operation of the roughing filter which affected the residence time of the influent greywater within the filter equipment passing in each of the three filter compartments therefore having a direct impact on turbidity removal as greywater passed through in each filter compartment. These results indicate that the horizontal roughing filter operation will turn to favour the higher turbidity removal when lower filtration rate is selected and will remove turbidity more effectively than any other higher filtration rate selected for the operation of the roughing filter. Such results obtained show that the horizontal roughing filter is capable of reasonably reducing turbidity removal despite the wide range of turbidity handled in the filter system and the influent greywater fluctuations that were evident in each filtration rate. The filtration rate of 0.3 m/h also meets the standard turbidity reduction required for slow sand filtration which must be below 50 NTU (Wegelin, 1996).

For the second objective, the operation of the HRF showed a high removal efficiency in most of the physical parameters such as turbidity, conductivity and total solids contents within the roughing filer due to the grading of gravel media in compartment 1, compartment 2 and compartment 3 prior to discharge of the effluent from the HRF. The highest percentage removal of the parameters analyzed was observed in compartment 3 with fine (9.5 - 6.7 mm) gravel media fractions. For the filtration rate of 0.3 m/h, the removal of turbidity, COD, total solids and average conductivity for compartment 3 were 87%, 50%, 76% and 1534-342 µS/cm respectively. However, for the overall performance of the filter, the turbidity was 90%, the total solids, 91%; COD, 63% and conductivity, 1534 - 342 µS/cm. All these particular values were for the low filtration rate of 0.3 m/h. A high removal in the compartment 3 is due to increase in solid particles depositing on a filter bed medium which encourages more resistance of solid pollutants thus trapping more solids in the filter due to the reduction in pore area as the filter operates.

All parameters analyzed for the performance of the horizontal roughing filter were compared statistically in order to scientifically analyze the data collected from the roughing filter and to investigate the effect of the filtration variables such as filtration rate and gravel media fractions on the performance of the roughing filter. The overall parameters statistically analyzed from the data collected showed significant difference. This was done in order to scientifically conclude on the HRF data collected to investigate the performance of the HRF.

These results demonstrate that the roughing filtration system has the potential of treating greywater in the peri-urban community to the standard for non-potable use standard and treated greywater may have good benefit for use in domestic greywater treatment schemes for recycling and possible reuse applications with its ability to reduce measured and analyzed greywater parameters. The roughing filtration demonstrated good potential and promising ability for the possible alternative performance and application for future use. These results indicate a good potential of the HRF performance in physical and chemical contaminants in greywater.

5.2. RECOMMENDATIONS

The research work presented in this thesis came up with various findings on the possibilities of greywater reuse and recycling for non-potable purposes in areas where there is water scarcity. The dissertation thus recommends;

- That a critical analyses of the data generated from the study be conducted to gain an understanding of public acceptability of greywater recycling and reuse is needed specifically, statistical modelling of collected data to draw conclusions about the important factors that influence public acceptance, when variables such as age, gender socio-economic status, education etc. are controlled for.
- That the influence of seasonal fluctuations on the performance of the horizontal roughing filter must be considered for comparison purposes.

5.3 RECOMMENDATIONS FOR FUTURE RESEARCH WORK

- Microbial analysis to investigate the impact on the performance of the horizontal roughing filter.
- To identify an effective polishing step for high quality effluent which could be used for potable purposes (drinking, cooking etc.).
- Life cycle assessment of the technology used in this study for peri-urban community.

REFERENCES

ABEDIN, S. B. AND RAKIB, Z. B. (2013) Generation and quality analysis of greywater at Dhaka City. *Environmental Research, Engineering and Management*, 2(64), 29-41.

ADEWUMI, J.R., ILEMOBADE, A.A. AND VAN ZYL, J.E., (2010) Decision support for assessing the feasibility of integrated wastewater reuse projects in South Africa. *Water Science Technology, Water Supply*, 10 (2), 251-267.

ADLAN, M.N., AZIZ, H.A. AND MAUNG, H.T. (2008) Performance of horizontal flow roughing filter using limestone media for the removal of turbidity, suspended solids, and biochemical oxygen demand and coliform organisms from wastewater. *International Journal of Environment and Waste Management*, 2(3), 203-214.

AFFAM, A. AND ADLAN M. (2013) Operational performance of vertical up-flow roughing filter for pre-treatment of leachate using limestone filter media. *Journal of Urban and Environmental Engineering*, 7(1), 117-125.

AHSAN, T. (1995) Process analysis and optimization of direct horizontal–flow roughing filtration. *PhD thesis report in Water Engineering. Delft, Holland*.

ALMEIDA, M.C., BUTLER, D. AND FRIEDLER, E. (1999) At source domestic wastewater quality. *Urban Water*, 1(1), 49-55.

ANTONOPOULOU, G., KIRKOU, A. AND STASINAKIS, A.S. (2013) Quantitative and qualitative greywater characterization in Greek households and investigation of their treatment using physicochemical methods. *Science of the Total Environment*, 454-455, 426-432.

ARMON, R., DOSORETZ, C.G., AZOV, Y. AND SHELEF, G. (1994) Residual contamination of crops irrigated with effluent of different qualities: a field study. *Water Science And Technology*, 30(9), 239-248.

AL-BAYATI, S.A. AND HABEEB, Z.S. (2009) Evaluation of horizontal flow roughing filtration performance. *Journal of Engineering and Technology*, 27(15), 2863-2878.

AL-JAYYOUSIE, O.R. (2003) Greywater reuse: towards sustainable water management. *Desalination*, 156(1), 181-192.

AMERICAN PUBLIC HEALTH ASSOCIATION, APHA. (1998) *Standards methods for the examination of water and wastewater*, 20th edition. American Water Works Association and Water Environmental Federation, Washington, DC.

AMERICAN PUBLIC HEALTH ASSOCIATION, APHA. (2005) *Standard methods for the examination of water and waste water*, 21st edition. Washington, DC. USA.

AMERICAN WATER WORKS ASSOCIATION, AWWA. (1992*) Membrane processes in potable water treatment*. Membrane Technology Research Committee. *Journal AWWA*, 59.

AMERICAN WATER WORKS ASSOCIATION, AWWA. (1999) *Water Quality and Treatment*, 5th edition, 1233 pages. Denver, CO. (ISBN 0-07-001659-3).

AWALEH, M.O. AND SOUBANEH, Y.D. (2014) Waste water treatment in chemical industries: the concept and current technologies, hydrology current research, *An Open Access Journal*, 5(1), 1-12.

BARRETT, J. M., BRYCK, J., COLLINS, M. R., JANONIS, B. A. AND LOGSDON, G. S. (1991) Manual of design for slow sand filtration, AWWA Research Foundation, American Water Works Association, Denver, CO, USA.

BODNAR, I., SZABOLCSIK, A., BARANYAI, E., UVEGES, A. AND BOROS, N. (2014) Qualitative characterization of household greywater in the Northern Great Plain Region of Hungary, *Environmental Engineering and Management Journal*, 13(11), 2717-2724.

BOYJOO, Y., PAREEK, V.K. AND ANG, M. (2013) A review of greywater characteristics and treatment processes, *Water Science and Technology*, 67(7), 1403-1424.

BOLLER, M. (1993) Filter mechanisms in roughing filters. *Journal of Water Supply Research and Technology – Aqua*, 42(3), 174 -185.

BROWN, R.R. AND DAVIES, P. (2007) Understanding community receptivity to water re-use: Ku-ring-gai council case study. *Water Science and Technology*, 55(4), 283-290.

BULNES, M. AND GARDUNO, F. (2009) Conference Call with SARAR Transformación, 20 May.

BURNAT, J.M.Y. AND MAHMOUD, N. (2005) Evaluation of on-site gray wastewater treatment plants performance in Bilien and Biet-Diko Villages/Palestine, Environment Protection Committee (EPC).

