Modification and application of the decentralised wastewater treatment technology for greywater treatment to reduce water needs

Dissertation presented for the degree of Doctor of Philosophy

By

Nosiphiwe P. Ngqwala

Supervisor: Dr Roman Tandlich

RHODES UNIVERSITY
Where leaders learn

Faculty of Pharmacy, Rhodes University, 2015

DECLARATION

By submitting this dissertation, I declare that the entirety of the work contained in thesis is my own original work, all the analyses were done by me with the help provided with the growth trials. The study was a proof of concept and I am the sole author therefore, that reproduction and publication thereof by Rhodes University will not infringe any third party rights and that I have not previously in its entirety or in part submitted it for obtaining any qualification.

Signature: ……………………………………… Date: ……………………………………

ABSTRACT

Water is a scarce resource that is being acknowledged as a limiting factor to further social-economic growth and development. Demand for freshwater is increasing with corresponding increases in human population, industrial and agricultural activities. Alternative sources, such as greywater and rainwater are often polluted. Though greywater can be used for non-potable purposes, such as irrigation, it still requires some measures of treatment to improve its quality. To improve on greywater quality to facilitate its reuse, decentralised wastewater treatment technologies carry a great potential as complementary and alternative means of wastewater management particularly in peri-urban areas. Five research goals are addressed in this thesis: (i) to monitor the performance of Fly Ash Lime Filter Tower (FLFT) in the treatment of greywater; (ii) to modify the Fly Ash Lime Filter Tower in the treatment of greywater in order to reduce the pH of the greywater, and improved on the reduction of chemical oxygen demand (COD) and coliform counts; (iii) to investigate the potential of the reuse of greywater for irrigation; (iv) to undertake a techno analysis of the FLFT system for commercial use; and (v) to evaluate the use of hydrogen-sulphide (H_2S) test kit to monitor faecal contamination of various water sources using a multidisciplinary approach. The modification of the FLFT indicated good treatment efficiency, reducing the concentrations of COD, chlorides, nitrates, ammonia and sulphate by 82.6%, 60.4%, 72.9%, 60.5%, and 53.9%, respectively; while the average pH was at 8.3. Greywater contains nutrients that are beneficial to the growth of most plants. Growth variables included biomass, stem height, number of leaves and number of vegetables harvested. Soil analysis showed no effects of the treated greywater on soil physico-chemical and microbial quality with bulk density 2.0g/cm3, average pH 7.4, total phosphorus 0.16mg/L 8, faecal coliform 0.3 CFU/100 ml. The tomatoes had high biomass and dry weight (150 g; 33g) than beetroot (35 g; 15 g). Crops irrigated with greywater significantly grew faster compared with those irrigated with tap water. The community approach highlighted the value of knowledge management in greywater reuse. It highlighted the importance of creating an institutional knowledge in water management using the H_2S kit. The techno-economic analysis was used to evaluate key factors and the activities that are relevant to develop a sustainable FLFT in order to gain insights into the possibility of developing, and incorporating a business model framework to support decision making in value creation and value capturing during the research and the scaling up of the system. By this, a long term perspective to accomplish sustainable FLFT service businesses can be achieved.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

APHA	American Public Health Association
AWWA	American Water Works Association
BAF	Biological Aerated Filters
BE	Betroot Experiment
BEL	Betroot Experiment Leaves
BES	Betroot Experiment Stem
BER	Betroot Experiment Roots
BCL	Betroot Control Leaves
BCR	Betroot Control Roots
BCS	Beetroot Control Stem
BD	Bulk Density
BOD	Biological Oxygen Demand
CARA	Conservation Of Agricultural Resources Act
CNT s	Carbon Nanotubes
CF	Coarse Filters
Cl^-	Chloride
COD:N:P	Chemical Oxygen Demand: Nitrogen Phosphorus ratio
COD	Chemical Oxygen Demand
$C_2H_4O_2$	Acetic Acid
DEQ	Department of Environmental Quality
DPME	Department of Performance Monitoring and Evaluation
DWAF	Department Of Water Affairs
DRWH	Domestic Rainwater Harvesting
EC	Electrical Conductivity
et al.	And others
EHB	Environmental Health And Biotechnology Research Group
EPA	Environmental Protection Agency
FAO	Food And Agriculture Organization
FC	Faecal Coliforms

FLFT	Fly Ash Filter Tower
FRT	Hydraulic Retention Time
GW	Greywater
GWA	Greywater Additive
GWW	Global Water Watch
GAC	Granular Activated Carbon
HCl	Hydrochloric Acid
H_2S	Hydrogen-Sulphide
HST	Health System Trust
IDP	Integrated Developmental Plan
ITU	International Telecommunication Union
KCC	Kowie Catchment Campaign
KOH	Potassium Hydroxide
MF	Membrane filtration
MDGs	Millennium Development Goals
MTTS	Mulch-Tower Treatment System
MT	Mulch-Tower
NWA	National Water Act
NWRS	National Water Resource Strategy
NWP	National Water Protection
NaCl	Sodium Chloride
NWA	National Water Act
$NO3^-$	Nitrate
$NH4^+$	Ammonium
$NH3^+$	Ammonia
NGO	Non-Governmental Organisation
NRW	Non-Revenue Water
NTUs	Nephelometric Turbidity Units
NRCAN	Natural Resource Canada
OM	Organic Matter
O^3	Ozone
PO_4^{3-}	Phosphate
P	Phosphorus

PMG	Parliamentary Monitoring Group
PD	Particle Density
PR	Percentage Removal Efficiency
RSA	Republic Of South Africa
SALGA	South African Local Government Association
SA	South Africa
SF	Sand Filters
SAWQG	South African Water Quality Guidelines
SANS	South African National Standards
SAR	Sodium Adsorption Ratio
SAPPI	South African Pulp and Paper Industries
SHRT	Short Hydraulic Retention Time
SEWPACKSA	Small Wastewater Treatment Works
SO_4^{2-}	Sulphates
Stats SA	Statistics South Africa
(SS)	Suspended Solids
TE	Tomatoes Experiment
TEL	Tomatoes Experiment Leaves
TES	Tomatoes Experiment Stem
TER	Tomatoes Experiment Roots
TCL	Tomatoes Control Leaves
TCR	Tomatoes Control Roots
TCS	Tomatoes Control Stem
TC	Total Coliform
TKN	Total Kjeldahl Nitrogen
TMIH	Tropical Medicine and International Health
TSS	Total Suspended Solids
Tur	Turbidity
UJ	University of Johannesburg
UV	Ultraviolet
UNICEF	The United Nations Children's Fund
UNMDG	The United Nations Millennium

	Development Goals
UN	United Nations
UNHDI	United Nations Human Development Index
U.S.A	Unites States Of America
USDA	Unites States Department of Agriculture
USEPA	United States Environmental Protection Agency
WEF	Water Environment Federation
WHO	World Health Organisation
WFP	World Food Program
WITS	University of the Witwatersrand
WMA	Water Management Areas
WSDP	Water Service Development Plans
WRS	Water Resource Strategy
w/v	Weight per volume e.g. g/L or mg/mL
ZAR	South African Rand (currency)

PUBLICATIONS RESULTING FROM THIS WORK

Tandlich, R., Luyt C.T., & **Ngqwala N.P**., 2014. A community-based rainwater monitoring and treatment programme in Grahamstown, South Africa, *Journal of Hydrocarbons Mines and Environmental Research,* , Vol 5, Issue 1, 46-51, ISSN: 2107-6510

Ngqwala N. P., Zuma B. M., and Tandlich, R. (2013). Greywater composition and treatment in a coastal area of South Africa (*5th International Scientific and Expert Conference proceedings TEAM 2013 Technique, Education, Agriculture & Management*) Prešov, 4th to 6th November 2013

Ngqwala N. P., Tandlich R., Madikizela P., Al-Adawi S., and Ahmed, S. (2014). Enhanced Mulch tower system for greywater treatment using water hyacinth (**manuscript submitted**)

Ngqwala N. P., Tandlich R., Al-Adawi S., Ahmed M, and Madikizela P. (2014). Use of low-cost system for greywater treatment for on-site use in subsistence agriculture (**manuscript submitted**)

Ngqwala N. P., Tandlich R., Madikizela P., and Chifunda E. (2014). The use of hydrogen-sulphide test kit to monitor feacal contamination of various water sources using a community based approach in underprivileged South Africa (**manuscript in preparation**)

CONFERENCES ATTENDED

12th IWA Conference: Small Water & Wastewater Systems and Resources Oriented sanitation, Reuse of greywater to retrench water needs, Muscat, Sultanate of Oman, November 2014, oral presentation

15th WaterNet /WAFSA/GWP-SA Symposium, Use of low-cost system for greywater treatment for onsite use in subsistence agriculture, Lilongwe- Malawi, October 2014, oral presentation

35th The Academy of Pharmaceutical Sciences (APSSA), The use of hydrogen-sulphide test kit to monitor faecal contamination of various water sources using a community based approach in underprivileged South Africa, Summerstrand Hotel, Port Elizabeth, September 2014, poster presentation

41st National Convention of the South African Chemical institute, Application of water hyacinth in greywater treatment, River Park East London, December 2013, poster presentation

3rd Young water professional's conference, Characterisation of saline greywater along coastal areas of South Africa, Stellenbosch, Cape Town, July 2013, poster presentation

Interdisciplinary Postgraduate Conference (Rhodes University), The effect of water hyacinth to improve greywater treatment system, Rhodes University Post graduate village- Grahamstown, September 2013, oral presentation

3's Company Conference (Pharmacy Academy) conference, the modification of pH to improve the impacts of recycled water, Lagoon Beach, Cape Town, July 2013 poster presentation

3rd Annual Pharmacy Research Symposium (Rhodes University), the modification of mulch tower treatment system to improve the impacts of recycled water November 2013, oral presentation

ACKNOWLEDGEMENTS

First and foremost, I praise God, the almighty for granting me the opportunity and the capabilities to proceed successfully in my PhD study. Phil 4:13.

Also, I wish to thank the National Research Foundation (NRF) and Rhodes University Research Council for their generous funding.

Similarly, my gratitude goes to my promoter Dr Roman Tandlich - my esteemed supervisor - for accepting me as your Ph.D student. Your warm encouragement, thoughtful guidance, critical comments, and corrections are deeply appreciated.

I can not forget my promoter - Dr Nelson Odume - for the trust you had in me, your insightful discussions, valuable advices, and support you offered during the whole period of my study, particularly your patience and guidance during the writing process.

Professor Srinivas, thank you too for your excellent advice to pursue this PhD study.

Equally, thank you Professor Limson for your continuous mentoring and friendly assistance in various aspects of life.

Mr. Musa Mlambo (skhokho sami), thank you as well for making sure that I have completed and finished the race well.

Again, let me express my sincere gratitude to my friends. I greatly appreciate your unconditional spiritual, financial assistance and your presence. You really were “Friends in need, friends indeed” to me and my family during my PhD study period.

Another word of gratitude goes to Women’s Academic Solidarity Association (WASA) for providing a good platform and a pleasant atmosphere at Rhodes for useful discussions. “Tshomi” thank you very much for making the atmosphere as friendly as possible. I will never forget the discussions and the good times that we had together.

Finally, I cannot finish without thanking my family. I warmly thank and appreciate my family from Eastern Cape family (Ngqwala- Ah! Siwela!), and the one in KwaZulu Natal (Mahlaba- Ah! Sukuza!) for your support in all aspects of my life. Not forgetting my sisters: - Balisa Ngqwala, Bawinile Mahlaba, and my lovely son, Ezile Likhona Ngqwala for assisting me in many ways than one. I am very grateful of and value all your cordial support.

I want to also acknowledge the Faculty of Pharmacy technical staff, Mr Purdon and Dave Morley, you really made my work way less heavy by making sure that I had all the materials and lab space I needed for my research.

The Environmental Health Research (EHB) group members, your contribution and your support is highly appreciated.

DEDICATION

I would like to dedicate this thesis to the black child and all the hustlers. It is a myth that poverty defeats our dreams. In fact, our own Malcolm X says "The future belongs to those who prepare for it today"

CHAPTER 1: INTRODUCTION

This chapter provides the overall structure of the study. It summarizes the major issues about water situation globally and in South Africa. Greywater treatment technologies are discussed and their importance is highlighted. The Fly Ash Lime Filter Tower (FLFT) - as a low cost treatment material for both domestic wastewater (greywater) and agricultural organic waste - is critically discussed. The rationale of the study, the aims and objectives of the study are also discussed.

1.1 Brief background

The management of greywater in the non-sewered areas of South Africa has been identified as a key area of research owing to the fact that very little, if any, provision has been made for it. Increased socio-economic development of South African communities has led to an overall increase in water demand for various purposes. If water reuse is to be implemented, it must be implemented sustainably taking into account technical, social, economic, environmental, institutional, and health dimensions. In the absence of proper and adequate sanitation facilities, the disposal of greywater can become a problem that has the potential to create a host of environmental and health risks, and this is particularly evident in the high density informal settlements surrounding major South African cities (Winter *et al.* 2011).

Greywater reuse has been recommended globally because of its potential to supplement freshwater resources, serving as a reliable water source for services delivery in remote and environmentally sensitive locations, mitigating rising costs of treating drinking water and wastewater and reducing sewage discharges to water bodies. Greywater reuse seems certain in South African communities especially those faced with a declining freshwater availability (Iemobade *et al.* 2012). Greywater consists of the discharges from kitchen sinks, showers, baths, washing machines and hand basins. Greywater is relatively low in pollution and therefore, after appropriate treatment, has great potential for reuse in non-potable applications, such as in irrigation, toilet flushing and laundry (Bino *et al.* 2010). The goal of this thesis was to modify decentralised greywater treatment system and to explore its reuse potential. The advantage of recycling greywater is that, it is a large water source with a low organic content and it represents about 70% of total consumed water, containing only 30% of the organic components and from 9 to 20% of the nutrients (Tsalakanidou *et al.* 2006).

1.1.1. Greywater treatment

Investigations into the treatment and recycling of greywater have been reported since the 1970's with the earlier studied technology, mainly physical treatment options, such as coarse filtration and membranes that were often coupled with disinfection processes (Bino *et al.* 2010; Carden *et al.* 2007; Eriksson *et al.* 2002). Subsequently, the research ventured in biologically-based technologies, such as rotating biological contactor or biological aerated filters and aerated bio-reactors (Luyt *et al.* 2012; Cecen *et al.* 2011; Burnat *et al.* 2010). Greywater can be physically, chemically, biologically treated and the combination of these treatment options has also been widely applied (Penn *et al.* 2012; Rabban, 2012; Ghunmi *et al.* 2011). Recently, through innovative research, simple physical separators coupled with disinfection processes were developed and installed in single houses (Rabban, 2012). Low cost treatment technology has the potential to reduce sanitation backlog in middle and low income countries. For instance, Whittington-Jones *et al.* (2011) investigated the performance of the pilot-scale mulch tower system for the treatment of greywater from low cost housing development in the Buffalo City Municipality, South Africa, where decentralisation of the sanitation services from the centralised municipal systems to on-site waste handling treatment and disposal were seen attractive. However, the case study showed a number of challenges spanning from institutional, technical and management issues. Similarly, Bino *et al.* (2010) in Jordan investigated the use of a low cost and easy to build treatment system made of plastic barrels in rural home gardens. Technically, greywater reuse infrastructure in terms of treatment, storage, distribution, operation and maintenance is similar to potable water infrastructure, and may thus, be designed and implemented in similar fashion (Ilemobade *et al.* 2009). Further, Prathapar *et al.* (2005), in Oman, designed and tested a low cost, low maintenance system-based and activated carbon, sand filtration and disinfection for the treatment of ablution water in a mosque. Few studies are published in South African in the area of greywater reuse. Furthermore, wastewater reuse research has been providing tools to guide wastewater reuse for non-potable domestic and institutional applications from centralised municipal supply (Adewumi *et al.* 2010; Ilemobade *et al.* 2009).

Recycled water has potential to reduce freshwater consumption particularly in areas with water shortages e.g. coastal zones. In South Africa, efforts aimed at treating greywater for reuse and recycling are often hindered by inefficient wastewater treatment processes, skills shortages and lack of sanitation infrastructure (Tandlich *et al.* 2009; Carden *et al.* 2007). To address these challenges, decentralised low cost treatment technologies are now being investigated with a view to implementing them in rural and peri-urban centres. Important low cost systems that are easily implementable are reactive filters. In reactive filters, wastewater percolates down through layered materials and in-situ treatment takes place through precipitation and straining (Tsalakanidou *et al.* 2006). The system can be implemented in decentralised settings from low-cost materials, such as wood chips, coarse sand and gravel (Zuma *et al.* 2009). The mulch-tower (MT) system is an example of such the reactive filter system. The MT has previously been used to provide partial treatment of greywater in South Africa, performing poorly in removing phosphates and indicator microorganisms from greywater (Zuma *et al.* 2009). PozzSand ® is a conditioned and low grade fly ash from the pulp and paper mill industry.

1.1.2. Greywater reuse

There are multiple ongoing research initiatives in South Africa regarding the potential of reusing greywater (Tandlich *et al.* 2009; Zuma *et al.* 2009; Tandlich *et al.* 2008; Engelbrecht & Murphy, 2006; Jacobs & van Staden, 2006; Jackons *et al.* 2006; Salukazana *et al.* 2006) and the potential impacts of greywater discharge activities (Gordon *et al.* 2009; Winter *et al.* 2008; Carden *et al.* 2007). In Zimbabwe, current focus on greywater is on its reuse, with little on its safe disposal measures despite the fact that greywater could contain both chemical and biological contaminants (Madungwe & Sakuringwa, 2007). Globally, very few countries have developed greywater reuse guidelines, for example, the United States of America: Hawaii Department of Health (1991); Colorado Department of Health (2004); California Department of Water Resources (Wilson *et al.* 1995); Department of Environmental Quality (2001). Using greywater for irrigating Carden crops is the commonest application of greywater reuse. In this case, the greywater is stored in tanks or diverted to the garden for immediate use. Advanced systems are also available that collect, filter and treat greywater for indoor use, such as toilet flushing or laundry washing. According to the WHO (2006b), providing on-site sanitation without greywater management plan is regarded as poor sanitation practice. Some studies (e.g. Carden *et al.* 2007; Austin *et al.* 2005; Esrey, 1998;) have shown that inappropriate greywater disposal could be detrimental to human health especially in areas where there is poor water supply and non-waterborne on-site sanitation. Most outbreaks, such as diarrhea occur in areas associated with poor sanitation (WHO, 2006). Poor or lack of basic sanitation contributes to 80% of deaths of children in the world (WHO, 2006b; Esrey, 1998).

1.2. Rationale of the study

Interest in water reuse is increasing all over the world including South Africa, because of its potential to supplement scarce freshwater resources in the face of the increasing demand and aridity. The management of greywater in the non-sewered areas of South Africa has been identified as a key area of research owing to the fact that very little, if any, provision has been made for it. Without water-borne sanitation, the disposal of greywater becomes a problem that has the potential to create a host of environmental and health hazards. This is particularly evident in the high density informal settlements that surround the majority of South African cities. If water reuse is to be implemented, it must be done sustainably. This study describes the advantages before and after greywater reuse, implementation and finally an economic analysis of the implemented greywater treatment system.

1.3. Purpose of the study

The purpose of this study is to monitor the performance and the modification of Fly Ash Lime Filter Tower in the treatment of greywater to reduce the pH and increase the removal of Chemical oxygen demand (COD) and coliforms, and investigate the reuse of greywater for irrigation. Similarly, it aims to evaluate the techno-economic analysis of the Fly Ash Lime Filter Tower (FLFT) system for commercial use and the use of hydrogen-sulphide test kit in monitoring faecal contamination using a community-based approach.

1.4. Main aim of the study

The main aim of this study is to investigate the greywater treatment system (Fly Ash Lime Filter Tower, FLFT) in the treatment of greywater and its effluent efficiency for reuse in irrigation. All the experiments in this thesis were conducted in the lab unless otherwise stated.

The research objectives of this study are to:

1. Characterise the performance of the current greywater treatment system (FLFT), chapter 3.
2. Modify FLFT using water hyacinth, *Eichhornia crassipes)*, chapter 4.
3. Test the reuse of greywater effluent for irrigation), chapter 5.
4. Characterise the physico-chemical composition of soil and plants as well as plant growth treated with greywater versus tap water), chapter 5.
5. Evaluate the usage of hydrogen-sulphide test kit to monitor faecal contamination of various water sources using a community based approach), chapter 6.
6. Evaluate the techno economic analysis of Fly Ash Lime Filter Tower system for the market), chapter 7.

1.5. References

Bino M., Al Beiruti S. and Ayesh M. (2010). Greywater use in rural home gardens in Karak, Jordan', in S.J. McIlwaine and M. Redwood (eds), Greywater Use in the Middle East: Technical, Social, Economic and Policy Issues, *Practical Action Publishing*, Rugby and CSBE, London.

Burnat J., Eshtayah I. (2010). On-site greywater treatment in Qebia Village, Palestine. In Greywater *Use in the Middle East*; McIlwaine, S., Redwood, M., Eds.; IDRC: Ottawa, Canada, Available Online: http://web.idrc.ca/en/ev-152492-201-1- DO_TOPIC.html (accessed on 31 March 2012).

Cecen F., Aktas O. (2011). Activated Carbon for Water and Wastewater Treatment: Integration of Adsorption and Biological Treatment, 1st ed., WILEY-VCH Verlag GmbH & Co. KGaA: Weinheim, Germany.

Colorado Public Health and Environment Department (2004). Guidelines on individual sewage disposal systems. *Water Quality Control Division Report* 5 CCR 1003-6.

Department of Environmental Quality. (2001). Water pollution control. Arizona Administrative Code. Title 18, Ch. 9. *Arizona, USA*.

Engelbrecht J.F.P. and Murphy K.O.H. (2006). What stops me from using greywater? *WISA 2006 Biennial Conference & Exhibition*. Durban, RSA.

Eriksson E., Auffarth K., Henze M. and Ledin A. (2002). Characteristics of grey wastewater. *Urban Water* 4 (1): Esrey S. (1998). Ecological sanitation, Stockholm: Sida (Swedish International Development Cooperation Agency), Sweden.85-104.

Ghunmi L.A., Zeeman G., Fayyad M. and Jules B. van Lier (2011). Greywater Treatment Systems: A Review, Critical Reviews in Environmental Science and Technology, 41:7, 657-698, DOI:

Gordon, D.(2001). Geographical structure and host specificity in bacteria and the implications for tracing the source of coliform contamination. . Microbiology, 147, 1079-1085.10.1080/10643380903048443.

Ilemobade A.A., Adewumi J.R. and van Zyl J.E. (2009). Assessment of the feasibility of using a dual water reticulation system in South Africa. *Water Research Commission*, Report No1701/1/09. Pretoria, RSA.

Jacobs H.E. and van Staden S. (2006). Direct on-site greywater reuse an illicit or illustrious options, *WISA 2006 Biennial Conference & Exhibition*. Durban, RSA.

Luyt C.D., Tandlich R., Muller W. J. and Wilhemi B.S. (2012). Review: Microbial Monitoring of Surface Water in South Africa: An Overview. *International Journal of Environmental Research and Public Health* 9**,** 2669-2693.

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.

Prathapar S.A., Jamrah A., Ahmed M., Al Adawi S., Al Sidairi S. and Al Harassi A. (2005). Overcoming constraints in treated greywater reuse in Oman. *Desalination* 186 (1-3): 177 – 186.

Rabbani K. S. (2012). Low Cost Domestic Scale Technologies for Safe Drinking Water," Appropriate Healthcare Tech- nologies for Developing Countries (AHT 2012), http://dx.doi.org/10.1049/cp.2012.1465

Salukazana L., Jackson S., Rodda N., Smith M., Gounden T., McLeod N. and Buckley C. (2006). Reuse of greywater for Agricultural irrigation. *WISA 2006 Biennial Conference & Exhibition*. Durban, RSA.

Tandlich R., Zuma B.M., Whittington-Jones K.J. and Burgess J.E. (2009). Mulch tower treatment system for greywater reuse Part II: destructive testing and effluent treatment. *Desalination* 242 (1-3): 57 – 69

Tsalakanidou I. (2006). Potential of reactive filter materials for small-scale wastewater treatment in Greece. Batch & Column Experiments. TRITA-LWR Master of Science Thesis. Stockholm, Sweden.

Wilson-JonES, T. and Rivett U. (2012). Using Mobile Phones To Monitor And Manage Water Supply Quality In Rural Environments. WISA 2012 Biennial Conference & Exhibition. Cape Town.

Winter K., Spiegel A., Armitage N. and Carden K. .(2011). Sustainable options for community-level management of greywater in settlements without on-site waterborne sanitation. Water Research Commission Report No. 1654/1/11. Pretoria, RSA.

Whittington-Jones K., Tandlich R., Zuma B. M., Hoossein S., Villet M. H. (2011a). Performance of the pilot-scale mulch tower system in treatment of greywater from a low-cost housing development in the Buffalo City, South Africa. *International Water Technology Journal* 1 (2): 165 – 181.

World Health Organisation. (2006a). WHO guidelines for the Safe use of wastewater, excreta and greywater. Volume IV ISBN 92 4 154685 9.

World Health Organization. (2006b). WHO overview of greywater management: health considerations. Discussed and approved at the regional consultation on national priorities and plans of action on management and reuse of wastewater

Zuma B., Tandlich R., Whittington-Jones K. and Burgess J.E. (2009). Mulch tower treatment system Part I: Overall performance in greywater treatment. *Desalination* 242 (1): 38 – 56.

CHAPTER 2: LITERATURE REVIEW

Issues pertaining to the water availability and water situation in South Africa are presented in this chapter. South African water policies and legislations are discussed and gaps, such as issues regarding the greywater production, pollution and implications are reviewed. Equally, greywater treatment technologies are discussed, although with major reference to greywater treatment using low cost material. Hence, greywater characteristics, treatability and potential for non-potable reuse are discussed in detail. The details of absorbent material used and their properties (i.e., fly ash, lime, mulch and fine sand) are provided to justify their selection. Finally, greywater reuse and concerns about possible contaminants are also reviewed because of their effects on the ecosystem. This provides technical literature review which supports experimental procedures that are presented in Chapters 3 – 7.

2.1. Introduction

Scarcity of freshwater resources is becoming a global concern (Mnisi & Winter, 2014; Tandlich *et al.* 2013). Pressure on water resources is higher in developing countries due to faster population growth and growing urban centres (Tandlich *et al.* 2013). South Africa is considered a developing country (Tandlich *et al.* 2013; UNHDI, 2012; Rodda *et al.* 2011), and - because of its geopraphical position - is among countries expected to experience acute water scarcity by 2025 (WHO, 2012).

Over 500 000 m3/day of greywater is produced in the non-sewered areas (rural and informal settlements) of the country (Luyt *et al.* 2012). The beneficiation of greywater could provide alternative water supply for non-potable purposes and eliminate health threats posed by inappropriate handling of greywater. Greywater accounts for about 70% of the volume of domestic wastewater. In rural and densely populated communities greywater is often reused without treatment (Carden *et al.* 2007).

Health risks to humans differ from site to site, and the management of greywater generated will, therefore, have to be tailored to site-specific conditions. Greywater disposal strategies are often neglected by local government and other relevant stakeholders (Tandlich et al.

2013; Luyt *et al.* 2012; Momba *et al.* 2009). In South Africa, greywater is a known cause for nuisance and health threats in informal settlements where it ponds between houses and in the streets drains. However, research has shown that greywater can be used to further sustainable development and resource conservation without compromising public health and environmental quality (Rabbani, 2012). It is further posited that greywater could be reused under most conditions with minimum treatment. This increases the need for developing appropriate technology to harness greywater in order to reduce pressure on freshwater resources. South Africa's development agenda is focused on addressing basic developmental challenges, such as economic growth, water scarcity, food security, health and environmental quality (Ilemobade *et al.* 2012).

2.2. Water scarcity

Water management is the pressing issue for both developed and developing countries, with United States of America (i.e., California) and Britain being the top leading countries, followed by the Middle East, North Africa and South Asia. Despite every country has been encouraged to reuse water to reduce its demand, the UN report found that over 2.0 billion people have limited access to safe water and nearly 800 million people lack even the most basic supply of clean water (WHO, 2012).They are all projected to experience water shortages over the next coming years because of decades of bad management and overuse (UN, 2013). It is a sad reality that over 40 countries in the world suffer from a safe drinking water deficit, more especially, in the developing world where 3 ½ million people die every year because lack of water, sanitation and improper hygiene (WHO and UNICEF, 2012).

Research shows that vectors, pathogens and parasites are found in higher concentrations in developing nation especially in tropical regions where conditions are more favourable for microbial growth (Mitchell & Gu, 2010). Water diseases, such as gastrointestinal diseases/disorders, are reported as the second leading global cause of death of children under the age of five years (HST, 2012; WHO and UNICEF, 2012). Gastrointestinal are associated with waterborne pathogens, causing symptoms, such as diarrhoea and vomiting. It is claimed that 90% diarrhoeal deaths are from children under five years and elderly are at greater risk of waterborne diseases, especially in unsanitary conditions (WHO/UNICEF, 2012).

Furthermore, it is estimated that by 2025, 2.7 billion people will not have access to safe drinking water (FAO and WFP, 2010). However, three major factors including 1) untreated municipal and domestic sewage; 2) untreated industrial effluents; and 3) agricultural run-off are attributed to the freshwater crisis in developing countries (ITU, 2013). Because of these emerging issues, many developing nations cannot afford to develop or sustain appropriate infrastructure, and as a consequence people in these areas may face water crisis. To this end, perceptions were recognised as a key element of the success of water reuse (May-Le, 2004; Po *et al.* 2003). In many water reuse schemes in the USA and Australia, perceptions have determined the acceptability of water reuse, with water reuse applications requiring little to no human contact (e.g. toilet flushing and irrigation) being the preferred amongst several reuse applications (Radcliffe, 2003).

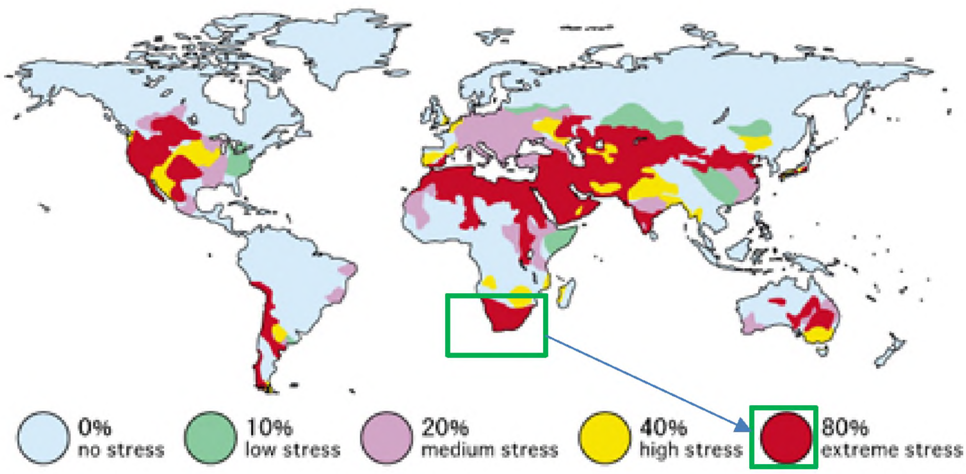


Figure 2.1: Estimated world water stress by 2025 (source: World Water Council documents and FAO and WFP 2010)

Several water reuse schemes failed because benefactors/decision-makers underestimated or ignored the importance of and or impact of varied social and economic factors (May-Le, 2004; Po *et al.* 2003). Hence, other methods, such as supplementing freshwater resources need to be explored (Osborn *et al.* 2013). An example is desalination technologies which are being developed and used worldwide to remove such salts from brackish water and seawater to produce water that meets the standards for drinking water or other intended uses (Gillip, 2014). This can also be accompanied by the use of reliable water services in remote or environmentally sensitive locations, such as membrane technologies that can produce water with minimal environmental impact and low chemical consumption (Ghasem *et al.* 2013).

Because of the affordability of water purifying systems there is a need to mitigate the rising costs of meeting drinking water treatment and wastewater discharge standards (Zarman *et al.* 2015). Despite the ambition of the Millennium Development Goals (MDGs), water supply and sanitation are still not met. Instead, there is a need to develop low-cost drinking water treatment technologies that should not only focus on removal of contaminants to reduce waterborne diseases, but also focus on the removal of micro pollutants to prevent dangerous chronic in large scale drinking water treatment plants (Ilemobade *et al.* 2012; HDRE, 2011).

2.3. Water situation in South Africa

South Africa is currently experiencing uneven distribution of water resources. It believed that this is compounded by inadequate sanitation infrastructure (Quinn *et al.* 2011; Rijsberman, 2006; Seckler *et al.* 1999). The United Nations Millennium Development Goals (UNMDGs) were designed - among other things - to alleviate poverty and to increase access to health services, including access to safe water. Goal 7a is aimed at environmental sustainability and 7b at halving the proportion of people without access to safe drinking water and basic sanitation by 2015 (United Nations, 2012). In 2010, 89.3% of the South African population had access to drinking water within 200 m of their homes (Statistics South Africa, 2011a). The South African Constitution of 1996 (Constitution of the Republic of South Africa, ss 27, No. 108 of 1996) grants the right of access to basic water supply and basic sanitation. Be that as it may, piped water was still unavailable to some pockets of the population in 2011. Approximately, 10.5% of the South African population indicated no access to piped water (Statistics South Africa, 2012d; Statistics South Africa, 2011d), which means that they are likely to use water of poor quality (Luyt *et al.* 2012; Tandlich & Muller, 2008).

Even though the country has had a good runoff for the last thirteen years leading to satisfactory dam storage - yielding an average of 81% (Nkondo *et al.* 2012; Pitman *et al.* 2011) - it is common knowledge that not long ago we had experienced extremely dry weather leading to the drying up of dams, so be wary of this claim. Nkondo *et al.* (2012) found that dams in Limpopo, North West and the Eastern Cape were at a lower capacity, around 70%, whilst dams in the other provinces were well above the 81% average (Nkondo *et al.* 2012). On the contrary, in isolated cases, such as Middle Letaba, a serious shortage of water was reported, and this was affecting domestic demand (Nel *et al.* 2013). Note well that water resources in South Africa are comprised of the three sources in the order of magnitude; surface water (77%); return flows (14%); and groundwater (9%). Major water user sectors in South Africa include agriculture (62%); domestic (27%); industrial (3.5%); afforestation (3.0%); mining (2.5%); and power generation (2.0%), respectively (Nkondo *et al.* 2012; Schmidt *et al.* 2012; Pitman *et al.* 2011).

The current level of non revenue water (NRW) for the country as a whole is 36.8% (Nkondo *et al.* 2012). Non revenue water is water that has been produced and is lost before it reaches the customer, through pipe leaks etc. Water services infrastructure is a critical element in the water services value chain that links the water resource, its treatment and conveyance with the user or customer. Effective infrastructure planning, maintenance, operations and management are of the utmost importance especially in rural areas (Schmidt *et al.* 2012). Sanitation infrastructure, such as toilets are not in place for most households in informal and rural settlements. When installed, they are not properly and regularly operated and maintained (South African Local Government Association; SALGA, 2009).

Nine percent of the South African population uses river, dam or spring water for their drinking water, and this is approximately 20% of the population in the Eastern Cape Province (Statistics South Africa, 2012a). South African households experienced water outages due to pipe breaks and about 36.2% of these water outages lasted longer than 15 days (Statistics South Africa, 2011c). Frequent infrastructure problems and interruptions in water supply are caused by pipe bursts and inadequate servicing of community taps (Momba *et al.* 2006b), inadequate operation of water treatment plants and skills shortages (Momba *et al.* 2009a; Momba *et al.* 2006b). These infrasture challenges could lead to drinking water of poor quality. The lack of water pressure from the pipe systems has been associated with increased risks of gastrointestinal disease, due to microbes entering the distribution system during these periods (Besner *et al.* 2011; Nygård *et al.* 2007). Thus, the water being distributed through pipes is not always safe (Lee & Schwab, 2005). Part of the well-run sanitation infrastructure should include the availability of the facilities for safe disposal of greywater. The greywater is the domestic wastewater without any input from the toilet (Ngqwala *et al.* 2013; Eriksson *et al.* 2009). Greywater, if not properly disposed, could be detrimental to human health because of its high organic content that favours the growth of indicator microorganisms and opportunistic pathogens.

Few studies have been published (Whittington-Jones *et al.* 2009; Zuma *et al.* 2009; Tandlich *et al.* 2008) in the area of greywater and wastewater reuse especially, with standards and guidelines. Rodda *et al.* (2010) and Carden *et al.* (2007) recommended guidelines to be followed whilst Wilson and Pfaff (2008) investigated perceptions of direct potable reuse of treated wastewater. Ilemobade *et al.* (2009) conducted a survey study which recorded the participants' preference for the reuse of non-potable waters for toilet flushing in comparison to other non-potable applications, such as car washing. This helped in providing tools to guide wastewater reuse for non-potable domestic and institutional applications from centralised municipal supply (Adewumi *et al.* 2010). However, the assumption is that improved water sources are safe and may result in an overestimation of the actual number of people using safe water (Clasen, 2012).

2.4. Greywater

Greywater is wastewater discharged from households, excluding black water (i.e., toilet water). This includes water from showers, bathtubs, sinks, kitchen, dishwashers, laundry tubs, and washing machines (see Figure 2.2). Depending on its source, greywater commonly contains soap, shampoo, toothpaste, food scraps, cooking oils, detergents and hair (Eriksson *et al.* 2002). It is believed that it also makes up the largest proportion of the total wastewater flow from households in terms of volume because in general, 50-80% of household wastewater is greywater (Adewumi *et al.* 2010; Ilemobade *et al.* 2009; Carden *et al.* 2007; & Salukazana *et al.* 2006). Wastewater from the bathroom is referred to as blackwater and different greywater flows may require different treatment methods that would render the water suitable for reuse.

Greywater contains a significant amount of chemical nutrients (see Table 2.1), that is, nitrogen and phosphorus. Generally, a normal "untreated" volume of greywater will produce approximately 45 g of nitrogen and 3 g of phosphorus per day (Nel *et al.* 2013; Nkondo *et al.* 2012 Pinto *et al.* 2007). The treatment of greywater may results in the recovery of nutrients, such as phosphorus that could be beneficial in reducing the amount of commercial fertilizer needed for gardens and lawns (Othman *et al.* 2012; Mcllwaine & Redwood 2010). Chemical contaminants found in bathroom greywater originate from shampoo, hair dyes, toothpaste and cleaning chemicals. Laundry water contains higher concentrations of chemical contaminants originating from soap powders and soiled clothes (sodium, phosphate, boron, ammonia, nitrogen). Laundry water is also high in suspended solids, lint, turbidity and chemical oxygen demand, and if it is applied to land untreated could lead to environmental and public health risk (Ryan *et al.* 2009; Pinto *et al.* 2007).

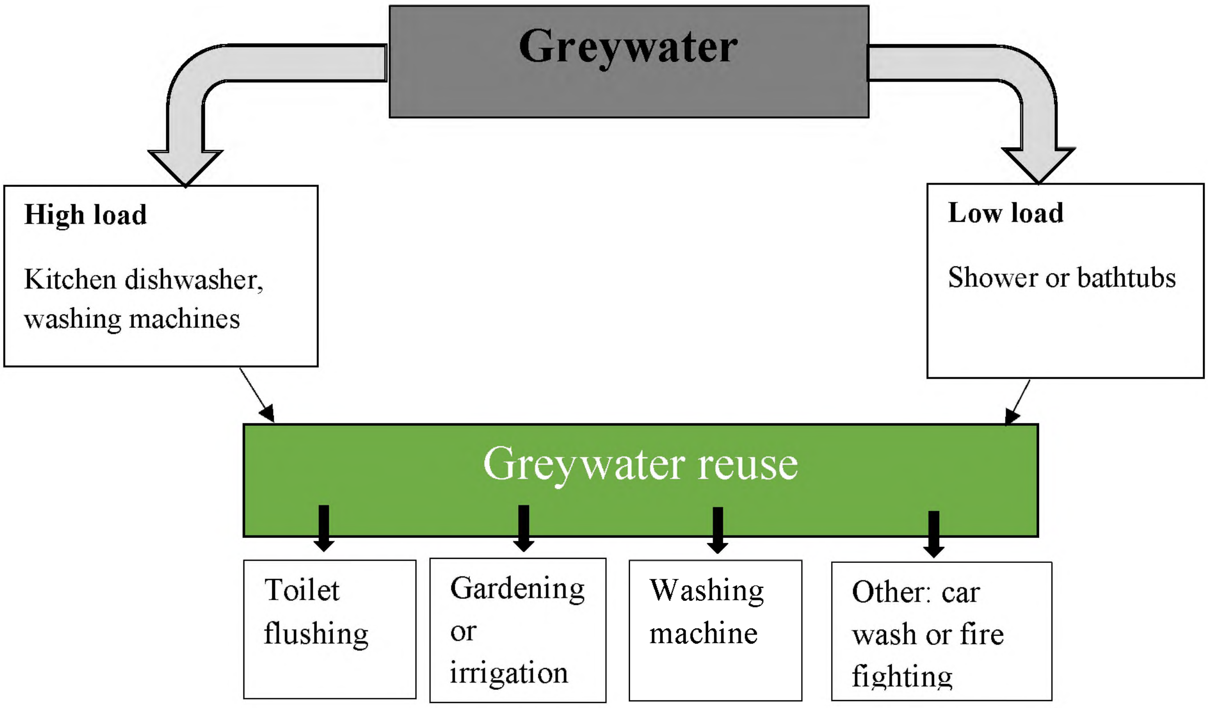


Figure 2.2: Sources of greywater and its application after appropriate treatment

Microbial quality of greywater is determined using the presence of faecal contamination. Greywater with high faecal contamination is considered hazardous (Burnat *et al.* 2010). However, as toilet waste is not included in the definition of greywater, faecal contamination is limited to activities, such as washing faecal-contaminated laundry (i.e., diapers), childcare and showering. Faecal contamination is measured by the use of common indicator organisms, such as coliforms and *Enterococci* (Eriksson *et al.* 2002). Wastewater generated from bathtubs, showers and hand basins is considered to be the least contaminated type of greywater. Thermotolerant coliform concentrations have been assessed in shower and bath water to be in the range of 102 to 105 cfu/100 ml (Pinto *et al.* 2010). Figure 2.2 above shows sources of greywater and its and its application after appropriate treatment:

2.4.1. Greywater quality

Each country has its own water quality requirements for greywater application. But, a normal criterion contains the assessment of the organics, solids, pH, temperature and microbiological content of the greywater (Jefferson *et al.* 2004); See Table 2.1). According to Zuma (2010), temperature is the important physical variables of the greywater that controls the microbial activity and could induce precipitation in the supersaturated waters. In their study they found that greywater temperature ranged from 18 to 38 °C. Yet, Othman *et al.* (2012) claimed that the quality of greywater varies depending on the volume of supply water consumed per person in a household; on the initial quality of the water supply; the source of the greywater; and on chemicals used in the washing or bathing process. The volume of supply water consumed by a household depends on the costs of supply water and on the water conservation measures being taken within the household (Pinto *et al.* 2007; Pinto *et al.* 2010). Table 2.1 below shows the typical greywater composition separated according to their sources of greywater and their application after appropriate treatment.

The level of nitrate can affect phosphate release and lead to reduced efficiency of biological phosphorus removal process. The cationic surfactants are the major source of the greywater nitrogen or amine nitrogen contamination (Widiastuti et al., 2008). In the biological systems, during the ammonification, the organic nitrogen is converted to ammonia through the amino acids hydrolysis. There was more oxygen within the reactor to speed up the ammonia oxidation, hence there were high levels on nitrogen release into the effluent. Total Kjeldahl nitrogen between 2.1 - 31.5 mg/l were reported by (WHO, 2006b); Henze et al., 2001) which was slightly above to what was obtained. The flyash has been reported to provide the low grade phosphate, however nitrate can affect phosphate release and lead to reduced efficiency (Zuma et al., 2009; Naicker et al, 2010).

Table 2.1: Typical greywater chemical composition

Component	Units	Concentration range
Suspended solids	mg/l	45 – 330
Turbidity	NTU	22 – 240
COD	mg/l	210 – 740[a]
BOD_5	mg/l	90 – 290
Nitrite	mg/l	< 0.1 - 0.8
Nitrates	mg/l	0.1 – 15
Ammonia	mg/l	< 0.1 - 25.4
Total Kjeldahl nitrogen	mg/l	2.1 - 31.5
Total phosphate	mg/l	0.6 - 27.3
Sulphates	mg/l	7.9 – 110
pH		6.6 - 8.7
Electrical conductivity	µS/cm	325 – 1140
Sodium	mg/l	29 – 230

Adapted from (Olawale, 2012; Henze et al. (2001)

Health risk associated with greywater is related to its microbial quality and is influenced by the point of irrigation, how the irrigation is carried out, and the type of crops being irrigated (Ryan *et al.* 2009). The microbial quality of kitchen greywater is generally the poorest of the greywater sources (at the point of irrigation). In terms of chemical quality, the least suitable greywater for irrigating sensitive crops and soils is laundry greywater, especially greywater from the first wash, due mostly to the high sodium concentrations and the high pH of laundry greywater. Greywater from the first laundry wash is also usually too hot for direct irrigation (Mcllwaine & Redwood, 2010).

2.4.2. Greywater reuse and application

Greywater reuse is beginning to find attraction because of growing human population leading to increased demand for freshwater resources (Tandlich, 2010). Although treated wastewater can be used for irrigating crops and other domestic purposes (Whittington-Jones *et al.* 2011b; & Zuma & Tandlich, 2010), the high cost associated with treating wastewater to strict microbiological standards means that occasionally untreated sewage wastewater is used for irrigation (*Ibid*). Bathroom greywater has significantly lower levels of pathogens than does sewage, and does not need treatment if its reuse for irrigation is properly managed (*Ibid*). Thus, bathroom greywater presents a potentially useful water resource for irrigating certain crops. As a result, most people all over the world and in South Africa use greywater, but not under a controlled regulatory system (Whittington-Jones *et al.* 2011a; Eriskson *et al.* 2002).

Greywater can be of benefit for both urban and rural areas. Recycled greywater can contribute to reducing the cost of water for gardening, crop irrigation and other domestic purposes including toilet flushing. The primary treatment of greywater, such as deposit pools where sedimentation occurs can enable it to be used in irrigation of parks, gardens, aquifer recharge, maintaining water levels in small ponds and lakes, but after secondary treatment, such as irrigation, toilet flushing and car washing (Ji & He, 2010). The deposition of greywater in pools reduces the volume of influent in septic tanks and water treatment facilities, and this reduces pumping treatment costs.

There are potential risks that are associated with the use of greywater that could reduce plant growth. For example, the transmission of infectious diseases and bioaccumulation of potentially toxic elements in plants, such as cadmium (Cd) that uses soil pore clogging and sodium (Na) (Rusan *et al.* 2007; Salukazana *et al.* 2005; Eriksson *et al.* 2002). The toxic chemicals results in groundwater contamination and soil degradation because of high sodium, salinity or other substances (Whittington-Jones *et al.* 2011a & b; Tandlich, 2010).The presence of microorganisms in the greywater has been investigated to indicate the potential human health threats (Eriksson & Donner, 2009). Most research reports that inappropriately handling and disposing of the greywater may pose a human health threats associated with the pathogenic microbial infections (Tandlich *et al.* 2013; Winward *et al.* 2010; Zuma *et al.* 2009; Carden *et al.* 2007). This is indicated by the presence of the enteric microorganisms, such as the *E.coli* and faecal coliforms (FC) in water which is indicative of the possible faecal contamination. This also reveals a risk of the concomitant presence of the pathogenic microorganisms, such as *Salmonella spp.*, *Cryptosporidium spp.*, *Shigella spp.*, *Legionella spp.* and enteric viruses (Winward *et al.* 2008).The total coliforms (TC) have also been widely used as the indicator organisms of the faecal contamination in the drinking and greywater (Finley *et al.* 2009; Tandlich *et al.* 2009; Zuma *et al.* 2009; Eriksson *et al.* 2002). Tandlich *et al.* (2009) and Zuma *et al.* (2009) reported the TC colony counts of over 106 CFU/100ml from the untreated greywater. However, their presence in the greywater is questionable as being indicative of the presence of the pathogenic bacteria.

2.5. Regulation of Greywater

Most countries, particularly in Africa are faced with challenges of providing enough safe water whilst also focusing on the regulatory aspects. As a result, the twin burden of providing and regulating water services concurrently may jeopardised the achievement of the Millennium Development Goals targeting at reducing by half the population of people without access to safe drinking water by 2015 in most African countries (Ajayi *et al.* 2012; UN, 2012).

2.5.1. Greywater regulation in South Africa

Water users typically refer to legislation or guidelines provided by national or regional authorities for guidance in resolving issues related to water quality, supply and quantity. However, the existing South African legislation and guidelines for water use, waste disposal and wastewater reuse do not address greywater. As a result, South African government has been perpetually transforming the water policy to better manage the quality, quantity and sustainability of South Africa's water resources whilst, optimally utilising them sustainably to ensure the socio-economic benefits for all South Africans (SHRC, 2014; SAICE and CSIR, 2011). The South African government aims to address previous socio-economic inequalities by ensuring that every South African has access to clean and potable water. However, greywater needs to be addressed as it is an alternative form to reducing the pressure on portable water. Preliminary investigation shows there is no fundamental objection in principle to the use of household greywater for irrigation. The reports are normally about precautions with regard to nuisances that are required in terms of Common Law, the Health Act No. 63 of 1977, and the National Water Act No. 36 of 1998. The nuisances are classified as smell odours or mosquito breeding) (DPME, 2013; DWA, 2013).

The precautionary principle is usually implemented in a qualitative manner, aligning with the South African Water Quality Guidelines (SAWQG) for irrigation, and WHO guidelines for human health risks (DWA, 2012; Salukazana *et al.* 2005). In the irrigation, the requirement (detailed in Chapter five) is that the irrigator may not use more than 50 cubic metres of wastewater on any given day, provided that the electrical conductivity does not exceed 200 mS/m, the pH is not less than 6 or more than 9, the Chemical Oxygen Demand (COD) does not exceed 5 000 mg/l after removal of algae, faecal coliform count does not exceed 100 000 per 100 mL, and the Sodium Adsorption Ratio (SAR) does not exceed 5 (Zuma &Tandlich, 2010; Carden *et al.* 2007).

In the South African Constitution of 1996, under the Bill of Rights, the mentioned of wastewater is about “disposal” of waste or water containing waste. The Act recognises the discharge of water containing waste to a water resource, as a water use. Due to inefficiency and or lack of the appropriate wastewater disposal systems, a tendency to dispose the greywater on the grounds outside the homesteads is a normal disposal method, especially in the densely populated communities (Carden *et al.* 2007). This only refers to the person who discharges water containing waste needs to obtain an authorization before discharging waste. However, more applicable to greywater use is the use of water containing waste for irrigation purposes as a controlled activity. The South African government has significantly increased the low income settlements connection to the clean piped municipal water sources (Nkondo *et al.* 2012; Schmidt *et al.* 2012; Pitman *et al.* 2011; Chaatterjee *et al.* 2010). This has resulted in the majority of citizens having access to potable water supplies. Be that as it may, approximately 20 million South Africans still lack access to the basic on-site water-borne sanitation.

Greywater irrigation is unlikely to benefit from the above requirement because of it quality that is unlikely to comply with the restrictions, specifically the one limiting the faecal coliform concentration restriction. However, an argument can be made that the greywater irrigation is likely to have a beneficial social impact in times of water scarcity. Particulars of potentially suitable treatment methods would need to be researched, or else greywater could be specifically excluded from the above requirements, but be included under other legislation. The disposed greywater normally soaks into the ground, thus potentially contaminating the groundwater, or run-off to the nearest streams and subsequently entering the surface waters (Zuma & Tandlich, 2010; Carden *et al.* 2007).

The South African economy is growing and is going to require additional water to meet the industrial, mining and strategic power generation requirements associated with the growth. At the provincial level, plans are being made to address poverty, improve the level of service delivery and to expand the local economies. These plans are captured in the provincial intergrated developmental plan (IDP's) and Water Service Development Plans (WSDP) of the local municipalities. Water is often an essential ingredient to the success of these plans. The delivery of the water involves not only the technical analysis to develop the water resource and to provide the infrastructure to supply the water, but the co-operation of government at all levels and across different departments. According to the WHO (2006b), provision of on-site sanitation without the greywater management plan is regarded as poor sanitation practice. Poor or lack of basic sanitation contributes to 80% of deaths of children in the world (WHO, 2006b; Esrey, 1998). In South Africa, in year 2000 and beyond, 43, 000 people - the majority of which are children less than 5 years old – reported dying from diarrhoeal diseases each year (Luyt *et al.* 2012). However, improvements in potable water supplies in informal settlement led to a significant improvement in public health with the average risk diarrhoeal diseases contraction among the children under 5 years of age decreasing from 18% in 2002 to 11% in 2010 (Health System Trust, 2011). If greywater is to be appropriately handled, disposed of or reused, its treatment is therefore essential to reduce the concentrations of its microbial and chemical components environmental, as well as health risks and the consequences on the economy and society. This study investigated the development of the effective low-cost, easy to maintain technologies for greywater treatment. Noting that greywater is not yet regulated in South Africa, this calls for its regulation.

2.5.2. Greywater regulation in other countries

Greywater use for agriculture is being practiced and encouraged in several countries. Most guidelines are for greywater use for irrigating ornamental plants, shade and fruit trees, with little on grass and vegetables. California, Arizona and New Mexico are the first and most active countries in undertaking research and implementing regulations and guidelines for greywater irrigation (WHO, 2012). Arizona is considered to have the most practical and progressive regulations, and similar ones to these regulations and guidelines have recently been adopted by New Mexico. These are states that experience some degree of water stress (Gillip, 2014). Examples of countries where progressive greywater irrigation legislation has been adopted include Jordan and the United States of America (U.S.A.). Due to problems experienced with permitting the use of greywater for irrigation, several states in the more arid parts of the U.S.A. and other countries have developed legislation to allow greywater use for irrigation in different circumstances (UN, 2012). Currently, twenty-two western states in the U.S.A. have regulations that govern the use of greywater for irrigation. Other countries that have carried out research and that have regulations and guidelines that help govern the use of greywater for irrigation include Australia, Cyprus and the Kingdom of Jordan. In countries with a federal system of government, such as Australia and the U.S.A., the individual states are responsible for the development of regulations and guidelines that govern greywater use. Experience in researching and regulating greywater irrigation for private garden purposes in Arizona and California has provided some insight into the way in which regulations affect public attitude to irrigating home gardens with greywater. For example, it has been noted that the California greywater irrigation legislation is complex and expensive to comply with, and has not led to popular use of greywater for irrigation (TMIH, 2014; ITU, 2013).

SADC states' water laws are independently developed by concerned countries, with a main aim of ensuring equitable water distribution, environmental and public health provision, there is a great trend of consorting SADC states' national water policies, legislations and regulations to enable integrated coordination between member states, as this is a requisite for the joint management of trans-boundary water resources. Protocol for Shared Watercourse Systems in the SADC Region was devised as one of the tools to enable such coordination (Treaty, 1995). The Swaziland Water Act (2002) stipulates the Government's responsibility to ensure environmental and human health protection, equitable water resources distribution whilst exercising and ensuring effect of the Swaziland's sovereignty over its natural resources. South African government developed the National Water Resources Strategy (NWRS) which was aimed at outlining schemes, objectives, planning and procedural guidelines in order to ensure protection, management and utilisation of the country's water resources. Republic of Lesotho aims to provide for the use and control, the protection and conservation of water resources for the country and for the connected purposes (Water Resources Act, 1978). This Act in conjunction with the Environmental Act acknowledges that pollution of water resources means any alterations of physico-chemistry and biological status of water bodies, leading to changes to the ecosystem biodiversity and or carrying human health threats (Water Resources Act, 1978). Namibian Water Act 24, 2004 states that the Government intends to ensure management, development, protection, conservation, and use of water resources; establish the Water Advisory Council, the Water Regulatory Board and the Water Tribunal; and provide for incidental matters. This is to ensure equitable water provisions, public and environmental health protection, sustainability and integrated management. In South Africa though legislation documents have been developed to protect water resources, little has been done to enforce them. In spite of the unending human ingenuity, the focus of water conservation in South Africa still excludes greywater as a viable water resource.

2.6. Greywater treatment

Depending on the quality of the greywater, different treatment steps can be considered in treating it (Penn *et al.* 2012). See Figure 2.4. Technologies examined for treating greywater are classified based on the treatment principle which can either be physical, biological, chemical, or a combination of these. Furthermore, Table 2.2 illustrates the technologies reviewed in terms of performance, operation, and the encountered problem (Ghunmi *et al.* 2011).

2.6.1. Physical treatment

Physical treatment systems (see Table 2.2) can be divided into two sub-categories: (i) sand filters and (ii) membranes. Sand filters have been be used alone or in combination with disinfection or with activated carbon and disinfection. The filters provide a coarse filtration of the greywater. However, sand filters achieved limited treatment of the different fractions present in the greywater (Friedler *et al.* 2006).

2.6.2. Biological treatment

A wide range of biological processes have been used for greywater recycling (see Table2.2). The concept involves the use of bacteria to remove organic material (contamination) from wastewater. The process uses the principles employed at sewage treatment works. Biological treatment processes include fixed film reactors; rotating biological contactor; anaerobic filters; sequencing batch reactor; membrane bioreactors; and biological aerated filters (BAF) (Ngqwala *et al.* 2013; Ghunmi *et al.* 2011).

2.6.3. Chemical treatment

Only three schemes using a chemical technology for greywater recycling were reported in the literature (see Table 2.2). The treatment technology of two of the schemes was based on coagulation with aluminium. The first one was a combination coagulation, sand filter and granular activated carbon (GAC) for the treatment of laundry greywater. This can also be a combination of electro-coagulation and disinfection for the treatment of low strength greywater. The most advanced domestic greywater treatment systems use a combination of biological and physical treatment. Such systems are best installed during construction and are not suitable for retrofitting into existing buildings due to cost and other practical difficulties. There is another method that is called extensive treatment which refers to the technology combining physical and biological treatment, generally produces the highest quality water. However, it needs careful operations and maintenance. This usually comprises constructed wetlands, such as reed beds and ponds (Tandlich *et al.* 2009; Zuma *et al.* 2009).

There are several greywater technology systems that have been developed (see Table 2.2), ranging from simple low-cost devices that divert greywater to direct reuse, such as in toilets or outdoor landscaping, to complex treatment processes incorporating sedimentation tanks, bioreactors, filters, pumps, and disinfection (NovaTec Consultants Inc. 2004). A number of greywater systems are home-built, meaning that the user is responsible for their maintenance.

Table 2.2: Greywater treatment methods, function and applications

Treatment method	**Function**	**Advantages**	**Disadvantage**	References
Disinfection	This involves the use of chlorine, ozone, or ultraviolet light to disinfect greywater.	Highly effective in killing bacteria if properly designed and operated, low operator skill requirement.	Create toxic by-products, such as Ozone and ultraviolet, can be adversely affected by variations in organic content of greywater.	Solley et al. (2010), Stalter et al. (2010).
Activated carbon filter	Activated carbon has been treated with oxygen to open up millions of tiny pores between the carbon atoms. These filters thus, are widely used to adsorb odorous or colored substances from gases or liquids.	Simple operation, activated carbon is particularly good at trapping organic chemicals, as well as inorganic compounds like chlorine.	High capital cost, only remove certain impurities	Rabban (2012); Sim et al. (2011); Reungoat et al. (2010).
Sand filter	Uses beds of sand or in some cases coarse bark or mulch which trap and adsorb contaminants as greywater flows through.	Simple operation, low operation cost and maintenance.	High capital cost, reduces pathogens, but does not eliminate them. Can clog and flood if overloaded.	Ghunmu, (2011); Sandhu et al. (2010).
Biological treatment	Involves the use of bacteria to digest the organic contaminants	High degree of operations accommodates greywater of varying qualities and quantities.	Expensive, complex operational requirements. Sometimes it does not remove all pathogens.	Joss et al. (2005); Biyela et al. (2012)

Membrane bioreactor	Uses aerobic biological treatment and filtration to consume organic contaminants and filtration of all pathogens.	Flexible, accommodating greywater of varying quality and quantity. Allows treated water to be stored indefinitely.	High capital cost and operating cost, complex operational requirements.	Cecen et al. (2011); Leal et al. (2010).

2.7. Greywater economy

Greywater reuse should be used to increase the economy while maintaining its cost for social and environmental benefits by contributing towards sustainable development and resource use. While greywater reuse is often considered primarily as a benefit in terms of water conservation, it also conserves energy, reduces waste water, and the water savings. Greywater reuse, such as toilet flushing saves municipal potable water. For example, in 2010, Johannesburg (Wits University) water tariff for potable water was R10.58/kℓ and, historically, this tariff has increased between 7 and 14% per annum (Olawale, 2012). Financing efforts would benefit from a variety of approaches, at different scales and across various sectors.

Reduction in sewage tariff promotes environmental benefit, for example, greywater collected resulted in the reduction of sewage being conveyed to the sewage treatment works downstream. Van Zyl et al. (2006) reported that 83% of potable water demanded in a middle-income area typically becomes sewage. The quantity of sewage not discharged into the sewer due to greywater was therefore estimated to be 83% of the potable water saved. In this case financing efforts should consider the co-benefits that could be provided to (and could also be paid by the municipality) water suppliers, energy suppliers, wastewater utilities, and additional water users. The beneficiation of greywater could provide alternative water supplies for non-potable purposes and eliminate health threats posed by inappropriate handling of greywater. In this project the greywater system is to be used in the decentralised settings where the sewage collection infrastructure is not available or cannot be built. The environmental impact study was conducted by soil and plant analysis.

2.8. The Fly Ash Lime Filter Tower composition

The Fly Ash Lime Filter Tower (FLFT) system is a cheap, low-tech and easy to operate and maintain flush through system and is designed to limit the potential for theft of the technology components. The concept is chosen as carrying the potential for the development of the on-site and appropriate greywater treatment system in informal and rural settlements for direct use in homes and schools, and related institution gardens. The system consists of biological and physicochemical treatment components, such as fly ash layer, sand, water hyacinth and gravel. This thesis investigated the development of the effective low-cost, easy to maintain technologies for greywater treatment.

The idea of the Mulch Tower (MT) for greywater treatment was developed and piloted in 2006 in the Scenery Park, East London, South Africa. The technology did not perform to its assumed levels. Zuma et al. (2009) then designed the new system. According to Zuma (2012), the MT removed 69.5% of faecal coliform, 44.6 % of COD, 32.5% of chlorides, 41% of sulphates, 39.6% of nitrates, and 42.2% of ammonia, respectively. The pH of the treated greywater was 10.6. Zuma's (2012) study showed that the system was unable to completely remove the faecal and total coliform, and reduce the pH to acceptable level.

In the present study, a sand filter layer was included in the fly ash since the biological filter did not require any chemical supplementation. It relied on the development of the biological biofilm formed by the microbial community in a similar method (Duncan, 1998), as detailed in the above section. This rationale was to explore the development of the bacteria, algae and protozoa as the biofilm and colloidal debris on the sand grains, which reduces the biodegradable organic matter through the biological processes (Calvo-Bado *et al.* 2003). The layer also served as the filtration layer which reduced the amount of the particulates percolating through the sand. Therefore, the major mode of the contaminant removals in the sand filter included the surface straining, interception, and transport, dissolved compounds interaction with sand particles, and attachment and desorption (Calvo-Bado *et al.* 2003). However, Zuma *et al.* (2009) reported inefficient MT performance that was composed of the mulch, sand and two different sizes of gravel layers. Hence, the MT was optimised during this study by adding a fly ash adsorbent supplemented with lime layer. This layer will apply sorption and coagulation principles. According to Eriksson and Donner (2009), sorption and settling processes have been shown to be dominant methods for metal removal in wastewater.

Fly ash is a by-product of the coal fired power and pulping plants (Phukan & Bhattacharyya, 2003; Agyei *et al.* 2002; Diez *et al.* 1999). Its physico-chemical properties are highly dependent on the coal source, type of coal burned and type of collector. The fly ash constitutes about 65 to 80% of coal ash, with particles size distribution ranging between 1 and

100 μm. Fly ash has been reported to provide low grade phosphate, potassium, sulphur, boron and metals (Gadd, 2007; Santhanam, 1979; Coal Fired Power Plant, 1975). Fly ash has been used in improving the soil moisture holding capacity, concrete replacement, cultivation material and zeolites for removal of various heavy metals in water (Naik *et al.* 2009; Jala & Goyal, 2006; Pathan *et al.* 2003).

Previous research has demonstrated the efficiency of fly ash in removing heavy metals (Weng & Huang, 1994; Yadawa *et al.* 1989), turbidity, fluoride, and COD (Banerjee *et al.* 1997; Swamy *et al.* 1997; Banerjee *et al.* 1995; Mott & Weter, 1975), phenolic compounds (Kao *et al.* 2000) and colour (Gupta *et al.* 1988). Fly ash and lime in the sysytem has a high potential of removing phosphate from greywater and is likely to stabilise the extent of removal over the lifetime of the MT reactor. A major problem with the pH from the greywater treatment as observed in previous study is solved (Zuma *et al.* 2009). Flyash also functions as coal desulphurisation agent when combined with lime, thus enabling the removal of sulphates from the flue gases (Fernández *et al.* 1997; Yaman & Küçükbayrak, 1996). The potential for the application of the reactive media, such as the fly ash from the coal powered stations in wastewater treatment has been widely investigated around the world (Tsalakanidou, 2006; Agyei *et al.* 2002). However, little research have investigated the efficacy of using the pulp and paper mill fly ash to treat wastewater treatment, yet its composition is comparable to that produced from the coal powered stations.

Lime seawater process has been well documented over the past years (Ayoub, 1994; Ayoub *et al.* 1992; Ayoub & Koopman, 1986; Ayoub *et al.* 1986; Vraie, 1978). This process demonstrates how the slaked lime ($Ca(OH)_2$) or caustic soda (NaOH) and the seawater provide hydroxyl, calcium, and magnesium ions when added to water in the presence of the carbonic ions.

Studies have reported that increasing pH to higher than 10.5 using lime/seawater can enable the effective removal by coagulation of the suspended particulates, phosphorus and nitrogen compounds and reduce the COD and BOD (Ayoub & Merhebi, 2002; Ayoub *et al.* 1999; Ayoub, 1994;) and sterilise microorganisms (Lu *et al.* 2009; see Chapter 4, section 4 for details). Ayoub *et al.* (1999) also noted that the dissolved solids increase between 1500 and 3000 mg/l during water treatment and this can be over-come by inducing the CaCO3, calcium sulphate (CaSO4), and sodium chloride (NaCl) deposition as recommended by Kaufmann (1982). This leads to the formation of a bittern (liquid bittern or dry bittern) with high concentrations of the magnesium salts and the limited amounts of the potassium and sodium salts. Enhancing the waste (water) treatment processes by the chemical supplementation, such as lime and magnesium has over the years gained attention as alternatives to biological treatment. The simplicity, efficiency and economic feasibility are some of the main factors that ascertain the choice between these two processes. This study explored fly ash ability to remove chemical components discussed above and microbial sterilisation by lime. Phosphate precipitation at increased pH due to lime was also investigated. The impact of the supplementation of pulp and paper PozzSand® flyash with lime to modify the MT, thereby providing the low-cost and effective greywater treatment technology was looked into.

2.8.1. Water hyacinth in waste water treatment

Water hyacinth (*Eichhornia crassipens*) is a free floating perennial aquatic plant with high nutrient absorption potential (Chunkao *et al.* 2012; Saraswats, 2010; Malik, 2007). It is a highly invasive plant grows faster than the native vegetation (Chunkao *et al.* 2012; Adewumi & Ogbiye, 2009). Adsorption techniques as means of treating greywater have also been considered which are also regarded as cost effective. These include the use of plants, activated carbon and different clays and sand (Chunkao *et al,* 2012; Bhattacharya *et al.* 2011). These are either incorporated in the already existing system or used solely for the treatment of wastewater (Bhattacharya *et al.* 2011; Chen *et al.* 2010). Several cases about the negative impact of water hyacinth have been reported and these include interference of plant with navigation in rivers and water supply (Zheng *et al.* 2009). Control strategies were implemented to control the growth of the plant. Physical treatment involves physical removal of the plant from the water streams with the disposal of the resultant waste in open lands (Malik, 2007; De Groote *et al.* 2003) and tons of waste are generated through this process (Ajayi & Ogunbayo, 2012). However, when viewing the waste generated from a useful resource perspective, there are numerous potential roles that this plant can play which can be beneficial (Ajayi & Ogunbayo, 2012; Jiambo *et al.* 2008; Malik, 2007). The driving factor for the use of plants is their known ability to absorb pollutants in wastewater and plants, such as

Eichhornia crassipes, in wastewater phytoremediation (Chen *et al.* 2010; Zheng *et al,* 2009). In this study, leaves of water hyacinth were used to reduce the pH of the system. Properties, such as surface area, surface charge, pore size distribution, functional groups on the surface of the plant, varied pH and nutrients, and most importantly tolerance to toxins were the essential factors perpetuating their use in phytoremediation (Chunkao *et al.* 2012).

2.9. Community approach methods

The use of trained community members allows people to get involved and to make a difference by decreasing pollution and also provide manpower. Motivation dwindles if volunteers do not perceive themselves as making a difference (Luyt *et al.* 2011a; Measham & Barnett, 2008). The key building block to get institutions, policymakers, city planners, engineers, public health professionals, and developers familiar with greywater reuse technologies is direct interaction in learning exchanges with professional colleagues. The South Africa challenge of frequent infrastructure problems and interruptions in water supply are due to pipe bursts and inadequate servicing of community taps (PMG, 2009b). The community may help to alleviate operation of water treatment plants and skills shortages (Momba *et al.* 2009a; Momba *et al.* 2006b).

Public perception of greywater as unsafe for reuse, or uncertainty about how safe to reuse greywater is a major challenge for its increased use, as it may cause outbreak of diseases. However, greater awareness of the potential of the greywater benefits and its cost effectiveness will all aid in the expansion of its responsible use. For example, most buildings - including houses, community centres and schools - often use domestic rainwater harvesting (DRWH) (Salukazana *et al.* 2005). Rainwater is considered a potable water source in the rural areas of developing countries, though its actual water quality has not been tested (Amin & Han, 2011; Tandlich *et al.* 2014). South Africa has a shortage of people to monitor water. Thus, there is little data available to make public health decisions. In South Africa, Grahamstown - a small town in the Eastern Cape - frequently experiences water outages because of old infrastructures (Quinn *et al.* 2010; DWAF, 2006). One advantage of the community monitoring water is the use of invaluable indigenous knowledge about the water resource from local leaders, within communities (Rossouw *et al.* 2006). Education of communities could help prevent further deterioration of rivers and offer safer water use, as stewardship is created (Conrad & Hilchey, 2011). Projects need buy in from the community to be sustainable (Mathabatha & Naidoo, 2004). The use of community monitoring programmes may increase the community's perception of service delivery and water quality, as it has with the Wilson- Jones project (2012). It also allows knowledge exchange between practitioners in the case of greywater architects, plumbers, and engineers, could benefit from touring greywater reuse projects in other countries to identify opportunities to replicate these technologies in their countries.

Citing the newspaper report, Kings (2015) and Lukwe (2014) claimed that Grahamstown community is very water conscious about unsafe drinking water and other reports around town. So many people are left wondering, if the water is indeed safe. Part of this thesis is to raise awareness about minimum treatment and regular monitoring of microbial quality of rainwater that can be accomplished, even in resource-limited environments, using a community microbial water quality monitoring programme. Chapter 6 reports on the results of the pilot phase of this type of programme that was run in the Grahamstown area of the Makana Local Municipality between years 2013-2014.

2.10. Conclusion and future directions

Greywater reuse is a promising strategy in terms of the significant local water, energy, and cost savings that it can produce. Few projects are on large scale in South Africa and the country is still struggling in terms of creating flexible greywater policies. However, there are also a variety of challenges facing the increased use of greywater in homes, agriculture, environment and businesses. All these challenges have hampered broad implementation of greywater reuse. Hence, there is a need to develop technologies that will treat greywater more extensively and that will require less complex infrastructure, easy and cheap maintenance and operation. In this study bathroom greywater is used because it has low contamination and nutrients that benefit plants. Appropriate technology means choosing a greywater treatment system that follows local greywater codes and matches the quantity and quality of water for its intended use. For instance, when greywater is reused in toilets of large buildings, this requires treatment and storage of large volumes of water before reuse and appropriate technologies include physical, chemical, or biological treatment and large scale storage systems. On the other hand, small scale systems that provide water for subsurface irrigation are well suited for simple diversion systems that filter, but do not treat greywater before reuse. In many cases, there is little information to help a consumer determine which type of treatment would be the most appropriate for a particular quantity and quality of source water. There is a clear need for industry standards in the realm of greywater treatment technologies. A wide array of commercially available greywater treatment technologies exists that have varying degrees of complexity and effectiveness. Industry standards are necessary to compare greywater treatment technologies and provide useful information to consumers. Much of the public concern around greywater reuse is related to a lack of information about the long-term health and environmental impacts of greywater. More work is needed, particularly on the long-term impacts of different qualities of greywater on soil and plant health for agricultural applications. Studies conducted by respected academic organizations and international research organizations would be very useful. There is a need for research to explore the long-term impacts of greywater on human health and soil chemistry.

2.11. References

Adewumi I. and Ogbiye A.S. (2009). Using water hyacinth (*Eichhornia crassipes*) to treat wastewater of a residential institution, *Toxicological and Environmental Chemistry* **91** (5):891–903.2012.

Agyei N.M., Strydom C.A. and Potgierter J.H. (2002). The removal of phosphate ions from aqueous solution by flyash, slag, ordinary Portland cement and related blends. *Cement and Concrete Research* 32 (12): 1889 – 1897.

Al-Beiruti S. (2010). Jordan: greywater treatment and use for poverty reduction in Jordan - Multiple Use water Services Group., from http://www.musgroup.net/page/553. (website accessed 23 September 2010).

Al- Hamaiedeh , H.D. (2010). The Impact of Greywater Reuse in Irrigation on Public Health and Safety. *Electronic Journal of Geotechnical Engineering*, 15(K), 1131-1138.

Al-Hamaiedeh, H.D., and Bino, M. (2010). Effect of treated greywater reuse in irrigation on soil and plants. *Desalination*, *256*(1-3), 115-119.

Al-Jayyousi, O.R. (2010). Greywater use: Islamic perspectives. In: *Greywater Use in the Middle East. McIlwaine and Redwood* (eds). IDRC.

Ajayi T.O., Ogunbayo A.O. (2012). Achieving environmental sustainability in wastewater treatment by “United Nations Human Development Index,” United Nations. [Online]. Available at http://hdrstats.undp.org/en/indicators/103106.html [Accessed; 23-Jul-2014].

Ayoub G.M. (1994). The Lime-Seawater Process: A Potential for Chemically Enhanced Wastewater Treatment. *Proceedings of the 1st Regional Conference of the American Society of Civil Engineers*. Saudi Arabia Sect., Bahrain.

Ayoub G.M. and Koopman B. (1986). Algal Separation by the Lime Seawater Process. *Journal of Water Pollution Control Federation* 58 (9): 924 – 931.

Ayoub G.M. and Merhebi F. (2002). Characteristics and quantities of sludge produced by coagulating wastewater with seawater bittern, lime and caustic. *Advances in Environmental Research* 6 (3): 277 – 284.

Ayoub G.M., Lee S.I. and Koopman B. (1986). Seawater Induced Algal Flocculation. *Water Research (G.B.)* 20 (10): 1265 – 1271.

Ayoub G.M., Lee S.I., Mazidji C.N., Seo I.S., Cho H.H. and Koopman B. (1992). Seawater Flocculation of Emulsified Oil and Alkaline Wastewaters. *Water Research (G.B.)* 26 (6): 817 – 823.

Ayoub G.M., Merehbi F., Abdallah R., Acra A. and El Fadel M. (1999). Coagulation of Alkalinized Municipal Wastewater Using Seawater Bittern. *Water Environment Research* 71 (4): 443 – 453.

Amin M. T. and Han M.Y. (2009). Roof-harvested Rainwater for Potable Purposes: Application of Solar Collector Disinfection (SOCO-DIS). *Water Research,* 43**,** 5225-5235.

Amin T and Han M. (2011). Domestic rainwater harvesting as an adaptation measure to climate change in South Africa. *Australian Journal of Basic and Applied Sciences,* 5**,** 1804-1813.

Banerjee K., Cheremisinoff P.N. and Cheng S.L. (1995). Sorption of organic contaminants by flyash in a single solute system. *Environmental Science and Technology* 29 (9):2243 – 2252.

Banerjee K., Cheremisinoff P.N. and Cheng S.L. (1997). Adsorption kinetics of o-xylene by flyash. *Water Research* 31 (2): 249 – 261.

Bhattacharya P., Ghosh S., Sarker S., Majumda S., Bandyopadhay S.(2011). Effectiveness of biosorption assisted microfiltration process for treatment of domestic wastewater. *Bioremediation Journal.* 15(4): 206-217.

Besner M.-C., Prevost M. and Regli S. (2011). Assessing the public health risk of microbial intrusion events in distribution systems: Conceptual model, available data, and challenges. Wat. Res., 45(3), 961-979.

Brooks, D.B., O.M. Brandes, and Gurman S. (2009). *Making the most of the water we have: the soft path approach to water management.* Earthscan Publications Ltd.

Bino M.S. Beiruti A and M. Ayesh. (2010). Greywater use in rural home gardens in Karak, Jordan. In: *Greywater Use in the Middle East. McIlwaine and Redwood* (eds). IDRC.

Biyela P.T., Ryu H., Brown A., Alum A., Abbaszadegan, M. and Rittmann B.E. (2012). Distribution systems as reservoirs of Naegleria fowleri and other amoebae. *Journal - American Water Works Association.* 104: 49–50.

Boulle L. (2011). The Republic of South Africa and the G20: Its Political, National Interests and Priorities as Member of the Process, G20, Perceptions and Perspectives for Global Governance Konrad Adenaur Stifftung. [Online]. Available: http://www.kas.de/upload/dokumente/2011/10/G20_E-Book/chapter_14.pdf (Accessed: 1- Oct-2013). G20: Perceptions and Perspectives for Global Governance.

Burnat J., Eshtayah I. (2010). On-site greywater treatment in Qebia Village, Palestine. In Greywater *Use in the Middle East*; McIlwaine, S., Redwood, M., Eds.; IDRC: Ottawa, Canada, Available Online: http://web.idrc.ca/en/ev-152492-201-1- DO_TOPIC.html (accessed on 31 March 2012).

Calvo-Bado L.A., Pettitt T.R., Parsons N., Petch G.M., Alun J., Morgan W. and Whipps J.M. (2003). Spatial and Temporal Analysis of the Microbial Community in Slow Sand Filters Used for Treating Horticultural Irrigation Water. *Applied and Environmental Microbiology* 69 (4): 2116 – 2125.

Cecen F., Aktas O. (2011). Activated Carbon for Water and Wastewater Treatment: Integration of Adsorption and Biological Treatment, 1st ed., WILEY-VCH Verlag GmbH & Co. KGaA: Weinheim, Germany.

Carden K., Armitage N., Winter K., Sichone O. and Rivett U. (2007). Understanding the use and disposal of greywater in the South Africa. *Water Research Commission* Report No. 1524/1/07. Pretoria, RSA.

Carden K., Armitage N., Winter K., Sichone O., Rivett U. Understanding the Use and Disposal of Greywater in the Non-sewered Areas of South Africa, WRC Report No. K5/1524, pub. *Water Research Commission*, Pretoria, South Africa. (2007).

Carden K. , Armitage N., Winter K., Sichone O. , Rivett U., Kahonde J. (2007) The use and disposal of greywater in the non- sewered areas of South Africa: part 1—quantifying the greywater generated and assessing its quality, *Water SA*, 33(4), 425-432.

Clasen T.F. (2012). Millennium Development Goals water target claim exaggerates achievement. Tropical Medicine and International Health [Online]. Available: http://dx.doi.org/10.1111/j.1365-3156.2012.03052.x.

Chalale T. (2007). Greywater Use: Towards Suitability for Small-Scale Irrigation, Hons Report, *School of Biological and Conservation Sciences*, University of KwaZulu-Natal, South Africa

Chen X., Chen X., Wen X., Weng B., Huang H. (2010). Water hyacinth (*Echhornia crassipes*) as an adsorbent for phosphorous removal from swine wastewater. *Bioresource Technology,* 101; 9025-9030.phytoremediation with water hyacinth (*Eichhornia crassipes*). *Journal of Sustainable Development,* 5(7); 80-90.

Chunkao K., Nimpee C., Daungmal K. (2012). King's initiatives using water hyacinth to remove heavy metals and plant nutrients from wastewater through Bueng Makkasan in Bangkok Thailand. *Ecological Engineering, 39*; 40-52.

Christova-Boal, D., Eden, R. and McFarlane, S. (1995). An investigation into greywater reuse for urban residential properties. *Desalination* 106: 391–397.

Conrad C.C. and Hilchey K.G. (2011). A review of citizen science and community-based environmental monitoring: issues and opportunities. *Environmental Monititoring and Assessment,* 176**,** 273-291.

Department of Performance Monitoring and Evaluation (DPME) . (2013). Quality of Sanitation in South Africa: Final Report on the Status of Sanitation Services, The Presidency, Republic of South Africa.

Department of Water Affairs (DWA). (2013). Strategic overview of the water sector in South Africa, Water Services Planning & Information Version 1.5. Accessed in 27 January 2015: http://nepadwatercoe.org/wp-content/uploads/Strategic-Overview-of-the-Water-Sector-in-South-Africa-2013.pdf.

Department of water affairs. (2012). *Water service institutions* [Online]. Johannesburg, South Africa: Department of Water Affairs. Available: http://www.dwaf.gov.za/IO/wsi.aspx [Accessed 15 September 2012].

Department of water affairs (DWA). (2009). Adopt-A- River Programme Phase II: Development Of An Implementation Plan Monitoring Models. *In:* ROSSOUW, L. (ed.). Pretoria, South Africa: Department of Water Affairs.

Department of water affairs and forestry .(2009). The Blue Drop Report 2009: version 1, South African Drinking Water Quality Management Performance. Pretoria, South Africa: Department of Water Affairs and Forestry.

Department of Water Affairs (DWAF) .(1996). South African Water Quality Guidelines, 2nd ed., Vol. 4, Agricultural Water Use: Irrigation, pub. *Department of Water Affairs and Forestry*, Pretoria, South Africa.

Diez M.C., Mora M.L. and Videla S. (1999). Adsorption of phenolic compounds and color from Bleached Kraft Mill effluents using allophanic compounds. *Water Research*33 (1): 125 – 130.

Duncan A. (1998). Slow Sand Filtration: Recent Developments in Water Treatment Technology. In: Graham H.J.D. (ed.) *Ecology of Slow Sand Filters*. John Wiley and Sons. New York, USA.

Eriksson E., Andersen H.R. and Ledin A. (2008). Substance flow analysis of parabens in Denmark complemented with a survey of presence and frequency in various commodities. *Journal of Hazardous Materials* 156 (1-3): 240 – 259.

Eriksson E., Andersen H.R., Madsen T.S. and Ledin A. (2009). Greywater pollution variability and loadings. *Ecological Engineering* 35 (5): 661 – 669.

Eriksson E., Auffarth K., Henze M. and Ledin A. (2002). Characteristics of grey wastewater. *Urban Water* 4 (1): 85-104.

Eriksson E., Auffarth K., Henze M., Ledin A. (2002). Characteristics of grey wastewater. *Urban Water* 2002, *4:* 55-15.

Eriksson E., Yan X., Lundsbye M., Madsen T.S., Andersen H.R. and Ledin A. (2007). Variation in grey wastewater quality reused for toilet flushing. *Proceeding of the 6th IWA Specialty Conference on Wastewater Reclamation and Reuse of Sustainability.* Antwerp, Belgium

FAO and WFP. (2010). The state of food insecurity in the world. Addressing food insecurity in protracted crises. Rome, FAO. (Available at: http://www.fao.org/docrep/013/i1683e/i1683e.pdf).

Friedler E. (2004). Quality of individual domestic greywater streams and its implication for on-site treatment and reuse possibilities. *Environmental Technology* 25 (9): 997 – 1008.

Friedler E. and Butler D. (1996). Quantifying the inherent uncertainty in the quantity and quality of domestic wastewater. *Water Science and Technology* 33 (2): 63 – 78.

Ghunmi L.A., Zeeman G., Fayyad M. and Jules B. van Lier (2011). Greywater Treatment Systems: A Review, Critical Reviews in Environmental Science and Technology, 41:7, 657-698, DOI:

Ghunmi A, L., Zeeman, G., van Lier, J. and Fayyad, M. (2008). Quantitative and qualitative characteristics of greywater for reuse requirements and treatment alternatives: The case of Jordan. *Water Sci. Technol* 58:1385–1396.

Ghasemi M., Parvini M., Sarafraz H., Mohammadi M.(2013). A review of water and wastewater treatment technologies in the Upstream Petroleum Industry of Iran

Gillip J.A. (2014) Characterization of the structure, clean-sand percentage, dissolved-solids concentrations, and estimated quantity of groundwater in the Upper Cretaceous Nacatoch Sand and Tokio Formation, Arkansas: U.S. Geological Survey Scientific Investigations Report 2014-5068: 23.

Gupta G.S., Prasad G. and Singh V.N. (1988). Removal of color from wastewater by sorption for water reuse. *Journal of Environmental Science and Health* A23 (3):205 – 217.

Ilemobade A.A, Olanrewaju1 O.O. and Griffioen M.L. (2000). Greywater reuse for toilet flushing at a university academic and residential building. *Water Institute of Southern Africa (WISA)* Biennial Conference, Cape Town, 6–10 May 2012. ISSN 1816-7950 (On-line) = Water SA Vol. 39 No 3 WISA 2012 Special Edition 2013.

International Telecommunication Union (ITU). (2013). The World in 2013 ICT Facts and Figures.

Tropical Medicine and International Health (TMIH) (2004). Burden of disease from inadequate water, sanitation and hygiene in low- and middle-income settings: a retrospective analysis of data from 145 countries, 19 (8): 894-905.

Jala S. and Goyal D. (2006).Flyash as a soil ameliorant for improving crop production - a review. *Bioresource Technology* 97 (9): 1136 – 1147.

Ji W. and Cai J. (2010). Efficiency and Economy of a New Agricultural Rainwater Harvesting System. *Chinese Journal of Population, Resources and Environment* 8:2.

Jiambo L.U., Zhihui F.U., Zhaozhang Y. (2008). Performance of water hyacinth systems in the treatment of wastewater from a duck farm and the effects of using water hyacinth as a duck feed. *Journal of Environmental Science*, 20;513-619.

Joss A., Keller E., Alder A.C., Gobel A., McArdell C.S., Ternes T. and Siegrist, H. (2005). Removal of pharmaceuticals and fragrances in biological wastewater treatment. *Water Research Journal*. 39, 3139–3152.

Kings S. (2015). South Africa's great thirst has begun. *Mail and gurdian*.

http://mg.co.za/article/2015-01-22- south-africas-great-thirst-has-begun. [accessed: 23rd January 2015]

Leal L. H., Zeeman G., Temmink H., Biusman, C. (2007). Characterization and biological treatment of greywater. *Water Science and Technology*. 56(5).193-200.

Lu S.G., Bai S.Q., Zhu L., Shan H.D. (2009). Removal mechanism of phosphate from aqueous solution by fly ash. *Journal of Hazardous Materials*. 161:95-10110.1080/10643380903048443.

Lukwe N. (2014). Locals say why they don't drink tap water. *Grocotts*, :http://www.grocotts.co.za/content/online-water-shortages-grahamstown-22-07-2014 [accessed: 25th August 2014]

Luyt C.D., Muller W.J. and Tandlich R. (2011). Low cost tools for microbial quality assessment of drinking water in South Africa. *Special Issue of the IOMC 2011 Conference Abstracts*. Conference e-Proceedings: HealthMed.

Luyt C.D., Muller W.J., Wilhelm B. S. and Tandlich R. (2010). Faecal contamination of potable water resources in South Africa: sources, monitoring and challenges for the future. *Environmental monitoring and assessment,* (submitted on 5th May 2010).

Luyt C.D., Muller W. J., Wilhelmi B. S. and Tandlich R (2011). Health implications of flood disaster management in South Africa. *18th Annual Conference of the International Emergency Management of Soci*ety, 7 – 10, Bucharest, Romania. 376-385.

Luyt C.D., Tandlich R., Muller W. J. and Wilhemi B.S. (2012). Review: Microbial Monitoring of Surface Water in South Africa: An Overview. *International Journal of Environmental Research and Public Health* 9**,** 2669-2693.

Mahmoud N. and Z. Mimi. (2008). Perception of House Onsite Greywater Treatment and Reuse in Palestinian Rural Areas. *Water Practice& Technology*, 3(3).

Maimon A., Tal A. Friedler E and Gross A. (2010). Safe on-site reuse of greywater for irrigation – A critical review of current guidelines. *Environmental Science and Technology*, 44: 3213-3220.

McGuigan KG., Conroy RM., Mosler H.J, du Preez M., Ubomba-Jaswa E., Fernandez-Ibañez P. (2012). Solar water disinfection (SODIS): a review from bench-top to roof-top. *Journal of Hazardous Materials,* 235-236: 29-46.

Mcllwaine, S., Redwood M. (2010). *Greywater Use in the Middle East Technical, Social, Economic and Policy Issues*; Replika Press: Haryana, India, pp. 1–162.

Momba M. N. B. and Kaleni P. (2002). Regrowth and Survival of Indicator Microorganisms on the Surfaces of Household Containers Used For the Storage of Drinking Water in Rural Communities of South Africa. *Water Research,* 36**,** 3023-3028.

Momba M. N. B., Madoroba E. and Obi C. L. (2010). Apparent impact of enteric pathogens in drinking water and implications for the relentless saga of HIV/AIDS in South Africa. *FORMATEX* [Online]. Available: http://www.formatex.info/microbiology2/615-625.pdf.

Momba M. N. B., Obi C. L. and Thompson P. (2009). A Survey of disinfection efficiency of small drinking water treatment plants: challenges facing small water treatment plants in South Africa. *Water SA,* 35**,** 485-493.

Momba M. N. B., Osode A. N. and Sibewu M. (2006). The Impact of Inadequate Wastewater Treatment on the Receiving Water Bodies Case Study: Buffalo City and Nkokonbe Municipalities of the Eastern Cape Province. *2006 Water Institute of South Africa (WISA) Biennial Conference.* Durban, South Africa: Water SA.

Momba M. N. B., Sibewu M., and Mandeya A. (2009). Survival of somatic and F-RNA coliphages in treated wastewater effluents and their impact on viral quality of the receiving water bodies in the Eastern Cape Province-South Africa. *Journal of Biological Sciences,* 9**,** 648-654.

Momba M. N. B., Tyafa, Z. and Makala N. (2004). Rural water treatment plants fail to provide potable water to their consumers: the Alice water treatment plant in the Eastern Cape province of South Africa: research letter. *South African Journal of Science,* 100**,** 307-310.

Mott H.V. and Weber W.J. (1992). Sorption of low molecular weight organic contaminants by flyash: consideration of enhancement of cut-off barrier performance. *Environmental Science and Technology,* 26 (6): 1234 – 1242.

Mott H.V. and Weter W.J. (1975). Sorption of low molecular weight organic contaminants by flyash. *Water Air Soil Pollution* 37:13 – 24.

Murphy K.O.H. (2006). A Scoping Study to Evaluate the Fitness-For-Use of Greywater in Urban and Peri-urban Agriculture, WRC Report No K5/1479/1/06, pub. *Water Research Commission*, Pretoria, South Africa.