BROWN, C. (2007) Greywater Recycling: Risks, benefits, costs and policy, *Paper submitted for presentation at 49th Annual New Zealand Waters and Wastes Association conference in Rotorua, New Zealand*, 19-21 September.

BRUVOLD, W. H. (1998) Public opinion on water reuse options. *Journal of the Water Pollution Control Federation*, 60(1), 45-50.

CARDEN, K., ARMITAGE, N., SICHONE, O., WINTER, K. AND RIVETT, U. (2006) Management options for the safe use and disposal of greywater in the non-sewered areas of South Africa. *Paper presented at the 3rd International Conference on Ecological Sanitation, 23 - 26 May 2005, Durban, South Africa*.

CARDEN, K., ARMITAGE, N., WINTER, K., SICHONE, O., RIVETT, U. AND KAHONDE, J. (2007a) The use and disposal of grey water in the non-sewered areas of South Africa: Part 1- quantifying the grey water generated and assessing its quality. *Water SA*, 33(4), 425-432.

CARDEN, K., ARMITAGE, N., WINTER, K., SICHONE, O. AND RIVETT, U. (2007b) *Understanding the use and disposal of greywater in the non-sewered areas in South Africa*, WRC Report No 1524/1/07, Water Research Commission, South Africa.

CHANG, Y.C., KAN, C.E., CHEN, C.T. AND KUO, S.F. (2007) Enhancement of water storage capacity in wetland rice fields through deep water management practice. *Irrigation Drain*, (56), 79-86.

CHRISTOVA-BOAL, D., EDEN, R.E. AND MCFARLANE, S. (1996) An investigation into greywater reuse for urban residential properties. *Desalination*, 106(1-3), 391-397.

CLARKE, B.A., LLOYD, B.J., CROMPTON, J.L., AND MAJOR, I.P. (1996) Cleaning of up-flow gravel pre-filters in multi-stage filtration water treatment plants. In: Graham, N. and Collins, R. (eds.). *Advances in slow sand and alternative biological filtration*, Wiley & Sons, Chichester.

CLEARY, S.A. (2005) Sustainable drinking water treatment for small communities using multistage slow sand filtration. *Master's thesis in Applied Science. Waterloo, Ontario, Canada*.

COLLINS, M.R., COLE, J.O., WESTERSUND, C.M., AND PARIS, D.B. (1994a) Assessing roughing filtration design variables. *Water Supply*, 12, 1-2.

COLLINS, M.R., WESTERSUND, C.M., COLE, J.O. AND ROCCARO, J.V. (1994b) *Evaluation of roughing filtration design variables*, AWWA research foundation, Denver, CO.

COLOSI, L. (2005) Extension associate in the department of policy analysis and management, Cornell Cooperative Extension, Cornell University.

CORNISH, R. (2006) One way Analysis of Variance, Mathematics learning support center**.**

CUMMING, G., FIDLER, F. AND VAUX, D.L. (2007) Error bars in experimental biology, *Journal of cell biology*, 177(1), 7-11.

DASTANAIE, J., NABI, G. R., NASRABADI, T., HABIBI, R. AND HOVEIDI, H. (2007) Use of horizontal flow roughing filtration in drinking water treatment. *International Journal of Environmental Science and Technology*, 4(3), 379-382.

DEL PORTO, D. AND STEINFELD, C. (2000) *What about graywater*: *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. 3-7. 2nd Edition. Pretoria.

DEPARTMENT OF WATER AFFAIRS AND FORESTRY, DWAF.(1999) General authorizations in terms of section 39 of the National Water Act. Government gazette 20 526 No. 1191, Government printer, Pretoria, South Africa.

DHEYAA, W.A (2009) Saving water and energy consumption in Baghdad. Baghdad, water consumption problem in Baghdad symposium, Baghdad Government.

DHEYAA, W. A., AYAD, S. M. AND RASHA, A. J. (2013) Modification of grey water treatment using combination of cascade aeration and Bio-filtration. *Journal of Environmental Science and Engineering B*, 2(8) 473-481.

DIXON, A., BUTLER, D., FEWKES, A., AND ROBINSON, M. (1999) Measurement and modelling of quality changes in stored untreated greywater. *Urban Water*, 1(4), 293-306.

DOLNICAR. S., HURLIMANN, A. AND GRÜN, B. (2011) What affects public acceptance of recycled and desalinated water? *Water Research*, 45(2), 933-943.

DOME, S. (2000) How to estimate and design the filter run duration of a horizontal flow roughing filter. *Thammasat International Journal of Science and Technology*, 5(2), 1-13.

DOMENECH, L. AND SAURI, D. (2010) Socio-technical transitions in water scarcity contexts: public acceptance of greywater reuse technologies in the Metropolitan Area of Barcelona. *Resources, Conservation and Recycling*, 55(1), 53-62.

ECONOMIC AND SOCIAL COMMISSION FOR WESTERN ASIA, ESCWA. (2003) *Waste-water Treatment Technologies: A general review*, Publication of United Nation, New York.

EHTESHAMI, M., TAKDASTAN, A., ALAVI, N., JAFARZADEH HAGHIGHIFARD, N., AHMADI MOGHDAM, M. KHAZAYI, M. AND SALEHI, A.B. (2011) Efficacy of HRF in COD removal from secondary effluent of Yasuj Municipal wastewater. *Armaghane Danesh*, 16(4), 391-399.

ERIKSSON, E., AUFFARTH, K., HENZE, M. AND LEDIN, A. (2002) Characteristics of grey wastewater. *Urban Water*, 4(1), 85-104.

ERIKSSON, E., AUFFARTH, K., EILERSEN, A.M., HENZE, M. AND LEDIN, A. (2003) Household chemicals and personal care products as sources for xenobiotic organic compounds in grey wastewater. *Water SA*, 29 (2), 135-146.

ERIKSSON, E., BAUN, A., HENZE, M. AND LEDIN, A. (2006) Phytotoxicity of grey wastewater evaluated by toxicity tests. *Urban Water Journal*, 3(1), 13-20.

ERIKSSON, E., BAUN, A., SCHOLES, L., LEDIN, A., AHLMAN, S., REVITT, M., NOUTSOPOULOS, C., AND MIKKELSEN, P.S. (2007) Selected storm water priority pollutants - a European perspective. *Science of the Total Environment*, 383(1-3), 41-51.

FINLEY, S., BARRINGTON, S. AND LYEW, D. (2009) Reuse of domestic graywater for the irrigation of food crops. *Water Air Soil Pollution*, 199(1- 4), 235-245.

FRIEDLER, E. (2004) Quality of individual domestic greywater streams and its implication for on-site treatment and reuse possibilities. *Environmental Technol*ogy, 25(9), 997-1008.

FRIEDLER, E., KOVALIO, R. AND GALIL, N.I. (2005) On-site greywater treatment and reuse in multi-story buildings. *Water Science and Technology*, 51(10), 187-94.

FRIEDLER, E., LAHAV, E., JIZHAKI, H. AND LAHAV, T. (2006) Study of urban population attitudes towards various wastewater reuse options: Israel as a case study. *Journal of Environmental Management*, 81(4), 360-370.

GALVIS, G., VISSCHER, J.T., FERNA'NDEZ, J. AND BERO'N, F. (1993) Pretreatment alternatives for drinking water supply systems: Selection, design, operation and maintenance. Occasional Paper 22. IRC, the Hague, the Netherlands.

GALVIS G., VISSCHER, J.T. AND LATORRE, J. (1998) Multi-stage filtration and innovation water treatment technology. International Reference Centre for Community Water Supply and Sanitation. The Hague, Netherlands and Universidad del Valle Instituto CINARA, Cali, Colombia.

GALVIS, G., LATORRE, J. AND VISSCHER, J.T. (1998) *Multi-stage filtration: an innovative water treatment technology*. IRC International Water and Sanitation Centre, the Hague, Netherlands, TP series, no. 34E.

GALVIS, G., LATORRE, S., OCHOA, A. E. AND VISSCHER, S. T. (1996) Comparison of horizontal and up-flow (senes) roughing filtration. In: Graham, N. and Collins, N. (eds.). *Advances in slow sand and alternative biological filtration*, John Wiley and Sons, Chichester, England.