Mzini L.L. and Winter K. (2014). Analysis of grey-water used for irrigating vegetables and possible effects on soils in the vicinity of Umtata Dam, Eastern Cape.Water SA Vol. 41 No. 1.

Mulder K, N. Hagens, and B. Fisher. (2010) "Burning water: a comparative analysis of the energy return on water invested," *Ambio*, 39(1): 30–39.

Naik H.K., Mishra M.K. and Rao-Karanam U.M. (2009). Rheological characteristics of flyash slurry at varying temperature environments with and without an addictive. *World of coal ash*. Lexington, KY, USA.

Nkondo M.N., Van Zyl F.C., Keuris H. and Schreiner B. (2012). Proposed National water resource strategy 2 (NWRS 2): Summary South Africa: Department of Water Affairs (DWA)

Ngqwala N.P., Zuma B.M. and Tandlich R. (2013). Greywater composition and treatment in a coastal area of South Africa (5th International Scientific and Expert Conference proceedings *TEAM 2013 Technique, Education, Agriculture & Management)* Prešov, 4th to 6th November 2013.

Olawale O.O. (2012). Integrated risk management in the implementation of dual grey and potable water reticulation systems in South Africa. PhD Thesis. Faculty of Engineering and the Built Environment, University of the Witwatersrand, Johannesburg y, South Africa.

Osborn N.I., Smith S.J., and Seger C.H. (2013), Hydrogeology, distribution, and volume of saline groundwater in the southern midcontinent and adjacent areas of the United States: *U.S. Geological Survey Scientific Investigations Report* 5017:58 p.

Othman A. Al-Mashaqbeh B., Ayoup M. Ghrair and Sharon B. Megdal. (2012). Greywater Reuse for Agricultural Purposes in the Jordan Valley: Household Survey Results in Deir Alla, *Water*, *4*, 580-596

Pathan S.M., Aylmore L.A. and Colmer T.D. (2003). Properties of several flyash materials in relation to use as soil amendments. Journal of Environmental Quality 32 (2): 687 – 93.

Pinto U., Maheshwari B. (2010) Reuse of greywater for irrigation around homes in Australia: Understanding community views, issues and practices. *Urban Water J. 7* (2), 141–153.

Prathapar S.A., Jamrah A., Ahmed M., Al Adawi S., Al Sidairi S. and Al Harassi A. (2005). Overcoming constraints in treated greywater reuse in Oman. *Desalination* 186 (1-3): 177 – 186.

Pinto U., Maheshwari B. (2007). *Issues and Challenges of Greywater Reuse for Irrigation in Australia—A Case Study of Western Sydney Region*; University of Western Sydney: Sydney, Australia.

Quinn C. H., Ziervogel G., Taylor A., Takama T. and Thomalla F. (2011). Coping with Multiple Stresses in Rural South Africa. *Ecol. Soc.*, 16(3), 10.

Rabbani K. S. (2012). Low Cost Domestic Scale Technologies for Safe Drinking Water," Appropriate Healthcare Tech- nologies for Developing Countries (AHT 2012), http://dx.doi.org/10.1049/cp.2012.1465

Ramon G., Green M., Semiat R. and Dosoretz C. (2004). Low strength greywater characterization and treatment by direct membrane filtration. *Desalination* 170 (3): 241 – 250.

Raymer D., and Buckle J. (2010). We are facing a water and sanitation crisis in South Africa. *WISA 2010 Biennial Conference & Exhibition*. Durban, South Africa: Water SA.

Reungoat J., Escher B.I., Macova, M., Argaud, F.X., Gernjak, J.K. and Keller, J. (2012). Ozonation and biological activated carbon filtration of wastewater treatment plant effluents. *Wat. Res.* 46, 863–872.

Reungoat J., Macova M., Escher B.I., Carswell S., Mueller J.F. and Keller, J. (2010). Removal of micropollutants and reduction of biological activity in a full scale reclamation plant using ozonation and activated carbon filtration. *Wat. Res.* 44, 625–637.

Ridderstolpe P. (2004). Introduction to Greywater Management , pub. *EcoSanRes Programme and Stockholm Environment*, Stockholm, Sweden .

Rijsberman F. R. (2006). Water scarcity: Fact or fiction? *Agricultural Water Management*, 80: 5-22.

Rodda N. K., Carden N., Armitage H. M. du Plessis. (2011). Development of guidance for sustainable irrigation use of greywater in gardens and small-scale agriculture in South Africa, WRC 40-Year Celebration Special Edition 37(5).

Rossouw L., Februarie D.A., and water research commission .(2006). *Guidelines for implementing volunteer water quality monitoring in South Africa,* Gezina, South Africa, Water Research Commission.

Ryan, A.M., Spash, C.L., Measham, T.G. (2009). Socio-economic and psychological predictors of domestic greywater and rainwater collection: Evidence from Australia. *J. Hydrol. 379*, 164–171.

SAICE and CSIR. (2011). SAICE Infrastructure Report Card for South Africa,.http://www.csir.co.za/enews/2011_jun/download/infrastructure_report_card_sa_2011. pdf, 14.

South African human right commission (SHRC). (2014). Report on the Right to Access Sufficient Water and Decent Sanitation in South Africa: Accessed in 01 January 2015: http://www.sahrc.org.za/home/21/files/FINAL%204th%20Proof%204%20March%20-%20Water%20%20Sanitation%20low%20res%20(2).pdf

Salukazana L., Jackson S., Rodda N., Smith M., Gounden T., Mc Leod N., and Buckley C. Plant growth and microbiological safety of plants irrigated with greywater. *3rd International Conference on Ecological Sanitation*, 23rd until 26th May 2005 Durban, South Africa. Peer-reviewed proceedings

Saraswats S., Rai J. P.N. (2010). Heavy metal adsorption from aqueous solution using *Echhornia crassipe* dead biomass. *International Journal of Mineral Processing.* 94; 203-206.

Sandhu C., Grischek T., Kumar P and. Ray C. (2010). Potential for Riverbank Filtration in India. *Clean Technologies and Environmental Policy*, 13(1): 1-22.

Salukazana L., Jackson S., Rodda S., Smith M., Gounden N., Macleod C., Buckley. (2005). Proc. 3rd Int. Conference on Ecological Sanitation

Seckler D., Barker R., Amarasinghe U. (1999). Water scarcity in the twenty-first century, *International Journal of Water Resource Development*, 15, 29-40, 1999.

Scholes L. and Shutes B. (2008). Catalogue of Options for the Reuse of Stormwater. SWITCH. (Available at: http://www.switchurbanwater.eu/outputs/pdfs/W2-2_GEN_RPT_D2.2.1b_Catalogue_of_options_for_reuse_of_stormwater.pdf

Solley D., Gronow C., Tait S., Bates J. and Buchanan A. (2010). Managing the reverse osmosis concentrate from the Western Corridor Recycled Water Scheme. *Wat. Prac. Technol.* 5:.42

Stalter D., Magdeburg A. and Oehlmann J. (2010). Comparative toxicity assessment of ozone and activated carbon treated sewage effluents using an in vivo test battery. *Wat. Res.* 44(8), 2610–2620.

Sim W.J., Lee J.W., Shin S.K., Song K.B. and Oh J.E. (2011) Assessment of fates of estrogens in wastewater and sludge from various types of wastewater treatment plants. *Chemosphere* 82, 1448–1453.

Swamy M.M., Mall I.D., Prasad B. and Mishra I.M. (1997). Removal of phenol by adsorption on coal flyash and activated carbon. *Pollution Research* 16 (3): 170 – 175.

Statistics South Africa. (2011). Water and Sanitation 2002–2010: In-Depth Analysis of the General Household Survey data. GHS Series. Pretoria, South Africa: Statistics South Africa, Pretoria, South Africa.

Statistics South Africa. (2011). General Household Survey 2010 Revised version ed. Pretoria, South Africa: Statistics South Africa, Pretoria, South Africa.

Tandlich R., Luyt C.T. and Ngqwala N.P. (2014). A community-based rainwater monitoring and treatment programme in Grahamstown, South Africa, *Journal of Hydrocarbons Mines and Environmental Research*, 5(1), 46-51, ISSN: 2107-6510.

Tandlich R., Chirenda T. G., Srinivas C. S. (2013). Gender aspects of disaster management in South Africa, *Journal of Disaster Risk Studies*, 5(4): 84.

Tandlich R., Zuma B.M., Whittington-Jones K.J. and Burgess J.E. (2009). Mulch tower treatment system for greywater reuse Part II: destructive testing and effluent treatment. *Desalination* 242 (1-3): 57 – 69.

Tandlich R. and Muller W. J. (2008). Methods for detection of faecal pollution and identifying its origins: linking the South African and the international context. Pretoria, South Africa: *Water Research Comission*.

Tandlich R., Zuma B.M., Dyongman S.A. and Slaughter A. (2008). Characterization of greywater from selected sites in South Africa for potential reuse in irrigation. Proceedings from the IASTED International Conference on Water Resource Management Africa WRM 2008, Gaborone, Botswana, Acta Press. Gaborone, Botswana.

Tsalakanidou I. (2006). Potential of reactive filter materials for small-scale wastewater treatment in Greece. Batch & Column Experiments. TRITA-LWR Master of Science Thesis. Stockholm, Sweden.

Tropical Medicine and International Health.. Burden of disease from inadequate water, sanitation and hygiene in low- and middle-income settings: a retrospective analysis of data from 145 countries. 19(8): 894-905.

United Nations. (2012). The Millennium Development Goals Report 2012. New York, United States of America: United Nations.

UN Inter-agency Group for Child Mortality Estimation. (2013). Levels & Trends in Child Mortality, Report 2013. *New York: United Nations Children's Fund.*

Vraie L. (1978). Chemical Precipitation of Wastewater with Lime and Seawater. *Progress in Water Technology* 10: 645 – 656.

Weng C.H. and Huang C.P. (1994). Treatment of metal industrial wastewater by flyash and cement fixation. Journal of Environmental Engineering 120 (6): 1470 – 1487.

Wilson-Jones T., and Rivett U. (2012). Using Mobile Phones To Monitor And Manage Water Supply Quality In Rural Environments. *WISA 2012 Biennial Conference & Exhibition.* Cape Town.

Winward G.P., Avery L.M., Frazer-William R., Pidou M., Jeffrey P., Stephenson T. and Jefferson B. (2008). A study of the microbial quality of greywater and an evaluation of treatment technologies for reuse. *Ecological Engineering,* 32 (2): 187 – 197.

Whittington-Jones K. (2007). Construction of greywater treatment systems for the Scenery Park (Buffalo City Municipality) pilot project, Phase 2 Report. Prepared for The Stockholm Environment Institute & EcoSanRes.

Whittington-Jones K., Tandlich R., Zuma B. M., Hoossein S., Villet M. H. (2011a). Performance of the pilot-scale mulch tower system in treatment of greywater from a low-cost housing development in the Buffalo City, South Africa. *International Water Technology Journal,* 1 (2): 165 – 181.

Whittington-Jones K., Tandlich R., Zuma B. M., Hoossein S., Villet M. H. (2011b). Performance of the pilot-scale mulch tower system in treatment of greywater from a low-cost housing development in the Buffalo City, South Africa. *Published in the peer-reviewed conference proceedings from the 15th International Water Technology Conference.* Alexandria, Egypt.

Whittington-Jones K., Tandlich R., Zuma B.M., Hoossein S. and Villet M.H. (2011). Performance of the pilot-scale mulch tower system in treatment of greywater from a low-cost housing development in the Buffalo City Municipality, South Africa. *Fifteenth International Water Technology Conference, IWTC 15 2010,* Alexandria, Egypt.

Whittington-Jones K., Tandlich R., Zuma B.M., Hoossein S. and Villet M.H. (2011b). Performance of the pilot-scale mulch tower system in treatment of greywater from a low-cost housing development in the Buffalo City Municipality, South Africa. *International Water Technology Journal,* I (2): 165 – 181.

WHO. (2006).“WHO Guidelines for the Safe Use of Wastewater, Excreta and Greywater, Volume IV, Excreta and Greywater Use in Agriculture”, pub. WHO Press, World Health Organisation, Geneva, Switzerland.

WHO/UNICEF Joint Monitoring Programme (JMP) for Water Supply and Sanitation. (2012). Progress on Sanitation and Drinking-Water,(2012) Update. Water situation in South Africa.

World Health Organization and UNICEF Joint Monitoring Programme (JMP). (2014). Progress on Drinking Water and Sanitation, 2014 Update.

World Health Organization (WHO). (2012). Global Health Observatory. Global Health Observatory Data Repository. Mortality and global health estimates: Child Mortality: Causes of Child Death: Number of Deaths by Cause: By Region: WORLD: Diarrhoeal diseases, World Health Organization (WHO). HDR Engineering, “Handbook of Public Water Systems,” John Wiley and Sons, New York, 2011.

Yadawa K.P., Tyagi B.S., Panday K.K. and Singh V.N. (1989). Flyash for the treatment of water enriched in lead (II). *Journal of Environmental Science and Health* 24(Pt A): 783 – 808.

Zheng J., Feng H., Lam H., P.K., Ding Y., Yu H. (2009). Removal of Cu (II) in aqueous media by biosorption using water hyacinth roots as a biosorbent material. *Journal of Hazardous Materials.* 171:780-785.

Zuma B.M. and Tandlich R. (2010). Public health implications of greywater production in South Africa. In: Fonn S, Padarath A, editors. South African Health Reviews 2010. Durban: Health Systems Trust; URL: http://hst.org.za/publications/876.

Zuma B., Tandlich R., Whittington-Jones K. and Burgess J.E. (2009). Mulch tower treatment system Part I: Overall performance in greywater treatment. *Desalination* 242 (1): 38 – 56.

Zuma B.M. (2010). Microbial ecology of the Buffalo River in response to water quality changes. Master of Science. Thesis, Rhodes University. Grahamstown, RSA.

Zuma B.M.. and Tandlich R. (2010). Public health implications of greywater production in South Africa. In: Fonn S. and Padarath A. (eds.). *South African Health Reviews*. Health Systems Trust. Durban, RSA.

CHAPTER 3: GREYWATER COMPOSITION AND TREATMENT IN A COASTAL AREA OF SOUTH AFRICA

A combination of the PozzSand® fly ash and lime was tested for possible application in greywater treatment in coastal areas of South Africa. This was done in a two-phase study. Firstly, the physical, chemical and microbial composition of greywater from a donor household was assessed over six weeks. Then, the FlyAsh Lime Filter Tower (FLFT) was used to treat the greywater. Further, experiments were undertaken in Chapter 4 to modify the FLFT system to manage the pH of the effluent, while maintaining the treatment efficiency observed in the preliminary study.

3.1. Introduction

Water scarcity is a global phenomenon (Carden *et al.* 2007; Seckler *et al.* 1999). A number of factors contribute to this state of affairs. It is argued that climate and service delivery considerations often cause limitations in drinking water supply (Ngqwala *et al.* 2013; Luyt *et al.* 2012; Rodda *et al.* 2011; Momba *et al.* 2006). With reference to South Africa, water scarcity is also exacerbated its semi-arid climate with a high geographical variability of precipitation that exists (Stager *et al.* 2012; Tandlich *et al.* 2009). Further, it is believed that pressure on drinking water resources is high in developing countries due to faster population growth and high rates of urbanization (Rodda *et al.* 2011).

Even though South Africa is a member of the G20 group (Boulle, 2013), and has reached a medium level of human development as indicated by the Human Development Index (UNHDI, 2012), it is still considered a developing country (Tandlich *et al.* 2013). Sadly, it projected that South Africa will likely reach physical water scarcity by 2025, mainly due to the water-intense activities, such as mining and agriculture (Tandlich *et al.* 2013). Wastewater treatment for reuse has been seen as one of the possible solutions to this problem (Zuma *et al.* 2009).

The rationale is that, treated wastewater could be recycled and used in activities where drinking water quality is not required, for example, toilet flushing or irrigation. This would reduce the freshwater consumption in areas with drinking water shortages, for example, coastal zones. Limited efficiency of wastewater treatment and skills shortages in the sector (Zuma *et al.* 2009), as well as lack of sanitation infrastructure (Carden *et al.* 2007), often prevent such efforts from being successful on the ground. The use of reactive filters is believed to be one of the solutions to the water scarcity problems. They are low-cost sanitation systems where wastewater percolates down a system of layered materials and in-situ treatment takes place through precipitation and straining (Tsalakanidou *et al.* 2006). They can be implemented in decentralized settings from low-cost materials, such as wood chips, coarse sand and gravel (Zuma *et al.* 2009). In this chapter the Flyash/Lime Filter Tower (FLFT) was composed using the pulp and paper fly ash and locally available low grade lime. The FLFT B was tested to observe whether it can produce a distinct improvement of the effluent quality. Consequently, the overall performance of the treatment system was evaluated.

3.1.1. Greywater treatment systems

A greywater treatment system consists of different treatment steps that may be considered, depending on the required quality of the effluent. Several treatment technologies were used in each step (Erickson *et al.* 2008). Technologies examined for treating greywater were classified based on the treatment principle: physical, biological, chemical, or a combination of these. Investigations into the treatment and recycling of greywater have been reported since the 1970's and mainly physical treatment options, such as coarse filtration or membranes often coupled with disinfection were the first technologies studied (Abu Ghunmi, 2009; Li *et al.* 2009; Eriksson *et al.* 2002). Depending on the economic aspects and the required final effluent quality, greywater undergoes different degrees of treatment before being reused or disposed. There are usually three degrees of treatment defined as primary treatment, secondary treatment, and tertiary treatment (Abu *et al.* 2008; Morel, 2005).

Primary treatment is the first step in wastewater treatment that is used to remove most materials that float or settle. Primary treatment removed about 30 percent of the carbonaceous biochemical oxygen demand from domestic sewage (Penn *et al.* 2012; Ghunmi *et al.* 2011; Finch *et al.* 2003). Secondary treatment is the second stage whereby bacteria consume the organic parts of the waste. This treatment removes floating and settled able solids, and about 90 percent of the oxygen-demanding substances and suspended solids. Disinfection is usually the final stage of secondary treatment (Solley *et al.* 2010; Stalter *et al.* 2010). Tertiary treatment is the last step that consists of an advanced cleaning of wastewater that goes beyond the secondary or biological stage. It removes nutrients, such as phosphorus, nitrogen, and mostly biological oxygen demand (BOD), and suspended solids (SS) (Leal *et al.* 2010; Finch *et al.* 2003). Each treatment stage can be accomplished by a certain system, such as centralised or decentralised systems. In some cases different treatment stages can be combined sequentially to obtain the required quality for reuse and disposal (Jefferson *et al.* 2000). Furthermore, the technologies are reviewed in terms of performance, operation, and the encountered problems (Morel, 2005).

3.1.2. Filtration and Physiochemical Processes

Several types of macro and membrane filtration units for greywater treatment were tested. The tested microfiltration units included a strainer series with pore size $\geq$ 0.17 mm, nylon sock-type filters, geotextile (filter sock) filters, fibrous (cloth) filters, coarse filters (CF), and sand filters (SF) (Friedler *et al.* 2006; Nghiem *et al.* 2006; Jefferson *et al.* 2000). The efficiency of the filtration techniques depends on the particle size distribution of greywater pollutants and the filters porosity. It is generally believed that the smaller the filters' porosity, the better the effluent quality (Ahn *et al.* 2007). Modification of the operational conditions, such as flow direction, short hydraulic retention time (HRT), and planting the filter media (i.e., constructed wetlands) (Pidou, 2007) is believed to improve the performances of filters. Also, filters can be developed that combine two types of treatment in the same unit (i.e., biofilters - combining physical and biological processes - and chemfilters (i.e., combining physical and chemical processes) (Jefferson *et al.* 2000; Christova *et al.* 1995).

3.1.3. Biological Treatment

A wide range of biological processes were used to recycle greywater, such as fixed film reactors, rotating biological contactor, anaerobic filters (Hernandez *et al.* 2008; Nolde, 1999), sequencing batch reactor, membrane bioreactors and biological aerated filters (BAF). Biological treatment of greywater followed by disinfection was used to guarantee risk free effluent. The system could be optimized for a minimal energy and maintenance (Nolde, 1999). Otterpohl *et al.* (1999) recommended the application of attached biomass to avoid activated sludge systems. Greywater treatment selection factors are the characteristics, the reuse requirements of the technology performance, energy demand and costs, and the geographical location (Pidou *et al.* 2007). These factors are inherently interrelated and influence each other.

Schemes for greywater recycling have been popular in most parts of the world. Further, countries, such as Oman designed and tested a low cost, low maintenance system based and activated carbon, sand filtration and disinfection for the treatment of ablution water in a mosque (Prathapar *et al.* 2005). Much research has also been done on greywater treatment possibilities, including conventional methods and decentralised treatment systems (Seckler *et al.* 2009; Zuma *et al.* 2009; Whittington-Jones *et al.* 2007). An example of such a decentralised greywater treatment system is the Mulch-Tower Treatment System (MTTS), developed by Zuma *et al.* (2009). A MTTS is an on-site biological greywater treatment system where greywater filters through alternate layers of materials, including mulch, coarse sand, fine and coarse gravel. The mulch-tower serves as a filter in removing the suspended solids of greywater, as well as the site for biodegradation where the filtrate may be broken down by aerobic micro and microorganisms. Decentralised systems are attractive in a South African context because of easy, on-site operation by the local population, even in remote locations.

3.2. The mulch tower project background

Rapid population growth and increasing industrial demand for high purity water increases the need to investigate and develop methods for greywater treatment, such as small-scale on-site biological treatment systems. The original concept and process principle for the three-step greywater treatment system was developed by Peter Ridderstolpe from WRS Uppsala Inc. (Ridderstolpe, 2007). The Mulch Tower (MT) system was developed and piloted at the Scenery Park, (Buffalo City Municipality, East London, South Africa), an informal settlement with intent to provide the primary and secondary greywater treatment (Whittington-Jones, 2007). This system was designed to have a greywater intake capacity of approximately 100 litres per day in one household. While the pilot system was being commissioned, Tandlich *et al.* (2009) and Zuma *et al.* (2009) simulated the MT at the laboratory-scale in 2006 – 2007. The pilot systems went online in 2009 and were monitored by Whittington-Jones *et al.* (2011a; and b). Zuma *et al.* (2009) reported the removal efficiency ranging between 24 – 28% in the chemical oxygen demand (COD), nitrates and sulphides, while a 52% removal efficacy was recorded for the total suspended solids (TSS). However, the system was unable to remove the faecal and total coliform microbial indicators (FC and TC), phosphates, chlorides, ammonia, and sulphates (Tandlich *et al.* 2009). In 2009 - 2011, Zuma and co-workers investigated flyash and a mixture of flyash and lime as potential sorbent materials that could be used to improve its greywater treatment capacities. The MTTS study was therefore modified and referred to as the Flyash/lime Filter Tower (FLFT) because of the introduction of flyash and lime as the filter-adsorbent and microbial sterilisation media. See figure 3.1 below:

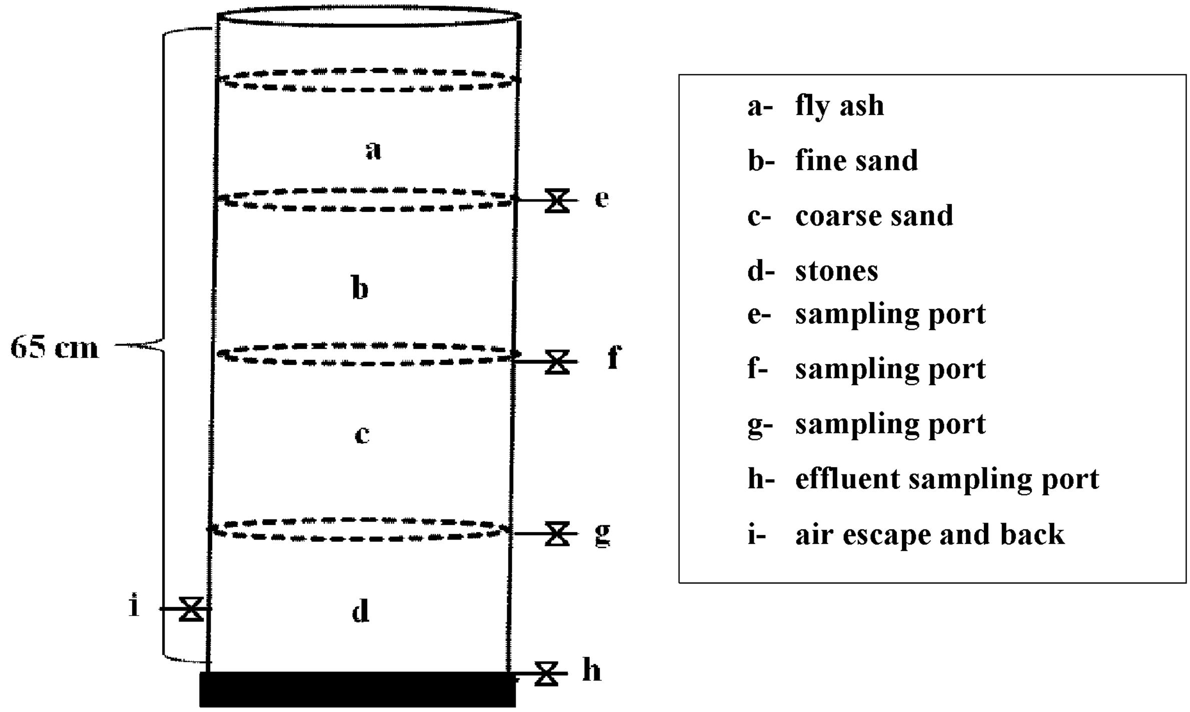


Figure 3.1: The original Flyash/lime filter tower greywater treatment reactor. The air escape port was made to ease air pressure that built up at the bottom of the reactor to allow for an eased influent percolation within the column. Letters a-i represents the composition of materials inside the tower.

The layers of flyash/lime 1, fine sand, coarse sand and 20 mm stones were set up in a 65 cm long, 15 cm wide FLFT column (see Figure 3.1 above). The FLFT system was manually fed with raw greywater (Zuma *et al.* 2009). The reactors were fed twice a day, with 3 litres of greywater in the morning and 2 litres in the afternoon. The influent and effluent samples were collected as composite fractions of individual feedings. The technology such as the mulch bed is not new. However, it was modified to create the tower suited for installation in the households with small plots as a flush-through system, with changes in the layer material to enable it to remove some greywater contaminants. The aim was to ensure that the technology modification did not alter the original plan of having the low cost, robust, sustainable and easy to maintain system.

3.3. Study aim

The Fly Ash Lime Filter Tower (FLFT) system developed by Zuma and co-workers is studied in this chapter for the treatment of the greywater from coastal areas of South Africa. The system was developed to be an effective low cost greywater treatment system for the on-site and small scale installations. The comparisons between the biological and physico-chemical parameters are used to measure the systems performance. The flyash/lime 1 mixture layer was added to enable removal of the inorganic and organic components and for sterilising bacteria. Then, a layer of the fine sand mixed with the silica sand was added to increase porosity while providing the additional effluent treatment through filtration process. Thereafter, a stone layer was added to increase porosity at the bottom of the reactor.

3.4. Experimental procedures

The study started with characterisation of greywater and then followed by the treatment methods designed by Zuma and others (Zuma *et al.* 2009). Greywater was obtained from one donour household in the coastal town of Kleinemonde, Eastern Cape Province of South Africa. The treatment performance of the FLFT was tested by obtaining samples of the untreated greywater (the influent) and the treated greywater (the effluent). For sample collection, 500 or 1000 ml Schott bottles (Sigma-Aldrich, Johannesburg, South Africa) were washed in 10% hydrochloric acid (Sigma-Aldrich, Johannesburg, South Africa), commercial detergent and MilliQ water (Millipore/Merck, Port Elizabeth, South Africa). These were then sterilised in the Model RAU-53Bd REX MED autoclave (Hirayama Manufacturing, Tokyo, Japan) at 121 °C/kPa for 15 minutes.

3.4.1. Materials and consumables

The pulp and paper mill flyash was obtained from SAPPI, Mandeni, RSA; lime from the Local farm, Grahamstown (Lime 1) and P & B Limeworks, Cape Town (Lime 2), RSA. The COD (test kit number: solution A (1.14679.0495) and solution B (1.14680.0495; range 500 – 10 000 mg/l), phosphate (test kit number: 1.14848.0001), nitrates (test kit number: 1.09713.0001), ammonium (test kit number: 1.14752.0001) and chlorides (test kit number: 1.14897.0001) were purchased from Merck (Pty.) Ltd. (Johannesburg/Cape Town, RSA). The following agars were purchased from Merck (Pty.) Ltd. (Johannesburg/Cape Town, RSA).

3.4.2. Sample collection

The samples were collected as described by Tandlich *et al.* (2008). After collection, it was stored in sealed 5 litre plastic drums at 15 ºC and used within 24 hours of collection. All microbiological, physical and chemical analyses were completed within 48 hours of collection, while the baseline treatment assessment was measured over a two-week period. The greywater used for the treatment performance testing was collected from the bathroom greywater and the kitchen greywater. The composition was measured over a six-week period to establish the ranges of greywater parameter values.

3.4.3. Microbiological analysis

At the laboratory, the samples of the FLFT influent and FLFT effluent were analysed for the faecal coliforms (FC) on all occasions. Faecal coliforms were enumerated on m-FC agar (Merck (Pty.) Ltd., Cape Town/ Johannesburg, South Africa), at 44.5°C for 24 hours. The mFc agar was prepared according to the manufacturer's instructions. The mFc agar (52 g) was dissolved in 1000 mL of deionised water by boiling for 1 minute, while being stirred. The agar was prepared in 1 L schott bottles (Labotec, Midrand, South Africa), the media autoclaving was performed in a Model RAU-53Bd REX MED autoclave (Hirayama Manufacturing, Tokyo, Japan). Samples were inoculated onto plates in a LA1200 BII laminar-flow hood. All incubations took place in one of the following incubators: the Labcon incubator Model FSIM B (Labmark, Johannesburg, South Africa), the TS 606/3-I incubator (WTW, Weilheim, Germany), the Labcon low temperature incubator LTIE 10 (Labmark, Johannesburg, South Africa) and/or the Heraeus Model FT 420 (Heraeus Kulzer GmbH, Dormagen, Germany). Membrane filtration (MF) filters (nylon, size 0.45 μm) for microbial enumeration and sterile petri dishes (90 mm) were procured from Spellboud Labs (Port Elizabeth, South Africa). Bacteria samples were either spread plated or membrane filtrated. Samples were analysed in duplicates or triplicates. The average of the replicates was recorded as the concentration. These enumerations concentrations were expressed in CFU/100 ml and all microbiological analyses were completed within 48 hours of sample collection.

3.4.4. Microbial and Physicochemical analysis

Greywater samples were analysed for concentrations of ammonium (NH_4^+), phosphate (PO_4^{3-}), nitrate (NO_3^-), chloride (Cl^-), sulphates (SO_4^{2-}) (catalogue number 1.14848.0001), chemical oxygen demand (COD) (test kit number: solution A; 1.14679.0495 and solution B; 1.14680.0495) and faecal coliforms (FC). Turbidity (Tur), electrical conductivity (EC) and pH of the samples were also determined. Unless stated otherwise, all quantitative analyses were performed according to Standard Methods (APHA, 1998). Besides SO_4^{2-} were determined using the relevant kits as purchased from Merck Pty. Ltd. (Johannesburg, South Africa). The COD concentrations were measured using the respective reagents and the reflux closed vessel method (APHA, 1998). Spectrophotometric measurements were performed using the Shimadzu 1200 UV/VIS spectrophotometer (Shimadzu, Johannesburg, South Africa). The EC and pH of the greywater samples were measured using the portable testers from Hannah Instruments (Port Elizabeth, South Africa). FC was determined using the membrane filtration technique (APHA, 1998) on the m-FC agar (Merck Pty. Ltd., Johannesburg, South Africa). Cells were trapped on the 47 mm GF-6 membrane filters (pore size 0.45 μm, Spellbound Labs, Port Elizabeth, South Africa). Turbidity (Tur) was measured using the Lutron TU-2016 portable turbidimeter (Test and Measurement Instruments CC, Johannesburg, South Africa). The SO_4^{2-} concentrations were determined using the United States Environmental Protection Agency (EPA) method 375.4 (EPA, 2008). Sterile plastic Petri dishes were purchased from EC Labs (Port Elizabeth, RSA). Duplicate measurements for all samples were conducted.

The treatment performance was tested by obtaining samples of the untreated greywater (the influent) and the treated greywater (the effluent).The reactor was fed twice a day with 3 litres of greywater in the morning and 2 litres in the afternoon. The influent and effluent samples were collected as composite fractions of individual feedings. Analyses on the influent and effluent were performed analogically as stated for the baseline greywater characterisation. Efficiency of treatment was assessed by calculating the percentage of removal for each parameter as defined in equation (3.1 below). The percentage removal efficiency (PR) was calculated using the following equation:

$$\text{Percentage Removal effincieny } (\%) = \left(\frac{\text{Cinfluent} - C_{\text{effluent}}}{C_{\text{influent}}}\right) \text{x } 100 \qquad \text{Equation}\ldots 3.1$$

In equation (3.1 above), PR is the percentage removal, while $C_{influent,\ effluent}$ are the concentrations or values for a given parameter in the influent (subscript influent) and the effluent (subscript effluent). The PR values are dimensionless while the units for a given parameter are listed in the results and discussion section.

3.5. Results and discussion

In this study, different strengths of greywater were sampled from different households in Port Alfred area of the Eastern Cape Province, South Africa, and the baseline composition was determined. This was done by measuring the concentrations of Cl^-, COD, CFU, NH_4^+, PO_4^3, NO_3^-, SO_4^{2-} and Tur. Data are summarized in Tables 3.1 and Table 3.2 and figure 3.2 below.

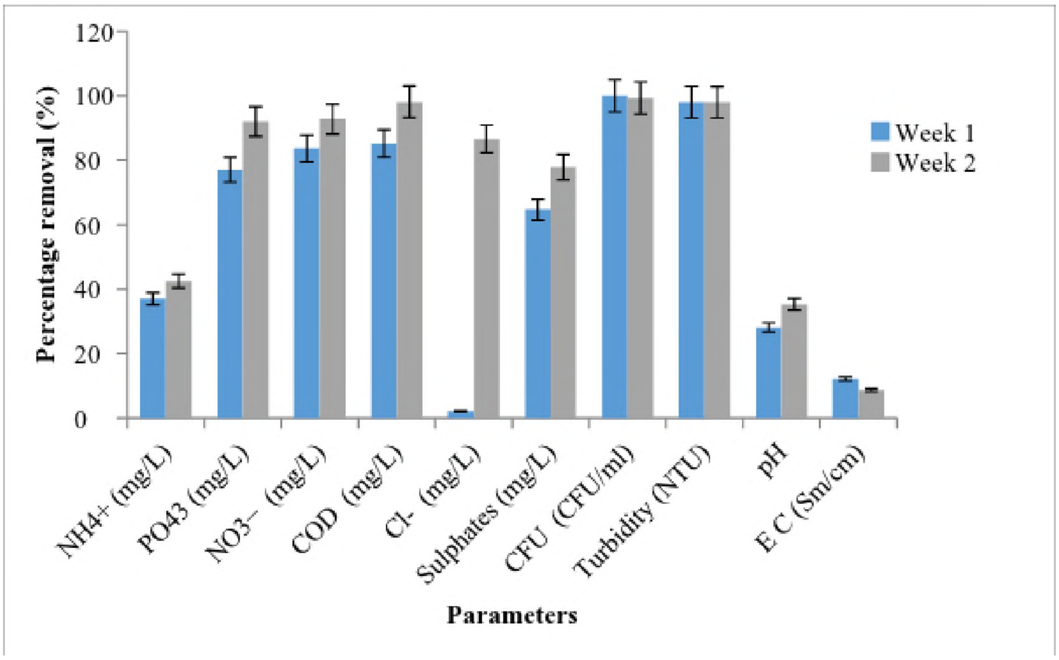


Figure 3.2: Percentage graph showing percentage removal from table 3 results

Key words NH_3 = Ammonia; PO_4^{3-} = Phosphate; NO_3^- = Nitrate; COD = Chemical oxygen demand; Cl^- =Chlorides; SO_4^{2-} = Sulphates; CFU= Colony forming unit; and EC= Electrical conductivity.

Due to the preliminary nature of the data presented and the variability in the composition of greywater for this data no statistical testing has been conducted. Values of turbidity for tap water and bathwater ranged from 8 ± 2 to 550 ± 99 NTUs. The values for Tur have been previously reported for greywater in South Africa by Tandlich et al. (2008) and this is similar to what has been reported for the bathroom greywater ranging from 782 ± 10 NTUs. For this comparison we opted to use bathroom greywater over sink greywater.

Data from the baseline greywater characterisation and the preliminary treatment are summarized in Table 3.1 and Table 3.2 below. Baseline characterisation of the greywater is necessary due to high variability of its composition among the various sources (Eriksson *et al.* 2009; Finley *et al.* 2009; Zuma *et al.* 2009; Tandlich *et al.* 2008). The NH_4^+ concentrations ranged from 0.51 mg/L recorded in week 6 up to 2.4 mg/L recorded in week 3. The PO_4^{3-} concentrations ranged from 0.54 mg/L recorded in week 3 up to 2.0 mg/L recorded in week 1. At the same time, the NO_3^- concentration interval spanned from 0.39 mg/L recorded in week 5 up to 2.4 mg/L recorded in week 1. The concentration of organic matter was measured as the COD content. It varied between 630 mg/L in week 4 and 1580 mg/L in week 2. The Cl^- concentration was recorded to range from 0.13 mg/L in week 4 and 48 mg/L in week 6. The SO_4^{2-} concentrations were shown to be inside the following interval: 110 mg/L (week 1) and 380 mg/L (week 4).

The FC concentrations were below the detection limit of 0 colony-forming units per 100 mL of greywater (CFUs/100 mL) during the first three weeks of the baseline study. Then the concentrations increased to between 150 CFUs/100 mL in week 5 and 490 CFUs/100 mL in week 6. The TUR values varied between 2.7 nephelometric turbidity units (NTUs) for week 4; and 620 NTUs in week 2. The minimum pH value was measured in weeks 3 and 4, with the respective value of 7.80. The maximum pH value was, on the other hand, recorded in week 1 when it stood at 8.50. Finally, the EC values ranged from 190 S/cm in week 5 and 1980 □S/cm in week 1. No EC value could be obtained in week 4 due to instrumental problems. The greywater values from Kleinemonde are comparable to those measured in Port Alfred (also a coastal area) by Tandlich *et al.* (2008). At the same time, the values span a narrower interval than recorded by Zuma *et al.* (2009). Between the background characterisation and greywater treatment, increases were recorded in levels FC, Tur, NO_3^- and NH_4^+. At the same time, the concentrations of SO_4^{2-} and COD decreased significantly.

Such variability has been reported for greywater in South Africa before (*Zuma et al.* 2009). Spike in the concentrations of FC, Tur and NH_4^+ indicate that a sewage pipe might have been broken in the vicinity of the tap water supply into the donour household (Ribbink, 2011). The FLFT system was able to decrease the higher influent concentrations and the percentages of the removal are shown in Figure 3.2.

Table 3.1: Physicochemical and microbial quality of bathwater greywater in Kleinemonde, Eastern Cape Province of South Africa

Parameter	W1[a]	W2[a]	W3[a]	W4[a]	W5[a]	W6[a]
NH_4^+ (mg/L)	1.9	2.2	2.4	0.52	2.1	0.51
PO_4^{3-} (mg/L)	2.0	1.6	0.54	1.3	1.0	1.0
NO_3^- (mg/L)	2.4	2.1	1.6	0.58	0.39	1.4
COD (mg/L)	0.80	1.58	1.18	0.63	1.36	1260
Cl^- (mg/L)	3.5	4.7	6.3	0.13	3.9	48
SO_4^{2-} (mg/L)	110	190	171	380	250	190
FC(CFU/100 ml)	0	0	0	250	150	490
Tur (NTU)	550	620	590	2.7	170	100
pH	8.50	8.30	7.80	7.80	8.00	8.20
EC (µS/cm)	1980	1970	1810	ND[b]	1900	1240

[a] W represents week in question

[b] Not determined due to instrumental problems with the EC tester.

The minimum *PR* value was observed in week 1 for Cl^- when no removal, but a 1% release of Cl^- from the FLFT system was recorded in week 1 of treatment. At the same time, the maximum removal efficiency of 100% was recorded FC in week 1. Contrary to the MT system (Zuma *et al.* 2009), the system was able to remove 78 and 92% of the PO_4^{3-} influent concentration, respectively. The PR for FC was 99 and 100% in both weeks of the sampling. The COD and NO_3^- removals were maintained as observed in MT system. Thus the problems of the original reactive filter system, namely MT, were addressed by the FLFT modification. Therefore the PozzSand® fly ash in combination with high purity lime is a potentially effective material for the treatment of greywater.

Table 3.2: Treatment efficiency of the greywater using the modified Fly Ash Lime Filter Tower in Kleinemonde, Eastern Cape Province of South Africa

Samples	Influent		Effluent	
Para-meter	W1[a]	W2	W1	W2
NH_4^+(mg/L)	54	47	34	27
PO_4^{3-} (mg/L)	2.0	2.1	0.45	0.17
NO_3^- (mg/L)	55	25	9.0	1.8
COD (mg/L)	50	51	7.4	1.0
Cl^- (mg/L)	31	25	32	3.3
SO_4^{2-} (mg/L)	5.2	6	1.9	1.3
FC (CFU/100 ml)	1000	720	0	5
Tur (NTU)	85	98	1.7	2.0
pH	9.2	7.9	12.8	12.0
EC (µS/cm)	1960	1940	1720	1771

[a] W represents week in question

The problem arises from high alkaline pH values of the FLFT effluent which ranged from 12.0 to 12.8 (see Table 3.2 above). The high pH sterilised the greywater and removed all the indicator/pathogenic microorganism (Zuma *et al.* 2009). However, it also resulted to corrosion of piping during irrigation operations, as well as led to the destruction of the soil structure upon discharge (DWAF, 1996a; DWAF, 1996b). Thus, further experiments are conducted in chapter 4 and chapter 5 to modify the FLFT system and manage the pH of the effluent, while maintaining the treatment efficiency. The FLFT for greywater treatment was developed and monitored for the removal of selected parameters including bacteria and chemical oxygen demand (COD). According to Zuma (2012), the thesis reported that the FLFT percentage removal abilities yielded treated greywater with faecal coliform of 69.5%, COD of 44.6%, chlorides of 32.5%, sulphates of 41%, nitrates of 39.6%, ammonium of 42.2% and the pH of 10.6. Their study showed that the system was unable to completely remove the faecal and total coliform as microbial indicators and high pH. High effluent pH was a major challenge. Further modification of the FLFT to increase treatment efficiency and decrease pH is investigated in this thesis. There were low levels of nitrogen Table 3.1 and high in levels in Table 3.2, this was indicated by an average nitrate concentration between 0.9 2. 04 mg/L % and 1.8- 55 mg/L cases. It is well known that the ammonification occurs due to the ammonifying bacteria ability to degrade the nitrogen compounds occurring in the wastewater. These microorganisms can occur under the aerobic and anaerobic conditions, can grow and be active at highly variable pH (Bernacka et al., 1995). In the biological systems, during the ammonification, the organic nitrogen is converted to ammonia through the amino acids hydrolysis. Under the aerobic conditions, this ammonia is either assimilated by the microorganisms to form the cellular mass or oxidized by the ammonia oxidizers such as the Nitrobacteriaceae family (Gallert and Winter, 2005). The activity of the facultative heterotrophic bacteria such as the Achromobacter spp., Aerobacter spp., and Bacillus spp. leads to the denitrification of the nitrate to nitrogen, resulting to its loss as the atmospheric nitrogen (Wielgosz et al., 2010). Based on this knowledge, the results show that there was not sufficient oxygen within the reactor to favour or speed up the ammonia oxidation, hence the ammonium ions release into the effluent was recorded. However, continued the nitrate concentration reduction in the effluent was indicative of that it was being taken up (or removed) and probably denitrified by the microorganisms.

3.6. Concluding remarks

In conclusion, greywater reuse systems offer a great option for creating the alternative source of water for non-potable uses, such as garden irrigation. This means it can reduce the pressure and the demand on the potable water sources. There are also other options, such as Waste Water Recycling (centralised and decentralised scale). Therefore, the PozzSand® fly ash is a potentially effective material for the treatment of greywater from coastal areas of South Africa.

Complete removal of indicator microorganisms was recorded and high phosphorus removal was also encouraging. The NH_4^+ concentrations ranged from 0.51 to 2.4 mg/L, while analogical PO_4^{3-} concentrations ranged from 0.54 to 2.0 mg/L. The NO_3^- concentration interval spanned from 0.39 to 2.4 mg/L. The chemical oxygen demand varied between 630 and 1580 mg/L. The Cl^- concentration was recorded to range from 0.13 to 48 mg/L. The SO_4^{2-} concentrations ranged from 110 to 380 mg/L. The faecal coliform concentrations varied between 0 and 490 colony-forming units per 100 mL. Turbidity ranged from 2.7 to 620 nephelometric turbidity units, while pH was inside the interval from 7.80 to 8.50. Electrical conductivity values ranged from 190 to 1980 μS/cm. The maximum removal efficiency in greywater treatment was recorded for faecal coliforms and it stood at 100%. The Fly Ash Lime Filter Tower system was able to remove up to 92% of PO_4^{3-}.

Further experiments are explained in Chapter 4 to modify the FLFT system to manage the pH of the effluent, while maintaining the treatment efficiency observed in this preliminary study. More advanced and more expensive systems are able to recycle greywater or wastewater to a high level where it can be used for external and above ground uses. These systems are not very popular due to their high capital costs and long or no payback periods. Payback periods are relatively high due to the current low cost of water. However, prices for water are expected to increase in the near future which would decrease payback periods.