GHAITIDAK, D.M. AND YADAV, K.D. (2013) Characteristics and treatment of greywater - a review, *Environmental Science and Pollution Research*, 20(5), 2795-2809.

GODFREY, S., SAXSENA, A., KUMAR, P., SWAMI, A. AND JOSHI, N. (2005) *A preliminary study on potential of greywater reuse system in water scarce and fluoride contaminated rural areas of Jhabua, Madhya Pradesh*, India Group, I.W.R.S. Water Reuse and Reclamation for Sustainability (WRRS), IWA, South Korea.

GODFREY, S., LABHASETWAR, P. AND WATE, S. (2009) Greywater reuse in residential schools in Madhya Pradesh, India - a case study of cost-benefit analysis. *Resources, Conservation and Recycling*, 53(5), 287-293.

GRATTAN, S.R. (2002) Irrigation water salinity and crop production. Publication 8066, University of California, Oakland.

GROSS, A., KAPLAN, D. AND BAKER, K. (2007) Removal of chemical and microbiological contaminants from domestic greywater using a recycled vertical flow bioreactor (RVFB). *Ecological Engineering*, 31(2), 107-114.

HERNÀNDEZ, L.L., ZEEMAN, G., TEMMINK, H. AND BUISMAN, C.(2007) Characterisation and biological treatment of greywater, *Water Science and Technology*, 56 (5), 193-200.

HERNANDEZ, L., TEMMINK, H., ZEEMAN, G., MARQUES, A. AND BUISMAN, C. (2008) Comparsion of three systems for biological grey water treatment. *Proceedings of sanitation challenge: New sanitation concepts and models of governance*, 357-364, Wageningen, Netherlands.

HURLIMANN, A. AND DOLNICAR, S. (2010) Acceptance of water alternatives in Australia. *Water Science and Technology*, 61(8), 2137-2142.

IBRAHIM, A.H., DAHLAN, I., ADLAN, M.N. AND DASHTI, A. F. (2013) Post-treatment of palm oil mill effluent from a polishing pond using a limestone horizontal roughing filter. *Caspian Journal of Applied Sciences Research*, 2(2), 112-119.

JAMRAH, A., AL-OMARI, A., AL-QASEM, L., AND ABDEL GHANI, N. (2006) Assessment availability and characteristics of gray water in Amman. *Water International*, 2(31), 210-220.

JAYALATH, J. (1994) Algae removal by roughing filter. 20th WEDC conference: Manual on water supply and treatment. Ministry of urban development, Government of India, New Delhi.

JEFFERSON, B., PALMER, A., JEFFREY, P., STUETZ, R. AND JUDD, S. (2004) Greywater characterization and its impact on the selection and operation of technologies for urban reuse, *Water Science and Technology*, 50(2), 157–164.

KAGUONGO, M. (2010) Reuse of grey water in peri-urban areas. Bachelor degree project in Mechanical Engineering, *Master's thesis in school of Technology and Society, University of Skövde in Dar es Salaam, Tanzania*.

KHATUN A., MURSHID S.M., AND BADRUZZAMAN A.B.M., (2011) *Greywater quality assessment and treatment from different sources in Dhaka, Bangladesh*. Accepted for the 3rd International Conference on Chemical Engineering, ICChE-2011, BUET, Dhaka, Bangladesh.

KHEZRI, S.M., MAJIDI, G., MANSOORIAN, H.J., ANSARI, M., ATABI, F.T., MOGADDAM, T.T. AND RASHTCHI, N. (2015) Efficiency of horizontal roughing filter in removing nitrate, phosphate and chemical oxygen demand from effluent of waste stabilization pond. *Environmental Health Engineering and Management Journal*, 2(2), 87–92.

KHONG, C. M. (2009) Perception and use of graywater in Berkeley, California. *Master's thesis. San Jose State University*.

KIMWAGA, R.J., MASHAURI, D.A., MBWETE, T.S.A., KATIMA, J.H.Y.AND JORGENSEN, S.E. (2004) Use of couple dynamic roughing filters and SHF constructed wetland system as appropriate technology for upgrading WSP effluents in Tanzania. *Physics and Chemistry of earth*, 29(15-18), 1243-1251.

LECHEVALLIER, M. W. AND MCFETERS, G.A. (1990) Microbiology of activated carbon. In: McFeters, G.A. (ed.). *Drinking water microbiology: progress and recent developments*, Springer-Verlag, New York, pp. 104-119.

LEDIN, A., ERIKSSON, E. AND HENZE, M. (2001) Aspects of groundwater recharge using grey wastewater. In: Lens, P., Zeeman, G. AND Lettinga, G. (eds.). *Decentralised sanitation and reuse: concepts, systems and implementation*, IWA Publishing, London, UK, pp. 354-370.

LEO, RESPICIUS, M. AND KIMWAGA, R. (2009) Assessment of greywater reuse potential in Arusha Municipality. Rosa Project.

LI, F., WICHMANN, K. AND OTTERPOHL, R. (2009) Review of technological approaches for grey water treatment and reuses. *Science of the Total Environment*, 407(11), 3439 -3449.

LIN, C.J., LO, S.L., KUO, C.Y. AND WU, C.H. (2005) Pilot-scale electrocoagulation with bipolar aluminium electrodes for on-site domestic greywater reuse, *Journal of Environmental Engineering*, 131(3), 491- 495.

LOSLEBEN, T.R., (2008) Pilot study of horizontal roughing filtration in Northern Ghana as pretreatment for highly turbid Dugout water. *Master's thesis in Civil and Environmental Engineering. Massachussets Institute of Technology*.

LUDWIG, A. (2006) *The new create an oasis with greywater*: *oasis design*, Santa Barbara, California.

LUDWING, A. (1995) *Builder's Greywater Guide*, Published by Oasis Design, Santa Barbara, CA , accessed through www.oasisdesign.net, 01 October, 2014.

MADUNGWE, E. AND SAKURINGWA, S. (2007) Greywater reuse: A strategy for water demand management in Harare? *Physics and Chemistry of the Earth* 32(15-18), 1231-1236.

MARTINEZ, D. Z., SOTO, C. AND CANDEL, B (2009) Experiences in the desalination of different brackish water, *Proceedings of the IDA World Congress*, Atlantis.

MAHVI, A.H. (2004) Performance of a direct horizontal roughing filter system in treatment of highly turbid water. *Iranian Journal of Environmental Health Science Engineering*, 1(1), 1- 4.

MAHVI, A.H., MOGHADDAM, M.A., NASSERI, S. AND NADDAFI, K. (2004) Performance of direct roughing filtration system in treatment of highly turbid water. *Iranian Journal of Environmental Health Science and Engineering*, 1(1), 1- 4.

MOFOKENG, N.M. (2008) The greywater situation in informal settlements of the Ekurhuleni Metropolitan Municipality-Eastern region (Gauteng, South Africa*). Masters in environmental management thesis. North-West University, Potchefstroom*.

MOREL, A. AND DIENER, S. (2006) *Greywater Management in low and middle-income countries: review of different treatment systems for households or neighbourhoods.* Sandec Report no 16/06, Swiss Federal Institute of Aquatic Science and Technology (Eawag). Dübendorf, Switzerland.

MUANDA, C. (2009) Investigation of anaerobic up-flow batch reactor for treatment of greywater in un-sewered settlements. *Master of technology thesis. Cape Peninsula University of Technology*.

MUANDA, C. AND 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.

MUHAMMAD, N., ELLIS, K., PARR, J. AND SMITH, M.D. (1996) Optimization of slow sand filtration. Reaching the unreached: Challenges for the 21st century, 22nd WEDC Conference, WEDC, Loughborough university, Leicestershire, pp.283-285.

MUKHOPADHAY, B., MUJUMDER, M., BARMAN, R.N., ROY, P.K. AND MAZUMDAR, A. (2009) Verification of filter efficiency of horizontal roughing filter by Wegelin's design criteria and artificial neural network. *Drinking Water Engineering and Science Discussions*, 2(4), 21-27.

MURPHY, K. (2006) *A scoping study to evaluate the fitness-for-use of greywater in urban and peri-urban agriculture*, WRC Report No. 1479/1/06.

NOLDE, E. (1999) Greywater reuse systems for toilet flushing in multi-story buildings – over ten years experience in Berlin. *Urban Water*, 1(4), 275-284.

NKWONTA, O.I. (2010) Roughing filters: an alternative passive pre-treatment of coal mine water in South Africa. *Masters technology in faculty of engineering and built environment, Tshwane university of technology*.

NKWONTA, O.I. AND OCHIENG, G.M. (2009) Roughing filter for water pretreatment technology in developing countries: a review. *International Journal of Physical Sciences*, 4(9), 455-463.

OCHIENG, G.M.M., OTIENO, F.A.O., OGADA, T.P.M., SHITOTE, S.M. AND MENZWA, D.M. (2004) Performance of multistage filtration using different filter media. *Water S. A.*, 30(3), 361-368.

OLANREWAJU, O.O. AND ILEMOBADE, A.A. (2015) Greywater reuse review and framework for assessing greywater treatment technologies for toilet flushing, *Science Domain International*, 5(4), 2-12.

ONGERTH, J. E. (1990) Evaluation of treatment for removing giardia cysts. *Journal American Water Works Association*, 83(6), 85-96.

OHIO ENVIRONMENTAL PROTECTION AGENCY, OEPA. (2007) Division of surface water revision. Small subsurface flow constructed wetlands with soil dispersal system rule reference: OAC 3745-42.

OKUN, D. A. (2000) Water reclamation and unrestricted non potable reuse: a new tool in urban water management. *Annual Review of Public Health*, 21(1), 223-245.

OSTERTAGOVA, E. AND OSTERTAG, O. (2013) Methodology and application of oneway ANOVA, *American Journal of Mechanical Engineering*, 1(7), 256-261.

OTHMAN, F., ALAA ELDIN, M.E. AND MOHAMED, I. (2012) Trend analysis of a tropical urban river water quality in Malaysia. *Journal of Environmental Monitoring*, 14(12), 3164-3173.

OTTOSSON, J. AND STENSTRÖM, T.A. (2003) Growth and reduction of microorganisms in sediments collected from a greywater treatment system. *Letters in Applied Microbiology*, 36(3), 168-72.

PACINI, V. (2005) Removal of iron and manganese using biological roughing up-flow filtration technology. *Water Research*, 39(18), 4463-4475.

PENTAMWA, P., THIPTHARA, W. AND NUANGON, S. (2011) Removal of hardness from Groundwater by Synthetic Resin from waste plastics. *International Journal of Environmental Science and Development*, 2(6), 479-483.

PIDOU, M, MEMON, F.A., STEPHENSON. T., JEFFERSON. B., AND JEFFREY, P. (2007) Greywater recycling: a review of treatment options and applications. *Proceedings of ICE-Engineering Sustainability*, 160(3), 119-131.

PIDOU, M., AVERY, L., STEPHENSON, T., JEFFREY, P., PARSONS, S.A., LIU, S., MEMON, F.A. AND JEFFERSON, B. (2008) Chemical solutions for greywater recycling. *Chemosphere*, 71(1), 147-155.

PO, M., KAERCHER, J.D. AND NANCARROW, B.E. (2003) *Literature review of factors influencing public perceptions of water reuse*, technical report 54/03, CSIRO land water, Victoria, Australia.

PO, M., NANCARROW, B.E., LEVISTON, Z., POTER, N.B., SYME, G.J. AND KAERCHER, J.D. (2005) *Predicting community behavior in relation to wastewater reuse: What drives decisions to accept or reject?* Water for a healthy country national research flagship, CSIRO land and water: Perth.

RABINDRA, B., MAJUMDER, M., MUKHOPADHAYAV, B., MAZUMDA, R.A. AND BANERJEE, G. (2008) Performance of HRF as a pretreatment unit before conventional water treatment system. Published at www.engi@phillica.com. Accessed on 01 June 2015.

RAMON, G., GREEN, M., SEMIAT, R. AND DOSORETZ, C. (2004) Low strength greywater characterization and treatment by direct membrane filtration. *Desalination*, 170 (3), 241–50.

RAZMIK, A., IRIS, E. AND ALEJANDRO, S.F. (2006) *Small scale wastewater treatment with separation in houses*, the Swedish Environmental Protection Agency (SEPA), Sweden.

REPUBLIC OF SOUTH AFRICA, DEPARTMENT OF HEALTH (2000) *Guidelines for good clinical practice in the conduct of clinical trials in human participants in South Africa.*

REVELLE, P. AND REVELLE, C. (1988) *The environment: issues and choices for society*, Jones and Bartlett Publishers, Boston.

RODDA, N., CARDEN, K. AND ARMITAGE, N. (2010) *Sustainable Use of Greywater in Small-Scale Agriculture and Gardens in South Africa*, WRC Report No. 1639/1/10, Water Research Commission, Pretoria.

ROESNER L., QIAN Y., CRISWELL M., STROMBERGER M. AND KLEIN, S. (2006) *Long-term effects of landscape irrigation using household graywater: Literature review and synthesis*. Water Environment Research Foundation (WERF) and Soap and Detergent Association (SDA), Washington DC, USA.

SANTAMARÍA, J. AND TORANZOS, G.A. (2003) Enteric pathogens and soil: a short review. *International Microbiology*, 6(1), 5-9.

SCHULZ, C.R., AND OKUN, D.A (1984) *Surface water treatment in developing countries*. J. Wiley, New York.

SIEGRIST, R., WITT, M. AND BOYLE, W.C. (1976) Characteristics of rural household wastewater. *Journal of the Environmental Engineering Division-Asce*, 102(3), 533-548.

SOSTAR-TURK, S., PETRINIC, I. AND SIMONIC, M. (2005) Laundry wastewater treatment using coagulation and membrane filtration. *Resources, Conservation and Recycling*, 44(2), 185-196.

TOZE, S. (2005) Reuse of effluent water-benefits and risks. *Agricultural Water Management*, 80(1), 147-159.

UNITED STATE ENVIRONMENTAL PROTECTION AGENCY, USEPA. (2004) *Guidelines for Water Reuse*. EPA/625/R-04/108.

WALLER, J.L. AND JOHNSON, M.H. (2013) Statistics and data analysis, analysis SAS global forum, Georgia Regents University, Augusta, Georgia.

WEGELIN, M. (1986) *Horizontal flow roughing filtration (HRF), design, construction and operation manual*, IRCWD Report No. 06/86, Zurich, Switzerland.

WEGELIN, M. (1996) *Surface water treatment by roughing filters - A design, construction and operation manual*, SANDEC Report No. 2/96, Dubendorf, Switzerland.

WEGELIN, M., BOLLER, M., AND SCHERTENLEIB, R. (1986) Particle removal by horizontal flow roughing filtration. *Aqua*, 42(3), 174-185.

WEGELIN, M., SCHERTENLEIB, R. AND BOLLER, M. (1991) The decade of roughing filters development of a rural water-treatment process for developing countries. *Aqua (Oxford)*, 40(5), 304-316.

WESTGARD, J.O., BARRY, P.L. AND QUAM, E.F. (1998) Basic QC practices: training in statistical quality control for healthcare laboratories, Madison, WL: Westgard Quality Corporation.

WORLD HEALTH ORGANISATION, WHO. (2002) Emerging and epidemic-prone diseases. In: global defence against the infectious disease threat. World Health Organization, Geneva (Chapter 4).

WIEL-SHAFRAN, A., RONEN, Z., WEISBROD, N., ADAR, E. AND GROSS, A. (2006) Potential changes in soil properties following irrigation with surfactant-rich greywater. *Ecological Engineering*, 26(4), 348-354.