Risks associated with greywater reuse include potential risk to human health in the form of faecal contamination if greywater or recycled wastewater that was not sufficiently treated got incontact with skin, or if the water is ingested. Potential environmental risks include contamination of soil and groundwater through accumulation of chemicals, which in turn could affect the health of vegetation and useful micro-organisms in the soil. These risks can be avoided and or minimised by following guidelines developed by government departments and adhering to the relevant codes of practice.

Due to the concept of greywater reuse being relatively new and technology constantly improving, and due to great variability in the system components and depending factors, it is still a challenge to develop an accurate cost benefit analysis for a Local Government facility that could be used as a generic model across all local governments. Benefits associated with greywater reuse include reduced water bills from not using scheme water for irrigation, reducing the amount of sewage discharged to the ocean or rivers, reducing the pressure on existing freshwater sources, reducing the impacts associated with development of new water sources, such as desalination plants, irrigating during sprinkler bans and potentially having a green garden all year round. The use of greywater by local government is seen to be innovative and leading by example, this will be explained in detail in chapter 5.

3.7. References

Ahn, K., Song, J. and Cha, H. (1998). Application of tubular ceramic membranes for reuse of wastewater from buildings. *Water Sci. and Technol* 38: 373–382.

Al-Jayyousi O. (2003). Greywater reuse: Towards sustainable water management. *Desalination* 156: 181–192.

American Public Health Association, APHA, AWWA and WEF (1998). American Public Health Association, American Water Works Association and Water Environment Federation. *Standard Methods for the Examination of Water and Wastewater.* 20th ed, WEF, Washington, D.C., USA.

APHA, AWWA and WEF, Standard methods for the examination of water and wastewater (1998). (Washington, DC; APHA.

Bernacka J., Kurbiel J. and Pawłowska L. (1995). Elimination of biogenic compounds from municipal sewage (in Polish). Instytut Ochrony Środowiska, Warszawa, 92.

Boulle L. (2011). The Republic of South Africa and the G20: Its Political, National Interests and Priorities as Member of the Process, G20, *Perceptions and Perspectives for Global Governance* Konrad Adenaur Stifftung. [Online]. Available: http://www.kas.de/upload/dokumente/2011/10/G20_E-Book/chapter_14.pdf (Accessed: 1- Oct-2013). G20: Perceptions and Perspectives for Global Governance

Carden K., Armitage N., Winter K., Sichone O., Rivett U. and Kahonde J. (2007). The use and disposal of greywater in the non- sewered areas of South Africa: part 1—quantifying the greywater generated and assessing its quality, *Water SA,* 33(4): 425-432.

Department of Water Affairs and Forestry (1996a). South African Water Quality Guidelines no. 4, Irrigation. Pretoria, RSA.

Department of Water Affairs and Forestry (1996b). South African Water Quality Guidelines no. 1 Domestic Water Use. Pretoria, RSA

Environmental Protection Agency. (2012). Sulphate (Turbidimetric). Method #: 375.4,“ Cornerstone Laboratory. Available:http://www.cornerstonelab.com/EPA-Methods/100-400/375_4.PDF (Accessed: 3-Feb-2012). For urban residential properties. *Desalination,* 106: 391–397.

Eriksson, E., Auffarth, K., Henze, M. and Ledin A. (2002). Characteristics of greywater. *Urban Water* 4: 85–104.

Finch C., Lillibridge, B., Fry, E., Lesikar B., Silvy, V., McNally M., Inni, E., and Ovuegbe E. (2003). Greywater literature research (San Antonio Water System).

Finley S., Barrington S. and Lyew D. (2009). Reuse of domestic greywater for the irrigation of food crops. *Water, Air, and Soil Pollution* 199 (1-4): 235 – 45.

Friedler E. and Hadari M. (2006). Economic feasibility of on-site greywater reuse multi-storey buildings. *Desalination* 190: 221–234.

Friedler E., Kovalio R. and Galil N. (2005). On-site greywater treatment and reuse in multistory buildings. *Water Sci. Technol*, 51(10): 187–194.

Gallert C. and Winter J. (2005). Bacterial Metabolism in Wastewater Treatment Systems In: Jördening H.J and Winter J. (eds.). Environmental Biotechnology. Concepts and Applications. Wiley VCH. Weinheim, Germany.

Ghunmi A, L., Zeeman, G., van Lier, J. and Fayyad, M. (2008). Quantitative and qualitative characteristics of greywater for reuse requirements and treatment alternatives: The case of Jordan. *Water Sci. Technol* 58:1385–1396.

Hernandez L., Zeeman G., Temmink H., Marques A., and Buisman C. (2008, May). Comparison of three systems for biological greywater treatment. Paper presented at *IWA Conference on Sanitation Challenges*, Wageningen, The Netherlands.

Jefferson, B., Laine, A., Parsons, S., Stephenson, T. and Judd, S. (2000). Membrane bioreactors and their role in wastewater reuse. *Water Sci. Technol* 41: 197– 204.

Li F., Wichmann K. and Otterpohl, R. (2009). Review of technological approaches for greywater treatment and reuses. *Science of the Total Environment*, 407(11), 3439-3449.

Leal L. H., Zeeman G., Temmink H., Biusman, C. (2007). Characterization and biological treatment of greywater. *Water Science and Technology.* 56(5).193-200.

Luyt C.D., Tandlich R., Muller W. J. and Wilhemi B.S. (2012). Review: Microbial Monitoring of Surface Water in South Africa: An Overview. *International Journal of Environmental Research and Public Health* 9**,** 2669-2693.

Momba M.N.B, Tyafa Z, Makala N,Brouckaert B.M. and Obi C.L. (2006). Safe drinking water still a dream in rural areas of South Africa. Case Study: The Eastern Cape Province, *Water SA* 32: 715-720.

Morel, A. and Diener, S. (2006). Greywater management in low and middle-income countries. Review of different treatment systems for households or neighbourhoods, Dübendorf, Eawag

Namibian Water Act. 2004, Act No. 24 of 2004. Government Gazette No. 3357, Republic of Namibia.

National Water Act. 1998, Act No. 36 of 1998. Government Gazette 398 (19182), Republic of South Africa.

NWRS – National Water Resources Strategy. 2004, Department of Water Affairs and Forestry. First edition. Pretoria, South Africa

Ngqwala N.P., Zuma B.M. and Tandlich R. (2013). Greywater composition and treatment in a coastal area of South Africa (5th International Scientific and Expert Conference proceedings *TEAM 2013 Technique, Education, Agriculture & Management)* Prešov, 4th to 6th November 2013.

Nolde, E. (1999). Greywater reuse systems for toilet flushing in multistory buildings over ten years' experience in Berlin. *Urban Water,* 1: 275–284.

Nghiem L., Oschmann, N., and Schafer, A. (2006). Fouling in greywater recycling¨ by direct ultrafiltration. *Desalination,* 187(1–3): 183–290.

Pidou M., Memon, F., Stephenson T., Jefferson B. and Jeffrey P. (2007). Greywater recycling: Treatment options and applications. *Proceedings of the Institution of Civil Engineers Engineering Sustainability* 160: 119–131.

Ribbink A.J. (2011).The Impact of climate change on food security among coastal communities of Keiskamma, in the Eastern Cape, South Africa, Final Project Report for 2011. *START Grants for Global Change Research in Africa*. [Online]. Available: http://start.org/download/gec11/ribbink-final-report.pdf [Accessed: 7-Oct-2013].

Ridderstolpe P. (2007). Mulch filter and resorption trench for onsite greywater management. EcoSanRes. Technical Report. Stockholm, Sweden.

Rodda N., Carden K., Armitage N. and du Plessis M.N. (2011). Development of guidance for sustainable irrigation use of greywater in gardens and small-scale agriculture in South Africa," WRC 40-Year Celebration Special Edition 37, 5.

Seckler D., Barker R. and Amarasinghe U. (2009). Water scarcity in the twenty-first century. *International Journal of Water Resource Development* 15: 29-40.

Stager J.C., Mayewski P.A., White J., Chase B.M., Neumann F.H., Meadows M.E., King C.D. and Dixon D.A.(2012). Precipitation variability in the winter rainfall zone of South Africa during the last 1400 yr linked to the austral westerlies. *Climate of the Past,* 8: 877-887.

Solley D., Gronow C., Tait S., Bates J. and Buchanan A. (2010) Managing the reverse osmosis concentrate from the Western Corridor Recycled Water Scheme. *Wat. Prac. Technol*. 5:.42

Stalter D., Magdeburg A. and Oehlmann J. (2010). Comparative toxicity assessment of ozone and activated carbon treated sewage effluents using an in vivo test battery. *Wat. Res.* 44(8), 2610–2620.

Swaziland Water Act. 2002. Act Number 7 of 2003. Republic of Swaziland.

Tandlich R., Chirenda T.G. and Srinivas, S. (2013).Gender aspects of disaster management in South Africa. *Journal of Disaster Risk Studies,* 5(4): Article 84.

Tandlich R., Zuma B.M., Dyongman S.A. and Slaughter A. (2008). Characterization of greywater from selected sites in South Africa for potential reuse in irrigation. Proceedings from the IASTED International Conference on Water Resource Management Africa WRM 2008, Gaborone, Botswana, Acta Press. Gaborone, Botswana.

Tandlich R., Zuma B.M., Whittington-Jones K.J. and Burgess J.E. (2009). Mulch tower treatment system for greywater reuse Part II: destructive testing and effluent treatment. *Desalination,* 242 (1-3): 57 – 69.

Treaty. 1992. Agreement Between the Government of the Republic of South Africa and the Government of the Republic of Namibia on the Establishment of a Permanent Water Commission. Signatory Document, signed by Representatives of the Two Governments. Noordoewer, 14 September 1992.

Tsalakanidou I. (2006). Potential of reactive filter materials for small-scale wastewater treatment in Greece. Batch & Column Experiments. TRITA-LWR Master of Science Thesis. Stockholm, Sweden.

Water Resources Act. 1978. Supplement No. 1 to Gazette No. 46 of 15th December, 1978. Republic of Lesotho.

Water Resources Regulation. 1980. Supplement No. 2 to Gazette No. 31 of 5th September, 1980, Republic of Lesotho.

Wielgosz E., Jóźwiakowski K. and Bielińska E.J. (2010). Numbers of ammonifying, nitrifying and denitrifying bacteria in sewage treated in a system of biological stabilisation ponds. *Teka Kom Ochr Kszt Środ Przyr - OL PAN* 7 (30): 446 – 456.

Whittington-Jones K. (2005). Design and monitoring of greywater treatment systems for the Scenery Park (Buffalo Municipality) pilot scale project, Phase 1 Report. Scarab Resource Innovations CC.

Whittington-Jones K. (2007). Construction of greywater treatment systems for the Scenery Park (Buffalo City Municipality) pilot project, Phase 2 Report. Prepared for The Stockholm Environment Institute & EcoSanRes.

Whittington-Jones K., Tandlich R., Zuma B. M., Hoossein S., Villet M. H. (2011a). Performance of the pilot-scale mulch tower system in treatment of greywater from a low-cost housing development in the Buffalo City, South Africa. *International Water Technology Journal,* 1 (2): 165 – 181.

Whittington-Jones K., Tandlich R., Zuma B. M., Hoossein S., Villet M. H. (2011b). Performance of the pilot-scale mulch tower system in treatment of greywater from a low-cost housing development in the Buffalo City, South Africa. Published in the peer-reviewed conference proceedings from the 15th International Water Technology Conference. Alexandria, Egypt.

Zuma B., Tandlich R., Whittington-Jones K. and Burgess J.E. (2009). Mulch tower treatment system Part I: Overall performance in greywater treatment. *Desalination*, 242 (1): 38 – 56.

Zuma B.M. (2010). Microbial ecology of the Buffalo River in response to water quality changes. M.Sc. Thesis, Rhodes University, Grahamstown, RSA.

Zuma B.M. and Tandlich R. (2010). Public health implications of greywater production in South Africa. In: Fonn S. and Padarath A. (Eds.). South African Health Reviews. Health Systems Trust. Durban, RSA

CHAPTER 4: ENHANCED MULCH TOWER SYSTEM FOR GREYWATER TREATMENT USING WATER HYACINTH

The FLFT treatment system for greywater treatment was developed and monitored for the removal of selected variables including bacteria and chemical oxygen demand (COD). In this chapter, the particular modifications include the addition of activated carbon, acetic acid and water hyacinth. For the laboratory-scale treatment, bathroom greywater was collected from the Kleinemonde and the Grahamstown areas, in the Eastern Cape Province of South Africa. The pH was measured in the morning and afternoon in all instances. Carbon coal and acetic acid did not have an impact because the pH only decreased for a short time. The use of water hyacinth indicated good treatment efficiency reducing the faecal coliform load/influent concentrations by 94.9%. The next objective was to use the effluent for irrigation studies to monitor the effect of the effluent on soil and plants.

4.1. Introduction

Human population growth and socio-economic developments are exerting pressure on already stressed freshwater resources (Naicker *et al.* 2010; Seckler *et al.* 1999). Salinisation, eutrophication, microbial pollution and acidification are among the major factors responsible for deteriorating water quality in South Africa (Ashton, 2009). In addition to deteriorating water quality, reduced water availability, due to depletion of groundwater and surface water quantity will constraint further social-economic developments if novel technologies are not urgently developed that will allow for the reuse of greywater (Tandlich *et al.* 2009; Seckler *et al.* 1999). Greywater emanates from showers, baths, washbasins, washing machines and kitchen sinks (Salukazana *et al.* 2006). Its composition depends mainly on factors such as cultural habits, living standard, demography and type of household chemicals/products used (Orlowsky *et al.* 2014). Bathroom greywater is regarded as the least contaminated source within a household because it usually contains less toxic products such as soaps, shampoos, toothpaste, and other body care materials (Rodda *et al.* 2011). The main purpose of greywater recycling is to substitute the precious drinking water for recycled and treated wastewater/greywater in applications which do not require water of drinking quality (Luyt *et* *al.* 2012, Rodda *et al.* 2012). Depending on the treatment technology, recycled greywater can be used for industrial purposes, irrigation, toilet flushing and laundry (Salukazana *et al.* 2006). Thus, application of recycled greywater can reduce fresh water consumption, and wastewater production. Bathroom greywater has been reported as the suitable type of greywater (Mohamed *et al.* 2014; Zuma *et al.* 2012; Carden *et al.* 2007; Eriksson *et al.* 2002). Greywater characteristics also vary according to its origin and for this reason; the least contaminated sources of household greywater should be prioritized for reuse. The literature data revealed that bathroom greywater sources accounted for about 50 – 60% of total greywater (Poyyamoli *et al.* 2013; Loh & Coghlan 2003). To the best knowledge of the authors, no research has been published for saline greywater in South Africa. Therefore, there is a need to improve water quality by investigating and developing methods for greywater treatment such as small-scale on-site biological treatment systems (Abou-Elela *et al.* 2010).

In low and middle-income countries, different domestic wastewater collection systems, that is, centralized or non-centralized are currently being used for a large portion of the population has inadequate access to proper sanitation technology (Carden *et al.* 2007). As discussed in Chapter 3, various treatment processes are suggested in the literature. However, the on-site greywater recycling is relatively a new practice. Only few systems are commercially available, and few were tested on full scale for long time period (Lefebvre & Moletta, 2006). A greywater treatment systems (GTS) collects, stores, treats and may disinfect greywater to the regulatory standards specified by the various government authorities. They can be installed in residential households in most sewered and non-sewered areas to provide treated greywater for irrigation use (including surface irrigation), toilet flushing, washing machines and washing of vehicles, paving and fences (Carden *et al.* 2007; Carden *et al.* 2006; Morel & Diener, 2006). Based on the prior advantages, in disadvantaged areas, systems for greywater treatment should be assembled from materials of low commercial value. The paper and pulp flyash used in this study is the PozzSand® and was chosen due to its low cost and availability while lime was used to enhance its removal efficiency.

Based on Chapter 3 results, the greywater effluent samples could not be used for irrigation, though the study showed that the extreme pH values encountered in bathroom greywater could potentially degrade soil structure. Overall, the data indicated limited potential of greywater reuse, but further study is required to optimise the pH of the greywater effluent. In this chapter, methods (carbon in the form of coal, acetic acid and water hyacinth) have been experimented to reduce the pH of the effluent. Carbon is mostly obtained from coal deposits and is gaining acceptance for pH control in water treatment plant (APHA, AWWA and WEF, 1998). In Chapter 5, data were used for an on-going study on modification of the Fly-ash-lime filter tower treatment system to improve the impacts of recycled water. The results were analyzed in the context of the water quality guidelines for irrigation water, as published by the then South African Department of Water Affairs and Forestry (DWAF, 1996).

4.1.1. Fly Ash Lime Filter Tower modification

The Mulch tower treatment system (MTTS) for greywater - where the removal of bacteria and chemical oxygen demand were monitored - was reported (Whittington-Jones *et al.* 2011; Zuma *et al.* 2009; Seckler *et al.* 1999). According to Zuma (2012), the Fly-Ash Filter Tower percentage removal abilities yielded treated greywater with faecal coliform of 69.5%, COD of 44.6%, chlorides of 32.5%, sulphates of 41%, nitrates of 39.6%, ammoniim of 42.2% and the pH of 10.6. This study showed that the system treatment efficiency was challenged with high pH. The control of the effluent pH did not comply with the standards of the Food and Agriculture Organization (FAO) range of 6.5-8.4 (Zuma *et al.* 2010; WHO, 2006; Seckler *et al.* 1999). High pH on irrigation water has water potentially degrade soil structure (DWAF, 1996).

4.1.2. Activated charcoal

Carbon has been used in greywater treatment as an adsorbent because of its ability to remove a large variety of compounds from contaminated waters. Carbon coal reduces high pH levels quickly and exhibits buffering properties as it reaches neutral pH levels (Amin *et al.* 2014). Activated carbon adsorption is an effective means for reducing organic chemicals, chlorine, lead, and unpleasant tastes and odours in water. Currently nanotechnology has been considered effective in solving water problems related to quality and quantity carbon nanomaterials such as carbon nanotubes (CNTs) that are used in wastewater treatment (Mulder *et al.* 2010). The are many greywater physical treatment technologies that use carbon in their treatment system such as direct nano-filtration membranes and the sand filters (Shannon *et al.* 2008; Ramon *et al.* 2004).

4.1.3. Acetic acid

Acids may be added to saline waters in some circumstances to lower the pH 12 (Ibrahim *et al.* 2001). Acetic acid (CH_3COOH) is a weak acid, that it is only a partially dissociated acid in an aqueous solution (Voet & Voet 2011). It has a pKa of 4.75 and it was chosen particularly because it is available to household residents in benign household products such as vinegar. Acetic acid can be used to lower the pH level in fluids. It is less corrosive than strong mineral acids and it dissociates to form acetate and hydrogen ions (Ouattara *et al.* 2012; Ibrahim *et al.* 2001).

4.1.4. Water hyacinth

Water hyacinth is a free-floating perennial aquatic plant that belongs to the class of *Eichhornia crassipes*. It is an invasive species and by getting rid of it in greywater treatment systems can help manage the environmental effects of the water hyacinth in South Africa. It has been generally considered as nuisance to water bodies because of it growing widely and sometimes uncontrollably. There remain several unknowns with regard to water hyacinth invasions (Sanmuga *et al.* 2014; Villamagna, 2009). Perhaps the most obvious information gap exists with respect to the effects of water hyacinth on waste water treatment. As a weed, this plant is highly invasive and propagates faster than the native vegetation (Chunkao *et al.* 2012; Adewumi & Ogbiye, 2009). Several cases about the negative impact of water hyacinth have been reported and these include interference of plant with navigation in rivers and water supply (Zheng *et al.* 2009). Control strategies were implemented to curb the growth of the plant. Physical removal as one of the strategies involves physical removal of the plant from the water streams with the disposal of the resultant waste in open lands (Malik, 2007; De Groote *et al.* 2003). While efforts are being made to reduce or control the growth of this weed, it will be plausible to seek how to use this weed beneficially. It is characterised by high absorption of nutrients that can be used to stabilize pH levels in the Flyash filter tower whilst preventing the growth of disease causing organisms (Adewumi & Ogbiye, 2009). The biomass prepared from the leaves of water hyacinth can be used as a sorbent for the removal of nitrate, phosphate, sulphate and faecal coliforms in greywater.

4.2. Aim of the study

The aim of this study was to improve the Fly Ash Lime Filter Tower treatment system and sought to derive value from water hyacinth by applying it for water treatment.

4.3. Experimental procedures

4.3.1. Sampling

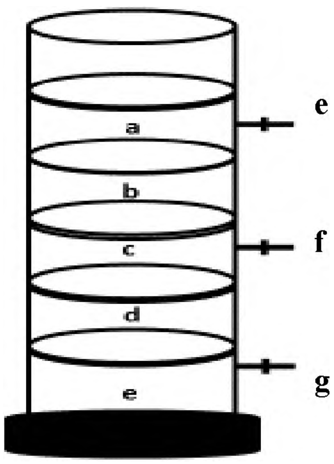
All glassware used was acid washed using 10% hydrochloric acid (HCl) (from Merck Pty Ltd- Cape Town). For the laboratory-scale treatment, bathroom greywater was collected from the Kleinemonde and Grahamstown area. The reactor was fed twice a day with 3 litres of greywater in the morning and 2 litres in the afternoon, for 13 weeks. The influent and effluent samples were collected as composite fractions of individual feedings. Analyses for physico-chemical and microbiological variables were undertaken two times a week. Samples were collected and microbiological analyses were performed immediately while the samples for chemical analysis were stored at 4 °C (Ashton, 2009; Carden *et al.* 2007 and Al-Mutaz & Al-Ghunaimi, 2001).The influent was treated through Fly Ash Lime Filter Tower treatment or reactor, the bathroom and the kitchen greywater for treatment was collected from the donor from the town of Kleinemonde. The Fly Ash Lime Filter Tower column contained layers of mulch, flyash-lime, fine sand, water hyacinth course sand and gravel (see Figure 4.1below). The fly ash was obtained from the waste management department of the South African Pulp and Paper Industries (SAPPI) waste in Mandini, KwaZulu Natal province. The treatment performance of the Fly Ash Lime Filter Tower was tested by obtaining samples of the untreated greywater (the influent) and the treated greywater (the effluent). The influent and effluent samples were collected as composite fractions of individual feedings.

4.3.2.Activated charcoal and acetic acid

In the first pH management experiment, 200 g of activated charcoal from Sigma-Aldrich (Johannesburg, RSA) was introduced in the reactor and the sample were analysed for physico-chemical and microbiological variables. For the second experiment, 100 ml acetic acid or carbonic was added to the reactor in the afternoon and a portion of the influent.

4.3.3. Water hyacinth

A 5 cm layer of water hyacinth was introduced to the reactor and the same feeding parameters were used (Figure 4.1 below). Analyses for physico-chemical and microbiological were undertaken twice a week over the thirteen weeks period of time. Samples were collected and microbiological analyses were performed immediately, while the samples for chemical analysis were stored at 4 °C. The samples were done as described by Tandlich *et al.* (2008) as described in chapter 3 (3.4.2).



- a- Flyash lime (15cm)
- b- Water hyacinth (5cm)
- c- Fine sand (7.5cm)
- d- Rough sand (7.5cm)
- e- Gravel (15cm)
- f- Sampling port
- g- Final effluent sampling port

Figure 4.1: The modified schematic presentation of Flyash/lime filter tower greywater treatment reactor

4.3.4. Microbiological and Physicochemical analysis

Greywater samples were analysed for ammonium, phosphate, nitrate, chloride, sulphates, turbidity, COD, pH and faecal coliforms (FC) according to standard methods, unless otherwise stated (APHA, 1998), The COD concentrations were determined on the Shimadzu 1200 UV/VIS spectrophotometer. These were generally carried in Chapter 3 (see 3.4.4 Physicochemical analysis and 3.4.5 Microbial analysis). The FC enumeration was conducted by spread-plating after decimal dilutions and/or membrane filtration (Judson *et al.* 2012; WHO, 2006). The pH and concentrations of electrical conductivity was measured using pH meter EC-PCTestr35 (Instrument Choice™, USA). Turbidity was determined using Lutron TU-2016 portable turbidity meter (Test and Measurement Instruments CC, Johannesburg, South Africa; APHA, 1998). Concentration of phosphate, nitrate, ammonium and chloride were analysed using the test kits with catalogue number 1.14848.0001, 1.09713.00011.14752.0001, and 1.14897.0001, respectively (Merck Pty. Ltd., Johannesburg, South Africa). The sulphate concentrations were determined using the United States Environmental Protection Agency (EPA) method 375.4 (USEPA, 1978). Absorbance measurements were taken using Biotek micro-plate reader (manufactured and supplied by Biotek Instruments Inc., Winoski, VT, USA). Sterile plastic Petri dishes were purchased from EC Labs (Port Elizabeth, RSA). Efficiency of the treatment was assessed by calculating the percentage removal of each variable defined in Equation 3.1 in Chapter 3.

4.3.5. Water hyacinth pKa

The effect of the water hyacinth biomass on pH was investigated through determining the pKa values. The pKa of the sorbents was determined using the titration method. Water hyacinth leaves were harvested from the green house, washed and dried overnight in the oven at 50℃. Secondly, 6 g of the ground and dried leaves was weighed out on the Pioneer PA214 analytical balance (Ohaus Corporation, Pinebrook, New Jersey, USA), transferred into different Erlenmeyer flasks and dissolved with MilliQwater. The pH was lowered to a pH below 2 using a concentrated hydrochloric acid (from Sigma Aldrich- South Africa). The mixture was titrated using a solution of KOH (1M) with simultaneous measuring of the pH until a pH of 11 was obtained. The pKa was determined by plotting a graph of pH against volume of KOH. This was standardised against potassium hydrogen phthalate ($C_8H_5KO_4$). The difference between the pH values and KOH values were determined separately. The difference in pH was divided by the difference in volume. The calculation of the pKa was done by the method of the first-derivative of pH against the volume. The answers were plotted against pH. After that, the highest peak was chosen and the pH value that corresponded to it was chosen as pKa. All the chemicals and consumables were purchased from Merck (Pty.) Ltd. (Johannesburg/Cape Town, RSA).

4.4. Results and Discussions

Acetic acid ($C_2H_4O_2$) was used to lower the pH level in clear brine completion fluids. It is less corrosive than strong mineral acids. This type of acid is also added to saline waters to lower the pH. Acetic acid was used in this study to lower the pH level in the Fly Ash Lime Filter Tower. This type of acid is accessible to household in the form of vinegar and it is less corrosive than strong mineral acids. On the first day, the acetic acid decreased the pH of the Flyash filter tower from 12 to 6, and acted as a buffering solution to day 10 (see Figure 4.2 below). The use of acetic acid caused bubbles that overflowed the system, which lasted for few days, as this was the result of the lime part of the fly ash lime layer to be dissolved and converted into the CO_2. The addition of acetic acid was destructive to the structure of the FLFT, thus not a viable option for management of the pH of the effluent by the households' occupants where FLFT would be installed for the management of greywater.

Activated charcoal is generally obtained from coal deposits and it is gaining acceptance for pH control in water treatment plant since it reduces high pH levels quickly.

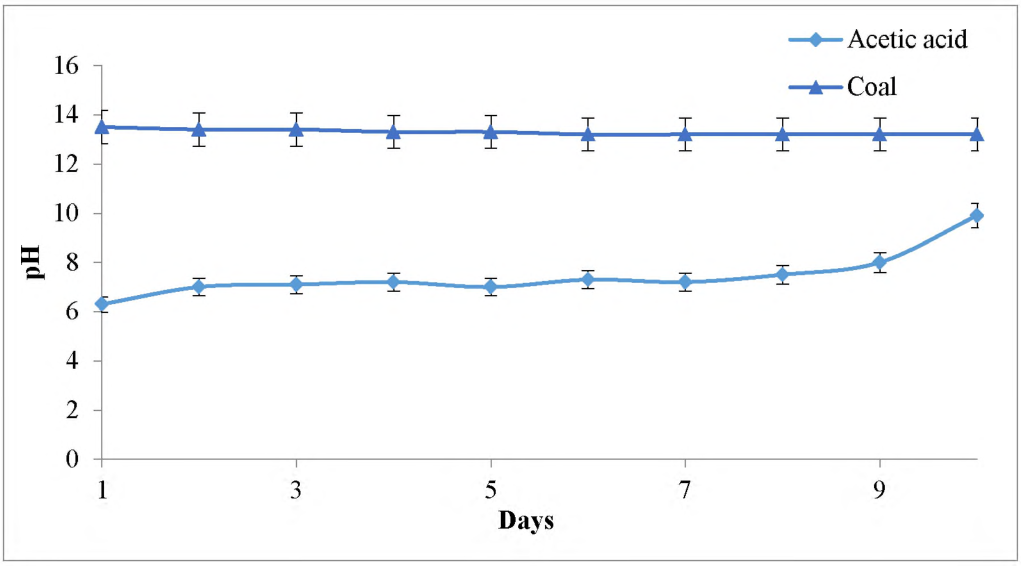


Figure 4.2: pH profile showing the effect of carbon in the form of charcoal, acetic acid in reactor by reducing the pH of Fly Ash Lime Filter Tower within a period of 10 days

The buffering advantage allowed precise end-point control without the danger of overshooting into undesirable low pH levels. In Figure 4.2 above, the carbon from charcoal did not have much effect on the fly ash lime and the reduction of pH. Hence, the pH remained at 13. This is because fly ash is a heterogeneous material as the elements are not evenly distributed throughout. However, for the objectives of this study more alternative methods of reducing pH are yet to be conducted. Many researchers have examined the use of natural ingredient as raw material for preparation of activated carbon and acetic acid (Cobb *et al.* 2012; Salman *et al.* 2012; Ouattara *et al.* 2012; Kaur *et al.* 2010). It was observed that activated carbon made from crop can be used as an effective adsorbent (Cobb *et al.* 2012).

The modification of Fly Ash Lime Filter Tower with water hyacinth proved a remarkable use of water hyacinth. Efficiency of treatment was assessed by calculating the percentage of removal for each parameter as defined in equation 3.1 in Chapter 3. The percentage removal efficiency (PR) was calculated using the following equation. Table 4.1 describes the percentage removal data of the Fly Ash Lime Filter Tower effluent of physicochemical and microbial quality removal efficiencies. It indicates an average percent salinity removal measured as electrical conductivity was between 18-30%. The samples also contained low levels of chemical oxygen demand with the percentage removal of 66-98% with average pH 8. Saline greywater is normally indicated by high levels of chloride and sulphates. This is reflected in electrical conductivity (Table 1 above). The maximum FC value was observed from the effluent of greywater sample from the treatment system which was approximately 90% CFUs/100 ml. The overall performance of the Fly Ash Lime Filter Tower was efficient, producing effluent of good quality (see Figure 4.3 below).The World Health Organization' (WHO) (2006) report specifies that FC for irrigation water should be less than 1000 CFUs/100ml to prevent adverse risks to human health, due to contact with the irrigation water during irrigation.

Table 4.1: Physicochemical and microbial quality of the treated effluent indicating the percentage removal efficiency (%) of the Flyash filter tower when it is modified with water hyacinth

Parameter Time	NH_3^+ (%)	PO_4^+ (%)	NO_3^+ (%)	COD (%)	Cl^-(%)	SO_4^{2-} (%)	CFU (%)	Turbidity (%)	Average pH	EC (%)
Week 1	41.68	59.53	68.65	62.98	64.67	44.46	90.92	98.08	7.90	27.66
week 2	55.50	48.58	72.66	72.65	81.26	37.55	100.00	98.21	8.20	6.86
Week 3	73.23	69.33	48.40	88.88	69.80	64.82	97.62	97.84	7.70	15.74
Week 4	35.91	55.71	63.82	78.09	44.12	35.07	100.00	98.57	7.75	4.66
Week 5	83.17	55.87	56.72	75.42	40.21	62.84	98.00	99.14	7.80	48.25
Week 6	74.59	59.73	65.25	71.81	55.87	33.25	99.70	86.17	7.98	78.36
Week 7	57.06	42.82	63.49	96.45	41.15	30.33	92.00	84.99	8.20	55.71
week 8	46.30	66.28	74.38	83.08	47.89	14.55	89.33	91.92	7.95	29.27
Week 9	52.07	79.03	80.21	70.70	44.53	64.81	91.67	92.91	8.30	31.29
Week 10	64.72	59.61	93.46	92.90	68.16	69.34	90.00	89.23	7.75	50.65
Week 11	90.89	99.41	75.17	82.41	57.24	80.67	86.33	85.57	7.85	36.58
Week 12	63.21	59.11	93.48	99.69	65.65	73.80	100.00	98.00	8.00	18.80
Week 13	47.86	64.17	92.44	98.23	99.98	88.67	98.00	91.00	8.10	18.00

Ammonia (NH_3), Phosphate (PO_4^+), Nitrate (NO_3^+), Chemical oxygen demand (COD), Chlorides (Cl^-), Sulphates (SO_4^{2-}), Colony forming unit(CFU) and electrical conductivity (EC)

The percentage removal equation was not used in calculating the pH.

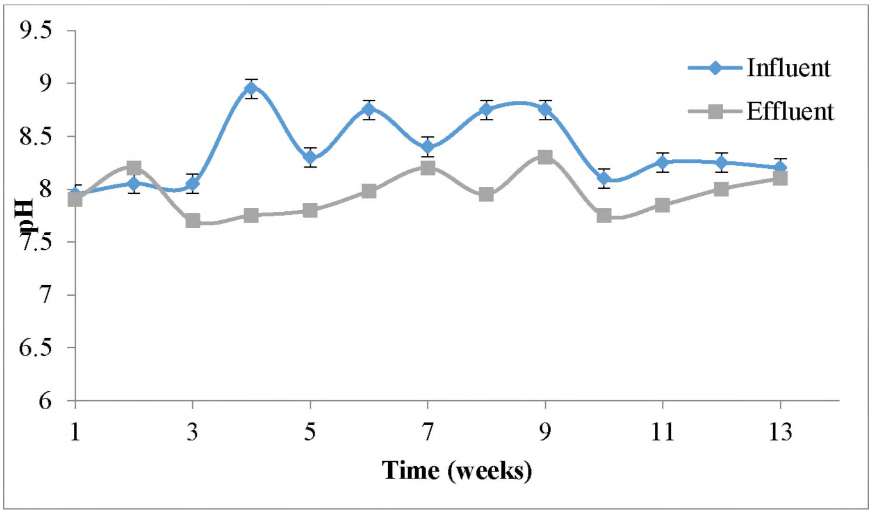


Figure 4.3: Effluent pH profile from the modified FLFT showing the effect of water hyacinth in greywater influent and effluent over the period of 13 weeks

The Fly Ash Lime Filter Tower tower treatment system for greywater were evaluated previously by Zuma and co-workers (Zuma *et al.* 2009), and managing the effluent pH was a challenge because it was not within the standards of the Food and Agriculture Organization (FAO) range of 6.5 to 8.4. Irrigation with water containing high pH results in degradation of the soil structure due to its high dissolved salt content which could have long term soil property impacts (Tigini *et al.* 2011; Finley 2009) .The World Health Organization (WHO) specifies that FC for irrigation water should be less than 1000 CFUs/100ml to prevent adverse risks to human health. According to Zuma and others (Zuma *et al.* 2010), the FLFT percentage removal abilities yielded treated greywater with faecal coliform of 69.5%, COD of 44.6%, chlorides of 32.5%, sulphates of 41%, nitrates of 39.6%, ammonium of 42.2% and the pH of 10.6. Their study showed that the system was unable to completely remove the faecal and total coliform as microbial indicators and high pH. This study indicated good treatment efficiency with values of faecal coliform counts of 85.14%, COD of 72%, chlorides of 55%, nitrates of 50%, ammonium of 57%, sulphates of 46% and the pH of 8. See Figure 4.4below:

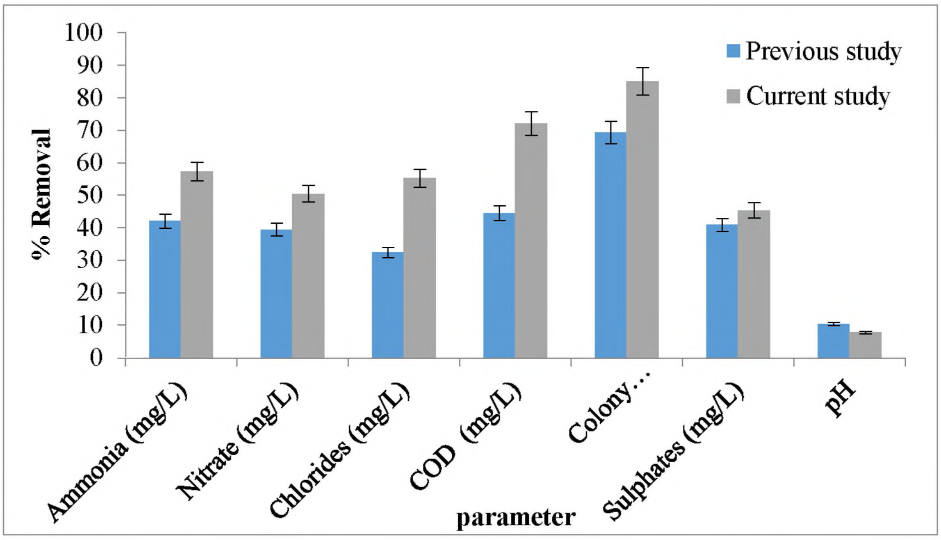


Figure 4.4: Comparative graph showing the percentage removal abilities yielded between the two studies. The dark grey bars indicate the previous study by Zuma and the light grey bar indicate the current study

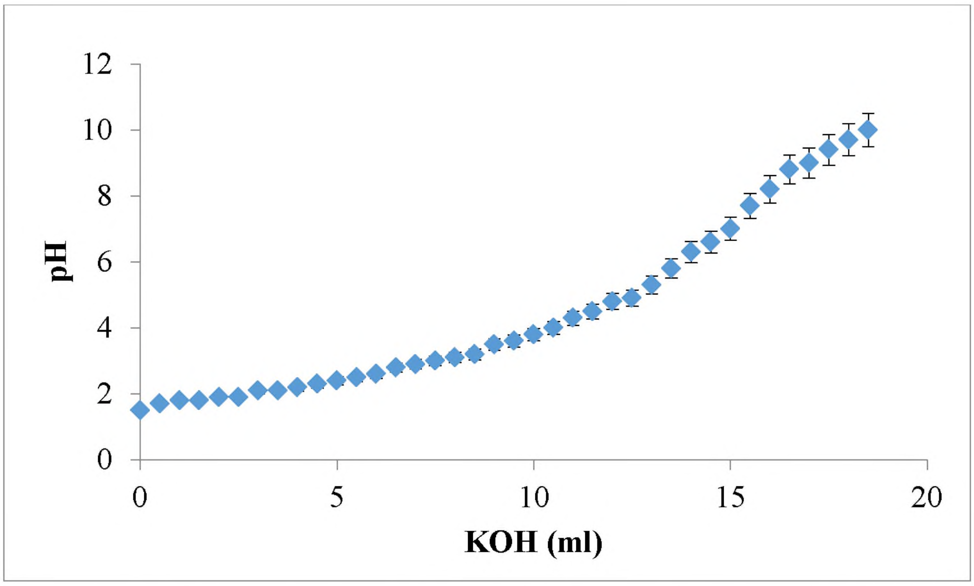


Figure 4.5: The graph showing determination of pKa by plotting a graph of pH against volume of KOH

The difference between the pH values and KOH values were determined separately. Then the difference in pH was divided by the difference in volume. The answers were plotted against pH. After that the highest peak was chosen and the pH value that corresponded to it was chosen as pKa.

Water hyacinth used in this study reduced both the pH and the faecal coliforms and the system was stable for more than 3 months. Water hyacinth has the ability to absorb pollutants in wastewater. The pH is mostly influenced by natural geological conditions at the site and the type of minerals found the soil (Ashton, 2009). The pH of the effluent was 10.6 which were high. This may have been influenced by lime. Lime is a mild mineral base that is used to increase the pH level in fluids. Water with a pH value greater than 7 indicates alkalinity, and that contributes to the taste of the water. The guidelines for irrigation water, published by DWAF 1996 report, specify that the optimum pH range of irrigation water is 6.5 to 8.4. If the pH value of irrigation water drops below 6.5 and this can lead to a reduction in yields of cultivated crops. This is a cause for concern since the water soluble salts such as the sodium and chlorides can present long term soil, crops and water resource challenges (Pinto et al. 2010). The FLFT influent greywater concentrations were Ammonium (944 mg/L), Nitrate (67 mg/L), Chemical oxygen demand (477 mg/L), Chlorides (434 mg/L), Sulphates (130 mg/L), Colony forming unit (756 CFU/100ml) and electrical conductivity (1333.3 μS/cm). The maximum removal efficiency in greywater treatment was faecal coliform was 90% which is 18 ± 0CFU/ml, chemical oxygen demand 153.8± 92.8 mg/L, chlorides of 135 ± 92 mg/L and sulphates of 91 ± 47mg/L (see Figure 4.4 above). In some cases water hyacinth is considered as a 'nuisance'. Hence, it can be harvested from water bodies and used in waste water treatment, after which it can be converted to other useful products. Due to climate change, it is imperative that we continue and refine our water hyacinth research efforts to reflect better the needs of managers.

Some studies focused its efforts on comparing sites with and without water hyacinth, while others examined the effects of water hyacinth removal. There are very few studies that report the potential use of water hyacinth for benefit of the ecosystem. The overall inconsistency in the nature of these studies makes it extremely difficult to make broad, sweeping conclusions. Water hyacinth also has been found to stabilize pH levels and temperature in experimental lagoons, thereby preventing stratification and increasing mixing within the water column (Rodda *et al.* 2011). The pKa determination study showed that the pKa of water hyacinth biomass was 3.7. pKa values determine the effect that the sorbent has on pH (see Figure 4.5 above). There is no literature about the pKa of water hyacinth leaves. However, it is known that pKa is influenced by the active sites on the biomass which contribute to the adsorption properties of the biomass (Komy *et al.* 2013). The obtained pKa value suggests that the biomass is acidic, thus has a potential to lower the pH.

4.5. Concluding remarks

This study has shown that water hyacinth can be used beneficially as an additive in water treatment. The efficiency of the Fly Ash Lime Filter Tower treatment method for greywater has been improved by the use of water hyacinth. The method used in this study resulted in acceptable pH, faecal coliform count and water physiochemical parameters levels. This study indicated good treatment efficiency with the concentrations of COD, chlorides, nitrates, ammonium and sulphate that were reduced by 82.6%, 60.4%, 72.9%, 60.5%, and 53.9%, respectively. The pH reading was 8. This method can be improved and used in rural communities owing to its low cost. The future objective will be the use of the effluent in irrigation studies to monitor the effect of the effluent on soil and plants. Irrigation with water containing high pH results in degradation of the soil structure (Tigini *et al.* 2011; Finley 2009). Some greywater contaminants are not capable of being treated or degraded in the soil. The most common among these is salt, which can comprise up to 30% of some laundry detergents and can cause damage to the soil structure. Methods aimed at reducing the treated effluent pH and optimizing the removal of indicator organisms were investigated in this study.

4.6. References

Abou-Elela S.I., Kamel M.M. and Fawzy MF. (2010). Biological treatment of saline wastewater using a salt-tolerant microorganism. *Desalination,* 250: 1–5.

Adewumi I. and Ogbiye A.S. (2009). Using water hyacinth (Eichhorniacrassipes) to treat wastewater of a residential institution, *Toxicological and Environmental Chemistry,* 91 (5):891–903.2012.

Amin T.A, Alazba A.A. and Manzoor U. (2014). A Review of Removal of Pollutants from Water/Wastewater. Hindawi Publishing Corporation, Advances in Materials Science and Engineering Volume 2014, Article ID 825910, 24 pages http://dx.doi.org/10.1155/2014/825910.

APHA, AWWA and WEF, Standard methods for the examination of water and wastewater (1998). (Washington, DC; APHA.

Al-Mutaz I.S. and Al-Ghunaimi M. A. (2001). pH Control in Water Treatment Plant by the Addition of Carbon Dioxide, The Ida *World Congress On Desalination And Water Reuse,* Bahrain, October– 31.

Ashton P.J. (2009). An Overview of the Current Status of Water Quality in South Africa and Possible Future Trends of Change. Water Ecosystems and Human Health Research Group, Natural Resources and the Environment Unit, CSIR, Pretoria

Card en K., Armitage N., Winter K., Sichone O., and Rivett, U. and Kahonde J. (2007) .The use and disposal of greywater in the non- sewered areas of South Africa: part 1 quantifying the greywater generated and assessing its quality. *Water SA*, 33 (4), 425–432.

Carden K., Armitage N., Sichone O. and Rivet U. (2006). Understanding the use and disposal of greywater in the non-sewered areas of South Africa. Water Research Commission Report No. K5/1524. Pretoria, RSA.

Christova-Boal, D., Eden, R. and McFarlane, S. (1995). An investigation into greywater reuse for urban residential properties. *Desalination* 106: 391–397.

Chunkao K., Nimpee C., Daungmal K. (2012). King's initiatives using water hyacinth to remove heavy metals and plant nutrients from wastewater through Bueng Makkasan in Bangkok Thailand. *Ecological Engineering, 39*; 40-52.

Cobb A, Warms M, Maurer EP. and Estevenchiesa, (2011). Low-Tech Coconut Shell activated charcoal production". *International journal for service learning in Engineering*, 17:93-104.

Department of Water Affairs and Forestry (DWAF) (2014). Water for Growth and Development Framework in South Africa Volume 7. http://www.dwaf.gov.za/WFGD/documents/WFGD_Frameworkv7.pdf

Department of Water Affairs and Forestry (DWAF) (1996). South African Water Quality Guidelines, Vol. 4 (Agricultural use: Irrigation), Pretoria.C.

Dobson R.S. and Burgess JE. (2007). Biological treatment of precious metal refinery wastewater: A review. *Minerals Engineering,* 20: 519–532.

Eriksson E., Auffarth K., Henze M. and Ledin A. (2002). Characteristics of greywater, *Urban Water,*4 (1), 85-104.

Friedler E. and Hadari M. (2006). Economic feasibility of on-site greywater reuse multi-storey buildings. *Desalination*, 190: 221–234.