WORLD HEALTH ORGANIZATION, WHO. (2006) Guidelines for the safe use of wastewater excreta and greywater-policy and regulatory aspects. Vol. 1, Geneva, Switzerland.

APPENDIX A

QUESTIONNAIRE SURVEY

Project Title: Peformance of a horizontal roughing filtration system in the treatment of greywater

Student Name: Mtsweni Sphesihle

Supervisors: Dr S. Rathilal/ Dr B.F. Bakare

Contact Number: 083 729 1446

Email: mtswenisihle@gmail.com/mtsweniS@mut.ac.za

Aim of the Questionnaire Survey: To investigate people's perceptions to the use of treated greywater

Introduction

The treatment of greywater receives growing interest when addressing critical issues related to water shortage and appropriate sanitation in South Africa and around the world. Greywater comprises basically domestic wastewater flows excluding water associated with the toilet. The perception of the public is very important and plays a major role that could lead to the success or failure of the project. Thus, this questionnaire is aimed at determining the perceptions of the public to the reuse of treated greywater. The question is grouped into two sections; (i) personal demographic data of the respondents and (ii) Research Questions.

SECTION 1: DEMOGRAPHIC DATA OF RESPONDENT

INSTRUCTION TO RESPONDENT
Unless instructed otherwise, please complete by making an X in the appropriate block

1.	**RACIAL GROUP**		
BLACK	COLOURED	INDIAN	WHITE

2.	**GENDER**
FEMALE	MALE

3.		**AGE GROUP**			
Under 19	20-29	30-39	40-49	50-59	Over 60

SECTION 2: SPECIFIC RESEARCH QUESTIONS

This section is grouped into three sections; (i) attitude towards the reuse of greywater (ii) concerns on health implications (iii) perceived advantage of greywater reuse. Please answer all questions sincerely has your response would help in the successful implementation of this project. Below are some instructions giving to follow before providing your opinion.

1. Please read carefully through each statement before giving your opinion. 2. Please make sure that you do not omit a question. 3. Please complete by making an 'X' in the appropriate block. 4. Please be honest when giving your opinion. 5. Please do not discuss statement. 6. Please return Questionnaire.

1. **ATTITUDE TOWARDS THE REUSE OF GREYWATER**

	Strongly Disagree	**Disagree**	**Not Sure**	**Agree**	**Strongly Agree**
Q1. I am comfortable using treated greywater for toilet/urinal flushing.					
Q2. I am comfortable using treated greywater for garden watering.					
Q3. I am comfortable using treated greywater from other buildings for toilet/urinal flushing or garden watering.					
Q4. I will only be prepared to use treated greywater for toilet/urinal flushing or garden watering only during drought or water shortage.					
Q5. I am comfortable with a dual water distribution system to be installed where I currently reside.					

2. **CONCERNS ON HEALTH IMPLICATIONS**

	Strongly Disagree	Disagree	Not Sure	Agree	Strongly Agree
Q1. I believe people might get sick from using treated greywater for toilet/urinal flushing.					
Q2. I believe people might get sick from using treated greywater for garden watering.					
Q3. Using treated greywater for toilet/urinal flushing or garden watering is disgusting.					

3. **PERCEIVED ADVANTAGE OF GREYWATER REUSE**

	Strongly Disagree	Disagree	Not Sure	Agree	Strongly Agree
Q1. Using treated greywater for toilet/urinal flushing and garden watering will have a positive impact on the environment.					
Q2. Using treated greywater for toilet/urinal flushing and garden watering will make our limited drinking water go further.					

Please return the completed questionnaire to: **S Mtsweni**
Attention:
Telephone number: 083 729 1446
Email: mtswenisihle@gmailcom; mtsweniS@mut.ac.za

Thank you for your co-operation.

APPENDIX B

ANALYTICAL PROCEDURES

STANDARD METHODS

1. PH MEASUREMENT

This is measured using a calibrated pH metre.

2. CONDUCTIVITY MEASUREMENT

This is measured using a calibrated conductivity metre.

3. TURBIDITY MEASUREMENT

Turbidity in water is caused by suspended and colloidal matter such as clay, silt, finely divided organic and inorganic matter, and plankton and other microscopic organisms. Turbidity is an expression of the optical property that causes light to be scattered and absorbed rather than transmitted with no change in direction or flux level through sample.

Determine turbidity as soon as possible after the sample has been taken. Gently agitate all samples before examination to ensure a representative measurement. Sample preservation is not practical; begin analysis promptly. Refrigerate or cool 4 °C, to minimize microbiological decomposition of solids, if storage is required. This is measured using a calibrated conductivity meter.

4. TOTAL SOLIDS

Total solids is the term applied to the material residue left in the vessel after evaporation of a sample and its subsequent drying in an oven at a defined temperature. The residue consists of organic and inorganic component of the waste.

Apparatus required

Porcelain crucibles

Drying oven

Analytical balance

Desiccator

Procedure

Heat clean dish to 103-105 °C for 1 hour. Store and cool dish in desiccator until cooled (needed). Weigh immediately before use.

Pipette 50 ml of well mixed sample to pre-weighed crucible

Weigh crucible contained with sample and place in an oven at 103 -105 °C for 24 hours.

Remove the crucible from the oven and placed in a dessicator to cool. Weigh the crucible

The total solids are therefore calculated as follows:

Total solids (mg/l) = ((A-B) x 1000)/(sample volume, ml)

A = weight of dried residue + dish, (mg)

B = weight of dish, (mg)

5. TOTAL DISSOLVED SOLIDS

Total dissolved solids, is the portion that passes through the filter. The type of filter holder, the pore size, porosity, area, and the thickness of the filter and the physical nature, particle size, and the amount of material deposited on the filter are the principal factors affecting separation of suspended from dissolved solids. Dissolved solids is the portion of solids that passes through a filter of 2.0 micron metre (or smaller) nominal pore size under specified conditions. Suspended solids is the portion retained on the filter.

Apparatus required

Porcelain crucibles

Drying oven

Analytical balance

Dessicator

Vacuum filtration apparatus (glass filter attached)

Procedure

Heat clean dish to 180 °C for 1 hour. Store and cool dish in dessicator until needed. Weigh immediately before use.

Assemble filtering apparatus and filter and begin suction. Filter about 150 ml of well mixed sample using vacuum filtration apparatus. If volume filtered fails to meet minimum yield, increase sample volume up to 1 L. If complete filtration takes more than 10 min, increase filter

diameter or decrease sample volume. Continue suction for about 3 min after filtration is complete.
Evaporate the portion that passes through the filter for 24 hours at 180 °C in an oven, cool in a dessicator to balance temperature, and weigh.

The total dissolved solids are therefore calculated as follows:

Total dissolved solids (mg/l) = ((A-B) x 1000)/(sample volume, ml)

A = weight of dried residue + dish, (mg)

B = weight of dish (mg)

6. VOLATILE SOLIDS

The volatile solids are required to the fraction of the total solids lost on ignition at 550 °C and serves as a measure of the organic (oxidizable) solids present in each sample analyzed.

Apparatus required

Porcelain crucibles

Drying oven

Analytical balance

Dessicator

Muffle furnace

Procedure

Residue from the determination of total solid is ignited in a muffle furnace at 550 °C for 20 mins. The volatile solid is therefore calculated as follows:

Total dissolved solids (mg/l) = ((A-C) x 1000)/(sample volume, (ml))

A = weight of dried residue + dish before ignition, (mg)

C = weight of residue + dish after ignition, (mg)

7. CHEMICAL OXYGEN DEMAND

The chemical oxygen demand measures the oxygen equivalent of that portion of the organic matter in a sample that is easily oxidized by a strong chemical oxidant. It is an important and rapidly measured parameter to measure the amount of organic compounds in stream and industrial waste studies, and in operational control of waste water treatment plants. The sample is digested for 2 hours in a strongly acidic dichromate solution, using silver sulphate as a catalyst and mercuric sulphate as a masking agent to prevent chloride interference. The dichromate is partially reduced by the oxidisable material present in the sample. The excess dichromate is titrated with ammonium iron (II) sulphate and the COD value calculated from the amount of dichromate.