Finley S., Barrington S. and Lyew D. (2009). Reuse of domestic greywater for the irrigation of food crops. *Water, Air, and Soil Pollution*, 199 (1-4): 235 – 45.

Ghunmi L.A., Zeeman G., Fayyad M. and Jules B. van Lier .(2011). Greywater Treatment Systems: A Review, Critical Reviews in Environmental Science and Technology, 41:7, 657-698, DOI: 10.1080/10643380903048443.

Harris R.F. and Sommers L. E (1968). Plate-dilution frequency technique for assay of microbial ecology. *Applied Microbiology,*16 (2): 330-334.

Ibrahim S. Al-Mutaz1, Mohammad A. and Al-Ghunaimi . (2001). pH Control in Water Treatment Plant by the Addition of Carbon Dioxide Presented at *The Ida World Congress On Desalination And Water Reuse*, Bahrain, October 26 – 31.

Jackson S., Rodda N. and Salukazana L. (2006). Microbiological assessment of food crops irrigated with domestic greywater. *Water SA,* 32 (5), 700-704.

Jassim M.Salman and Khalid A.AL. Saud. (2012). Adsorption of 2-4 dichlorophenoxy acetic acid onto Date seeds activated carbon: equilibrium, acetic acid and thermodynamic studies”. *International Journal of chemical science*, 10(2), 677-690.

Jefferson, B., Laine, A., Parsons, S., Stephenson, T. and Judd, S. (2000). Membrane bioreactors and their role in wastewater reuse. *Water Sci. Technol,* 41: 197– 204.

Judson S., LeCompte and Wright A.N. (2012). Saline Irrigation of Five Diverse Landscape Species for the Southeastern United States©. 57th Annual Southern Nursery Association Research Conference Proceedings

Kaur A and D K Vohra. (2010). “Study of bulk liquid membrane as a separation technique to recover acetic acid and propionic acids from dilute solution”. *Indian journal of chemical technology*, 117: 133-138.

Komy Z.R., Abdelraheem W.H. and Ismail N.M. (2013). Biosorption of $Cu^{2+}$by *Eichhorniacrassipes*: physiochemical characterization, biosorptionmodeling and mechanism. *Journal of King Saud Univeristy-Science,* 25 (1): 47-56.

Lefebvre O. and Moletta R. (2006). Treatment of organic pollution in industrial saline wastewater: A literature review. *Water Res*. 40: 3671–3682

Luyt C. D., Tandlich R., Muller W. J. and Wilhelmi, B. S. (2012). Microbial monitoring of surface water in South Africa. *Int. J. Environ. Res. Pub. Health*, 9(8), 2669-2693.

Mulder K, N. Hagens, and B. Fisher.2010. “Burning water: a comparative analysis of the energy return on water invested,” *Ambio*, 39 (1): 30–39.

Mohamed R.M.S.R., Chan C.M., Senin H., and Kassim A.H.M.(2014). Feasibility of the direct filtration over peat filter media for bathroom greywater treatment. *J. Mater. Environ. Sci*, 5 (6): 2021-2029

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. 14/06). Duebendorf: Swiss Federal Institute of Aquatic Science (EAWAG).

Naicker P., Smith MT., Rodda N., Jonsson H. and Ridderstolpe P. (2010). An evaluation of an onsite biological greywater treatment system when exposed to different loading scenarios Proc. *Biennial Conference of the Water Institute of South Africa*, 18 to 21 April, Durban, South Africa.

Orlowsky B., Hoekstra A.B., Gudmundsson L., and Seneviratne I.S. (2014). Today's virtual water consumption and trade under future water scarcity. Open Access Environ. Res. Lett. 9.

Ouattara K, M.Gouli, SEllo, A.Yapo and A.Trokourey. (2012). "Adsorption of acetic acids on different carbons", *.International journal of engineering and technology*, .4(10):4398-440.

Rodda N., Carden K., Armitage N. and du Plessis H.M. (2011). Development of guidance for sustainable irrigation use of greywater in gardens and small-scale agriculture in South Africa. *WRC 40-Year Celebration Special Edition.* 37:5.

Rodda N., Salukazana L., Jackson S.A.F. and Smith M.T. (2011). Use of Domestic Greywater for Small-scale Irrigation of Food Crops: Effects on Plants and Soil. J. Phys. Chem. Earth. DOI: 10.1016/j.pce.2011.08.002.

Salukazana L., Jackson S., Rodda N., Smith M., Gounden T., McLeod N. and Buckley C. (2006). Reuse of greywater for Agricultural irrigation. WISA 2006 *Biennial Conference Exhibition*. Durban, RSA.

Sanmuga E., Priya P. and Selvan S. (2014).Water Hyacinth (Eichhorniacrassipes) - an efficient and economic adsorbent for textile effluent treatment - A review *Arabian Journal of Chemistry*. http://dx.doi.org/10.1016/j.arabjc.2014.03.002

Stephen R.C., Emily H. Stanley. and Jake Vander Zanden M. (2011). State of the World's Freshwater Ecosystems: *Physical, Chemical, and Biological Changes Annual Review of Environment and Resources* 36: 75-99.

Seckler D., Barker R. and Amarasinghe U. (1999).Water scarcity in the twenty-first century, *International Journal of Water Resource Development,* 15 (1-2), 29-40.

Shannon M.A, P. W. Bohn, M. Elimelech, J. G. Georgiadis, B. J. Mar˜ıas, and A. M. Mayes, (2008). Science and technology for water purification in the coming decades," *Nature*, 452(7185): 301–310, 2008.

Tandlich R., Zuma B.M., Whittington-Jonesc K.J. and Burgess J.E. (2009). Mulch tower treatment systems for greywater reuse Part II: destructive testing and effluent treatment. *Desalination,* 242 (1–3): 7–69.

United States Environmental Protection Agency (1978). Sullphate (Turbidimetric). Method #: 375.4. http://www.cornerstonelab.com/EPA-Methods/100-400/375_4.PDF (accessed 3 September 2013).

Villamagna A. (2009). The ecological effects of water hyacinth (Eichhorniacrassipes) on Lake Chapala, Mexico. Ph.D. Thesis. Virginia Polytechnic Institute and State University, Blacksburg.

Voet D. and Voet J.G. (2011). Biochemistry, 4th Edition, John Wiley & Sons, New York. An excellent introduction to biochemistry.

Whittington-Jones K., Tandlich R., Zuma B. M., Hoossein S., Villet M. H. (2011a). Performance of the pilot-scale mulch tower system in treatment of greywater from a low-cost housing development in the Buffalo City, South Africa. *International Water Technology Journal,* 1 (2): 165 – 181.

Whittington-Jones K., Tandlich R., Zuma B. M., Hoossein S. and Villet M. H. (2010). Performance of the pilot-scale mulch tower system in treatment of greywater from a low-cost housing development in the Buffalo City, South Africa. Published in the peer-reviewed conference proceedings from the *15th International Water Technology Conference, to be held in Alexandria*, Egypt, from 28th till 30th May 2011.

World Health Organization, Guidelines for the safe use of wastewater, excreta and greywater. (2006). Excreta and greywater use in agriculture. (WHO Press, Geneva, Switzerland. Volume 4.

Wutor V.C., Togo C.A. and Pletschke B.I. (2009). Suitability of total coliform β-galactosidase activity and CFU counts in monitoring faecal contamination of environmental water samples. *Water SA,* 35 (1): 85 – 88.

Zheng J., Feng H., Lam H., P.K., Ding Y., Yu H. (2009). Removal of Cu (II) in aqueous media by biosorption using water hyacinth roots as a biosorbent material. *Journal of Hazardous Materials.* 171:780-785.

Zuma B.M. and Tandlich R. (2010). Public health implications of greywater production in South Africa. In: Fonn S. and Padarath A. (Eds.). *South African Health Reviews*. Health Systems Trust. Durban, RSA.

Zuma B., Tandlich R., Whittington-Jones K. and Burgess J.E. (2009). Mulch tower treatment system Part I: Overall performance in greywater treatment, *Desalination*, 242 (1-3), 38- 55.

CHAPTER 5: IRRIGATION TRIAL WITH THE FLFT EFFLUENT AND THE EVALUATION OF THE IMPACT ON SOIL PROPERTIES

Greywater use is a potentially beneficial means of reducing the demand for potable water use for irrigation. It could also reduce the volume of wastewater discharges into freshwater resources, thereby reducing potential risk of eutrophication caused by effluent. The use of greywater could encourage people to use environmental friendly chemicals in their households to reclaim nutrients, which would have otherwise been wasted. The aim of this chapter is to treat and characterize greywater to determine its suitability for crop irrigation. Two vegetable crops, tomato (*Solanum lycopersicum*) (above ground) and beetroot (*beet*) crops (below ground), were irrigated. The soils were analysed for selected physico-chemical variables and nutrient content to determine the effects of greywater irrigation. This study demonstrated that treated greywater can be used for effective irrigation of crops with little or no detrimental effects on soil or plant growth.

5.1. Introduction

Two challenges Africa is facing in this 21st century are effective use of restricted water resources and ensuring food security, especially for poor communities. Greywater contains nutrients that are beneficial to the growth of most plants (Rodda *et al.* 2011). Therefore, to reuse greywater for irrigation of food crops in a small-scale urban agriculture can improve food security and contribute to environmental improvement in poor communities (Naicker *et al.* 2010). Various treatment processes are suggested in the literature, but since the on-site greywater recycling is a relatively new practice, only a few systems are commercially available, and few have been tested on industrial scale over longer time periods (Chaillou, 2011; Ilemobade *et al.* 2012; Wilson-Jones, 2012; Wielshafran *et al.* 2006). In South Africa biological treatment system for greywater, comprising an above-ground mulch tower has been evaluated (Ridderstolpe, 2007; Whittington-Jones *et al.* 2011a & b; Rodda *et al.* 2010b; Jackson *et al.* 2006; 2010; Naicker *et al.* 2010). There are only few that are tested and operating at a large scale.

Greywater use in urban agriculture is potentially beneficial for a number of reasons, such as reducing the demand for potable water use for irrigation, environmental degradation, and eutrophication (Rodda *et al.* 2011). Further, the use of greywater can encourage people to use environmental friendly chemicals in their households and reduce the risk of harmful compounds like endocrine disruptors (Ji &He, 2010; Winward *et al.* 2010). Carden *et al.* (2007a & 2007b), conducted site surveys throughout South Africa into the generation and disposal of greywater. The results showed that there is resistance on food irrigation and using the greywater without greywater management plan is regarded as poor sanitation practice purposes.

Soil is a complex, living, and dynamic component of the agro-ecosystem. It is subject to alteration, and can either be degraded or wisely managed. A thorough understanding of the ecology of the soil ecosystem is the key part of designing and managing agro ecosystems in which the long-term fertility and productive capacity of the soil is maintained (Naicker *et al.* 2010). Measuring biological, chemical and physical factors determine soil quality to establish a foundation for assessing the health of the soil (Jackson *et al.* 2006). Ultimately, indicators of sustainability can be grounded in the assessment of soil conditions and how they change as a result of the choices that one makes in managing the irrigation system. In this study, the effect of greywater re-usage for irrigation was tested on soils and plants by analysing their several physico-chemical variables, such as metal and nutrient concentrations.

5.1.2. Greywater treatment

Greywater accounts for 65% to 75% of the domestic water consumption in peri urban areas of developing countries where the water consumption per capita ranges from 20 to 30 L/capiuta/day (Elmitwalli *et al.* 2003; Eriksson *et al.* 2002; Morel & Diener, 2006). It can be argued that the potentially negative impacts from greywater reuse are in contamination with water supply services and where little or no consideration has been given to the planning and management of greywater. Greywater contains contaminants of concern that include suspended solids, pathogens, nutrients, grease as well as organic micro-pollutants from household chemicals and pharmaceuticals that may be present due to urine contamination (Eriksson *et al.* 2009). Laundry water contains higher chemical concentration, such as sodium, phosphate, boron, ammonia, nitrogen and is high in suspended solids. Thus, reusing laundry water untreated to land could lead to environmental damage, as well as posing a threat to public health (Ryan *et al.* 2009; Pinto *et al.* 2007). Kitchen greywater contains a higher level of chemical oxygen demand (COD) and total suspended solids (TSS) than greywater from the bathroom and laundry (Li *et al.* 2009). An increasing worldwide interest in water recycling technologies, such as greywater treatment and reuse suggests that additional research is critical to elucidate the effects of using greywater for irrigation.

5.2. Study aim

The overarching aim of this chapter is to demonstrate the impotance and the benefits of treated greywater for effective irrigation of crops with little or no detrimental effects on soil or plant growth using common crops *beet (*beetroot) and *Solanum lycopersicum* (tomato) as the model. Crops were chosen.

5.3. Experimental procedures

In carrying out the aims of this study, both above-ground (tomato) and below-ground (beetroot) crops were planted, and monitored. These crops were planted in white mead trays (40 litters) at the green house facility of Waainek Research Laboratory, Rhodes University, (see Figure 1). In each crop, four mead trays were used: two for tap water irrigation served as a negative control and the two for the effluent from fly ash-lime filter tower water as an experiment. The plants were purchased from the Grahamstown nursery and were irrigated for 3-4 months.

5.3.1. Greywater analysis

The greywater (i.e., the effluent from Fly-ash Lime Filter Tower with water hyacinth modification in Chapter 3 and Chapter 4) was analysed prior to using it for irrigation of the studied crops, and for physico-chemical and microbiological analysis. The analysis included: Ammonium (NH_4^+), Phosphate (PO_4^{3-}), Nitrate (NO_3^-), Chemical oxygen demand (COD), Chlorides (Cl^-), Sulphates (SO_4^{2-}), faecal coliforms, and electrical conductivity (EC).3.4.3. The analyses were conducted using methods described in Chapter 3.4 (see microbiological analysis and 3.4.4. physicochemical).

5.3.2. Plant analysis

The number of leaves per plant were randomly selected and counted once a week for measurements to assess plant growth and leaf area. The centimetres were measure using a ruler. For dry mass of the leaves (g) the leaves were washed thoroughly with distilled water; oven dried at 65 ^{0}C for 72 hours; and the dry mass was determined. Plant growth was measured weekly. The measured parameters included stem height, size of leaves, number of leaves, number of fruits, and dry weight. Harvested crops were assessed for micro nutrients, fresh and dry weights. The selected microelements and metals assessed here, courtesy of Chemtech Laboratory Services (Pty) Ltd, included (Aluminum (Al), Calcium (Ca), Cadmium (Cd), Chromium (Cr), Copper (Cu), Iron (Fe), Mercury (Hg), Potassium (K), Magnesium (Mg), Sodium (Na), Lead (Pb), Silicon (Si) and Strontium (Sr). Metals were extracted from the soil and fruits. The analytical procedure followed EPA Method 200.7: Based on NIOSH Method 7300, while using an Inductively Coupled Argon Plasma Optical Emission Spectrometer (ICAP-OES). Although reported in this are metal analysis, dry weight and biomass were compared.

5.3.3. Soil analysis

Soil from the mead trays of the two plants was analysed for physico-chemical and microbiological parameters and nutrient content prior and after irrigated with greywater and tap water. The physico-chemical analysis included electrical conductivity (EC), organic matter (OM), phosphorus (P), particle density (PD), bulk density (BD), total Kjeldahl nitrogen, and pH (Miller, 2010; Janssen & Koopmann, 2005; Nelson & Sommers, 1996).

pH and electrical conductivity: The measurements were done using the method described by Sikora and Kissel (2000) as standard media for leaching protons from soil: calcium chloride ($CaCl_2$) 0.01M and potassium chloride (KCl) 1M. The amount of the soil was weighed out on the Pioneer PA214 analytical balance (Ohaus Corporation, Pinebrook, New Jersey, USA) and different variations of water and buffers were measured. The pH was measured using a glass electrode which was immersed in soil solution (slurry) of water containing different variations on the type of solution added in weight per volume (w: v); (1:3 [soil/ water]; 1:3 [soil/0.01 M CaCl2]; 1:3 [soil/ 1M KCl]; 1:6 [soil /water]. The soil and water solution were stirred vigorously at room temperature and the slurry was allowed to set for 15 minutes. The Cyberscan 5000 pH electrode was used to measure the pH of the soil slurry.

Bulk density: Samples were taken with a core sampler which consists of a metal cylinder, sharpened on one end, and a sampler head with a handle for pushing the cylinder into the soil. The aluminium can with lid was weighed out on the Pioneer PA214 analytical balance; recorded; and kept in the UFE 700 oven (Memmert, Schwabach, Germany) at 105 °C for at least one day after the soil was dried; cooled; weighed; and recorded. Samples were repeatedly kept in Gallenkamp Muffle Furnace, Thermo Scientific at 400 °C overnight, after the soil was dried; cooled; weighed; and recorded. Everything was recorded in a table (See Appendix 3). The bulk density was calculated using the formula, Bulk density = mass of dry soil (g)/ volume of solids (cm^3) (Refer to Appendix 1B).

Particle size density: Water was slowly added to the soil and mixed thoroughly and vigorously shaken until the flask was full. The air bubbles were allowed to rise to the surface and float foam out of the flask by adding a few more drops of water. The flask was wiped outside; dried; and weighed out on the Pioneer PA214 analytical balance. The entire content was then descanted into a waste bucket and rinse flask. The flask was refilled with water; wiped outside; dried; and weighed. Everything was recorded in a table (See Appendix 1).

Loss on ignition (LOI): Soil Organic content of air was dried; sieved using sieves ranging from 63 to 250 µm (Fluka Sieve Standard, Sigma-Aldrich, Johannesburg, RSA); and the soil samples were determined using Loss on ignition (LOI) method (Nelson & Sommers, 1996). The soil samples were air-dried to remove moisture and each one screened through a 2-mm soil sieve. The crucibles were put at 105 °C in a drying oven for 24 hours to remove moisture and allowed to cool in a desiccator for 4 hours. Ten grams (g) soil sample (f) was placed in porcelain crucible and dried at 105 °C for 24 hours and then ignited at 400°C in muffle furnace for 24 hours, with the resultant mass weighed out on the Pioneer PA214 analytical balance. The LOI corresponds were calculated using the following equation:

$$\text{Loss Of Ignition}(\%) = \left(\frac{\Delta m(g)/}{ms(g))}\right) x\ 100 \quad \text{Equation}.................................5.1$$

Δm *(g* (Loss of mass after ignition) = Mass of soil dried at 105°C (m_s) – mass of soil ignited at 400°C (m_c)

m_s Mass of soil dried at 105°C

m_c Mass of soil ignited at 400°C

The organic matter (OM) content of the samples was measured using the weight loss on ignition method.

Phosphorus: Total phosphorus was determined using (EPA/600/R-93/100, Method 365.1) by digesting sample (0.1g/ml) using ammonium persulphate digestion (Janssen & Koopmann, 2005). Phosphorus was quantified by a spectrophotometric method involving the formation of antimony-phosphate-molybdate, yellow complex that is reduced by ascorbic acid (0.1mol/l) to a blue color. Calibration curve was done using 5mg/l phosphate stock solution of KH_2PO_4.

5.4. Enumeration of Bacteria

The nutrient agar and m-FC agar were prepared in 1L schott bottles, provided by Labotec, Midrand, South Africa. All the agars were autoclaved in a Model RAU-53Bd REX MED autoclave (Hirayama Manufacturing, Tokyo, Japan). Samples were inoculated onto plates in a LA1200 BII laminar-flow hood. All incubations took place in one of the following incubators: the Labcon incubator Model FSIM B (Labmark, Johannesburg, South Africa), the TS 606/3-I incubator (WTW, Weilheim, Germany), the Labcon low temperature incubator LTIE 10 (Labmark, Johannesburg, South Africa) and/or the Heraeus Model FT 420 (Heraeus Kulzer GmbH, Dormagen, Germany). Membrane filtration (MF) filters (nylon, size 0.45 μm) for microbial enumeration; Oxoid gas generating kits for anaerobic enumeration for use with the anaerobic gas jars; sterile petri dishes (90 mm) were procured from Spellbound Labs (Port Elizabeth, South Africa). Bacteria samples were either spread plated or membrane filtrated. Samples were analysed in duplicates or triplicates. The average of the replicates was recorded as the concentration.

Figure 5.1: Experiment showing the tomatoes and beetroot in mead trays, this photo was taken with a phone during sampling period

5.4. Results and Discussions

5.4.1. Greywater

For a system using greywater to irrigate vegetables, various exposure routes have to be assessed and their influence needs to be assessed for different groups within the community. The first risk would be from handling the greywater, either in collection or in handling it during irrigation. Results of physico-chemical and microbiological characterisation of the treated greywater from the Fly Ash Lime Filter Tower system (as shown in Table 5.1), shows ammonia ranging between14.5-16.3 (mg/l), phosphate 0.4- 1.0 (mg/l), nitrate 24.5- 16.9 (mg/l), cod 229.5- 82.8 (mg/l), chlorides 0.59- 0.3 (mg/l), sulphates 20.2- 7.5 (mg/l), colony forming unit (0.00 cfu/ml), turbidity 10.0- 14.4 NTU, pH 8.00- 9.2, electrical conductivity 510.00-1110.00 µS/cm were within the literature values reported in various studies (Whittington-Jones *et al.* 2011a; Zuma & Tandlich, 2010). These values were closely consistent and within the expected range of the greywater. From these observations, grey-water contained minimum concentrations of Cl^- 0.6- 0.3 mg/L and was even below the limit of 100 mg/ℓ given in the South African Water Quality Guidelines (DWAF, 2015). Grey-water at pH 8.0- 9.0 falls within an accepted range of pH (6.5–9) indicating the likelihood that this water is suitable for irrigation (Bauder *et al.* 2014). However, the elevated Electric conductivity(EC) -10- 01110.0 mS /m could increase the risk to human health, plants or soil as the observed EC was within a range of 40 to 200 mS/m (Rodda *et al.* 2011). Meeting the compliance has not been a South African challenge. Other states like California have greywater irrigation legislation that is complex and expensive to comply with, and has resulted to less use of greywater for irrigation (ITU, 2013; TMIH, 2014). The effluent had a significant pH. Greywater was reported to have high level of pH (Wielshafran *et al.* 2006) which normally results in the degradation of soil breakdown to form aggregate structure. When soil pH exceeds 8-8.5, some micronutrients deficiencies occur (Zuma *et al.* 2009). Greywater contains nutrients that are beneficial to the plant growth. Therefore, greywater could be the other way to improve food security (see Figure 5.2 and Figure 5.3).

The presence of the microorganisms, such as the faecal and total coliforms, *E coli, Pseudomonas aeruginosa, Staphylococcuss spp*. in greywater have been used as the indicators of faecal contamination and subsequent human health threat (Eriksson & Donner, 2009). South African research published in the area of greywater and wastewater reuse has been few: Ilemobade *et al.* (2009) and Adewumi *et al.* (2010). Carden *et al.* (2007) and Wilson & Pfaff (2008), who investigated the use of greywater and community perceptions of direct potable reuse of treated wastewater, recommended guidelines for the management of greywater. Similarly, Rodda *et al.* (2010) and Ilemobade *et al.* (2009) recommended guidelines and survey on small-scale agricultural irrigation. The health risk associated with greywater is related to the microbial quality of greywater at the point of irrigation; on how irrigation is carried out; and the type of crops being irrigated (Ryan *et al.* 2009).

5.4.2. Soil

Environmental effects of greywater on soils can be positive and negative depending on how it is managed. For instance, in rural areas grey-water is disposed of directly on the ground near to dwelling places and often results in various health and environmental hazards, such as pollution of wetlands, contamination of underground water supply and infiltration of salts, oils and grease into the soil (Van Vuuren, 2007). However, in this study the water was treated and met the requirements for irrigation reuse (see Table 5.2). The bulk density (3.05 g/cm3) contained in greywater contributed to the total loading of organic matter in the soil over time and therefore, supported crop production (Rusan *et al.* 2007). The benefits of greywater irrigation on plant growth and crop yields (see Figure 5.2; 5.3-5.6) were evident in studies conducted by Salukazana *et al.* (2005) and Misra *et al.* (2009).

Generally, the particle densities for soils ranged from 2.60 to 2.75 g/cm^3 for mineral particles (Table 5.2). The tomato soil had particle density 1.73-4.66 g/cm^3 compared to beetroot soils with 1.7- 2.2g/cm^3. Particle density measurements provided information about the kinds of material present in a soil. This proved that the tomato soil consists of minerals that have ~~a~~ high density. This information provided insight into the geologic history of the soil and its composition. A low particle density <1.0 g/cm indicated high organic matter content. It also provided the information about the potential release of carbon from the soil into the atmosphere as the organic matter decomposes over time.

Table 5.1: Physicochemical and microbial quality of the treated bathroom greywater

Parameter	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Week 12
Ammonia (mg/L)	15.53	14.53	15.73	15.46	15.56	15.66	15.76	15.86	15.96	16.06	16.16	16.26
Phosphate (mg/L)	0.51	0.41	0.61	0.61	0.66	0.71	0.76	0.81	0.86	0.91	0.96	1.01
Nitrate (mg/L)	28.95	24.95	26.95	24.95	23.95	22.95	21.95	20.95	19.95	18.95	17.95	16.95
COD (mg/L)	329.53	229.53	289.53	242.87	222.87	202.87	182.87	162.87	142.87	122.87	102.87	82.87
Chlorides (mg/L)	0.93	0.59	0.73	0.55	0.45	0.35	0.25	0.15	0.05	0.05	0.15	0.25
Sulphates (mg/L)	25.22	20.22	22.22	19.55	18.05	16.55	15.05	13.55	12.05	10.55	9.05	7.55
Colony forming unit (CFU/ml)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Turbidity (NTU)	9.52	10.00	5.00	3.65	1.39	0.87	3.13	5.39	7.65	9.91	12.17	14.43
pH	7.50	8.00	7.80	8.07	8.22	8.37	8.52	8.67	8.82	8.97	9.1	9.03
Electrical conductivity (µS/cm)	1010.00	1110.00	8410.00	1091.00	14610.00	18310.00	22010.00	1010.00	1110.00	8410.00	1091.00	510.00

Ammonia (NH_3), Phosphate (PO_4^+), Nitrate (NO_3^+), Chemical oxygen demand (COD), Chlorides (Cl^-), Sulphates (SO_4^{2-}), Colony forming unit(CFU) and electrical conductivity (EC)

Table 5.2: Average soil physicochemical properties of tomatoes trays

Parameter	OS	GW	TW	GW	TW	GW	TW	GW	TW	GW	TW
Loss on ignition (LOI) (%)	19.94	59.39	59.12	19.72	18.94	19.72	18.94	19.72	18.94	19.72	18.94
Particle size density (g/cm3)	1.73	1.64	0.33	1.22	4.66	1.22	4.66	1.22	4.66	1.22	4.66
Bulk density (g/cm3)	5.33	2.31	5.84	3.05	2.20	3.05	2.20	3.05	2.20	3.05	2.20
Average pH	7.53	7.08	7.55	7.08	7.55	7.08	7.55	7.08	7.55	7.08	7.55
Total Phosphorus mg/L	0.13	0.16	0.16	0.13	0.16	0.13	0.16	0.13	0.16	0.13	0.16
Electrical conductivity (EC) (µS/cm)	3.49	83.50	650.50	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00
Feacal coliform (CFU/ml)	0.57	0.14	0.33	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86
Aerobic bacteria (CFU/ml)	44.00	97.33	69.75	53.57	70.67	53.57	70.67	53.57	70.67	53.57	70.67
Anaerobic bacteria (CFU/ml)	22.40	13.67	2.67	36.86	40.00	36.86	40.00	36.86	40.00	36.86	40.00

OS = original sample, GW= greywater and TW=tap water

Figure 5.2: Harvested crop after irrigation experiment

However, irrigation with greywater had values Loss on ignition (LOI) (19.72%), Particle size density (1.22g/cm3), Bulk density (3.05 g/cm3), Average pH 7.08, Total Phosphorus 0.13 mg/L, Electrical conductivity (20.0 EC, Faecal coliform 53.07, Aerobic bacteria 53.07, Anaerobic bacteria 36.86.40 had significantly greater biomass and dry weight, whereas tap water irrigated vegetables showed poor growth with values of Loss on ignition (LOI) (18.94 %), particle size density (4.66 g/cm3), Bulk density (2.20 g/cm3), average pH 7.55, total Phosphorus 0.16 mg/L, electrical conductivity (320 μS/cm), faecal coliform of 0.86, aerobic bacteria 70.67, anaerobic bacteria 40.00. Increased plant growth noted in crops irrigated with greywater in this study is in accordance with those obtained (Rodd *et al.* 2011; Salukazana *et al.* 2006; Wielshafra *et al.* 2006) who observed that crops irrigated with treated effluent, which had raised inorganic nutrients, produced higher growth and yields than similar crops irrigated with ground water.

The microbiology of soils is an important consideration for wastewater reuse. Soil characteristics are often affected by microbes as they may cause changes in pH, mineralization of organic matter, and flow and transport of liquids through the soil. In both tap water and greywater, the Faecal coliform were less than 1 (0.17 CFU/100 ml); the aerobic and anaerobic bacteria were less than 100; aerobic bacteria (44.00- 40.00 CFU ml) and anaerobic bacteria (22.40 -39.43 CFU ml). Moreover, waterborne pathogens may survive in soil and potentially compromise public health. Faecal coliform (FC) bacteria were measured as a surrogate of pathogen persistence in the soil. In all the soils from the mead trays the soil analysis showed few counts of FC (see Table 5.3 below). Factors that promoted the FC survival in soil included moisture content, soil type (linked to particle size distribution and OM content), temperature, pH, source application rate and characteristics, nutrient availability and competition (Jamieson *et al.* 2002).

Table 5.3: Average soil physicochemical properties from beetroot tray

Parameter	OS	GW	TW	GW	TW	GW	TW	GW	TW	GW	TW
Loss on ignition (LOI) (%)	19.94	63.74	56.34	35.46	56.34	35.46	56.34	35.46	56.34	35.46	56.34
Particle size density (g/cm3)	1.73	2.12	2.35	1.67	1.38	1.67	1.38	1.67	1.38	1.67	1.38
Bulk density (g/cm3)	5.33	2.06	1.76	2.00	1.76	2.00	1.76	2.00	1.76	2.00	1.76
Average pH	7.53	7.40	7.58	7.08	7.55	7.08	7.55	7.08	7.55	7.08	7.55
Total Phosphorus mg/L	0.13	0.14	0.16	0.16	0.17	0.16	0.17	0.16	0.17	0.16	0.17
Electrical conductivity (EC) (µS/cm)	3.49	303.0	476.5	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0
Feacal coliform (CFU/ml)	0.17	0.71	0.61	0.41	0.71	0.41	0.71	0.51	0.71	0.31	0.71
Aerobic bacteria (CFU/ml)	44.00	97.33	92.83	36.14	40.00	36.14	40.00	36.14	40.00	36.14	40.00
Anaerobic bacteria	22.40	40.00	36.86	57.14	39.43	57.14	39.43	57.14	39.43	57.14	39.43

(CFU/ml)											

OS = original sample, GW= greywater and TW=tap water

Monitoring the plant growth studies was to determine if irrigating with greywater had a net effect to inhibit growth. All plants appeared healthy from all soils. No significant differences observed in plant dry weight and biomass results. All the figures where closely the same (Figure 5.3 and figure 5.5). This means that treated greywater has no negative effects on the soil and plant growth.

5.4.3. Plants

Plant biomass is an important factor in the study of functional plant biology and growth analysis, and it is the basis for the calculation of net primary production and growth rate (Wielshafran *et al.* 2006). Generally, tomatoes had high biomass compared to beetroot with an average biomass (tomatoes (26.59 g); onions (8.929 g) compared to the ones irrigated with tap water (tomatoes (26.5 g); onions (9.96 g). Moreover with the dry weight crops irrigated with greywater had an average dry weight (tomatoes (86 g); onions (21.01 g) tomatoes (81.23 g); onions (18.35). Crops irrigated with greywater significantly grow faster compared to those irrigated with tap water with high biomass on leaves (Reichman & Wightwick, 2013). Organic matter plays various important roles in the soil ecosystem, all of which are of importance to sustainable agriculture. In general, response of plants marked by a reduction in plant growth, such as germination, root and shoot length, and overall dry mass (Agarwal & Pandey, 2004). The quality of irrigation water not only affects crop yield, but also internal and external qualities of the product (Zavadil, 2009). The plants irrigated with greywater had an average biomass (tomatoes (26.59 g); onions (8.929 g) compared to the ones irrigated with tap water (tomatoes (26.5 g); onions (9.96 g). Moreover with the dry weight crops irrigated with greywater had an average dry weight (tomatoes (86 g); onions (21.01 g); tomatoes (81.23 g); onions (18.35). See Figure 5.5 - Figure 5-8. Both tap water (average pH 7.55; EC 20) and greywater (average pH 7.08; EC 20) had good pH values despite these reports on the accumulation of heavy metals and elevation of pH and EC. Some findings suggested that it does not pose any risks to the health of soils (Faruqui and Al-Jayyousi, 2002; Pinto *et al.* 2010). Whereas, Sharvelle and co-workers (2012) investigated the effect of grey-water irrigation over the long term (more than 5 years) on landscapes, and observed accumulation of salts in soils which posed a risk to leach down to the water table. Weil-Shafran & co-workers (2006) discovered that the pH of soils irrigated with greywater was significantly lower than that of soils irrigated with potable water, and suggested that this change was probably due to enhanced bacterial activities, such as respiration.

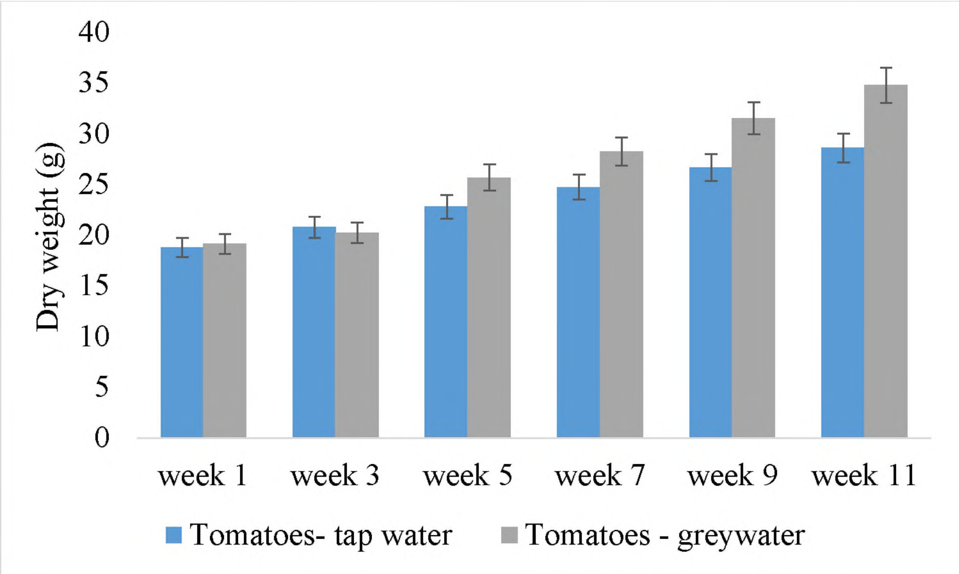


Figure 5.3: Average total plant dry weight (tomatoes) dry weights throughout one crop cycle.

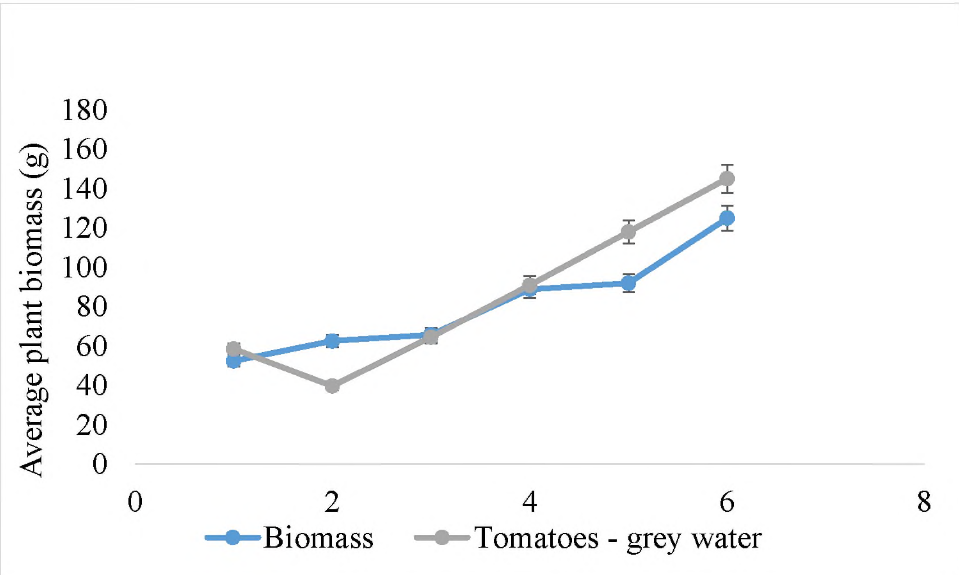


Figure 5.4: Average total plant biomass (tomatoes) monitored throughout one crop cycle.

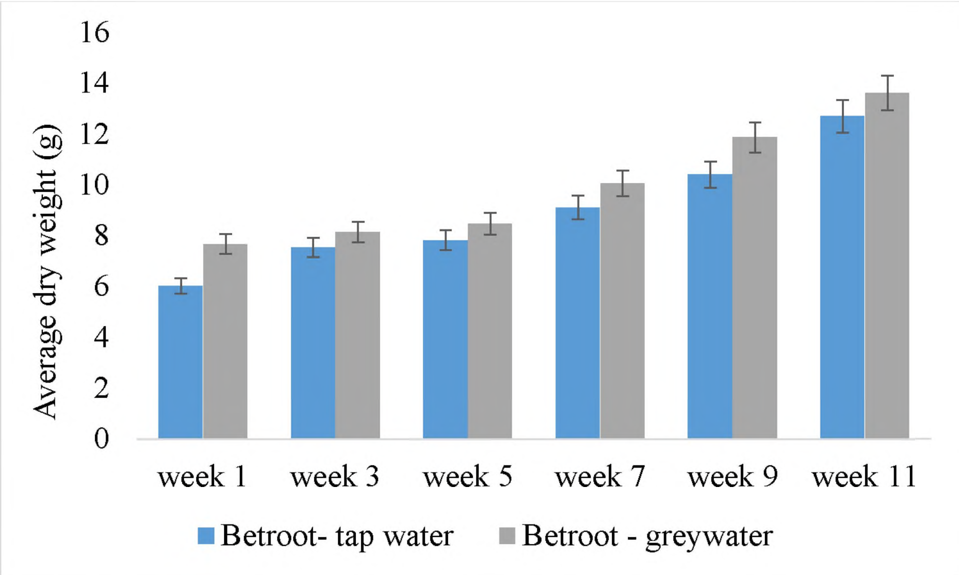


Figure 5.5: Average total plant dry weight (beetroot) monitored throughout one crop cycle.

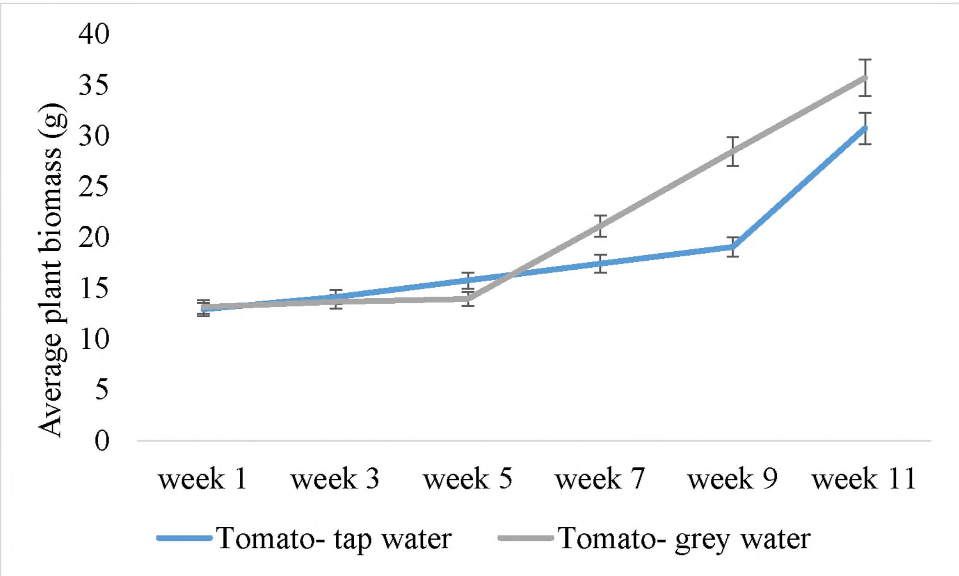


Figure 5.6: Total plant biomass (beetroot) monitored throughout one crop cycle.

Metal analysis has made a significant contribution to the greywater reuse field, allowing review of evidence for various elemental composition effects on the plants and the soils. Both plants were analysed for elements (Aluminum (Al), Calcium (Ca), Cadmium (Cd), Chromium (Cr), Copper (Cu), Iron (Fe), Mercury (Hg), Potassium (K), Magnesium (Mg), Sodium (Na), Lead (Pb), Silicon (Si) and Strontium (Sr). The plants irrigated with greywater generally had higher concentrations compared to those irrigated with tap water effluent which contradicts the biomass results (Figure 5.3-5.6) where the plants irrigated with the greywater plants has a higher biomass compared to the tap water plants). This was evident in the amount of aluminium in the leaves for beetroot BEL (5.8 mg/g); BCL (1.45 mg/g) and tomatoes TEL (6.2 mg/g) and tomatoes TCL (1.8 mg/g).

Table 5.4: The metal analysis showing the effect of irrigation water quality on betroot

Metals concentration (mg/g)													
Samples	Al	Ca	Cd	Cr	Cu	Fe	Hg	K	Mg	Na	Pb	Si	Sr
BER	5.22	1.51	0.71	-	0.47	0.06	0	0.18	1.75	0.00	0.83	48.69	338.33
BES	5.80	1.01	-	0.87	0.27	0.00	0	0.58	2.84	0.01	0.12	47.47	552.67
BEL	5.39	2.58	0.99	-	0.80	0.04	0	0.43	2.26	0.0	0.62	52.03	325.67
BCR	42.33	2.69	0.62	2.02	0.52	0.03	0	0.11	2.49	0.0	0.70	39.89	349.50
BCS	3.77	0.48	-	0.51	0.20	0.00	0	0.17	1.10	0.0	0.14	18.87	656.67
BCL	1.45	0.12	0.45	0.57	0.19	0.00	0	1.73	2.02	0.0	0.06	21.69	398.33

BER (betroot experiment roots), BES (betroot experiment stem), BEL (betroot experiment), BCR (betroot control roots), BCS (beetroot control stem) and BCL (betroot control leaves)

(Aluminum (Al), Calcium (Ca), Cadmium (Cd), Chromium (Cr), Copper (Cu), Iron (Fe), Mercury (Hg), Potassium (K), Magnesium (Mg), Sodium (Na), Lead (Pb), Silicon (Si) and Strontium (Sr))

This also disapproves the findings by Surendran and Wheatly (1998) which state that heavy metals were much lower in concentration than those found by in greywater generated from bath shower activities. There were significant differences in heavy metals in the both tomato and the beetroot samples except in the case of Hg, K, Mg, Na and Pb (Table 5.4 and Table 5.5). However, the tomatoes metal concentrations seemed to be slightly higher in tomatoes (Table 5.5) compared to the beetroot (Table 5.6). The Pb was found to be less than 1mg/g in beetroots plants which was falling within the South African guidelines for irrigation set Target Water Quality Range (TWQR) of 1 mg/l for Pb (DWAF, 1996) and FAO (1979). However, in tomatoes it was higher both in control TCR (312.64 mg/g) and the experiment TER (214.18 mg/g).

Table 5.5: The metal analysis showing the effect of irrigation water quality on tomatoes

Metals concentration (mg/g)												
Samples	Al	Ca	Cd	Cr	Cu	Fe	Hg	K	Mg	Na	Pb	Si	Sr
TER	2.63	0.08	57.99	72.94	44.92	3.02	0	0.03	0.15	0.14	214.18	3.76	11.57
TES	2.02	0.03	213.33	53.93	29.42	4.94	0	0.02	0.10	0.11	152.21	3.22	6.82
TEL	6.21	0.07	107.78	121.62	85.67	12.56	0	0.06	0.21	0.37	436.66	6.53	18.13
TCR	3.89	0.17	136.33	145.64	46.15	3.40	0	0.08	0.44	0.35	312.64	5.78	25.09
TCS	1.38	0.07	60.99	51.43	47.41	1.15	0	0.03	0.16	0.11	85.24	4.45	7.86
TCL	1.85	0.03	116.52	32.12	41.90	4.50	0	0.02	0.24	0.08	212.14	2.45	7.09

TER (tomato experiment roots), TES (tomato experiment stem), TEL (tomato experiment), TCR (tomato control roots), TCS (tomato control stem) and TCL (tomato control leaves)

(Aluminum (Al), Calcium (Ca), Cadmium (Cd), Chromium (Cr), Copper (Cu), Iron (Fe), Mercury (Hg), Potassium (K), Magnesium (Mg), Sodium (Na), Lead (Pb), Silicon (Si) and Strontium (Sr))

This is consistent with similar observation made by Al-Hamaiedeh and Bino (2010) who found no difference in the absorption of macro nutrients by plants when irrigated with greywater and fresh water. The quality of greywater for use as an irrigation source determines the quality of plant. For example, greywater containing high chloride ion concentration (175-350 mg/l) causes leaf damage in sensitive crops, such as tomato and betroot (Ayers &Westcot, 1994; Bauder *et al.,* 2007). There was a significant difference in Cd caused by irrigating tomato (57 mg/g) and the beetroot (0.17 mg/g) with greywater and this is supports the results found by Qishlaqi *et al* (2008), who observed that there was an increase in Cd in spinach and lettuce when irrigated with wastewater irrigation. The Na concentration was low in Tomato (0.01 mg/g) compared to beetroot (0.01 mg/g). A study report by Mini & Winter 2015 reported that greywater with excessive levels of toxic elements, such as and cadmium (Cd), that cause soil pore clogging and sodium (Na) could reduce plant growth. Both plants showed subsistence amount of Fe. Generally, Green leafy vegetables are known to be good source of plant metabolisim (Mini & Winter 2015). Both Mg and K were found to be substantial, tomato (837.64- 194.12 mg/g) K and (202.86- 1736.68 mg/g), beetroot (389.85- 39.62 mg/g) K and 175.07- 38.56 mg/g) as they are the important element which plays an important part in many of the vital physiological processes in the plant growth, but are required in relatively small concentrations (Rusan *et al.*, 2007; Salukazana *et al.*, 2005).