Apparatus required

Digester unit

Erlenmeyer flasks

Pipettes

10 ml and 5 ml automatic bottle top dispensers

Digital titrator

Reagents

Standard potassium dichromate $K_2Cr_6O_7$ digestion solution: 0.0167 M

Add to about 500 ml distilled water and 4.913 g $K_2Cr_6O_7$, previously dried at 105 °C for 2 hours.

Add 167 ml conc. sulphuric acid H_2SO_4 and 13.3 g Mercuric sulphate $HgSO_4$.

Dissolve and cool to room temperature before diluting to 1L.

Sulphuric acid H_2SO_4/Silver Sulphate reagent Ag_2SO_4 (COD reagent)

Add 26 g of silver sulphate crystals or powder to 2.5 l of concentrated sulphuric acid using a magnetic stirrer. Shake well and leave for 2 days for dilution.

Ferroin indicator 2 drops

Dissolve 1.485 g 1:10 phenontroline monohydrate and 0.695 g ferrous sulphate ($FeSO_4.7H_2O$) in distilled water and dilute to 100 ml.

Dissolve 39.2 g Fe $(NH_4)_2(SO_4)_2.6H_2O$ in distilled water. Add 20 ml conc. sulphuric acid H_2SO_4 and dilute to 1 L. Standardize daily against standard potassium dichromate $K_2Cr_6O_7$ digestion solution.

Standard preparation

Add 3 ml of standard $K_2Cr_6O_7$ digestion solution to 5 ml of distilled water. Add 7 ml COD reagent and cool it down. Prepare a standard $K_2Cr_6O_7$ solution daily to correct any variation in the concentration of the Ferrous Ammonium Sulphate. Titrate with FAS Titrant using 2 drops of ferroin indicator.

Procedure

Add 5 ml sample to each digester tube

Add 5 ml distilled water to another vessel (blank)

Add 3 ml potassium dichromate digestion solution into each vessel

Add 7 ml sulphuric acid reagent (with silver sulphate) in each vessel

The acid must be poured down the wall of the flask while flask is tilted. If sample is too concentrated it will turn green and a higher dilution of a sample must be used

Prepare a blank with each set of samples consisting of 5 ml distilled water in place of sample together with all reagents and digest together with samples

Digest for 2 hrs at 150 °C

Transfer contents from tube into 100 ml flasks for titration

Titrate the excess dichromate in the digest mixture with standard ferrous ammonium sulphate using 2 drops of ferroin indicator

Titrate from a sharp green /orange to red brown end point

Take reading.

Calculation

COD (mg/l) = ((Blank-Titration)x(molarity of FAS x 8000))/(sample (ml))

Molarity of FAS = (Volume x 0.0167 M $K_2Cr_6O_7$ solution Titrated (ml))/(volume FAS used in Titration (ml))

8. BOD

BOD is the amount of dissolved oxygen required by aerobic biological organisms in a body of water to break down organic material present in a given water sample at certain temperature over a specific time period. The BOD value is most commonly expressed in milligrams of oxygen consumed per litre of sample during 5 days of incubation at 20 °C and is often used as a robust surrogate of the degree of organic pollution of water. BOD is the principle test to give an idea of the biodegradability of any sample and strength of the waste.

Apparatus and reagents required

BOD system

300 mL incubation bottles

A nitrifying inhibitor (ATH) (N-allylthiourea)

Procedure

Add a sample volume into the incubation bottles, this depends on the range of BOD estimated in the collected sample.

Add drops of ATH based on the sample size then place in the BOD system for 5 Days. Below is the table showing relationship between sample volume and the drops of ATH required.

Sample volume	Measuring range (mg/l)	ATH (drops)
428	0 - 40	10
360	0 - 80	10
244	0 - 200	5
157	0 - 400	5
94	0 - 800	3
56	0 - 2000	3
21.7	0 - 4000	1

APPENDIX C

STATISTICAL TERMS AND DESCRIPTIONS

STANDARD DEVIATION

Standard deviation is a widely used measurement of variability or diversity used in statistics and probability theory. It shows how much variation or "dispersion" there is from the average (mean, or expected value). A low standard deviation indicates that the data points tend to be very close to the mean, whereas high standard deviation indicates that the data are spread out over a large range of values. In science, researchers commonly report the standard deviation of experimental data, and only effects that fall far outside the range of standard deviation are considered statistically significant – normal random error or variation in the measurements is in this way distinguished from causal variation (Cumming et al., 2007).

To calculate some basic statistics: sample mean, sample variance, and sample standard deviation, one can use AVERAGE (.), VAR(.), and STDEV(.) functions to obtain the values. See the following pictures (Cumming et al., 2007).

ERROR BARS

Error bars are used on graphs to indicate the error, or uncertainty in a reported measurement. They give a general idea of how accurate a measurement is, or conversely, how far from the reported value the true (error free) value might be. Error bars often indicate one standard deviation of uncertainty, but may also indicate the standard error. These quantities are not the same and so the measure selected should be stated explicitly in the graph or supporting text (Cumming et al., 2007).

Error bars can be used to compare visually two quantities if various other conditions hold. This can determine whether differences are statistically significant. Error bars can also show how good a statistical fit the data has to a given function. Scientific papers in the experimental sciences are expected to include error bars on all graphs, though the practice differs somewhat between sciences, and each journal will have its own house style (Cumming et al., 2007).

CONFIDENCE INTERVALS

Often, you will obtain an estimate of the standard deviation from a previous study or a pilot study. Since this estimate is based on a sample, it is important to understand its precision. This can easily be calculated since the square of the sample standard deviation follows a chi-squared distribution. This confidence interval does assume that the population you are sampling from is normally distributed. Once a confidence interval has been obtained, it would be wise to enter both values (the confidence limits) into the appropriate place in the sample size calculations to provide a range of possible sample size values (or of statistical power) (Cumming et al., 2007).

ONE-WAY ANOVA

One way analysis of variance (ANOVA) is used to compare several means. This method is often used in scientific or medical experiments when treatments, processes, materials or products are being compared. In ANOVA the question of interest is, "Do all our groups come from populations with the same mean?". To answer this it is needed to compare the sample means. However, even if all the population means were identical, one would not expect the sample means to be exactly equal - there will be always be some differences due to sampling variation. The question therefore becomes, "Are the observed differences between the sample means simply due to sampling variation or due to real differences in the population means?" This question cannot be answered just from the sample means - it is also need to look at the variability of whatever is measured. In analysis of variance one compares the variability between the groups (how far apart are the means?) to the variability within the groups (how much natural variation is there in our measurements?). This is why it is called analysis of variance (Cornish, 2006; Ostertagova and Ostertag, 2013).

ANOVA is based on two assumptions. Therefore, before we carry out ANOVA, one needs to check that these are met:

1. The observations are random samples from normal distributions.
2. The populations have the same variance, σ2. Fortunately, ANOVA procedures are not very sensitive to unequal variances - the following rule can be applied:

If the largest standard deviation (not variance) is less than twice the smallest standard deviation, one can use ANOVA and our results will still be valid.

So, before carrying out any tests one must first look at the data in more detail to determine whether these assumptions are satisfied:

1. Normality: If you have very small samples, it can sometimes be quite difficult to determine whether they come from a normal distribution. However, one can assess whether the distributions are roughly symmetric by:
    a. Comparing the group means to the medians - in a symmetric distribution these will be equal and
    b. Looking at boxplots or histograms of the data. Equal variances: one can simply compare the group standard deviations (Cornish, 2006; Ostertagova, and Ostertag, 2013).

COEFFICIENT OF VARIATION

The coefficient of variation (COV) is equal to standard deviation (SD) divided by the mean. Hence, if you know the coefficient of variation and the mean, one can estimate SD. This estimate is normally used to show reliability, variation and as well as consistency in the measured data using standard deviation and the mean (Westgard et al., 1998).