Generally flyash contain high concentration of metals. The amount of strontium was 398 mg/g from Table 5.5, generally Flyash contain Sr 76853 mg/L, a metalloids like that adsorb in the oxide surfaces (Nollet et al., 2003; Jegadeesan et al., 2008).The flyash consists of solid surface such as SiO_2, Al_2O_3, Fe_2O_3 and TiO_2 which contains the electric charges that allow the adsorption of metal cations such as arsenate, borate and sulphates (Huggins et al., 2008). The greywater has also been shown to contain heavy metals and up to 900 xenobiotics (Eriksson et al., 2002).

5.5. Concluding remarks

The objective of this project was to evaluate the impact of irrigating vegetable crops with treated greywater, which met the international microbial safety standards for unlimited food crop irrigation (WHO 2006). This has proved that greywater can be used beneficially to quench the water needs in South Africa. The treated soil used in this study was found to contain high levels of organic matter with the bulk density of 3.05 g/cm^3 and a particle density <1.0 g/cm. There was no presence of pathogenic organisms (Faecal coliform were less than 1 (0.17 CFU/100 ml); aerobic bacteria (44.00- 40.00 CFU ml); and anaerobic bacteria (22.40 -39.43 CFU ml) in the greywater which can pose a real health risk to humans into contact with it. Generally, tomatoes had high biomass compared to beetroot with an average biomass (tomatoes (26.59 g); onions (8.929 g) compared to the ones irrigated with tap water (tomatoes (26.5 g); onions (9.96 g). Moreover, with the dry weight crops irrigated with greywater had an average dry weight (tomatoes (86 g); onions (21.01 g) tomatoes (81.23

g); onions (18.35). This method can be improved and used in rural communities owing to its low and cheap cost. The future goal that detailed in chapter 7 is likely to be different from this chapter because of the high EC, sodium absorption ratio (SAR) and sodium concentrations in greywater, indicating that sodium toxicity, soil salinisation and soil sodicity may present problems.

5.6. References

Al-Hamaiedeh, H.D., and Bino, M. (2010). Effect of treated greywater reuse in irrigation on soil and plants. *Desalination*, *256*(1-3), 115-119.

Carden K., Armitage N., Sichone O. and Rivet U. (2006). Understanding the use and disposal of greywater in the non-sewered areas of South Africa. Water Research Commission Report No. K5/1524. Pretoria, RSA.

Carden K., Armitage N., Winter, K., Sichone O., Rivett, U and Kahonde J. (2007). The use and disposal of greywater in the non-sewered areas of South Africa: Part 2 – Greywater Management Options, *Water SA* 33:4.

Department of Water Affairs and Forestry (DWAF) (1996). South African Water Quality Guidelines, Vol. 4 (Agricultural use: Irrigation), Pretoria.C.

Elmitwalli, T. and Otterpohl, R. (2007). Anaerobic biodegradability and treatment of greywater in up flow anaerobic sludge blanket (UASB) reactor. *Water Research* 41(6), 1379-1387.

Eriksson E., Auffarth K., Henze M. and Ledin A. (2002). Characteristics of greywater, *Urban Water*, 4 (1), 85-104.

Eriksson, E., Andersen, H.R., Madsen, T.S. and Ledin, A. (2009). Greywater pollution variability and loadings. *Ecological Engineering*, 35, 661-669.

FAO and WFP (2010). The state of food insecurity in the world. Addressing food insecurity in protracted crises. Rome, FAO. (Available at: http://www.fao.org/docrep/013/i1683e/i1683e.pdf).

Jackson S., Rodda N. and Salukazana L. (2006). Microbiological assessment of food crops irrigated with domestic greywater. *Water SA*, 32 (5), 700-704.

Janssen E and Koopmann R (2005). Determination of total phosphorus, total nitrogen and nitrogen fractions; Desk study 16 in Project Horizontal; www.ecn.nl/horizontal

Li F., Wichmann K. and Otterpohl, R. (2009). Review of technological approaches for greywater treatment and reuses. *Science of the Total Environment*, 407(11), 34393449.

Metcalf and Eddy F. (2003). Wastewater Engineering: Treatment and Reuse. 4th Ed. New York, NY 10020, USA: McGraw-Hill Companies, 1221 Avenue of Americas.

Miller, R.O. and D.E. Kissel. (2010). Comparison of soil pH methods on soils of North America. Soil Science Society of America Journal 74: xxx-xxx

Morel. A. and Diener, S. (2006). Greywater Management in Low and Middle-Income Countries. Review of different treatment systems for households or neighbourhoods. http://www.eawag.ch/organisation/abteilungen/sandec/publikationen/publications_ewm/downloads_ewm/Morel_Diener_Greywater_2006.pdf [Accessed on 11th September, 2010].

Naicker P., Smith MT., Rodda N., Jonsson H. and Ridderstolpe P. (2010). An evaluation of an onsite biological greywater treatment system when exposed to different loading scenarios Proc. Biennial Conference of the Water Institute of South Africa, 18 to 21 April, Durban, South Africa.

Nelson DW and Sommers LE (1996). Total carbon, organic carbon, and organic matter. Methods of Soil Analysis, Part 3. Chemical Methods. Soil Science Society of America Book American Society of Agronomy, Madison, WI. Series, 5: 961-1010.

Pinto U., Maheshwari B. (2010). Reuse of greywater for irrigation around homes in Australia: Understanding community views, issues and practices. *Urban Water J.* , *7* (2), 141–153.

Pinto U., Maheshwari B. (2007) *Issues and Challenges of Greywater Reuse for Irrigation in Australia—A Case Study of Western Sydney Region*; University of Western Sydney: Sydney, Australia.

Ridderstolpe P. (2007). Mulch Filter and Resorption Trench for Onsite Greywater Management. Report for a demo facility built in Kimberley, South Africa. EcoSanRes Programme, Stockholm Environment Institute, Stockholm, Sweden. 27 pp.

Rodda N., Carden K., Armitage N. and du Plessis H.M. (2011). Development of guidance for sustainable irrigation use of greywater in gardens and small-scale agriculture in South Africa. WRC 40-Year Celebration Special Edition 37:5.

Rodda N, Salukazana L, Jackson S.A.F. and Smith M.T. (2011a). Use of Domestic Greywater for Small-scale Irrigation of Food Crops: Effects on Plants and Soil. *J. Phys. Chem. Earth*. DOI: 10.1016/j.pce.2011.08.002.

Rodda N, Carden K and Armitage N. (2010b). Sustainable Use of Greywater in Small-scale Agriculture and Gardens in South Africa, Technical Report. WRC Report No. 1639/1/11. Water Research Commission, Pretoria, South Africa. 283 pp

Salukazana L., Jackson S., Rodda N., Smith M., Gounden T., McLeod N. and Buckley C. (2006). Reuse of greywater for Agricultural irrigation. WISA 2006 Biennial Conference Exhibition. Durban, RSA.

Tandlich R., Zuma B.M., Whittington-Jonesc K.J. and Burgess J.E. (2009). Mulch tower treatment systems for greywater reuse Part II: destructive testing and effluent treatment. *Desalination*, 242 (1–3): 7–69.

Whittington -Jones KJ and Tandlich R (2010). Performance of Pilot Biological Greywater Treatment Systems in Scenery Park (Buffalo City Municipality, South Africa). Report prepared for the Stockholm Environment Institute and EcoSanRes. 22 pp.

Wielshafran 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, 348-354.

Wilson-Jones T., and Rivett U. (2012). Using Mobile Phones To Monitor And Manage Water Supply Quality In Rural Environments. *WISA 2012 Biennial Conference & Exhibition.* Cape Town.

Winward G.P., Avery L.M., Frazer-William R., Pidou M., Jeffrey P., Stephenson T. and Jefferson B. (2008). A study of the microbial quality of greywater and an evaluation of treatment technologies for reuse. *Ecological Engineering* 32 (2): 187 – 197.

World Health Organization, Guidelines for the safe use of wastewater, excreta and greywater. (2006). Excreta and greywater use in agriculture. (WHO Press, Geneva, Switzerland. Volume 4.

Zuma B.M. and Tandlich R. (2010). Public health implications of greywater production in South Africa. *In: Fonn S. and Padarath A.* (Eds.). South African Health Reviews. Health Systems Trust. Durban, RSA

CHAPTER 6: A MODEL PARADIGM FOR THE ROLL-OUT OF THE FLFT INTO GREYWATER TREATMENT IN COMMUNITIES

In this chapter, the study aimed at designing information tools using a community-based approach. A modified hydrogen-sulphide (H_2S) test kit was used to detect faecal contamination of different water bodies. A workshop was conducted with participants to educate them about the study at hand. The community-based approach proved to be a platform that could be of benefit to elucidate water issues in communities. Workshop participants found the test kit easy to use, indicating that they can be easily used by community members. The community based approach could enable regular water quality testing in rural areas while providing a base line alert system to identifying problem areas. The approach proved cost-effective, reducing transport and laboratory costs.

6.1. Introduction

In South Africa, about 11% (1.4 million) of households, both formal and informal, are yet to be provided with basic sanitation infrastructure. These households are predominantly in the widely dispersed rural settlements of KwaZulu-Natal, North West and the Eastern Cape. Based on an assessment of the provision of water services, 23 municipalities (9% of the total) in South Africa were in a crisis state, with an acute risk of disease outbreak; and a further 38% were at high risk, with the potential to deteriorate into a state of crisis (SAICE and CSIR, 2011), DWA, 2013; DPME, 2013; SHRC, 2014). While national averages seemed to indicate progress, but when disaggregated in historically poor areas, they reflect limited access to basic water and sanitation services. National statistics show that, eighty five percent (85%) of households have access to Reconstruction and Development Programme (RDP) acceptable levels of water (SHRC, 2014). However, in KwaZulu-Natal Province, 14.1% of households do not have access to water. In terms of sanitation, over 70% of all households in South Africa have access to Reconstruction and Development Programme (RDP) acceptable sanitation level. However, in the Eastern Cape, about 12.5% of households have no access sanitation services (DPME; 2013; SHRC, 2014). Frequent pipe breaks and insufficient maintenance services are common and these increase the risk of microbial contamination of potable water distribution systems (Chowdhury, 2012; Benser *et al.* 2011; Luyt *et al.* 2011). Soil particles can thus enter water distribution systems causing microbial contamination of potable resources through leaks, thus affecting water taste, colour and odour. These characteristics play a large role in the public perception of water quality (Wright *et al.* 2012a). As a result of dwindling public confidence in public water supply systems, members of the public now frequently rely on alternative sources, such as bottled, spring, borehole or rainwater. Several cases of failures of public water supply systems were reported in South Africa, and in particular, the Eastern Cape Province (DWA, 2013). The Makana Local Municipality, in the Eastern Cape, where Rhodes University is located ranked 7th in potable water service delivery in the province with very low frequency of compliance monitoring (Tandlich *et al.* 2013; Velaphi, 2014). The non-compliance in monitoring increases the levels of dissatisfaction of inhabitants regarding quality of potable water (PSAM, 2014). Such disaffection forces the citizens to turn to alternative water sources, such as rainwater and rivers.

Several studies have shown that the concentration of indicator microorganisms in rainwater often exceed regulatory limits for human consumption (Luyt *et al.* 2013; Amin *et al.* 2011). Indicator bacteria are used as surrogates for routine water quality assessment. The indicator bacteria are mostly of the Enterobacteriaceae family, of which the total coliform group is a subset consisting of *Escherichia ssp.*, *Citrobacter spp.*, *Enterobacter spp.* and *Klebsiella spp.* (Rompré *et al.* 2002, José Figueras & Borrego, 2010). It is therefore important that microbial quality of water be monitored regularly (Health System Trust, 2011; Gillip, 2014; UN, 2012). If microbial contamination, such as faecal contamination is detected then water should be subjected to minimum treatment, such addition of bleach prior to human consumption (Murray *et al.* 2004). Awareness about minimum treatment and regular monitoring of microbial quality of water need to be accomplished, even in resource-limited environments, using a community-based microbial water quality monitoring approach. Community monitoring has been used to track changes in river pollution and extend the monitoring power of the government, even though the data is not used for legal purposes (Wilson-Jones, 2012; Savan *et al.* 2003). Global Water Watch (GWW) provides assistance to the US Environmental Protection Agency using registered volunteer community-based monitoring groups (Auburn University and Global Water Watch, 2012). Water Watch (WWW) helps to assist NGOs set-up water monitoring, protection or restoration of environment groups (DWA, 2012). Governments are often constrained both financially and by skilled manpower. The use of trained community members allows people to get involved and to make a difference by decreasing pollution (Savan *et al.* 2003; Overdevest *et al.* 2004). The chapter describes the training of community members employed by the municipality but also the training of volunteers from a local NGO. The approach described in this chapter involves the monitoring and training of environmental personnel employed by the Makana Local Municipality (Whittington-Jones *et al.* 2011; Tandlich *et al.* 2011).

A two-fold strategy was followed in the recruitment of the volunteers for this project on the use of the improved H_2S test kit (referred to as test kit in further text). The first involved making contact with the Kowie Catchment Campaign (hereafter KCC) in the western part of Grahamstown; and the second involved contacting the Makana Local Municipality staff for the eastern part of Grahamstown (a previously disadvantaged area). Prior to this study, there had been previous contacts with KCC regarding microbial water-related issues in the past. An important factor for considering KCC was that most KCC members have rainwater tanks istalled in their households, enabling easy access to rainwater tanks sampling sites. KCC also provided a context to gain insights into major uses of, and public health threats emanating from rainwater consumption in Grahamstown. The first part of the project involving engagement with KCC was undertaken in the western part of the Grahamstown (the main town in the Makana Local Municipality). The second part of the project initiated in May 2013 involved engagement with staff of the Makana Health and Environment Department. The general outline of the project was provided to the municipal official and the potential use of the test kit discussed. Through these meetings and engagements, a group of local youth were recruited by the municipality from the low-income segment of the population for training in environmental monitoring and management. The group was made up of youth that was trained to gather data on littering in public areas and biodiversity in the parks managed by the local municipality. Seventeen youth community members (i.e., project participants, hereafter referred to as trainees) were trained. All trainees had secondary school education. In the course of the study, it was thus decided that involvement with the group offers the best avenue for rolling out the microbial water quality test kits.

6.1.1. Hydrogen sulphides kit

The hydrogen sulphides (H_2S) test kit was used for monitoring microbial water quality in the community-based approach followed in this study. The H_2S strip test allowed for the detection of hydrogen sulphide producing bacteria. Positive confirmation indicated that the water source, in this case rainwater, contained faecal matter and thus potentially harmful to human health when consumed (Luyt *et al.* 2011a). The H_2S strip test is a bottle with a piece of paper impregnated with nutrients. The paper released the nutrients into the water once the sample was added and the kit hand-shaken, allowing the bacteria to grow. The bottles were usually kept at room temperature in a sunlight protected box. The hydrogen sulphide strip test (H_2S strip test) was designed to be used in rural settings at ambient temperature (25°C).Thus, an incubator is not required, and requires minimally trained people (Jagals, 2003). The H_2S strip test had many different incarnations, and no version is standard. Microbes belonging to the *Enterobacteriaceae* group produced hydrogen sulphide by the reduction of sodium thiosulphate (Sobsey & Pfaender, 2002). The method has been used in other countries e.g. Bangladesh (Gupta et al. 2008). It is well-suited to tropical and temperate regions (Sobsey & Pfaender, 2002).

A positive result was visualised by the formation of an iron sulphide precipitate which caused the medium to turn black within 72 hours of sample collection (Gupta *et al.* 2008; Genthe & Jagals, 2003). The precipitate is produced as a result of the reaction between hydrogen sulphide ferric ammonium citrate and the group of *Enterobacteriaceae* microbes that produce hydrogen sulphide by the reduction of sodium thiosulphate. The H_2S strip test was used to identify faecal contamination in the in various water bodies and the relation to other bacterial culturing methods, as well as its viability as a cheap method for the community to use. This test is far cheaper than culturing or enzymatic methods (Luyt *et al.* 2011a) and does not require highly trained technicians to perform the test which can be done on site with no incubation equipment required (Genthe & Jagals, 2003).

NEGATIVE POSITIVE

Figure 6.1: The illustration of the results interpretation of the hydrogen-sulphide test kit.

6.1.2. Community based approach in water monitoring program

South Africa has a shortage of people to monitor water, and ther a result there is little data available to make public health decisions (Luyt *et al.* 2011a). Citizens have been continuously taking municipalities to court over water issues (Raymer & Buckle, 2010), for example, Kirkwood in the Sundays River Valley Municipality (du Plessis & Ndlangisa, 2014) and the Rustenburg rate Payers Association (Moore, 2015). Not only is South Africa a water-stressed country (Quinn *et al.* 2011; Otieno & Ochieng, 2004; Seckler *et al.* 1999), but Grahamstown is also a water scarce region (DWAF, 2004, 2006).

In trying to improve drinking water quality, the South African National Department of Water Affairs introduced the blue drop certification programme that uses incentive to encourage and promote excellence in the entire value chain of drinking water quality treatment and management (DWAF, 2012). Based on the blue drop programme, drinking water quality must comply with South African National Standards (SANS) 241.2006 criteria. The programme also promotes communication of water quality results between water services providers, authority, and consumers. Thus, through the programme, water quality results can be communicated to rural dwellers (Wilson-Jones & Rivett, 2012). Thus, the use of the H2S test kit in community monitoring approach can help raise awareness about water quality among community members. The H2S test was provided for in the DWA blue drop certification programme provided no other methods are possible. When H2S is used, positive results must be confirmed with ColilertTM (DWAF, 2009).

The South African National Water Resources Strategy (NWRS) provides room for the design and implementation of monitoring programmes, for example, including the National Microbial Monitoring Programme and the Adopt-a-River Programme (Rossouw *et al.* 2006). These programmes are used for planning and policy making, and are governed by strict quality control procedures (DWA, 2009). These programs assist in monitoring streams, rivers, lakes, reservoirs and other aquatic environments).

6.2. Materials and methods

In Makana Municipality where public perception of poor water quality is high, a multidisciplinary approach is needed to prevent health problems that could emerge as a result of drinking water of poor quality (Waring & Brown, 2005). Public health teams need an epidemiologist and environmental health specialist as members (Connolly, 2005). The water supplied or used needs to be assessed for quality and adequate treatment needs to be identified (Connolly, 2005). Water needs to be distributed through the most appropriate source, ensuring availability of sufficiently good quality water (Connolly, 2005). Al-Jayyousi *et al.* (2010) highlighted the value of knowledge management in greywater reuse. The authors presented a model of knowledge management that shows how institutional knowledge can be created in water management, and concluded that water knowledge is created through developing a process of transforming water implicit knowledge to explicit knowledge. Lack of the information and inadequate sanitation may result in an increased outbreak of waterborne diseases.

6.2.1. Preparation of the H_2S sampling kits

The H_2S kit was prepared using the method described by Luyt *et al.* (2011a), which was modified by the addition of deoxycholate (0.5% w/v) that inhibit non-faecal bacterial growth, decreasing false positive result occurrence. This kit contained peptone (40g), dipotassium hydrogen phosphate (3g), ferric ammonium citrate (1.5g); sodium thiosulphate anhydrous (2 g); Teepol (2 mL), L-cysteine (25 mg); distilled water (100 mL). The medium was mixed with a magnetic stirrer for 30 minutes and then left to stand for 15 minutes forming a coffee brown colour. A one millilitre aliquot was absorbed into a 5 cm by 10 cm piece of filter paper which had been folded and placed into a sterile urine jar (Spellboud Labs, Port Elizabeth, South Africa). The jars with the filter paper were placed into the UFE 700 oven (Memmert, Schwabach, Germany) overnight at 54°C. The H_2S strip tests had 20 mL of sampling water placed aseptically into the bottles. These were sealed and hand shaken to suspend the media, before being incubated at room temperature (18-25°C) for 72 hours. Samples were checked for the presence of a black precipitate, which was recorded as a positive result, every 12 hours. The remaining the initial yellow colour or which turned grey without going black within the 72 hour time limit were tested and recorded as negative.

6.2.2. A community-based rainwater monitoring and treatment programme

The first phase of community-based monitoring and treatment programme was based on the combination of the modified hydrogen-sulphide test (hereafter referred to as e test kit) (Luyt *et al.* 2011). The pamphlet detailing the sources of faecal contamination and treatment of rainwater tanks was designed using literature data and applied as source of reference information to educate the community (see Appendix 2 for details) (Luyt *et al.* 2011). Control samples were taken and analysed using the test kit and the *E. coli* concentration on the m-TEC selective agar (Sigma-Aldrich, Johannesburg, South Africa). This was done to obtain reference data for the applicability of the test kit in relation to regulatory data water quality data.

Bacterial enumerations, sterilisation, and samples processing were performed as described by Tandlich *et al.* (2011). The volunteers were recruited through collaboration with a local non-governmental organisation (NGO), the Kowie Catchment Campaign (referred to as KCC in further text). Firstly, the chairperson of the KCC was contacted and a dedicated e-mail list was set up with KCC membership and the authors. This e-mail list was then used to recruit particular volunteers with an installed rainwater tank from amongst the KCC membership. A total of eight volunteers from the KCC membership took part and were given seven test kits each. A short introduction into the principle of the test kit took place and the sampling procedure was demonstrated to the volunteers by the project team. Agreement was made that one rainwater tank per household would be sampled by the volunteers once a week for six to seven weeks. Members of the project team would come and sample each rainwater tank on two or three occasions throughout the six-week sampling period. The aims of these visits were to get feedback from the volunteers on the use of the test kits and their experiences with their rainwater. The authors also provided the volunteers with opportunities to report on any problems that arising.

The samples taken by the project team was subjected to the enumeration of *E. coli* (the standard indicator microorganism for faecal contamination of potable/drinking water in South Africa) and the test kit procedure. These samples are termed control samples in further text. The aim of the control samples was to determine the rate of correspondence between the test kit positive results and the m-TEC agar which is commercially available for the enumeration of E. coli. Such determination were recently done for the m-FC agar, but more correspondence rate data is needed to widen the acceptability of the test kit by the water regulatory community in South Africa (Tandlich *et al.* 2012; Luyt *et al.* 2011). After the inaugural meeting, the volunteers were emailed the pamphlet on maintenance and treatment of rainwater. The dedicated email list was used as the primary communication avenue and the dissemination avenue for results during the remainder of the project.

6.2.3. The use of hydrogen-sulphide test kit to monitor faecal contamination of various water sources

Seventeen youth members from the Makana Local Municipality attended the workshop. Two pamphlets were handed out, one detailing the sources of faecal contamination. A wastewater pamphlet about waste water treatment was compiled based on literature and distributed to the participants. The second pamphlet contained the information about the kit and the use of the H_2S strip kit (Luyt *et al.* 2011). These pamphlets were applied as the reference information to educate the community. The first step was to familiarize the participants with laboratory health and safety issues. The primary objective was to provide a safe, accessible environment within the laboratory and for trainees to conduct their work with maximum flexibility for safe research and teaching. The participants were given a background on the sources of faecal contamination of water resources; waterborne diseases; wastewater treatment; water quality and water testing. Participant exposure to the above mentioned information was through lectures, videos, pamphlet and questionnaires (see Figure 6.1). Water sampling demonstration was conducted within Rhodes University premises on different sites including bathroom water and tank water.

The participants were divided into four groups each with four people. Formal lecturing sections were held with the trainees, followed by a laboratory demonstration on how to manufacture the kit. The sampling demonstration was done at Rhodes University to familiarize the participants on how to take samples. This was done by sampling kitchen greywater, bathroom greywater and rain water tank in the Faculty of Pharmacy at Rhodes University. All the participants were each given four test kits to take home for water sampling at designated sites. Control samples were taken and analysed using the test kit. This was done to obtain reference data for the applicability of the test kit in relation to regulatory water quality data. The samples were collected from the eastern part of Grahamstown. Specific sampling points included household taps, household tanks, communal taps, communal tanks, community halls and schools. This was done to test if the skill has been implemented thoroughly. Follow up write up (assignment) and presentations were done in order to test participant's articulation skills.

On each workshop day, participant had a focus group discussion, providing verbal input about the program, and also filling out questionnaire to provide feedback on the usefulness of the test kit and their experience of the water issues in their local community (see Appendix 2B). When participants alluded to any water quality issues, they were provided with necessary information regarding the solution to such issues.

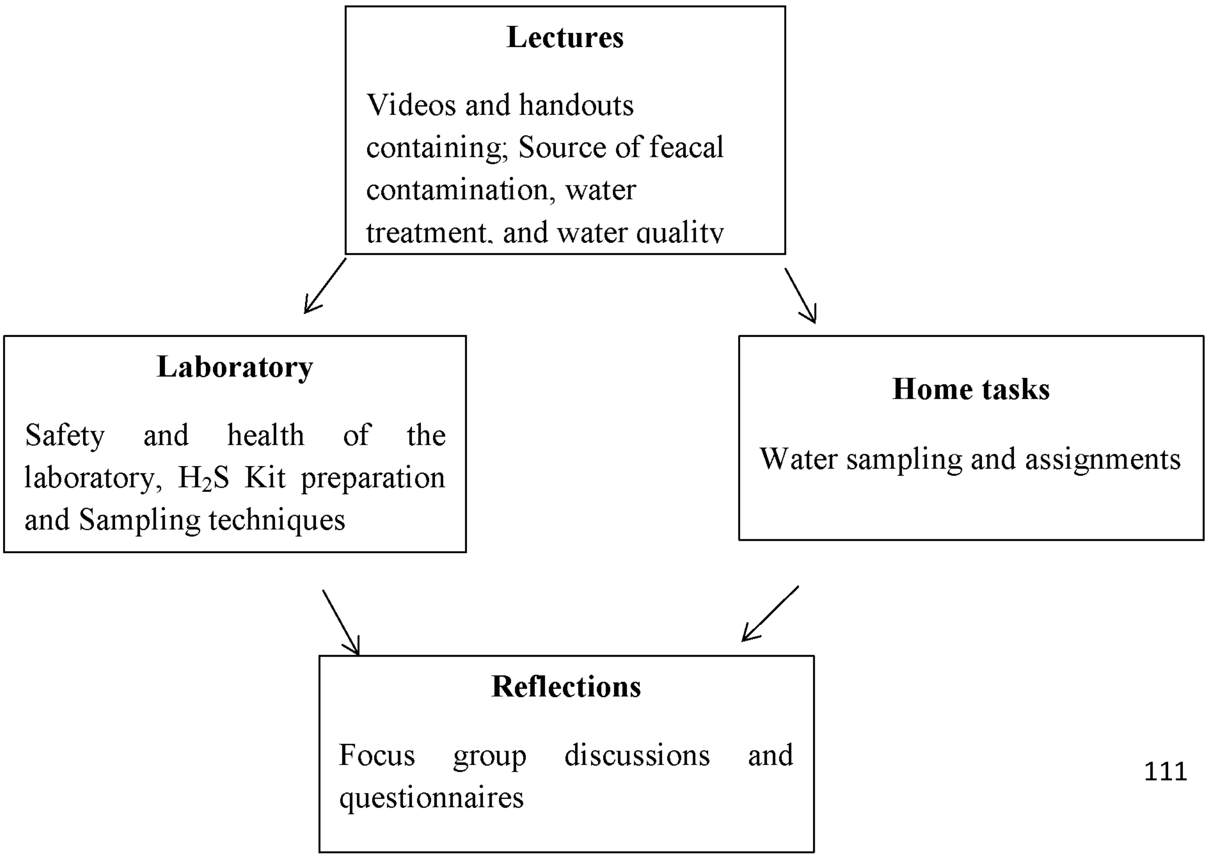


Figure 6.2: Schematic model of basics steps performed in a community based approach

6.3. Results and discussion

The first phase: Seven out of the original eight volunteers from KCC maintained contact and continued the testing or feedback for the duration of the six-week agreed sampling period. A total of eight rainwater tanks were sampled where one volunteer sampled two tanks due to an urgent need for microbial water quality data. In two of the seven households, the rainwater tank was connected to the household water supply and used for potable purposes throughout the duration of the sampling period. In the remaining five households, the rainwater tanks had outside dispensing taps and the rainwater was only used as emergency supply during water outages.

No cases of diarrheal diseases were reported by the volunteers during the six-week sampling period. The results from the sampling using the test kits and the control samples are shown in Tables 6.1 and 6.2, respectively. Between four and seven samples were taken by the volunteers, giving a total of 55 samples using the test kit. No microbial contamination was found in four out of the eight sampled water tanks. The remaining four tanks were positive for faecal contamination in one or two occasions. The problems were communicated by the volunteers to the authors and advice was given to dose the bleach into the rainwater tank according to the pamphlet in Appendix 2A. In all cases, the follow-up samples were negative using the test kit.

Table 6.1. Results of the test kit sampling by volunteers in the respective rainwater tanks

Number of positive volunteer test kit samples	Number of volunteer test kit samples taken	Tank description	Site number
0	7	Rainwater tank with connection to household water supply	1
1	7	Outside rainwater tank, no connection to household water supply	2
0	4	Outside rainwater tank, no connection to household water supply	3
0	7	Outside rainwater tank, no connection to household water supply	4
2	7	Outside rainwater tank, no connection to household water supply	5
0	7	Outside rainwater tank, no connection to household water supply	6
1	5	Outside rainwater tank, no connection to household water supply	7
1	7	Rainwater tank with connection to household water supply	8

Table 6.2. Results of the control samples and the description of interventions to remedy microbial rainwater quality problems.

Control *E. coli* (CFUs/ 100 mL)	Positive control test kits	Control samples taken	Treatment	
< 0	0	1	None	1
< 0	2	2	1 Bleach addition by the volunteer and 2 additions after the control sample results were communicated by the project team	2
0-4	2	2	1 Bleach addition after the control sample results were communicated by the project team	3
< 0	0	2	None	4
0-35	1	2	1 Bleach addition by the volunteer and 1 addition after the control sample results were communicated by the project team	5
< 0	0	1	None	6
0-4	0		1 Bleach addition by the volunteer and 1 addition after the control sample results were communicated by the project team	7
< 0	0	1	1 Bleach addition by the volunteer	8

The volunteers found the test kit and the pamphlet easy to use. Remedial action was done on-site when needed. 87.5% of the original volunteers completed the sampling in the scope of this project, even though 25% of all volunteers did not sample every week as agreed at the start of the project. Overall the programme did deliver the desired results and provides a paradigm for microbial rainwater quality monitoring in rural municipalities with low where local government find it difficult to comply with monitoring frequency in terms of regulation.

.

The control sample results indicate that the problems in the microbial quality of the rainwater tested were detected by the volunteers themselves, as well as the project team (see Tables 6.1 and 6.2 for details). The *E. coli* concentrations ranged from between 0 and 35 colony-forming units/100 mL (designated CFUs/100 mL in further text) and the correspondence rate between the test kit results and the *E. coli* enumeration was 71%. The concentrations of *E. coli* in Grahamstown rainwater was previously reported ranging from 0-1 CFU/100 mL (DWAF, 1996). Thus the data from this study spans a wider interval in comparison to literature data. The *E. coli* concentrations indicated that the rainwater should not be used for drinking and domestic uses unless chlorination or boiling is done prior to treatment (Tandlich *et al.* 2011).

The second phase: Grahamstown East. The trainees were very enthusiastic and participated during the lecture by asking and answering questions. After receiving the kits the group took a serious initiative and went around the community to collect samples. 0f the total of 44 collected samples, 92% were negative and 8% positive (see Table 6.3). The positive results were from the preschool tanks, a communal taps, and the river (see Figure 6.2). The data from these areas indicated that the water from these sources should not be used for drinking and domestic uses unless chlorination or boiling is performed first. This is based on the medium to high risk to human health (SADWAF, 1996).

Rainwater is relatively free from impurities compared to the river water except those picked up by rain from the atmosphere, however the quality of rainwater may deteriorate during harvesting, storage and household use (Luyt *et al.* 2012). Factors, such as wind-blown dirt, leaves, faecal droppings from birds and animals, insects and contaminated litter on the catchment areas can be sources of contamination of rainwater, leading to health risks from the consumption of contaminated water from storage tanks. The risks from these hazards can be minimized by good design of hygiene practice.

Table 6.3: Results of the test kit sampled by volunteers in the respective sampling sites

Positive (+) or	Negative (-)	Number of samples	Sampling sites
1	21	22	Street tap
0	8	8	House hold tap
1	1	2	School tank
0	3	3	House hold tank
1	2	3	Communal tank
2	0	2	River (Stream)
0	1	1	Drum

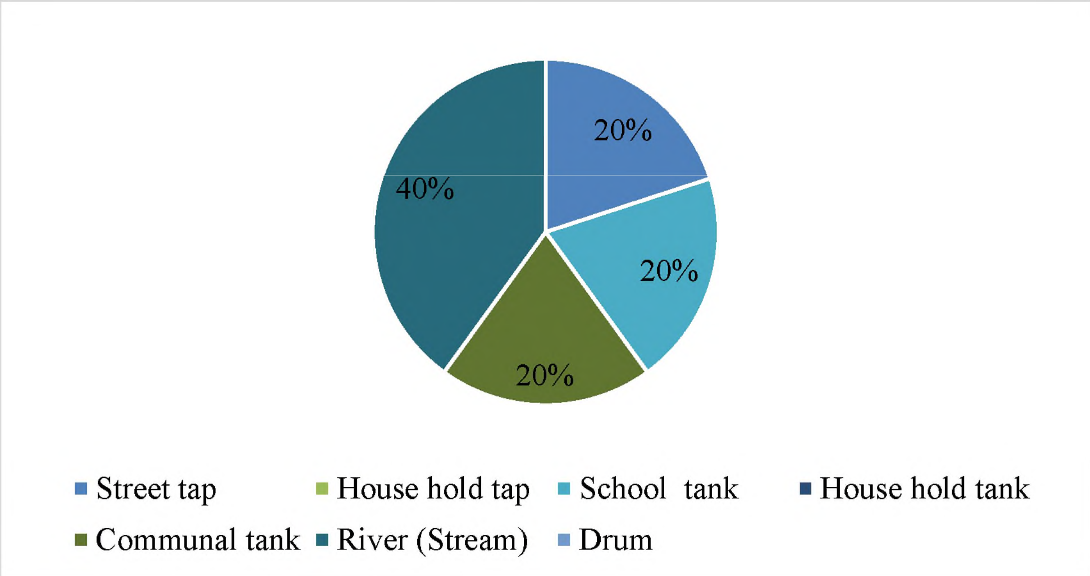


Figure 6.3: Faecal contaminated water sources sampled during the workshop

Figure 6.4: Communal tap sampled during the workshop

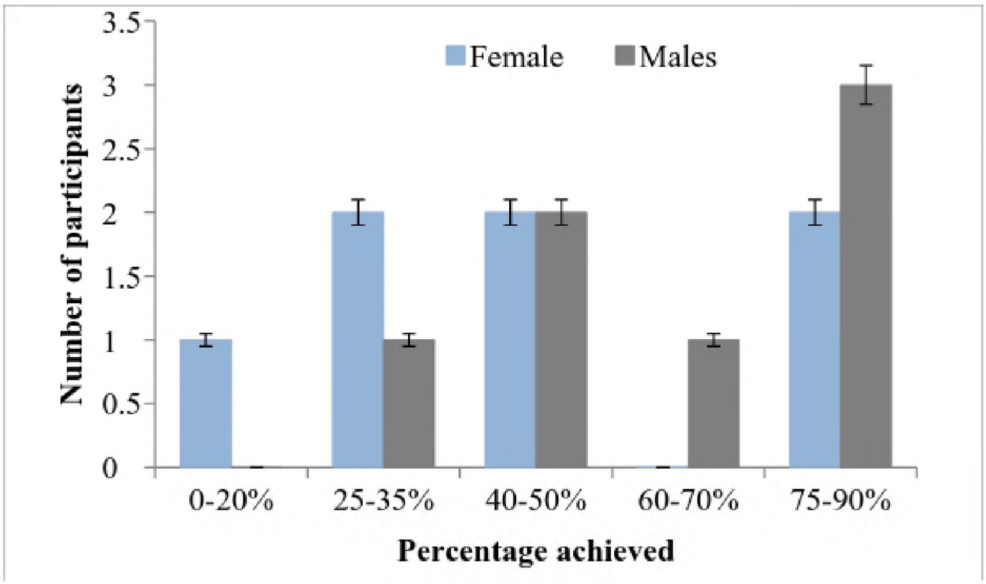


Figure 6.5: Percent trainee's a performance in understanding of background information provided regarding microbial water quality during the workshops

The communal tap with positive results is located in a farm area with 33 households that live in informal settlements, and all these households depend on one communal tap with inadequate sanitation (Figure 6.3). Inadequate sanitation may result in an outbreak of waterborne diseases. Unreached by public services, people in rural and peri-urban areas of developing countries make their own arrangements for water services or pay excessively high prices to water vendors for meagre water supplies.

The stream was positive because of sewage leaks and the concern was that this water is going through the stream to Kowie River where some of the community members use its water for domestic purpose. Lack of access to safe drinking water and basic sanitation can have a strong positive effect on human health, the development and management of water resources as a whole has significant health implications. The impact of deficient water and sanitation services falls primarily on the poor (Murray *et al.* 2004).

Presentations were conducted to test the articulation skills trusting that the participants will build presentation skills and be able to present what they have learnt to the community. While the sampling task, preparation use the kit was marked out of 20 marks (see Figure 6.3) 50% of the participants enjoyed calculations and learned that they have to be precise with their measurements, whilst the other 50% were unable to calculate their results because of poor mathematic backgrounds. Reflective sessions undertaken with participants revealed that participants enjoyed the experience of being exposure to an advanced laboratory environment compared to their previous experiences in high school laboratory environments (Wolf, 2014). Wolf (2014) state the emergency need of empowering communities through corporate social responsibility using the case of China, India and Australia. Having previously experience water quality problems in their communities, participants were keen in acquiring more knowledge about waste and wastewater treatment. It is believed that the knowledge acquired will be put to use and be of benefit to their communities as majority of the participants were environmental facilitators, dealing local environment issues. The training provided an insight by highlighting some new aspects that affect the environment. From the questionnaire the participants indicated that the H_2S kit could be a benefit to everyone from Makana Municipality. Participants most liked being in the lab and calculations were least liked. They imagined themselves teaching the children up until their youth (from 5-35 years old) at the township either in a community hall or a community school about the H_2S kit. This encourages the need of empowerment not only for gender equity, but also for the economic sustainability of global primary industries (Marslen, 2015). 40% of the participants indicated not clearly understood the term water quality, though the implications were noted as health and recycling water.

Poor communities are believed to be the ones that are mostly affected by water quality, especially children and women. The assumption is that the municipality is responsible for the water quality and they believe that since municipality is involved with water treatment they are liable to make sure that safe water reaches everyone (Dennis, 2013). There is a shortage of people in South Africa who skilled to monitor water, thus little data available to make public health decisions. Citizens are taking municipalities to court over issues of sanitation and water (Luyt *et al.* 2011a; Raymer & Buckle, 2010). Rhodes University as the research institution is also capable of assisting the community (Luyt e*t al.*, 2011). Water quality can be improved or prevented by saving water, by community work together with the stakeholders and improved infrastructure. The use of community monitoring programmes may increase the community's perception of service delivery and water quality (Wilson- Jones & Rivett, 2012). There is no local information available with regard to water quality. However, there are programs in place to meet the needs of the community. There are rain water tanks installed in the streets and schools and there is an ongoing communication between the community and the municipality, such as alerting the members when there will be no water.

6.4. Concluding remarks

An information pamphlet was designed on the contamination sources of rainwater and the modified test kit was successfully used by the NGO volunteers to detect faecal contamination. The modified hydrogen-sulphide test kit and a combination of the E. coli enumerations correctly identified microbial water quality problems. Collaboration between the authors and the community volunteers assisted in remedying problems. The correspondence rate between the m-TEC E. coli enumeration and the hydrogen-sulphide test kit was 71%. A community based approach to investigate the microbial quality from various resources was conducted to create the community awareness and promote their engagement with water related issues. The workshop was designed to inform the participants about the microbial contamination of various water sources and detections using the hydrogen sulphide test kit. The kit was used to identify microbial water quality problems. The participants followed the theory. The practical assignment, however, posed a challenge for only 33% of the participants managed to get above 50%.

Samples were collected from house taps, tanks, communal taps, community halls and schools. The results show that the majority (92%) of the sampled water were negative, and 8% were positive, respecticely when tested for faecal contamination. The questionnaire revealed that participants perceived the H2S kit as a tool that might be beneficial to the community. The model was perceived as one that could be applied in Makana for rainwater awareness and quality monitoring programmes. It could be a vehicle for the roll-out of the water hyacinth modified fly ash lime filter tower (this will be described in Chapter 7). Lack of the information and inadequate sanitation may result in an increased outbreak of waterborne diseases. The community based approach can be utilised as a platform that could elucidate water issues in communities.

6.5. References

Abou-Elela S.I., Kamel M.M. and Fawzy M.F. (2010). Biological treatment of saline wastewater using a salt-tolerant microorganism. *Desalination* ,250: 1–5.

Al-Jayyousi, O.R. (2010). Greywater use: Islamic perspectives. In: *Greywater Use in the Middle East. McIlwaine and Redwood* (eds). IDRC.

Amin T. and Han M. (2011). Domestic Rainwater Harvesting as an Adaptation Measure to Climate Change in South Africa. Austr. *J. Bas. Appl. Sci*, 5, 1804-1813.

Besner M.-C., Prevost M. and Regli S. (2011). Assessing the public health risk of microbial intrusion events in distribution systems: Conceptual model, available data, and challenges. *Wat. Res*, 45(3), 961-979.

Bulcock, L.M. and Schulze, R.E. 2011. Climate Change and a Case Study in Rainwater Harvesting: A 2011 Perspective. In: Schulze, R.E. 2011. A 2011 Perspective on Climate Change and the South African Water Sector. Water Research Commission, Pretoria, RSA, WRC Report 1843/2/11, Chapter 8.4, 249-254.

Chowdhury S. (2012). Heterotrophic bacteria in drinking water distribution system: a review. Environmental Monitoring and Assessment, 184, 6087-6137.

Dennis N. (2013).Water education and institutional development: Reaching Water Security through Cooperation UNESCO, 2013, ISBN 9231042564, https://books.google.co.za/books?id=hQZqAQAAQBAJ&pg=PA127&lpg=PA127&dq=empowering+the+community+through+the+workshops+in+water&source=bl&ots=t_PyVYzWTY&sig=_uoUWstDbv75gIRUf8eBs2NSSzA&hl=en&sa=X&ei=WqbpVJBHsbuUpOpgogP&ved=0CEYQ6AEwBzgK#v=onepage&q=empowering%20the%20community%20through%20the%20workshops%20in%20water&f=false

DWAF (2009). A Drinking Water Quality Framework for South Africa: Minimum Requirements for Blue Drop Certification Blue Drop Certification Requirements. Pretoria, South Africa: Department of Water Affairs and Forestry.

Department of Performance Monitoring and Evaluation (DPME) (2013). Quality of Sanitation in South Africa: Final Report on the Status of Sanitation Services, The Presidency, Republic of South Africa.

Figueras J.M. and Borrego J.J. (2010). New perspectives in monitoring drinking water microbial quality. *International Journal of Environmental Research and Public Health*, 7, 4179-4202.

Gillip J.A. (2014) Characterization of the structure, clean-sand percentage, dissolved-solids concentrations, and estimated quantity of groundwater in the Upper Cretaceous Nacatoch Sand and Tokio Formation, Arkansas: U.S. Geological Survey Scientific Investigations Report 2014-5068: 23.

Luyt C. D., Muller W. J. and Tandlich R. (2011). Factors influencing the results of microbial surface water testing in South Africa. *Int. J. Med. Microbiol*, 301(S1): 28-29.

Luyt C. D., Tandlich R., Muller W. J. and Wilhelmi, B. S. (2012). Microbial monitoring of surface water in South Africa. *Int. J. Environ. Res. Pub. Health*, 9(8), 2669-2693.

Marslen T. (2015). Empowering Women in Agriculture: Australia and Beyond, Global Food and Water Crises Research Programme. *Strategic Analysis Paper*.

Meays C. L., Broersma K., Nordin R. and Mazumder A. (2004). Source Tracking Fecal Bacteria in Water: A Critical Review of Current Methods. *J. Environ. Manage*. 73, 71-79.

Murray K.., du Preez M., Kuhn A. L. and van Niekerk H. (2004). A pilot study to demonstrate implementation of the national microbial monitoring programme, WRC Report No. 1118/1/04; Water Research Commission: Pretoria, South Africa.

Nygård K., Wahl E., Krogh T., Tveit O. A., Bøhleng E., Tverdal A. and Aavitsland P. (2007). Breaks and Maintenance Work in the Water Distribution Systems and Gastrointestinal Illness: A Cohort Study. *Int. J. Epidemiol*, 36(4), 873-880.

OVerdevest C., Orr, C.H. and STEPENUCK K. (2004). Volunteer stream monitoring and local participation in natural resource issues. Human Ecology Review, 11, 177-185.

Parliamentary Monitoring Group (PMG, 2009). Regional Departments of Water Affairs in Eastern Cape, Western Cape and Limpopo on their Support to Local Municipalities. Available at: http://www.pmg.org.za/report/20090909-briefings-regional-departments-water-affairs-eastern-cape-western-cap (website accessed on 19th August 2013).