POST-HOC TESTS

Post hoc tests are designed for situations in which the researcher has already obtained a significant omnibus F-test with a factor that consists of three or more means and additional exploration of the differences among means is needed to provide specific information on which means are significantly different from each other (Ostertagova, and Ostertag, 2013).

Post Hoc tests are a critical step in the ANOVA process because they allow us to determine which plans are different from the others.

There are several possible Post Hoc tests to choose from based upon the specifics of your analysis.

1. Fishers LSD and Tukey
2. Scheffe', Bonferroni, (Ostertagova, and Ostertag, 2013).

CHI-SQUARE TESTS

A chi-square test is used to examine the association between categorical variables. The levels of categories for each variable can be two or more. The types of research questions that can be addressed are according to Waller and Johnson (2013) are:

1. Are two (or more) proportions in a single categorical variable different from hypothesized population values?
2. Is there an association or dependence between two categorical variables?
3. Are two (or more) proportions different from each other?
4. Is there a difference of risk (or odds) of an event between two groups?

ONE- AND TWO-SAMPLE T-TESTS

T-tests are used to examine differences between means. The types of research questions that can be addressed according to Waller and Johnson (2013) are:

1. Is the sample mean of a single continuous variable in a single group of individuals different from a particular hypothesized population value?
2. Are the sample means of a single continuous variable different between two different groups of individuals?

INTERPRETING THE P-VALUE

The p-value is a form of numerical estimation of the reliability of our assumption that the difference in means is real and not due to chance. In general, researchers say that a p-value less than 0.05 is statistically significant, which means that we are sure that the result we see (the difference in means) is not due to chance. Therefore, when reporting the results of pre/posttest on evaluation or surveys, one could report that a t-test confirms that the change on a given item were "significant at a $p<0.05$ level" (COLOSI, 2005).

APPENDIX D

RAW DATA

CHARACTERISATON OF GREYWATER FROM LOW INCOME COMMUNITY: BIOLOGICAL OXYGEN DEMAND (BOD)			
	BATH(mg/l)	LAUNDRY(mg/l)	KITCHEN(mg/l)
Week 1	85	380	320
Week 2	92	420	350
Week 3	245	600	812
Week 4	253	400	738
Week 5	249	500	775
Week 6	199	360	420
Week 7	191	350	634
Week 8	168	300	787

CHARACTERIZATION OF GREYWATER FROM LOW INCOME COST COMMUNITY: (pH)			
SAMPLE	LAUNDRY	BATH	KITCHEN
1	7.28	9.25	6.30
2	7.30	10.50	6.50
3	7.35	11.50	6.20
4	7.41	8.32	6.40
5	7.45	8.32	6.30
6	7.52	8.35	6.80
7	7.61	10.10	6.23
8	7.62	10.20	6.29
9	7.65	10.50	6.23
10	9.21	8.45	6.31
11	9.23	8.45	6.32
12	9.24	8.47	6.21
13	10.12	8.70	6.70
14	10.63	8.70	6.50
15	9.65	8.70	6.40
16	10.42	10.21	6.50
17	10.74	10.23	6.40
18	10.84	10.31	6.80

19	10.82	10.20	6.70
20	10.11	10.40	6.40
21	10.12	10.10	6.20
22	9.52	10.20	6.50
23	9.51	10.10	6.50
24	9.52	10.40	6.30
25	9.84	9.20	6.70
26	9.45	9.20	6.20
27	9.51	9.40	6.10
28	10.65	10.35	6.23
29	10.74	10.32	6.26
30	10.76	10.30	6.20
31	9.52	10.11	6.30
32	9.54	10.14	6.50
33	9.65	10.13	6.40
34	10.30	10.50	6.40
35	10.30	6.71	6.40
36	10.31	6.78	6.30
37	10.80	7.90	6.50
38	10.90	9.30	6.50
39	10.70	9.32	6.40
40	9.50	9.30	6.40
41	9.50	9.30	6.50
42	10.00	9.40	6.40
43	10.40	9.10	6.70
44	10.40	9.60	6.50
45	10.50	9.50	6.70
46	9.20	9.40	7.00
47	9.30	9.40	6.90
48	9.20	9.20	6.40
49	9.12	9.30	6.70
50	9.14	9.50	6.80
51	9.15	9.80	6.40
52	10.40	9.40	6.40
53	10.30	9.70	6.40
54	10.31	9.40	6.20
55	11.20	8.10	6.40
56	10.40	8.10	6.50
57	11.50	10.00	6.70
58	10.40	7.80	6.70
59	10.50	7.90	6.70
60	10.80	6.90	6.20

CHARACTERIZATION OF GREYWATER FROM LOW INCOME COST COMMUNITY: (µS/cm)			
SAMPLE	LAUNDRY	BATH	KITCHEN
1	320	120	445
2	220	160	968
3	240	150	700
4	300	220	750
5	200	210	793
6	100	170	968
7	550	200	1629
8	426	120	1634
9	450	432	1400
10	300	300	450
11	300	100	463
12	220	100	470
13	300	160	450
14	320	120	457
15	320	110	465
16	300	180	463
17	320	170	457
18	350	160	455
19	140	200	450
20	150	230	456
21	120	220	478
22	250	140	254
23	250	140	245
24	250	150	255
25	450	140	561
26	455	170	549
27	450	140	556
28	300	300	630
29	300	320	630
30	300	300	631
31	300	160	631
32	200	160	628
33	200	140	600
34	320	200	654
35	320	300	650
36	20	400	650
37	340	150	478
38	400	140	456
39	400	110	480

40	160	100	100
41	120	100	120
42	180	120	130
43	300	100	890
44	400	170	889
45	200	200	885
46	200	200	745
47	200	110	700
48	200	110	700
49	200	145	875
50	500	145	145
51	250	150	123
52	300	350	400
53	200	350	456
54	260	250	745
55	300	450	1200
56	400	450	995
57	370	460	1000
58	350	200	1500
59	200	200	1580
60	300	1650	1502

CHARACTERIZATION OF GREYWATER FROM LOW INCOME COST COMMUNITY: TURBIDITY (NTU)			
SAMPLE	LAUNDRY	BATH	KITCHEN
1	50	60	260
2	50	70	245
3	49	75	255
4	100	100	200
5	110	120	200
6	110	140	200
7	145	200	150
8	145	220	150
9	146	255	151
10	452	360	250
11	452	300	250
12	452	290	250
13	50	44	50
14	55	45	50
15	57	44	50
16	89	80	60
17	90	70	60

18	91	90	60
19	96	220	200
20	97	240	200
21	97	200	200
22	45	77	30
23	45	80	32
24	50	81	33
25	120	30	100
26	125	26	100
27	130	28	110
28	55	45	40
29	56	44	42
30	58	44	45
31	420	370	300
32	440	369	300
33	444	368	300
34	444	100	300
35	442	99	300
36	440	102	300
37	300	90	400
38	300	89	400
39	310	88	410
40	200	66	240
41	200	65	245
42	220	65	246
43	250	375	300
44	249	375	290
45	255	375	290
46	310	25	60
47	300	25	60
48	300	25	60
49	89	45	250
50	88	45	250
51	90	44	250
52	440	10	120
53	444	12	120
54	442	12	120
55	320	17	85
56	320	20	80
57	320	21	90
58	110	66	90
59	110	66	99
60	110	65	89

CHARACTERIZATION OF GREYWATER FROM LOW INCOME COST COMMUNITY: CHENICAL OXYGEN DEMAND (mg/l)			
SAMPLE	LAUNDRY	BATH	KITCHEN
1	2160	960	1748
2	1176	840	2040
3	2141	399	1988
4	1968	600	1981
5	1924	2000	1976
6	1927	440	1985
7	1968	840	1935
8	840	480	1852
9	2285	857	1985
10	2036	1301	1972
11	1008	1278	1971
12	1317	573	1985
13	1944	1600	1781
14	1392	2440	2023
15	2265	1200	1879
16	1680	1600	1920
17	1152	840	1435
18	2424	1280	1653
19	1018	1360	1200
20	871	1600	1901
21	1580	2480	1835
22	1680	1760	1680
23	1605	520	2040
24	787	1200	2024
25	802	1200	1459
26	1202	1680	1976
27	1459	1920	1886
28	1677	2440	1864
29	1701	1680	1765
30	2073	2600	1859
31	2024	1120	1968
32	761	1480	1488
33	1293	399	1464
34	1224	920	1824
35	792	1320	1320
36	1464	2306	2040
37	1840	600	1992
38	2060	1480	2116
39	2251	1420	1756

40	1529	2400	1647
41	1529	2440	1985
42	2539	1560	1765
43	1491	640	1800
44	873	2280	2120
45	864	1520	1713
46	1358	840	2485
47	1392	1720	1577
48	1777	1120	2226
49	1920	861	2796
50	1512	1563	1704
51	1038	632	3953
52	1920	1487	2667
53	2064	2447	1547
54	1224	1477	2392
55	1248	2520	3000
56	552	2240	2720
57	1008	2275	3440
58	2160	1451	3725
59	1267	980	2667
60	672	2116	2954

HORIZONTAL ROUGHING FILTER (HRF)DATA: CONDUCTIVITY (μS/cm) AT A FILTRATION RATE OF 0.3 (m/h)				
Influent	Compartment 1	Compartment 2	Compartment 3	Effluent
1383	1326	1313	1199	225
1055	1001	944	931	200
1200	1140	1190	650	250
1580	1565	1559	945	343
1383	1324	1309	709	511
1381	1324	1308	710	325
1925	1920	1869	1292	522
1590	1510	1490	790	120
1591	1521	1498	998	420
1855	1840	1821	1421	423
1990	1910	1884	1280	541
1991	1921	1200	1107	260
1056	1050	900	981	482
1525	1445	1311	928	150
1991	1900	1612	1380	120
1592	1576	1504	1015	190
1320	1240	1010	628	195
1400	1310	900	494	110
1312	1923	1311	1225	472
1500	1401	1385	885	180
1200	1130	1120	990	250
1100	1383	1201	1129	642
1821	1761	1541	1423	350
1720	1665	1645	1321	600
1524	1499	1102	861	432
1400	1330	1244	1120	520
1600	1530	1521	1245	410
1800	1740	1611	1516	500
1900	1860	1852	1587	254
2010	1970	1963	1811	364

HORIZONTAL ROUGHING FILTER (HRF) DATA: CONDUCTIVITY (μS/cm) AT A FILTRATION RATE OF 0.5 (m/h)				
Influent	Compartment 1	Compartment 2	Compartment 3	Effluent
1565	1527	1127	905	315
1800	1760	1314	1241	1023
2000	1950	1647	1463	700
1994	1919	1654	1294	412
1700	1650	1400	1045	800
1721	1681	1321	1163	900
2042	1989	1589	1294	608
1423	1378	1141	1000	650
2312	2272	1891	1011	710
1921	1876	1378	941	425
1421	1371	1178	800	341
2431	2353	1910	1055	385
1762	1712	1201	899	412
1856	1806	1541	1165	741
2512	2212	1712	1989	410
2041	1981	1345	945	500
1978	1940	1877	950	600
2220	2100	1966	1412	610
1436	1401	1312	1120	711
1536	1516	1456	1120	720
1551	1455	1277	1454	945
1478	1453	1323	1123	989
2514	2479	2296	2102	712
1967	1814	1612	1413	1212
1235	1205	1100	1011	900
1754	1719	1168	1021	786
1631	1666	1536	1074	554
1781	1741	1645	1400	1100
2141	2106	2014	1600	1400
1423	1403	1345	1100	1078

HORIZONTAL ROUGHING FILTER (HRF) DATA: CONDUCTIVITY (µS/cm) AT A FILTRATION RATE OF 1 (m/h)				
Influent	Compartment 1	Compartment 2	Compartment 3	Effluent
1968	1745	1296	1145	524
1925	1789	1700	1645	700
2101	1578	1421	1245	754
1948	1845	1654	1542	1045
1456	1431	1245	1145	787
1910	1890	1541	1389	1032
1878	1800	1148	1001	978
1723	1708	1542	1201	1108
1812	1795	1641	1423	1178
1921	1901	1899	1632	1541
1640	1600	1578	1310	853
2011	1997	1890	1522	1463
2103	2000	1945	1696	1598
2001	1283	1190	1096	732
2012	1985	1465	1345	245
2314	2100	2000	1300	1287
2090	1866	1483	1198	1049
2000	1992	1800	1600	1578
2115	2100	1989	1005	645
1542	1386	1300	1021	760
2100	1900	1800	1145	578
2131	2114	2099	1878	400
2490	2280	2198	1725	989
2141	1844	1800	1745	700
1232	1222	1211	1100	1023
1406	1370	1390	900	480
1875	1644	1478	1398	1300
2141	2000	1945	1000	600
1836	1800	1789	1420	1170
1874	1800	1599	1125	1100

HORIZONTAL ROUGHING FILTER (HRF): TURBIDITY (NTU) AT A FILTRATION RATE OF 0.3 (m/h)				
Influent	Compartment 1	Compartment 2	Compartment 3	Effuent
219	115	100	108	22
331	323	190	135	21
356	321	201	154	26
367	342	190	120	41
396	209	187	125	30
394	326	263	177	26
232	212	183	157	29
236	184	166	129	30
411	305	195	140	29
356	313	260	148	28
260	245	243	221	27
156	120	102	194	22
250	190	140	110	21
226	200	169	121	25
241	160	140	111	30
200	180	168	160	25
258	200	181	174	14
350	295	230	243	26
350	293	290	255	30
258	210	187	167	25
420	370	362	355	25
393	322	310	301	20
390	345	333	321	25
230	221	201	194	22
231	221	208	198	35
330	310	297	292	25
278	269	257	250	53
270	248	240	210	40
334	321	300	294	30
320	319	298	290	20

HORIZONTAL ROUGHING FILTER (HRF): TURBIDITY (NTU) AT A FILTRATION RATE OF 0.5 (m/h)				
Influent	Compartment 1	Compartment 2	Compartment 3	Effuent
430	363	340	171	45
393	200	180	292	73
402	376	347	255	75
237	235	170	114	24
231	210	209	202	115
229	220	170	193	140
278	266	208	202	80
270	265	210	180	105
334	300	237	152	56
315	300	202	180	80
300	294	289	275	30
400	311	300	198	31
400	378	364	361	30
400	310	301	299	42
396	362	324	320	28
400	395	310	360	30
350	210	189	157	24
400	250	241	240	27
300	278	231	220	26
380	314	300	187	40
400	390	302	321	40
390	385	194	187	45
400	285	280	275	30
360	355	275	258	30
350	311	300	294	30
390	385	287	267	30
400	211	200	198	20
290	215	200	194	25
400	385	210	200	16
390	314	297	294	17

HORIZONTAL ROUGHING FILTER (HRF): TURBIDITY (NTU) AT A FILTRATION RATE OF 1 (m/h)				
Influent	Compartment 1	Compartment 2	Compartment 3	Effuent
110	100	70	60	52
160	156	136	133	108
300	251	204	149	81
294	226	199	128	98
160	156	140	129	104
140	121	101	93	73
258	244	220	170	70
280	275	201	190	140
350	283	194	162	126
230	210	160	92	89
300	295	290	29	60
240	231	227	214	40
330	310	300	279	50
278	270	264	254	47
280	267	241	201	55
334	330	300	190	60
290	287	282	211	50
260	247	240	220	70
330	320	300	196	40
390	387	311	298	40
350	340	310	298	45
155	140	110	97	40
295	294	260	240	38
320	311	300	187	52
220	210	201	189	55
240	197	160	155	80
315	310	294	275	37
214	210	200	190	47
310	300	295	290	60
255	200	180	178	50