Public Service Accountability Monitor (PSAM) (2014). 25th August 2014. Accessed 27th October 2014: Available at http://www.psam.org.za/press-release/1544/open-letter-with-regard-to-governance-andaccountability-failings-in-makana-municipality-that-require-provincial-government-intervention-inaccordance-with-section-139-of-the-constitution-.htm

Quinn C. H., Ziervogel G., Taylor A., Takama T. and Thomalla F. (2011). Coping with Multiple Stresses in Rural South Africa. *Ecol. Soc*, 16(3), 10.

Raymer D. and Buckle J. (2010). We are facing a water and sanitation crisis in South Africa. WISA 2010 Biennial Conference & Exhibition. Durban, South Africa: *Water SA*.

Rompré A., Servais P., Baudart J., DE-Roubin, M.R. and Laurent P. (2002). Detection and enumeration of coliforms in drinking water: current methods and emerging approaches. *Journal of microbiological methods*, 49, 31-54.

Rossouw L., Februarie D.A., and water research commission (2006). *Guidelines for implementing volunteer water quality monitoring in South Africa,* Gezina, South Africa, Water Research Commission.

Savan B., Morgan A.J. and Gore C. (2003). Volunteer environmental monitoring and the role of the universities: the case of Citizens' Environment Watch. *Environmental management*, 31, 561-568.

SAICE and CSIR (2011). SAICE Infrastructure Report Card for South Africa,.http://www.csir.co.za/enews/2011_jun/download/infrastructure_report_card_sa_2011. pdf, 14

Seckler D., Barker R. and Amarasinghe U. (1999). Water Scarcity in the Twenty-first Century. Int. J. Wat. Res. Develop., 15(1-2), 29 - 42.

South African National Department of Water Affairs (2011). Blue Drop System: Makana Local Municipality. Available at: http://www.dwa.gov.za/dir_ws/DWQR/Default.asp?Pageid=42&WQDate=2011/12/15&Provid=2&WSACode=EC104 (website accessed on 19th August 2013).

South African National Department of Water Affairs and Forestry (1996). South African Water Quality Guidelines, Vol. 1 (Domestic use) In: Department Of Water Affairs And Forestry (Ed.). Pretoria (RSA) Department of Water Affairs and Forestry, Pretoria, South Africa.

South African human right commission (SHRC) (2014). Report on the Right to Access Sufficient Water and Decent Sanitation in South Africa: Accessed in 01 January 2015:

http://www.sahrc.org.za/home/21/files/FINAL%204th%20Proof%204%20March%20-%20Water%20%20Sanitation%20low%20res%20(2).pdf

Statistics South Africa (2011). Water and Sanitation 2002–2010: In-Depth Analysis of the General Household Survey data. GHS Series. Pretoria, South Africa: Statistics South Africa, Pretoria, South Africa.

Statistics South Africa (2011). General Household Survey 2010 Revised version ed. Pretoria, South Africa: Statistics South Africa, Pretoria, South Africa.

Tandlich R., Chirenda T. G., Srinivas C. S. (2013) Gender aspects of disaster management in South Africa, *Journal of Disaster Risk Studies*, 5(4): 84.

Tandlich R., Luyt C. D., Gordon A. K. and Srinivas, C. S. (2011). Concentrations of indicator organisms in the stored rainwater in the Makana Municipality, South Africa. Published in the peer-reviewed proceedings from the Air and Water Components of the Environment Conference held in Cluj, Romania from 23rd until 24th March 2012, pp. 89-96 (ISSN: 2067-743X).

United Nations (2012). The Millennium Development Goals Report 2012. New York, United States of America: United Nations.

Velaphi S. (2014). Makana under administration for 3 months.The New Age Newspaper. Access 27th October 2014: Available at http://www.thenewage.co.za/136231-1016-53-Makana_under_administration_for_3_months

Waring, S. C. and Brown, B. J. 2005. The Threat of Communicable Diseases Following Natural Disasters: A Public Health Response. *Disaster Management & Response*, 3, 41-47.

Wilson-Jones, T. and Rivett U. (2012). Using Mobile Phones To Monitor And Manage Water Supply Quality In Rural Environments. WISA 2012 Biennial Conference & Exhibition. Cape Town.

Wolf R. (2014). Empowering Organizations through Corporate Social Responsibility. IGI Global, ISBN 1466672951, 9781466672956, page 206-305.

Wright J.A., Yang H., Rivett U. and Gundry S.W. (2012a). Public perception of drinking water safety in South Africa 2002-2009: a repeated cross-sectional study. BMC Public health, 12, 556

CHAPTER 7: TECHNO ECONOMIC ANALYSIS OF THE FLY ASH LIME FILTER TOWER

In this chapter, the general socio-techno-economic key factors and activities of relevance for the development of a sustainable greywater treatment system were explored. There is a need for incorporating a business model framework to enable decision making in value creation and value capturing. This study showed that the Fly Ash Lime Filter Tower (FLFT) has great potentials to reach a broad market via the key partner networks. Through the use of the recycled resources explored in Chapters 3; 4 and 5, customers can build their own virtual FLFT system, making it easier and cheaper for them to perform tests before the technology enters the market. The FLFT system is evaluated for both short-term perspective and long-term sustainability.

7. Introduction

On-site greywater treatment fly ash lime filter tower (FLFT) was developed through two PhD and an honours projects undertaken at Rhodes University. The FLFT was developed to treat greywater (domestic wastewater excluding toilet inputs) in areas that lack proper wastewater conveyance system, such as informal settlements and rural areas of South Africa (Zuma *et al.* 2009). Makana municipality, situated within the Cacadu district in the Eastern Cape of South Africa frequently experiences supply of water of poor quality compared with quality standards recommended by the South African Department of Water and Sanitation (Tandlich *et al.* 2014). Although since 2004 access to water and sanitation infrastructures within the Makana municipality has increased, increasing demand as a result of growing number of informal settlements is placing further pressure on the supply system, leading in part to water shortages (Tandlich *et al.* 2013).

At the national level, since the advent of democracy, increased rural-urban migration has led to the proliferation of informal settlements in several urban South African centres. Although between 96% and 98% of people living in informal settlements have access to safe drinking water and improved basic sanitation services (defined as the on-site dry latrines, ventilated improved pits or similar toilet), solid waste and wastewater are still not properly treated and handle in most of these settlements in South Africa (Tandlich & Muller, 2008; Luyt *et al.* 2012).

Furthermore, water distribution pipe bursts and insufficient maintenance of infrastructures often limits the usability communal drinking water taps and other sources. Lack of qualified human capacity, inadequately skilled technical, and operational staff are argued as one of the major challenges facing water infrastructure failure in our communities. This in turn lead to the production of drinking water with high level of microbial contamination and even frequent interruption in water supply systems. For example, in 2010, about 48% of the households in South Africa experienced water supply interruption (Zuma *et al.* 2010; Luyt *et al.* 2012). In the years to come, municipal greywater will be expected to contribute substantially to both domestic and agricultural water use in South Africa. However, to achieve the full potentials of greywater reuse, it has to fulfil four main criteria (hygienic safety, aesthetics, environmental tolerance and economic feasibility) (Nolde, 1999; Li *et al.* 2009). The achievement of these criteria will depend on, among other factors, the technical and economic measures aimed at mitigating the risks associated with the implementation of greywater reuse.

The FLFT system treats greywater on-site through a series of filter layers including ash, biological material, coarse sand, fine and coarse gravel. The FLFT serves both as a filter in removing the suspended solids of greywater and as a site for biodegradation where the filtrate may be broken down by aerobic micro and macro organisms (as described in Chapter 3). Technology treats greywater, making it fit for reuse in crop irrigation and other domestic purposes, such as toilet flushing. Technology also enables proper handling and disposal of greywater (Ngqwala *et al.* 2013). In Chapters 5 and 6 greywater effluent from the FLFT system was evaluated for reuse in irrigation and the technology is efficient and reliable.

7.1. Study aim

In this chapter, socio-techno-economic key factors and activities for the future development of a sustainable greywater treatment system were explored. There is a need for incorporating a business model framework for enabling decision making in value creation and capturing. This study aims to show that the FLFT has great opportunities to reach a broad market. The partners and customers will get access to a great variety of technical competences as well as water technology resource for remote areas. Through the use of the recycled resources explored in Chapter 3; 4 and 5, customers can be responsible for their own virtual FLFT system which makes it easier and cheaper for them to maintain.

7.2. Technology need: Is there a problem of market need?

Technical and economic factors are important in determining the viability of a new technology (Adewumi, 2011; WHO (2006). Technical measures include the selection and implementation of the most suitable technology, determining downstream demand and preventive measures put in place to ensure that the use of recycled water in dual pipe schemes is environmentally sustainable (USEPA, 2005). South Africa produces over 500 000 m^3/day of greywater in the non-sewered areas (rural and informal settlements) (Luyt *et al.* 2012; Carden *et al* 2007). The benefit of using greywater could provide alternative water supplies for non-potable purposes. Greywater accounts for about 70% of volume domestic wastewater and its reuse without treatment in rural and densely populated communities is a common practice (Zuma *et al.* 2012). Untreated greywater has the potential to serve as a diseases-causing microorganism transmission medium. The actual public health risks will differ from site to site and the management of greywater generated at a particular site will, therefore, have to be tailored to site-specific conditions. Greywater disposal strategies are often neglected by local government and other relevant stakeholders. In South Africa, greywater is a known cause for nuisance and health threats in informal settlements where it ponds between houses and on the streets' drains (Olanrewaju, 2012). Therefore the technology presented here is tailor-made to address this by containing greywater at source of production, treating it for beneficiary use in vegetable gardens and educating communities about health and hygiene within their areas. This is more relevant to the province of the Eastern Cape which mostly rural and in towns consisting of lots of informal settlements without proper wastewater conveyance systems (Zuma, 2012; Luyt *et al.* 2012).

7.3. The filter tower technology product, process and the service

While economic measures involve employing various instruments to determine the economic feasibility of a proposed project, economic measures also consider the optimal use of limited resources, opportunities cost and comparisons between the competing technological options (WHO, 2006). The FLFT consist of the biological and physicochemical treatment components as follows: the fly ash/lime layer for the removal of the inorganic and organic components and for sterilising bacteria, biological layer for substrata surface for promotion of the biofilm development to facilitate organic matter biodegradation (Zuma *et al.* 2010; Pathan *et al.* 2003). The fly-ash is a by-product of the coal-fired power generation and pulping plants (Phukan & Bhattacharyya, 2003). The fly ash has a high potential to remove phosphate from greywater because of its calcium content. As a soil additive, fly ash can be used for improving soil's moisture holding capacity and it has also been shown to function as a zeolite for removal of the various heavy metals in water/wastewater treatment (Pathan *et al.* 2003; Jala & Goyal, 2006; Naik *et al.* 2009). In the fly-ash-lime filter tower with water hyacinth modification (FLFT), the biofilm acts as a biological barrier leading to increased biodegradation of easily-degradable components and, in some cases, even the recalcitrant compounds (see Chapter 4). The layer of fine sand mixed with silica sand was prepared to increase porosity while providing additional effluent treatment, that is, in a fashion similar to that of sand filtration. The stone layer was added to increase porosity at the bottom of the reactor.

Water hyacinth have been used to absorb pollutants in wastewater (Chen *et al.* 2010) to reduce the pH of the system as described in Chapter 4 and in Madikizela (2014). The FLFT is a cheap, low-technology and easy to operate and maintain flush through system and is designed to limit the potential for theft. This is based on the low-cost material used for the assembly of the FLFT. The technology is chosen as carrying the potential for the development of the on-site and appropriate greywater treatment system in informal and rural settlements for direct use in homes and schools and related institutions gardens. Greywater will be collected from the residence near the FLFT physical location. The reactor will be fed daily with greywater from the donor household(s).

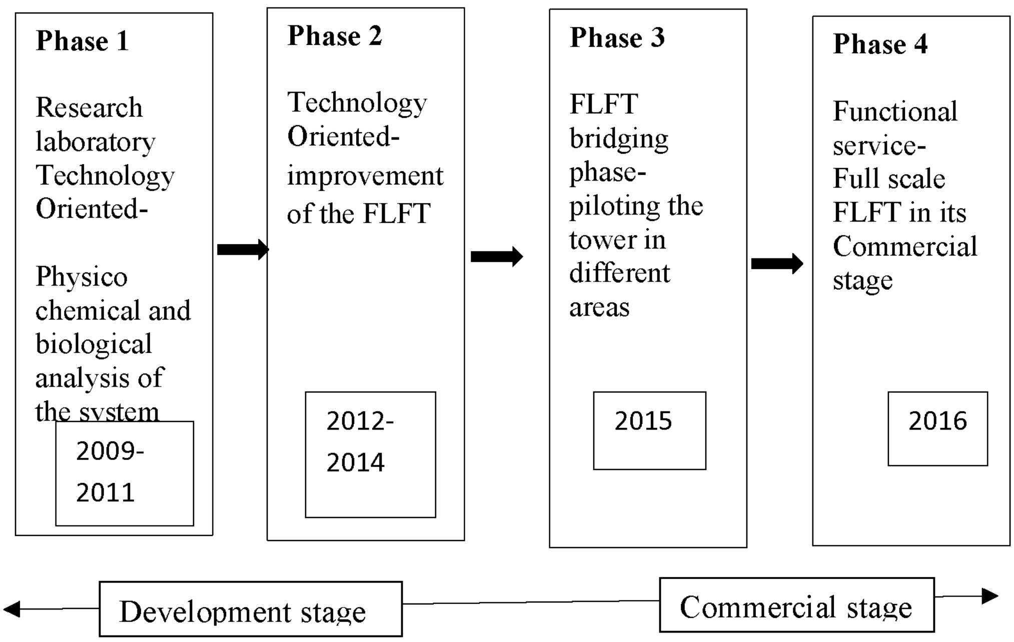
Several treatment methods have been used for greywater treatment based on physico-chemical and biological processes (Ngqwala *et al.* 2013). Reactive filters are low-cost sanitation systems where wastewater percolates down a system of layered materials and in-situ treatment takes place through precipitation and straining (Tsalakanidou *et al.* 2013). The FLFT is a reactive filter type system which will have to be applied in the greywater treatment under a wide range of conditions encountered in South Africa. The cost and energy requirements of these systems vary, usually increasing with higher levels of treatment.

Various treatment processes are suggested in the literature, but since on-site greywater recycling is a relatively new practice, only a few off-the-shelf systems are commercially available, and even less were tested on full scale for long time periods. Most treatment units reported in the literature and advertised commercially are based on physical processes (filtration and disinfection), while the more current ones incorporate biological treatment (Pidou *et al.* 2007; Li *et al.* 2009). Current market existing technologies in South Africa are from Ozone Services Industries, Water conservation, Bio-systems and Cape Water Solutions. Generally, technologies that treat greywater more extensively often require more complex infrastructure and operation, more frequent maintenance, and normally have higher costs and energy requirements.

Ozone Services Industries provides a wide range of Ozone (O^3) solutions and Ultraviolet (UV) systems for commercial, industrial, and domestic markets in water purification (Ozone service industries, 2014). The treatment involve the use of oxidise micro-organisms and various heavy metals, such as iron and manganese in the water treatment market. Water conservation use green technology to safely treat wastewater and they are one of the companies that are popular to treat greywaterFor example rainwater tank filter and Grey Flow Water systems that automatically divert, filter and disperse the water to the garden through the drip line irrigation (Water conservation Pty Ltd, 2015). Bio-systems SA offer scientific services and products for the biological treatment of effluent. They offer both filtration and biological treatment. Filtration is mostly done using Rhino Filter that utilises re-usable/replaceable what? (Bio-systems SA, 2015). The biological treatment uses Greywater Additive (GWA) which comprise of blend of selected, natural, water-cleaning microbes supplied as a dry powder in a customized domestic pack. Cape Water Solutions is an approved Water Rhapsody franchisee supplying filter systems for greywater recycling for irrigation and rainwater harvesting and reuse of water inside home (Cape Water Solutions, 2015). Most of these companies are affiliated with Small Wastewater Treatment Works Suppliers Association (SEWPACKSA) to provide a unified representative body of suppliers of package plants to create a sustainable, self-regulated industry. The SEWPACKSA facilitate co-operation amongst all stakeholders to develop and agree to standards of quality with a view to regulating the package plant industry regarding best practice in design parameters, acceptable processes and technologies, and in construction certification.

Ilemobade *et al.* (2013) investigated locally available greywater technologies (Water Rhapsody Conservation Systems) as the preferred system appropriate for two pilot sites (University of Johannesburg (UJ) and University of the Witwatersrand (WITS). The selection was based on the fact that it was cheap, rugged, functional and easy to change/upgrade if and when necessary. Perceptions highlighted included respondents' preferences to reuse greywater for toilet flushing rather than irrigation (Li *et al.* 2009). The FLFT systems shall be set up in 70-100L plastic containers. The treatment system shall be placed near the garden and coupled with a drip irrigation systems

The FLFT designed in this study is a cheap, easy-to-use technology requiring minimal resources for repairs, maintenance and operation. It was also design to limit the potential for theft of the components. The system also favours the rapid growth and development of both microorganisms and macrofauna (e.g. worms) necessary for the rapid degradation of considerable amounts of fat and food particles, thus eliminating the screening process). For these reasons, he FLFT is considered an appropriate technology that can be deployed on a large scale and the proposed phases for the launched of the technology into the South African market are provided in Figure 7.1.



*Phase 1= P1, Phase 2= P2; Phase3 = P3; Phase 4 = P4

Figure 7.1: Schematic illustration of phases involved in the development and commercialisation of the fly ash lime filter tower technology

The project is based in the Eastern Cape at Rhodes University where it is currently in the bridging phase (P3) (Figure 7.1).Scaling up will soon commence. By setting up a pilot study within 5 residences, onsite treatment of greywater, investigating the storage methods of the treated water, characterisation of treated wastewater and the use se of treated wastewater for flushing toilet and irrigation. This will take place from March to July 2015.

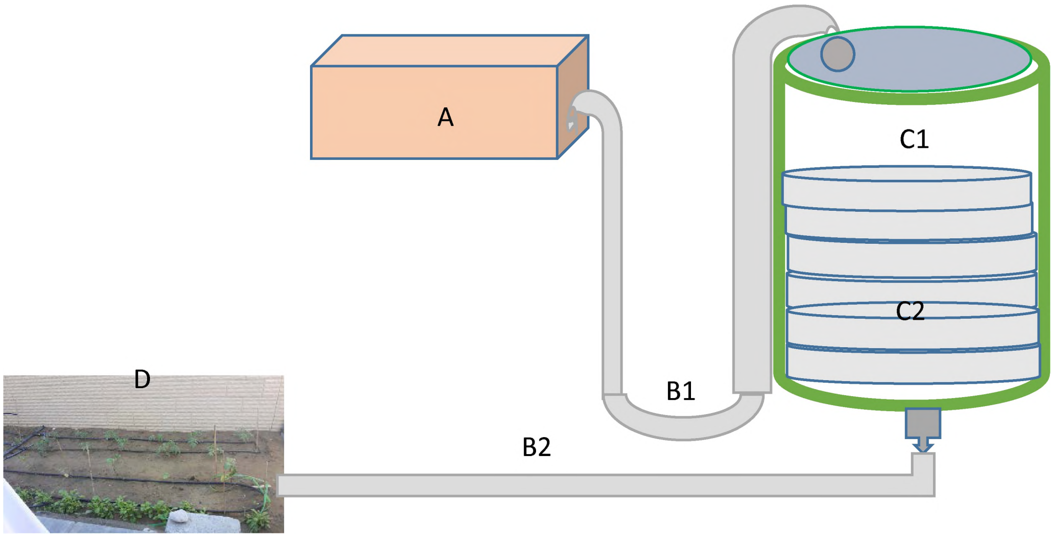


Figure 7.2: Schematic representation showing how the FLFT will look like. A- is represented as a house, B1 and B2 are pipe connections, C1- is the influent (water) level, C2- FLFT system discs and D- greywater used for irrigation

The FLFT market strategy is characterised as to be in secondary phase, and the FLFT services in the phase project is in the forefront of the fuzzy front end of innovation. In phase 1 "early process of ideas" development is in many respects technique driven, where the technical skills of the founders are decisive for the generation of new ideas. In this case, the technology was developed by Zuma *et al* (2009). In 2012 phase 2 was handed over to other research group members where they focused on the improvement of the FLFT to increase its efficiency. In phase 3 the technology constitutes became the platform of the project and it is of high importance to focus on such aspects. However, the commercialisation aspect is also highly relevant for possibilities of bringing the FLFT to the market. The FLFT services associated with the P2 project is at present moving from Phase 3 to Phase 4 where distinct actions are needed to take place. Real customers need technologies that are developed for attractive services that fill a particular function and helps customers/users of the system to develop their competitive advantages. The P4 needs to be further developed and also show that customers are reached and that attractive offerings are available. Offerings can be made in this phase or be directly designed and adjusted to the particular customers' needs. This will be first preliminary business model is in this phase designed and organized see figure 7.2. After this the project will continue to explore on the P4-work processes and maturity phases of the FLFT market in relation to the financial base which will be detailed in Table 3.

Installation of the optimised system in different settlements will assist when dealing with technical innovations as it is important to involve all stakeholders to increase the potential for market success. It is therefore, of vital importance for the FLFT technology to involve both their presumptive users as well as their customers to understand their needs as well as the social impact the innovations that are being tested in the system might have. While contributing in the maturity of the technology, which also influences end-users possibilities to contribute to the development of the technology where immature technology is more likely to render user feedback. However, the business aspect is also highly relevant for possibilities of bringing the FLFT services to the market. Much of the public concern around greywater reuse is related to a lack of information about the long-term health and environmental impacts of greywater. Domenech *et al.* 2010; Kulabako *et* al. 2009; Carden *et al.* 2009). This pilot study will answer some of the questions as it will examine the long-term impacts of greywater on human health and soil chemistry. Information from SEWPACKSA and international research organizations would be especially useful create a sustainable and self-regulated industries (SEWPACKSA, 2015). Greywater reuse is often considered primarily as a benefit in terms of water conservation, it also conserves energy, saves or reduces waste, and therefore the FLFT technology will use different financing approaches (Pidou *et al.* 2007; Li et al. 2009). Therefore, financing efforts will consider the cobenefits that could be provided to water suppliers, energy suppliers, wastewater utilities, and additional water users. This will better public information and awareness of the opportunities, benefits and risks associated with greywater will be necessary to expand greywater reuse through greywater education and outreach.

7.4. The purpose of the technology model

There are two general approaches to innovation: market-pull and technology push (Rennings 2000). A technology push implies that a new invention is pushed through Research and Development (R&D). In contrast, in market-pull, a new technology is developed through R&D in response to an identified market need (Brem 2009; Smith 2007). In the market pull approach, the market is the main source of innovation, and new product development is a direct consequence of explicit needs expressed by the consumers (Dell'Era *et al.* 2010). The developed technology in this study could be considered as technology push, hinged on the need for removal of phosphorus and indicator microorganisms. However, the launch of the technology will be driven by both market pull and technology push. It is also driven by market pull because of the necessity for decentralised systems, which are difficult to vandalise unlike centralised system that are easily targeted. At the same time, the uncontrolled rate of urbanisation will be yet another market pull factor for its uptake in the market. The developed technology can help rural settlement dwellers, farmers, and private home owners to reduce their water consumption by reusing greywater. Reducing water consumption is particularly important in communities, such as Grahamstown that experiences incessant water shortages and interruptions. With a growing student population in Grahamstown and increasing overall population, the scaling up of the project will help contribute to water reuse and thus reducing the burden on the already over-stretched infrastructures. Furthermore, the full-scale implementation can enable exchange of information between institutions, policymakers, city planners, engineers, public health professionals, and developer.

General costs of treating greywater are high, but decentralised treatment systems have been used on farms, at teaching institutions and in rural areas (Mwenge & Taigbenu 2011). In 2008, 78% of South Africa's rural population had access to improved water sources, while access in the urban population was estimated at 99% (UNICEF & WHO 2012). Studies show greywater as not suitable for drinking without treatment, unless it is treated to levels accepted for human consumption (Amin & Han 2011). It can provide a source of gardening watering, toilet flushing, house cleaning, similar to portable water. There may be risks associated with human contact in the houses, thus gardening on vegetation which will not be consumed without cooking is the safest use. Household level treatment is expensive and time consuming and is thus not often practised (Monyai 2004). General costs of treating rainwater are high, but greywater have been used on farms, at teaching institutions and in rural areas for the poor (Mwenge & Taigbenu 2011).

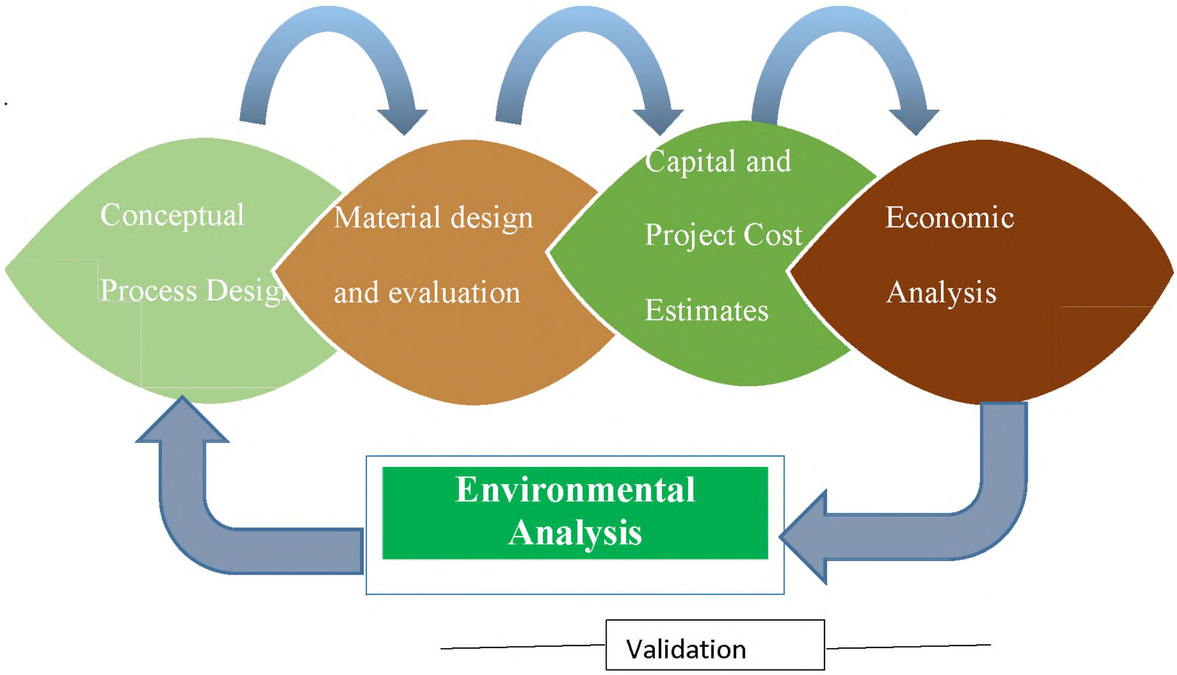


Figure 7.3: Different phases in technology and business exploitation

7.5. Commercialisation

There are steps that needed to further activities that would be required before marketing the FLFT, such as upscaling, regulation issues (e.g. labelling and designs), tower packaging, evaluation and monitoring strategies (see Figure 7.3). These regulations constitute to discharge the FLFT effluent that is acceptable levels according to WHO guidelines (WHO & UNICEF 2012). This means that the FLFT effluent must be fully compliant with the wastewater reuse regulation. However, due to the increased urban migration, there is growing pressure on these systems and some peri-urban areas fall outside the municipal boundaries (Parkinson & Tayler 2003). Hence, decentralised wastewater treatment plants carry a great potential as additives and alternative means of wastewater management particularly in peri-urban areas. This pressure to treat waste onsite does not exclude the industries, such as agriculture, mining and textile. Salukazana *et al.* (2006) successfully demonstrated the potential of irrigating vegetables using greywater by employing appropriate techniques, such as subsurface irrigation. The greywater reclamation for reuse purpose provides an exciting and viable opportunity to increase the existing and traditional water supplies while assisting in closing the loop between water supply and wastewater disposal. The South African irrigation guidelines, on the other hand, aims to provide specifications of the water quality required for specific irrigation purpose (DWAF 1996a). From these two irrigation guidelines, it is clear that the South African guidelines exclude the poor water quality use in irrigation, whilst WHO acknowledges benefits of the non-potable water provided that the necessary precautions are taken prior reuse.

The objectives will include: setting up a pilot study with five of the residence within the Grahamstown, onsite treatment of greywater, investigate the storage methods of the treated water, characterisation of treated wastewater and the use the treated wastewater for flushing toilet and irrigation. The first stage will be to set up a design for plumbing and storage. Treatment of greywater will involve packaging material into discs (as indicated in Figure 7.2) so that the clients should just replace a disc instead of changing the whole system. The effluent and the irrigated crops will be monitored.

The FLFT concept demonstrated the advantages of using low cost material in the treatment of varied waste (waters) products. The materials that will be used in this technology will provide distinctly higher overall removal efficiency of the contaminants tested, showed lots of simplicity, thus enabling even a non-skilled personal to use them (see figure 7.3). The optimal design of the FLFT system pilot-scale will allow its roll-out to both the rural and urban communities. The FLFTs can also be used in the households where there is water borne sanitation as the pre-treatment of the domestic wastewater prior to release to the conveyance system to the centralised wastewater treatment works (see figure 7.3). However, for any technology to be used as the on-site sanitation provision tool, it is crucial that institutional, technical and management arrangements are taken into serious consideration.

During the piloting communities will be educated about the technology option available so that they can be involved in selecting the best available option. More research is also required to investigate the stability in irrigation. This will be carried under environmental analysis stage (see figure 7.3). Capital and project cost estimates will be explained in details under business plan model (Table 7.3).

7.6. SWOT analysis

A SWOT (strength, weaknesses, opportunities and threats) analysis is an important component that must be undertaken when commercialising new innovations and technologies. A SWOT analysis of the developed technology in this study is provided in Table 7.1.

Table 7.1: SWOT analysis of the business

Strengths	o Waste materials are used for greywater treatment o Fly ash filter tower is a visible technology to reclaim water with decentralised waste collection settings o Low cost, easy-to-use and efficient in treating greywater
Weaknesses	o New business, with no or little public awareness o Greywater is difficult to store for a long time o Research questions that still need to be answered
Opportunities	o Large demand of a treated water o Could serve both rural and urban settlement
Threats	o Routines and old-fashioned thinking-consumers are not used to this type of technology that needs maintenance o Competition between suppliers and quality requirements o Amount of water produced could be lesser than the demand

The research questions that still need to be answered, include the chemical composition of the fly ash can vary depending on the suppliers and may have the potential exists for the leaching of the heavy metals into the soil and the treated effluent. This will be addressed by the current ongoing research within the research group.

7.8. Customers

Before marketing the product the pilot scale will be implemented between 2014 and 2016 to evaluate the customer needs and large scale acceptance by the public. The pilot-scale of the FLFT will be similar to the one reported by (Whittington-Jones *et al.* 2011). Six houses (three in the township and three in town) of the Makana Municipality will be selected as the sample of the project. On-site, verbal instructions and demonstration about the operation and maintenance of the FLFT will be provided to the houses' occupants. After this, the house occupants will be in charge of day-to-day maintenance, while the researchers will only visit the sites for oversight purposes. The research analyses questions will be addressed during this phase. The manufacturer intend to develop and sell the product, however, the current plan is to establish relationships with business development companies to assist with our product development and issues of sustainability. We will also establish relationships with relevant engineering and marketing institutions while a relationship with Rhodes University will enable continued product improvement and also allow dealing with real time problems should they arise once the system is online. The partnership will be developed with the relevant government departments, such as Water and Sanitation and Rural Development and Agrarian Reforms together with local NGOs.

7.9. Collaborations towards exploitation of innovation

Fly ash filter tower technology is at its infant stage and not enough customers exist yet. However, other phases of the research project are ongoing, for example, upscaling of the system and the use of the system for domestic purposes. Rhodes University is involved in the research and development of the technology. Partnership with the stakeholders and collaborators will promote experimentally driven approach in future research and intensifies the usage experimental facilities.

Table 7.2: Technical and commercial risks pertaining to the FLFT and mitigation measures

Risk Description	Likelihood	Impact	Management
Product quality: failure to perform to expected standards	Unlikely: lots of research into the efficacy of the material, the simplicity of the system will allow easy changing of the system to suite real times circumstances	Production of undesirable smells, mosquito infestation	Ensure regular operation and maintenance and timely changing of filters
Human resources management: Poor management skills; labour disruptions	Unlikely: Managers will be well-mentored, and project management systems will be employed	Poor cash flows leading to bankruptcy, labour unrest leads to loss of productivity	Management training, adhering to project and financial controls systems
Logistics	Possible: Main markets far from sites of production	Increased overhead costs (transport)	Focus on saturating local markets first, expand production through establishing at site of new markets
Market loss	Possible: Competitor offers similar product at lower price	Loss of market share, loss of income if prices adjusted downwards	Brand strength, strong technical support to improve product quality, lower production costs
Feed stock availability	Unlikely: materials , such as sand and rocks are readily available while fly ash is produced in excess by Eskom	Poor production and loss of income. Inability to meet customer demand	Prevent operation breakdown, keep good communication and

	and Sappi		relationships with raw material suppliers

7.10: Financial planor key resources demands

Table 7.3. The current internal assessment indicates that the pilot study for the FLFLT system would require the following resources to be operated

Demand	Related Financial Cost
Physical Resource Tanks (100L/day) Pipes Discs (FLFT discs) Labelling	 R10 000.00 R10 000.00 R3 000.00 R3 000.00
Human resources Research coordinator Project coordinators Plumber	 R50 00.00 R50 00.00 R50 00.00
Running costs Research	 200 000.00
Total Estimate Demand Cost	R376 000.00*

*The cost can be eliminated in case of a donor/sponsor/volunteer service and the amount produced will depend on the size of the system.

*Once the product is ready the estimated cost for the system to be installed in one house range from R2000 - R4000.

7.11. Final conclusions

Currently Environmental Health and Biotechnology Research Group (EHB) (Rhodes University) and the collaborators are still discussing how to create a business offer for customers. The funding for experimental explorations is fundamental. Whilst the financial goal of the phase 3 of the project is the development of a sustainable FLFT system for both short term and long term perspectives, this will enable dealing with management of resources and develop activities and businesses that fit with to the current resources available and the future resources planned to acquire.

7.12. References

Adewumi I. and Ogbiye A.S. (2009). Using water hyacinth (Eichhorniacrassipes) to treat wastewater of a residential institution, *Toxicological and Environmental Chemistry* 91 (5):891–903.2012.

Amin T and Han M. (2011). Domestic rainwater harvesting as an adaptation measure to climate change in South Africa. *Australian Journal of Basic and Applied Sciences,* 5**,** 1804-1813.

Archer, B. N., Cengimbo, A., De Jong, G. M., Keddy, K. H., Smith, A. M., Sooka, A., Ntshoe, G. & Blumberg, L. 2009. Cholera Outbreak in South Africa: Preliminary Descriptive Epidemiology on Laboratory-Confirmed Cases, 15 November 2008 To 30 April 2009. Communicable Diseases Surveillance Bulletin, 7, 3-8

Andersson, S. 2010. The Fuzzy front end of produt innovation processes, The influence of Uncertainty, Equivocality and Dissonance in social processes of evolving product concepts, Dissertation Accounting and Control, Luleå university of technology, ISSN: 1402-1544, ISBN: 978-7439-172-5.

Bhattacharya P., Ghosh S., Sarker S., Majumda S., Bandyopadhay S.(2011). Effectiveness of biosorption assisted microfiltration process for treatment of domestic wastewater. *Bioremediation Journal.* 15(4): 206-217.

Biosystems-SA (2015). Biosysytems. [Onlinehttp://www.biosystemssa.co.za/[Accessed 08 02 2015].

Cape Water Solutions -SA (2015). Cape Water Solutions. [Online http://www.watersolutions.co.za/ [Accessed 08 02 2015].

Carden K., Armitage N., Winter K., Sichone O. and Rivett U. (2007). Understanding the use and disposal of greywater in the South Africa. *Water Research Commission*, Report No. 1524/1/07. Pretoria, RSA.

Chen X., Chen X., Wen X., Weng B., Huang H. (2010). Water hyacinth (*Echhornia crassipes*) as an adsorbent for phosphorous removal from swine wastewater. *Bioresource Technology,* 101; 9025-9030.phytoremediation with water hyacinth (*Eichhornia crassipes*). *Journal of Sustainable Development,* 5(7); 80-90.

Dell'Era, C., Marchesi, A. and Verganti, R. 2010. Mastering technologies in design-driven innovation, *Research Technology Management*, 53 (2): 12-23.

Ilemobade A.A., Adewumi J.R. and van Zyl J.E. (2009). Assessment of the feasibility of using a dual water reticulation system in South Africa. *Water Research Commission*, Report No1701/1/09. Pretoria, RSA.

Luyt, C. D., Tandlich, R., Muller, W. J. & Wilhelmi, B. S. 2012. Review: Microbial Monitoring of Surface Water in South Africa: An Overview. *International Journal of Environmental Research and Public Health* 9**,** 2669-2693.

Luyt C.D., Muller W. J., Wilhelmi B. S. and Tandlich R (2011) Health implications of flood disaster management in South Africa. *18th Annual Conference of the International Emergency Management of Soci*ety, 7 – 10, Bucharest, Romania. 376-385.

Madikizela P. (2012). Water hyacinth in greywater remediation. Honours in Biotechnology Thesis. Rhodes University, South Africa.

Monyai, P. B. 2004. Health - related water quality and surveillance model for the Peddie district in the Eastern Cape. Pretoria (RSA): *Water Research Commission*.

Moore N. (2015). Makhazeni's municipal Disaster. Daily Maverick http://www.dailymaverick.co.za/article/2015-01-21-steady-decline-emakhazenis-municipal-disaster/#.VOmefPmUd9g

Mwenge Kahinda, J. and Taigbenu, A. E. 2011. Rainwater harvesting in South Africa: Challenges and opportunities. Physics and Chemistry of the Earth, Parts A/B/C, 36, 968-976.

du Plessis C. and Ndlangisa S. (2014). Corrupt officials face 10-year ban. City Press : http://www.citypress.co.za/politics/corrupt-officials-face-10-year-ban/

Ngqwala N.P, Zuma B.M. and Tandlich R (2013). Greywater composition and treatment in a coastal area of South Africa International Scientific Forum, ISF 2013 12-14 December 2013, *Tirana, Albania Proceedings*, vol.3.

OVerdevest C., Orr, C.H. and STEPENUCK K. (2004). Volunteer stream monitoring and local participation in natural resource issues. Human Ecology Review, 11, 177-185.

Ozone service industries SA (2015). Ozone service industries. Available at: http://www.ozonize.co.za/ [Accessed 08 02 2015].

Pidou M., Memon, F., Stephenson T., Jefferson B. and Jeffrey P. (2007). Greywater recycling: Treatment options and applications. *Proceedings of the Institution of Civil Engineers Engineering Sustainability* 160: 119–131.

Pathan S.M., Aylmore L.A. and Colmer T.D. (2003). Properties of several flyash materials in relation to use as soil amendments. Journal of Environmental Quality 32 (2): 687 – 93.

Prathapar S.A., Jamrah A., Ahmed M., Al Adawi S., Al Sidairi S. and Al Harassi A. (2005). Overcoming constraints in treated greywater reuse in Oman. *Desalination* 186 (1-3): 177 – 186.

Quinn C. H., Ziervogel G., Taylor A., Takama T. and Thomalla F. (2011). Coping with Multiple Stresses in Rural South Africa. *Ecol. Soc*, 16(3), 10.

Raymer D., and Buckle J. (2010). We are facing a water and sanitation crisis in South Africa. *WISA 2010 Biennial Conference & Exhibition*. Durban, South Africa: Water SA.

Salukazana L., Jackson S., Rodda N., Smith M., Gounden T., McLeod N. and Buckley C. (2006). Reuse of greywater for Agricultural irrigation. *WISA 2006 Biennial Conference & Exhibition*. Durban, RSA.

Seckler D., Barker R. and Amarasinghe U. (1999).Water scarcity in the twenty-first century, *International Journal of Water Resource Development*, 15 (1-2), 29-40.

Small Wastewater Treatment Works Suppliers Association -SA (2015). Small Wastewater Treatment Works Suppliers Association. [Online http://www.sewpacksa.co.za/ / [Accessed 08 02 2015].

Tandlich R. and Muller W. J. (2008). Methods for detection of faecal pollution and identifying its origins: linking the South African and the international context. Pretoria, South Africa: Water Research Comission.

Tandlich R., Luyt C. D., Gordon A. K. and Srinivas, C. S. (2011). Concentrations of indicator organisms in the stored rainwater in the Makana Municipality, South Africa. Published in the peer-reviewed proceedings from the Air and Water Components of the Environment Conference held in Cluj, Romania from 23rd until 24th March 2012, pp. 89-96 (ISSN: 2067-743X).

Tandlich R., Luyt C.T. and Ngqwala N.P. (2014). A community-based rainwater monitoring and treatment programme in Grahamstown, South Africa, *Journal of Hydrocarbons Mines and Environmental Research*, 5(1)1:46- 51, ISSN: 2107-6510

Tsalakanidou I. (2006). Potential of reactive filter materials for small-scale wastewater treatment in Greece. Batch and Column Experiments. TRITA-LWR Master of Science Thesis. Stockholm, Sweden.

United Nations (2012). The Millennium Development Goals Report 2012. New York, United States of America: United Nations.

UNICEF & World Health Organization (2012). Progress on Drinking Water and Sanitation. 2012 update. United States of America: WHO/UNICEF Joint Monitoring Programme for Water Supply and Sanitation

Waring, S. C. and Brown, B. J. (2005). The Threat of Communicable Diseases Following Natural Disasters: A Public Health Response. *Disaster Management & Response*, 3, 41-47.

Whittington-Jones K., Tandlich R., Zuma B. M., Hoossein S., Villet M. H. (2011a). Performance of the pilot-scale mulch tower system in treatment of greywater from a low-cost housing development in the Buffalo City, South Africa. *International Water Technology Journal,* 1 (2): 165 – 181.

WHO (2006), "WHO Guidelines for the Safe Use of Wastewater, Excreta and Greywater, Volume IV, Excreta and Greywater Use in Agriculture", pub. WHO Press, World Health Organisation, Geneva, Switzerland.

WHO and UNICEF. (2012). Millennium Development Goal drinking water target met, Sanitation target still lagging far behind. 6 March 2012.

Zuma B.M. (2012). The efficacy and applicability of the low-cost adsorbent materials in wastewater treatment. PhD of Science Thesis. Rhodes University, South Africa.

Zuma B., Tandlich R., Whittington-Jones K. and Burgess J.E. (2009). Mulch tower treatment system Part I: Overall performance in greywater treatment. *Desalination*, 242 (1): 38 – 56.

Zuma B.M.. and Tandlich R. (2010). Public health implications of greywater production in South Africa. In: Fonn S. and Padarath A. (eds.). *South African Health Reviews*. Health Systems Trust. Durban, RSA.

CHAPTER 8: FINAL DISCUSSIONS, CONCLUSION AND RECOMMENDATIONS

This chapter presents the overall discussion and how the results compare with the current literature. The system modifications plan and recommendations based on the laboratory and analytical findings are also discussed. Conclusions for this study and recommendations for future work are also presented in this chapter.

8.1. Final discussions

In developing but water deficient countries like South Africa adequate water is required to meet developmental goals. A delicate balance for access to water that is of good enough quantity and quality for both human consumption and ecosystem processes has to be struck (National Water Act 1999). Human population growth and further socio-economic developments are placing pressure on already stressed freshwater resources. Greywater should be regarded as a valuable resource and not as a waste. In low- and middle-income countries, different domestic wastewater collection systems, i.e., centralized or non-centralized ones, are currently being used and a large portion of the population has inadequate access to proper sanitation technology. Small-scale on-site biological treatment system for greywater treatment and the greywater reuse for irrigation were explored in this study. Results show this as a promising approach with the several potential advantages from the public health and environmental point of view, and the reduction in the demand for water resources. Fundamentally, greywater treatment should be assembled from materials of low commercial value specially disadvantaged areas. The current process of low-cost on-site greywater treatment involving a combination of a mulch filter, biological treatment in artificial media and discharge of the treated water to a resorption or infiltration for greywater treatment has been evaluated previously (Zuma et al. 2009; Whittington-Jones et al. 2010). There are few greywater technologies that are operating on a full scale and this increase the need of the emerging technologies to reach their level of maturity and be commercialised.

Despite the described inadequate greywater management risks discussed in chapter 2 (2.5 and 2.7), there is a need the regulatory aspects guidance in resolving issues related to water quality, supply and quantity. Greywater has, nevertheless, a great potential to reduce the water stress currently faced by regions in the world. Greywater reuse is an effective measure for saving water on the domestic level. Where water is scarce and expensive, greywater reuse may lead to considerable economic and service delivery benefits. While identifying global technology trends, which will influence the competitiveness and future development of South African industries, there is a need to focus on identifying areas for innovation so as to reduce industrial dependency on foreign technology, whilst ensuring that these technology bring innovation. The main purpose of greywater recycling is to substitute the precious drinking water in applications which do not require treated water. Non-potable reuse applications include industrial, irrigation, toilet flushing and laundry washing dependent on the technologies utilised in the treatment process. With greywater recycling reduce the amount of fresh water consumption as well as wastewater production, in addition is regarded as an additional water source, an increased supply for irrigation water can be ensured which will in turn lead to an increase in agricultural productivity. The potential exists to reduce potable water consumption by supplementing it with recycled greywater.

The general theoretical literature on greywater treatment and reuse and specifically in the context of developing countries like South Africa is inconclusive on several vital questions within the regulation standards and the methods used for recycling. The study sought to answer two of these questions:

1. Greywater treatment technology and its performance
2. Reuse of greywater for irrigation

These questions were explored and accentuated using the highlighted objectives in chapter 1 the main results findings are chapter specific and were summarized within the respective chapters (chapter 3 to chapter 7).

In chapter 3 The PozzSand® fly ash in combination with lime is tested for possible application in greywater treatment in South Africa. Measurements of the physical, chemical and microbial composition of greywater were taken from the treated greywater.

The baseline NH_4^+ concentrations ranged from 0.51 to 2.4 mg/L, while analogical PO_4^{3-} concentrations ranged from 0.54 to 2.0 mg/L. The NO_3^- concentration interval spanned from 0.39 to 2.4 mg/L. The chemical oxygen demand varied between 630 and 1580 mg/L. The Cl- concentration was recorded to range from 0.13 to 48 mg/L. The SO_4^{2-} concentrations ranged from 110 to 380 mg/L. The faecal coliform concentrations varied between 0 and 490 colony-forming units per 100 mL. Turbidity ranged from 2.7 to 620 nephelometric turbidity units, while pH was inside the interval from 7.80 to 8.50. Electrical conductivity values ranged from 190 to 1980 µS/cm. The maximum removal efficiency in greywater treatment was recorded for faecal coliforms and it stood at 100 %. The Fly Ash Lime Filter Tower system was able to remove up to 92 % of PO_4^{3-}.

Between the background characterisation and greywater treatment, increases were recorded in levels faecal coliform (FC), Turbidity (Tur), Nitrates (NO_3^-) and ammonia (NH_4). At the same time, the concentrations of sulphates (SO_4^{2-}) and chemical oxygen demand (COD) decreased significantly. Such variability has been reported for greywater in South Africa before (Zuma et al. 2009). Spike in the concentrations of FC, Tur and NH_4^+ indicate that a sewage pipe might have been broken in the vicinity of the tap water supply into the donor household (Ribbink et al. 2011). The pH was highly alkaline pH with FLFT effluent ranged from 12.0 to 12.8. The high pH will sterilise the greywater and remove all the indicator/pathogenic microorganism (Ngqwala et al. 2013). However, it will also result corrosion of piping during irrigation operations, as well as lead to the destruction of the soil structure upon discharge (DWAF, 1996). Fly ash is a potentially effective material for the treatment of greywater from coastal areas of South Africa. Complete removal of indicator microorganisms was recorded and high phosphorus removal is also encouraging. The greywater values from Kleinemonde are comparable to those measured in Port Alfred (also a coastal area). At the same time, the values span a narrower interval than recorded by Zuma et al. 2012, and the system was further investigated for its efficiency in chapter 4.

Further modification of the FLFT to increase treatment efficiency and decrease pH was investigated in this study. The particular modifications included the addition of activated carbon, acetic acid and water hyacinth. Acetic acid did not work in this instance the system overflowed this is because the concentration of the acetic acid could not be optimised without destruction of the fly ash lime layer in the FLFT due to the dissolution of calcium carbonate or calcium hydroxide in the lime. Secondly, the remained remaining acetic acid that did not dissociate was believed to be reduced directly on the metal surface and that was going to be the disadvantage because it will result in corrosion (Singer et al. 2004). Because acetic acid is volatile it was omitted from the methods used to reduce the pH of the FLFT (Sun et al. 2003). It was the same with carbon in the form of charcoal was chosen because of its advantage in pH control in water treatment plant and non-corrosive to pipe (Mishra et al. 2010; Naik et al. 2009; NRCNA, 2006). Unfortunately the charcoal it did not spike any change in the system. It was selected because of its property of being cheap and accessibility and also requires no handling costs (Evangelou, 1996). The use of water hyacinth indicated good treatment efficiency reducing faecal coliform counts by 94.9 %. Water hyacinth has also showed the economic benefit and efficiency to control of eutrophication, where the land is inexpensive and easily available (USDA, 2010). The next objective was to use of the effluent for irrigation studies to monitor the effect of the effluent on soil and plants. The concentrations of COD, chlorides, nitrates, ammonia and sulphate were reduced by 82.6 %, 60.4 %, 72.9 %, 60.5 %, and 53.9 %, respectively pH reading was 8.3. The pH after being treated with water hyacinth was stable for over 3 months. Water hyacinth is a free floating perennial aquatic plant with high absorption of nutrients that can be used to stabilize pH and temperature levels in the FLFT whilst preventing the growth of disease causing organisms. Greywaters can become cross-contaminated with micro-organisms from human excreta. Adewumi and Ogbive (2009) conducted a study using floating and running reed bed system of water hyacinth and proved that it can reduce up to 99% of faecal coliform (FC) and total coliform from raw wastewater. Water hyacinth has the potential for purifying wastewater by absorbing and concentrated heavy metals, such as lead, cadmium, mercury, and nickel in high quantity without exhibiting visible signs of toxicity (Sanuga et al. 2014; Chunkao et al, 2012; Bhattacharya et al. 2011; Ajayi and Ogunbayo, 2012). The small amount of water hyacinth dead biomass is required for treatment efficiency. Reports regarding the experiences regarding greywater reuse for irrigation are reported in many parts of the world (Sofroniou and Bishop, 2014; Ohlsson et al. 2014; Othman et al. 2012; Madungwe and Sakuringwa, 2007).

The aim of this study was to treat and characterize greywater to determine its suitability for crop irrigation. Two vegetable crops, tomato (above ground) and beetroot crops (below ground) were irrigated with the FLFT effluent. The soils were analysed for selected physico-chemical variables and nutrient content to determine the effects of greywater irrigation. The plants irrigated with greywater had an average biomass (tomatoes (26.59 g); onions (8.929 g) compared to the ones irrigated with tap water (tomatoes (26.5 g); onions (9.96 g). Moreover with the dry weight crops irrigated with greywater had an average dry weight (tomatoes (86 g); onions (21.01 g) tomatoes (81.23 g); onions (18.35). Crops irrigated with greywater significantly grow faster compared with those irrigated with tap water with high biomass on leaves (Reichman and Wightwick, 2013).

A number of studies have investigated the impacts of untreated greywater usage on pathogen and standard water quality parameters (e.g phosphorus) with fewer studies looking at soil and plant health (Pandey et al. 2012; Rodda et al. 2011). There has been particularly little research investigating the impacts of greywater on trace elements in plants or soil (Misra et al. 2010; Rodda et al. 2011) and on soil ecotoxicology. Soil analysis showed no effects of treated greywater on soil physico-chemical and microbial with variables. Greywater contains nutrients that are beneficial to the growth of most plants. This study demonstrates that treated greywater can be used for effective irrigation of crops with little or no detrimental effects on soil or plant growth. Where soil and plant health studies have occurred they have tended to concentrate on a narrow range of traditional parameters , such as plant yield, pH, electrical conductivity and major nutrients (Pandeyet al. 2012). The risk associated with the consumption of crops irrigated with greywater is difficult to evaluate because of a lack of published microbiological standards for fresh produce and some uncertainty related to the effectiveness of the tomato and beetroot.

A modified hydrogen-sulphide (H2S) test kit was used to detect faecal contamination of different water bodies. During the first part of the workshop the study an information pamphlet was designed on the contamination sources of rainwater and the modified test kit was successfully used by the NGO volunteers to detect faecal contamination. The modified hydrogen-sulphide test kit and a combination of the E. coli enumerations correctly identified microbial water quality problems. The rate of correspondence between the m-TEC E. coli enumeration and the hydrogen-sulphide test kit was 71 %. The kit can be used to identify microbial water quality problems. Based from the results of the workshop the kit is easy to use and it can be used by community members. Using community based approach in South Africa could provide more regular testing to wider rural areas while providing a base line alert system to identify problem areas (Rogers, 2013). It could also be cost effective, as it decreases transport and laboratory costs.

During the second phase the participants followed the theory and the practical however the assignment posed a challenge since only 33% of the participants managed to get above 50%. Samples were collected from house taps, tanks, communal taps, community halls and schools. Ninety two percent of the results were negative and 8% were positive for faecal contamination. From the questionnaire the participants indicated that the H2S kit might be beneficial to the community. Lack of the information and inadequate sanitation may result in an increased outbreak of waterborne diseases. The community based approach as a platform that will be of benefit to elucidate water issues in communities (Luyt et al. 2011). The attendance at the meetings by the trainees was always at 100 %. All trainees seemed to be excited about the test kit and the potential it had in providing the community with a tool to address the ongoing water quality issues in the eastern part of Grahamstown. Adding to the challenge of water resource analysis is the shortage of technical skills both in the private and public sector to support the management of the water resources. Although the basic questions answerable by water resource analysis have not changed, the institutional and legislative environments have evolved with the implementation of the National Water Act (NWA) and the Water Services Act. At the same time, the sampling skills of the trainees were not sufficiently developed to collect water samples which could be used for compliance monitoring by the Makana Municipality. Lack of skills or insufficient development of skills has been an ongoing problem in the Eastern Cape for the past several years (Tandlich et al. 2014; Luyt et al. 2012; Whittington-Jones et al. 2011). In this situation, the work with the test kit should continue and be widened to include more in-depth training for the trainees in water sampling.

Up to this date plans at the municipal, provincial level are being made to address water issues to improve the level of service delivery and to expand the local economies. These plans are captured in the provincial Integrated Developmental Plan (IDP) and Water Service Development Plans (WSDP) of the local municipalities. Water technologies need to be developed to amend the existing systems. The FLFT system is evaluated for both short term perspective and long term perspective that will enable dealing with management of resources and develop activities and businesses that fit with to the current resources available and the future resources planned to acquire. The challenges that water resource planners in South Africa will be facing in the future are ongoing. The core questions to be answered regarding the roles of water resource analysis have not changed: How much utilisable water is available? Is the water quality acceptable and how does the current and future water use compare with what is available? How is the water resource to be conserved and developed to meet the projected water requirements with water of a suitable quality? How can the sustained utilisation of the water resource be balanced with the protection of aquatic ecosystems (ecology) through an appropriate implementation of the Ecological Reserve?

The increased costs of supply and pressure on the water quality of water resources have made reconciliation strategies , such as recycling of effluent, water conservation and demand management and desalination more plausible. The FLFT consist of cheap biological and physicochemical treatment components

This thesis has been prepared to provide the perspective on the future framework for water resource analysis in both urban and rural areas. The framework includes laboratory, technical and institutional aspects of water management. The techno economic analysis shows that the Fly Ash Lime Filter Tower (FLFT) has great opportunities to reach a broad market via the key partner's networks. In this FLFT technology analysis provides a large knowledge and resource base. The socio-techno-economic key factors and activities of relevance for the development of a sustainable greywater treatment system. In this process there is a need of incorporating a business model framework for enabling decision making in value creation and value capturing. Through the use of the recycled resources explored customers can build their own virtual FLFT system which makes it easier and cheaper for them to afford.

8.2. Concluding remarks and future work

This thesis evaluated the FLFT concept which demonstrated the advantages of using low cost materials in the treatment of varied waste (waters) products. The materials used in this technology provided distinctly higher overall removal efficiency of the contaminants tested, showed lots of potential thus enabling even a non-skilled personal to use them. In the context of the challenges facing water resource management in South Africa and given the status of the prevailing analysis techniques, an evaluation of constraints and opportunities are presented to serve as background for a proposed framework for future water resource analysis in the country. The optimal design of the FLFT system pilot-scale which will allow its roll-out to both the rural and urban communities. In the context of the challenges facing water resource management in South Africa and given the status of the prevailing analysis techniques, an evaluation of constraints and opportunities are presented to serve as background for a proposed framework for future water resource analysis in the country. The environment within which water resource analysis is performed is described by focusing on aspects , such as: regulations, institutions, information challenges, and available technical expertise. This thesis presents possible future technology in water conversation needs and makes recommendations as to how these needs could be fulfilled. Communities should be educated about the technology option available so that they can be involved in selecting the best available option. The project will continue to investigate the scaling up of the system and the installation to develop the prototype. Regulation issues (e.g. labelling and designs), tower packaging, evaluation and monitoring strategies.

8.3. References

Adewumi I. and Ogbiye A.S. (2009). Using water hyacinth (Eichhorniacrassipes) to treat wastewater of a residential institution, *Toxicological and Environmental Chemistry,* 91 (5):891–903.2012.

Amin T and Han M. (2011). Domestic rainwater harvesting as an adaptation measure to climate change in South Africa. *Australian Journal of Basic and Applied Sciences,* 5**,** 1804-1813.

Ajayi T.O., Ogunbayo A.O. (2012). Achieving environmental sustainability in wastewater treatment by "United Nations Human Development Index," United Nations. [Online]. Available at http://hdrstats.undp.org/en/indicators/103106.html [Accessed; 23-Jul-2014].

Bhattacharya P., Ghosh S., Sarker S., Majumda S., Bandyopadhay S.(2011). Effectiveness of biosorption assisted microfiltration process for treatment of domestic wastewater. *Bioremediation Journal,* 15(4): 206-217.

Chunkao K., Nimpee C., Daungmal K. (2012). King's initiatives using water hyacinth to remove heavy metals and plant nutrients from wastewater through Bueng Makkasan in Bangkok Thailand. *Ecological Engineering, 39*; 40-52.

Dell'Era, C., Marchesi, A. and Verganti, R. (2010). Mastering technologies in design-driven innovation, *Research Technology Management*, 53(2): 12-23.

Department of Water Affairs and Forestry (DWAF) (1996). South African Water Quality Guidelines, Vol. 4 (Agricultural use: Irrigation), Pretoria.C.

Luyt, C. D., Tandlich, R., Muller, W. J. & Wilhelmi, B. S. (2012). Review: Microbial Monitoring of Surface Water in South Africa: An Overview. *International Journal of Environmental Research and Public Health,* 9**:** 2669-2693.

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.

Monyai, P. B. (2004). Health - related water quality and surveillance model for the Peddie district in the Eastern Cape. Pretoria (RSA): *Water Research Commission*.

Mwenge Kahinda, J. and Taigbenu, A. E. (2011). Rainwater harvesting in South Africa: Challenges and opportunities. *Physics and Chemistry of the Earth, Parts A/B/C*, 36: 968-976.

Ngqwala N.P., Zuma B.M. and Tandlich R. (2013). Greywater composition and treatment in a coastal area of South Africa (5th International Scientific and Expert Conference proceedings *TEAM 2013 Technique, Education, Agriculture & Management)* Prešov, 4th to 6th November 2013.

Othman A. Al-Mashaqbeh B., Ayoup M. Ghrair and Sharon B. Megdal (2012). Greywater Reuse for Agricultural Purposes in the Jordan Valley: Household Survey Results in Deir Alla*, Water*, *4*, 580-596

Pathan S.M., Aylmore L.A. and Colmer T.D. (2003). Properties of several flyash materials in relation to use as soil amendments. *Journal of Environmental Quality* ,32 (2): 687 – 93.

Ribbink A.J. (2011).The Impact of climate change on food security among coastal communities of Keiskamma, in the Eastern Cape, South Africa, Final Project Report for 2011. *START Grants for Global Change Research in Africa*. [Online]. Available: http://start.org/download/gec11/ribbink-final-report.pdf [Accessed: 7-Oct-2013].

Rodda N., Carden K., Armitage N. and du Plessis H.M. (2011). Development of guidance for sustainable irrigation use of greywater in gardens and small-scale agriculture in South Africa. *WRC 40-Year Celebration Special Edition.* 37:5.

Rodda N., Salukazana L., Jackson S.A.F. and Smith M.T. (2011). Use of Domestic Greywater for Small-scale Irrigation of Food Crops: Effects on Plants and Soil. J. Phys. Chem. Earth. DOI: 10.1016/j.pce.2011.08.002.

Salukazana L., Jackson S., Rodda N., Smith M., Gounden T., McLeod N. and Buckley C. (2006). Reuse of greywater for Agricultural irrigation. *WISA 2006 Biennial Conference & Exhibition.* Durban, RSA.

Tandlich R., Luyt C.T. and Ngqwala N.P. (2014). A community-based rainwater monitoring and treatment programme in Grahamstown, South Africa, *Journal of Hydrocarbons Mines and Environmental Research*, 5(1): 46- 51, ISSN: 2107-6510

UNICEF & World Health Organization. (2012). Progress on Drinking Water and Sanitation. 2012 update. United States of America: WHO/UNICEF Joint Monitoring Programme for Water Supply and Sanitation

WHO (2006), "WHO Guidelines for the Safe Use of Wastewater, Excreta and Greywater, Volume IV, Excreta and Greywater Use in Agriculture", pub. WHO Press, World Health Organisation, Geneva, Switzerland.

Whittington-Jones K., Tandlich R., Zuma B. M., Hoossein S., Villet M. H. (2011a). Performance of the pilot-scale mulch tower system in treatment of greywater from a low-cost housing development in the Buffalo City, South Africa. *International Water Technology Journal,* 1 (2): 165 – 181.

WHO and UNICEF. (2012). Millennium Development Goal drinking water target met, Sanitation target still lagging far behind. 6 March 2012.

Zuma B., Tandlich R., Whittington-Jones K. and Burgess J.E. (2009). Mulch tower treatment system Part I: Overall performance in greywater treatment. *Desalination*, 242 (1): 38 – 56.

APPENDICIES

Appendices: Additional comments from experimental events and secondary data are provided in the appendix section.

Appendix 1

Table 1: pH readings of soil

Soil sample	Ratio	Soil (g)	Water (ml)	Original values	pH calculate values
a.	1:3 [soil/ water]	10	30	7.4	7.289
b.	1:3 [soil/0.01 M CaCl2]	10	30	6.9	6.791
c.	1:3 [soil/ 1M KCl]	10	30	6.3	6.197
d.	1:6[soilwater]	10	60	7.3	7.187
				Average	6.866

Table 2: Bulk density data

	Weight/ grams	1	2
a.	Empty beaker/g	30.46	32.30
b.	Beaker + soil/g	80.07	96.38
c.	Beaker + water/g	82.10	96.61
d.	Empty Aluminium can/g	103.16	109.67
e.	Aluminium can + soil/g	152.66	173.96
f.	Aluminium can + soil after 105^0C	151.80	172.60
g.	Weight of soil	0.860	1.36
h.	Volume of soil/ml [c-b]	49.61	64.08
i.	Dry weight of soil [e-d]	49.5	64.29
j.	Soil bulk density	0.997	1.003

Porosity = 1 - (bulk density / particle density)

Table 3: Soil Particle density

	Soil parameters	1	2
a.	**Weight of Flask/g**	30.60	40.91
b.	**Weight of flask + water/ g**	93.76	104.40
c.	**Weight of water [b-a]**	63.16	63.49
d.	**Weight of flask + water/g**	80.31	90.80
e.	**Weight of flask + water + soil/g**	93.76	104.40
f.	**Weight of water [e-d]/g**	13.45	13.6
g.	**Difference in water mass [c-f]/g**	49.71	49.89
h.	**Volume of soil solids / cm^3**	49.71	49.89
i.	**Particle density (Dp) of soil (g/cm^3)**	0.5029	0.501

Table 4: Change in mass of soil during LOI procedure

Crucible no	**1**	**2**
A. Empty crucible	17.64	20.05
B. Crucible + soil/g	22.64	25.05
C. Crucible + soil after 105°C /g	22.53	24.96
D. Crucible + soil after 400°C/g	21.98	24.47
E. Mass of air-dried soil/g	5.00	5.00

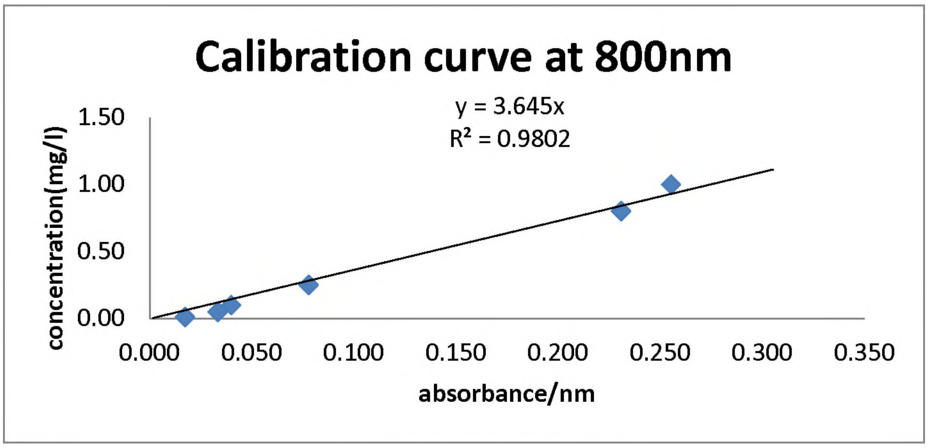
(m_s/g) = (B-A)		
F. Mass of soil dried at 105°C m_s) = (C-A)	4.89	4.91
G. Mass of soil ignited at 400°C m_c/g) = (D-A)	4.34	4.42
H. Loss of mass after ignition Δm/g	0.5	0.49
I. LOI (%)	11.2	9.97

Table 5: Nitrogen results of soil

Sample	Volume of sample /ml	Titrant/ml	Calculated concentration
Control-NH_4Cl	60	0	0
1 (Soil)	70	0	0
2 (Blank)	65	0	0

Table 6: Phosphorus results of soil

Sample	Average Absorbance	phosphorus concentration
1 (0.1g of soil)	0.642	0.17
2 (0.2 g of soil)	1.021	0.3



Calibration curve was done using 5mg/l phosphate stock solution of KH_2PO_4

Appendix 2A

1. A. The H_2S strip test

The H_2S strip test

The H_2S strip test allows you to identify if hydrogen sulphide producing bacteria are present in the tank. If this is the case then the rainwater tested contains faecal matter and is potentially dangerous to human health upon consumption.

The H_2S strip test is a bottle with a piece of paper impregnated with nutrients inside it. The paper will release the nutrients into the water once the sample has been added and the kit hand-shaken. This will allow the bacteria to grow.

The bottles can be kept at room temperature in a sunlight protected box.

To use the H_2S strip test you will have to:

- Allow the water to run for thirty seconds.
- Then let the water run slowly, before opening the bottle
- Without touching the inside of the bottle with your hands. Half fill the bottle with water to the line indicated on the bottle.
- Close the bottle and shake the bottle.
- Place in a sunlight protected box in a warm place.
- Check the bottle for a colour change.
- Check the bottle every 12 hours for 72 hours (3 days).

- Colour changes after 72 hours are not positive results.
- If the water turns a black colour then the test shows that bacteria are present. (Positive result).
- All the water in the bottle must be discarded into the sewage system. Be careful to wash your hands carefully after doing this. The bottle should be discarded with the refuse.

When the test is positive the water is not suitable for drinking without first boiling or treating with disinfectant. If the rainwater is being used for irrigation of food which is cooked before being consumed, then no actions needs to be taken, however if it is being used for drinking or washing then place 5ml (for every 1000ml of water) of sodium hypochlorite or jik (not perfumed) into the tank. Never place more than 25ml into the tank. Allow the tank to stand unopened for at least 12 hours before using the water. Preventively add half a glass (150 ml of bleach) into a 5000 litre or standard rainwater tank once or twice a month.

Negative Positive

Appendix figure 1A. A picture of the H_2S strip test with a negative result (left) and a positive result (right).

Appendix 1A. Problems and how to correct them:

Problem	Cause	Ways to prevention	Observation of problem	Maintenance
Sludge in the tank	Soil particles from the air	Filters or first flush	Soil in the roof	Clean the tank every 2-3 years
Mosquitos or worms	Stagnant water inside pipe bends or dirty gutters where which mosquitoes laid their eggs or midges laid their eggs	Seal all tank openings, install pipes to prevent water from stagnating	Larvae in the water Mosquitoes around the tank	Place screening filters to prevent mosquitoes entering the tanks (like a fine kitchen sieve). Clean gutters to prevent stagnant water
Faecal matter on roof or around the tank	Bird and animal droppings, decomposing leaf litter	Prevent opening which allow animals or birds into the tank. Trim overhanging trees which encourage birds to sit over the roofs	Bird droppings on the roof, soil on the roof Bird droppings in the tank Leaves on the roof. Check tank for dead animals Positive H_2S strip test result.	Trim branches over hanging the trees. Clean the gutters and the roof Inspect regularly Check seals on the tank. If tanks are contaminated then empty and clean or disinfect the tank
Smelly water due to leaf litter degradation	Trees overhanging the roof. Degrading vegetation in the tank or soil	Use leaf excluders Clean gutters and use filters	The smell or colour of the water Visible leaves in the tank	Empty the tank and clean it with non-perfumed jik or sodium hypochlorite Ensure no light is entering the tank

	Light entering the tank causing algal growth			Clean the leaf litter excluders/ filters. Clean the gutters If lots of leaves are present in the tank then clean the tank
Coloured water	Degradation of painted roofs, tiles. Resuspended sediment	Maintain the roof	A difference in colour between the rainwater and the tank water. Slime on the inside of the tank Small white fakes	Remove sediment from the tank Repaint roof if it is degrading with lead free paint Clean the tank and disinfect it.
H_2S strip test positive	Microbial growth in the tank	Screens and filters to prevent leaves entering the tank Trimming overhanging trees	Check the tank using the H_2S strip test every month	Disinfect the tank with 5ml of 12.5% sodium hypochlorite without perfume. Trim trees and clean gutters Only use water for gardening if not disinfected

Appendix 2B

1. B. The questionnaire

Programme feedback form

Please would you complete the following questions so that I can evaluate the strengths and weaknesses of this training programme? There are no right or wrong answers – your honest opinion is important. I might use this feedback for my own research. If I do this, I will make certain that any parts of your form I use will remain anonymous.

Permission to use this data:…………………Signature…………………………………………

Date:

Question Guide (questionnaire) for water quality testing workshop in Grahamstown

Has the consent form been explained and have the consent forms been signed?

Introduction

South Africa is a country subject to water scarcity due to the contribution of climatic, geographic and human variables. This chronic water scarcity has arisen in a changing political arena. However water unites than divides peoples and societies. The concept of water cooperation entails working together towards a common goal, in a way that is mutually beneficial and this clearly supports our National Development Plan Vision for 2030.

The predominant problem linked to South Africa's water resources is how to allocate water amongst the competing uses of long term environmental and human welfare, without compromising the needs of the country's urban poor. Water is a cross-cutting issue which demands attention at all levels and across sectors. Water issues involve many stakeholders with conflicting and competing needs and cross multiple physical, political and jurisdictional boundaries. Cooperation is necessary to deal with issues , such as water allocation decisions, upstream and downstream impacts of water pollution and construction of infrastructures, overexploitation, deciding on financing management of water resources and water services.

Gender

Male ☐ /female ☐

1. How did you find out about this programme?

2. Are you pleased to be part of the programme?

   a. Yes ☐ / No ☐
   b. Why?

3. What do you expect to learn from the program

4. What aspects of the programme do you like the most?

5. What aspects of it do you like the least?

6. Who do you think would benefit the most from learning to use this H_2S kit? Why?

7. When you imagine yourself teaching other people to use this kit, who are the people that you teach – describe them in terms of age, gender and the community

8. Where do you imagine yourself teaching them? – describe the place and give a possible address?

9. What do you understand by the term: water quality?

10. Why is water quality important?

11. In any community, who do you think is most affected by poor water quality?

    a) Why?

12. Who do you think is responsible for water quality in Grahamstown?

    a) Why?

13. Do people in the community worry when they experience water quality problem?
    Yes ☐ / No ☐

a) Who is likely to worry the most?

b) Why

14. Do you think water quality is a problem in your community?

Yes ☐ /No ☐ , please discuss.

15. Do you think that water quality can be improved or prevented? Please discuss.

16. How can water quality be improved?

17. What can YOU do to improve water quality?

18. Is there a source of information regarding water quality issues in your community?

Yes ☐/ No ☐, please describe where.

a) If it is there, do you think it is accessible to the community?

b) In what group of people please describe place, gender and age

19. What has the community practiced regarding addressing the water quality issues?

Closing remarks and Way Forward

20. Is there anything you feel we missed that you would like to talk about?

21. If yes, can you please add what you feel we may have missed?

22. From what we have discussed, what is the major water issue that urgently needs to be addressed in the community?

23. In your opinion, would an educational program for the water issues in the community regarding these conditions be of benefit?

24. If yes, for which condition would you like me to start an educational program that can address the major maternal issue?

25. Would you all participate voluntarily in that education program?

26. If yes, are there any suggestions as input in the educational program to improve water issues in Grahamstown?

27. What is the best way to organise this educational program?

28. Would the community members participate actively in this planned educational program?

Thank you for your feedback and your time

Rhodes University

Faculty of Pharmacy

P O Box 94

Grahamstown, 6140

4 April 2016

Dr Roman Tandlich

RE: Corrections of the thesis according to the examiners

This letter serves to confirm that corrections have been done according to the examiners suggestions as follows:

Examiner 1: Erwin Nolde

Page 10, Figure 2.1: the green frame should be correctly placed.

- Comment accepted, in page 10, Figure 2.1: the green frame is correctly placed.

Page 14: The statement in first paragraph that "normal greywater will produce approximately 45 g of nitrogen and 3 g of phosphorous per day" is not plausible. A definition of "normal" greywater is missing. Does it include or exclude kitchen greywater? It is not clear if this comment is based on greywater volume per person and day or person and year or household per day! Please elaborate. In Table 2.1 (Page 16), Total Kjeldahl Nitrogen is between 2.1 and 31.5 mg/l, which is resulting from a volume of 1.5 to 20 m3 of (normal) greywater?? Several sources of literature are available, which describe volumes, loads and concentrations of different greywater sources, which should have been cited and discussed in this paper.

- Comment accepted, the clarity have been provided on page 14.

Page 14, Figure 2.2: This is incorrectly presented. The organic load from showers and bathtubs represent the low load fraction of greywater not the high load (e.g. kitchen, laundry, etc.)

- Comment accepted in page 14, Figure 2.2 has been corrected

Do you suggest that greywater should be separated into two fractions?

- Comment accepted: Yes table 2.1 shows the typical greywater composition separated according to their sources of greywater and their application after appropriate treatment

Page 16, Table 2.1: what are the greywater resources?

- Comment rejected, Table 2.1 below shows the typical greywater composition separated according to their sources of greywater and their application after appropriate treatment.

Table 2.1 (page 16) and own results later do not say anything about the origin (sources from hotel, single-family household or office. There is no further reference when and how the samples had been taken as random samples (which would be worthless for the influent) or 24 hours quantity proportional samples had they been homogenised, sedimented or filtrated? There is no information on that.

- Comment rejected, on page 15 Table 2.1 below the typical greywater composition separated according to their sources of greywater and their application after appropriate treatment.

Page 18 – 21, Section 2.5: The presentation of regulations on greywater reuse in Section 2.5 is a bit confusing. Some countries have, other do not have regulations for greywater recycling and reuse. Some allow greywater reuse only for irrigation but not for indoor use, etc. There are different regulations for different reuse options. It might be clearer to the reader if you can present major guidelines/regulations in form of a table. Page 21: literature citations are largely missing in the text concerning greywater regulations in other countries.

- Comment: Accepted, more information on has been added in page 21

Page 25. Greywater economy is an important topic. Greywater as centralised or decentralised systems? What is affordable for RSA? Target low-income consumers or high consumers such as hotels? A figure about water cost development in RSA could be very useful here.

- Comment accepted and addressed on page 26 where it is stated that (In this project the greywater system is to be used in the decentralised settings where the sewage collection infrastructure is not available or cannot be built. The environmental impact study was conducted by soil and plant analysis.

Pager 30, Section 2. 10 Your statement “bathroom greywater is used because it has low contamination and nutrients that benefits plants”. Plants require nutrients and low load greywater sources (bathtubs and showers) have usually low N & P which is limiting to plant growth. A contradiction!

- Comment rejected, it has been stated in several sentences in the thesis that greywater has low contamination and nutrients that benefit plants.

Page 43: Qoute: “The Fly Ash Lime Filter Tower system is cheap, low tech and easy to operate and maintain…..” Here I miss precise data. What is cheap and easy to operate? A period of six weeks is not sufficient time for assessment!

- Comment rejected, it has been stated in the thesis that The Fly Ash Lime Filter Tower system contain materials that are locally available and easy to access since they can be recycled. This section was done over 6 months the examiner only looked at chapter 3 and the study id still continuing for further investigations.

Page 46, Section 3.2 Mulch tower is in the section title is not missing in the section or the corresponding Figure 3. Figure 3.1 is not self-explanatory and it requires more elaboration. Also data on the sand particles size is missing. Mulch is an organic material which is biodegradable and can give additional COD load to the greywater! Had this been investigated? Does mulch have to be added from time to time? Figure 3.1 shows the flyash/lime filter. The characterisation of the Fly Ash Lime Filter Tower and its dimensioning are not early worked out and described. Additional photos of the system could be more self-explanatory and helpful.

- Comment accepted, an additional sentence (Letters a-i represents the composition of materials inside the tower) to figure 3.1 has been added

Comment rejected, water hyacinth can be used as a sorbent and has high ability to absorb pollutants in wastewater and plants and plays an important role in phytoremediation.

Comment rejected, the system details has been scientifically published by Zuma et al 2010 and Ngqwala et al 2013.

Page 49, Section 3.2.2 (Sample collection): Collection of samples is an important topic, only a cross reference to Tandlich et al. (2008) is not sufficient. Please state clearly how samples have been taken.

Comment rejected, the sample collection has been described in page 46 “The reactors were fed twice a day, with 3 litres of greywater in the morning and 2 litres in the afternoon. The influent and effluent samples were collected as composite fractions of individual feedings”

It is well known that greywater inflow concentrations can vary widely with time; greywater from a dropping tap can result in a BOD close to 0 mg/l and if shortly afterwards kitchen water enters the system BOD can be 10,000 mg/l and more.

 Comment accepted, agree with the comment.

Page 50, Section 3.4.4: Faecal coliforms (FC) is not a physiochemical parameter! I further miss information on the hydraulic retention time of tested unit, which is very important.

 Comment accepted, microbial analysis has been added to 3.4.4. Microbial and Physicochemical analysis.

The flow rate was assessed by measuring the hydraulic retention time (HRT). This was done by evenly pouring 5 liters of fresh greywater onto the Fly Ash Lime Filter Tower, and then measuring the time taken for the water to emerge in the FLFT sampling sump as flow rate (Figure 3.1). The HRT was calculated as being a volume of the reactor divided by the flow rate. The volume of the FLFT was 0.16 m^3 which was calculated using the $V=\pi r2h$ and the HRT. **Pages 53-54**: There is much inconsistency in the units and unreasonable measurements, which need to be checked. Tables 3.1 and 3.2 should be checked. Table 3.1 heading gives information on the origin of greywater which is missed in Table 3.2

 Comment accepted, the origin of the greywater has been added on table 3.2.

What could be the reason that nitrogen is so low in Table 3.2 and high in Table 3.2?

 Comment accepted, the discussion has been added on **page 54**.

Please also check the units for consistency. **In Table 3.1** EC is µS/cm while in Table 3.2 it is mS/cm!

 Comment accepted, unit in Table 3.2 has been corrected to µS/cm

EC of 190 µS/cm in week 5 seems unrealistic. COD in W6 in **Table 3.1** has to be checked! Is there an explanation to this very high COD concentrations?

 Comment accepted, EC unit of 190 S/cm in week 5 has been corrected to1900 µS/cm

Don’t trust a COD effluent value below 5 mg/l, here 0.98 mg/l (**Table 3.2**, W2 effluent). The detection limit will be shown.

 Comment accepted, COD value has been round off to the n earest number = 1 mg/L

Further it has be esaid that pH > 11.5 is corrosive and dangerous on skin contact. Also plants require lower pH for growth.

 Comment rejected, on page 42 it is stated that the experiments were undertaken in Chapter 3 and 4 to modify the FLFT system to manage the pH of the effluent, while maintaining the treatment efficiency observed in the preliminary study.

Page 65. Figure 4.1:Where is the input, where is the output of the system? Please elaborate scheme. Water hyacinths between fly ash lime and sand without contact to light! Please supply us with photos in order to understand the system and how it works.

 Comment rejected, the system is the moderation of the one in chapter 3 on page 46 the only change was an addition layer of water hyacinth. Photos are not shown because the system is under development.

Page 69, Table 4.1The table legend is misleading and unclear. The table should present physicochemical and microbial parameters of the influent and final treated effluent. There are only one set of parameters!! To which do they belong, influent or effluent?

 Comment accepted, Table legend has been corrected to indicate that these are the treated effluent results

The table also shows very high EC concentrations in the range of saltwater which is 45 – 55 mS/cm. Can hyacinths survive in this salty environment? Such high salt concentrations are known to be corrosive to plants and cannot be used for irrigation (food production). Turbidity in the range of 90-100 NTU seems to be more or less for untreated greywater!

 Comment accepted, the units have been corrected from mS/cm to µS/cm, and water hyacinth act as a sorbent.

1. Total Phosphate in Table 2.1 page 14 (influent values) is between 0.6 and 27.3! Why is the effluent much higher in Table 4.1 up to 100 mg/l?

 Comment: accepted, these are the percentage removal not the actual amount and the error has been corrected.

The results of CFU/100ml in Table 4.1 over the period of 13 w eeks are nearly constant! Can this be explained? I have never encountered such low variations in bacterial counts, neither in influent nor effluent!

□ Comment rejected, it has been stated on page 70 that water hyacinth has the ability to absorb pollutants in wastewater.

Page 71, Figure 4.4: Speaking of % Removal of pH is a logarithmic scale and lower pH is not removal of H ions!

□ Comment accepted, it has been indicated on page 68 that the percentage removal equation was not used in calculating the pH. .

Page 88, Table 5.1 the table legend should describe where the greywater comes from and with which system it had been treated. COD> 200 mg/l is more or less untreated greywater, but NTU<5 makes me wonder if the results are correct. I am also surprised about the high EC up to 22, 0010 uS/cm and very low concentrations of chlorides and sulphates. This does not correlate with each other and should be elaborated.

□ Comment accepted, the origin of the water have been specified on page 88. Add more information

In literature, it is documented that water for irrigation should be below 1500 uS/cm and not have more than 3000 . Here it is up to 7 times more!

□ Comment: accepted, the error was in units and the units have been changed from (µS/cm) to (%)

Page 89 & 91, Tables 5.2 & 5.3: Missing units for EC and bacteria Pages 95 & 96, Tables 5.4 & 5.5:

□ Comment accepted, and the units have been corrected from the tables in chapter 5.

Units have to be checked (mg/g) and explained in the heading if it is the relation to dry or wet matter.

□ Comment rejected, the method is explained on page 81 that it is using dry weight.

High metal concentrations e.g Sr 1398.3 mg/g had to be explained, maybe there is an error in the units.

□ Comment: accepted, The reason for high Sr concentration has been discussed on page

Page 100, Chapter 6 the topic of the thesis is greywater. Why the hydrogen sulphides kit is used for rainwater and not for greywater research? Here I miss information on this method and its correlation to the standard microbiological methods.

 Comment rejected, hydrogen sulphides kit is not used for greywater because using water hyacinth has proven to reduce the colony hence there is no need of the kit. The metod has been explained on page 101.

Page 121, Chapter 7 it is stated that customers can build their own virtual FLFT system but more details and specific information about the system is missing. Based on the published data, it is not possible to repeat or verify the results. Where should the treatment unit be placed, how can it be fed (pump, bucket,..), solid particles should be removed before greywater enters the tower? Is the input on the top or at the bottom (flow direction)? What is the diameter of the tower, the gravel size, and the eater volume that can be treated daily? Nothing is mentioned about the hydraulic retention time of the greywater in the system! What is the expected life time of the filter system and is there a problem of surface clogging? What kind of maintenance and technical know-how is necessary for plant operation?

 Comment accepted, information has been added on page 124. The FLFT systems shall be set up in 70-100L plastic containers. The treatment system shall be placed near the garden and coupled with a drip irrigation systems

Page 65 indicates that they are placed between lime and sand in level b. This is a bit misleading! A photo would be very helpful here.

 Comment rejected, Figure 7.2 is adapted from the FLFT in page 65.

Statements on scale-up of the FLFT reactor from laboratory scale to a real treatment plant (for example 1-10 m3/d) had been missing, in addition to energy, repair and maintenance requirements.

 Comment rejected, it has been indicated in chapter 3 and 4 that the system will be upgraded from generating 5L/day to 100 L/day on page 113.

In the literature review, I miss links to literature in the internet, which is widely available with very good literature sources, why?

 Comment rejected, literature is limited in techno economic analysis of greywater systems

Examiner 2: Konrad Soyez

The structure of the thesis only partly follow that list of research objectives so that it is difficult to understand which chapter belongs to which of the objectives.

- **Comment accepted, minor changes have been made in chapter 1 page 5 to align the thesis with chapters**

This is a quite broad field of research objectives covering totally different matters of science such as microbiology, soil chemistry, plant biology, engineering, to mention some of them, which fact indicates that no deeper research into each of them will be possible in one thesis and integrated practice oriented approach is intended. This statement becomes evident e.g. If one considers the scope of the chapters e.g. for the technology only 13 pages including literature.

- **Comment rejected, this is a fairly new research in the country and limited information is available in the context of South Africa as results each chapter has its own significance. Chapter 7 has 13 pages because of the limited information available however, this part of the research will be carried forward by a Masters Research project.**

In case of research objective 1 it would be expected to get a clear analysis of the technology and the construction of the tower system which was to modify however that is missed. Obviously the system was under research by another person (Zuma) who was the developer. However, the findings of that previous study are not clearly presented.

- **Comment rejected, schematic representation of the tower is represented and explained in chapter 3 page 46.**

The presentation of the H2S test kit and the community based activities are doubtlessly one of the most interesting chapters of the thesis, however there was no real need for that context of the grey water research. Grey water is not mentioned in this chapter.

- **Comment rejected, the reason why the greywater is not mentioned in this chapter is because it was not used. The kit detects sulphur producing bacteria and**

mostly in contaminated waters. There were no bacteria detected after greywater treatment.

The thesis do not state in every case if the candidate did the experiments and analysis by The thesis do not state in every case if the candidate did the experiments and analysis by herself or were done by co-workers.

- **Comment accepted, minor changes have been made in chapter 1 page 5 to state that all the experiments in this thesis were conducted in the lab unless otherwise stated.**

As mentioned before the thesis deal with a broad spectrum of research fields which all use their specialised methods and techniques, e.g. soil science, water quality characterization including microbial analysis, engineering of the tower reactor, plant growth and fertilization as well as economy and sociology. It is clear that the candidate was able to choose appropriate methods and cooperate with other scientists to get the results needed. The thesis do not state in every case if the candidate did the experiments and analysis by herself or were done by co-workers. Nevertheless, one aspect seems of importance: A statistical analysis is missing; even the idea that such an analysis would be necessary is not mentioned. A real statistical proof of the results will not be possible in case of such small numbers of plants. E.g. in case of the irrigation experiments it is stated that they yield for tomatoes was 26.59 and 26.5 (which is not given as 26.50!) by irrigation with greywater and tap water ,resp and the conclusion is that "crops irrigated with grey water significantly grow faster …" which statement is impossible or wrong. A statistical proof which only allows a statement of "significance" without a statistical proof is a common mistake in many scientific papers. Another point is that consistency in the number of digits after the point is essential in research: on page 92 in case of tomatoes 26.59 and 26.5 and in case of onions 8.929 are mentioned as average values which means the usage of 1, 2 and 3 digits after the point – which pretends different kinds of precision.

- **Comment rejected, this is stated on the declaration page and in the method that the work was done by me in the lab.**

Each chapter contains a thorough literature survey which however consists mostly of South African sources. As far as I know the sources mentioned contain a variety of international sources and summarize the results so that I assume the candidate has sufficient acquaintance with the current international literature. In one case a source is cited which is but not found in the literature list (a German source, Nolde 1999, page 122).

 Comment rejected, reference Nolde 1999 is available in page 57

The thesis contain a lot of the information however often in unexpected context: From my point of view the systematic of the presentation of the research activities is poor. It should have started with a description of the water problem in RSA- a fact which is mentioned many times in the whole thesis mostly in the introduction of the chapters and using nearly the same phrases instead of one time concentrated. It should be followed by a clear definition of the term “grey water” and in which way it could substitute tap water and its normal composition which makes clear that a treatment is necessary before its usage. Such a definition is sometimes given but not consistent.

 Comment rejected, water problems in RSA have been explained on page 18 under Section 2.3 and 2.5 and greywater has been described in section 2.4

As a next point I expected a thorough analysis of the regulation of grey water usage both outside and in RSA, especially the papers by the water research commission who published a grey water irrigation manual in March 2015. In the thesis international regulations mentioned are limited to some US states and Mexico however a lot of work has been done in Germany and other European countries –mostly as proposals and without their implementation in the legislation.

 Comment rejected, greywater s regulation in RSA has been presented in section 2.5 and other countries legislation has been looked at.

That topic should be followed by a survey of technological needs of grey water treatment as well as of technologies developed and /or applied and marketed internationally and in RSA, however this was unexpectedly given in chapter 7 under the headline techno-economic analysis and comprises not more than one page. One aspect mentioned here is of importance for developers of such systems: Theft prevention and it would have been of value to find out other specific needs under that environment. I would than expect a description of the concrete tower system under study and its improvement options under given natural and infrastructural conditions followed by a critical review of its disadvantages including the use of Filter Ash which is an environmentally suspect substance.

 Comment accepted, the survey will be considered in the next phase of the research.

Next point the research into the application of greywater substituting tap water for irrigation. At the end a real economic analysis and the preconditions for implementation into practice especially in under developed regions and the community participation context. Here some of the findings of the H2S method could be considered.

It is not always clear which result is a finding of the work and which is from others. In a variety of cases statements of well-known or simple facts are unnecessarily documented by citation e.g. “Plant biomass is an important factor in the study of plant biology “ which indicates a kind of misunderstanding scientific honesty or precision.

□ Comment rejected, the citations are justified based on the text of the chapters.

In case of the SWOT analysis it seems that a more thorough understanding of the analysis targets would be necessary which must refer to the technology that grey water is difficult to store, and under threats it is useless to state that the amount of water produced could be less than demand. This is a question of the layout capacity and not of the technology as such.

Comment rejected, greywater is difficult to store because of the smell and precipitation, the amount of water produced could be less than a demand because greywater produced might not be enough to carry all the necessary needs.

In Table 7.2 under risk description “Logistics” it is mentioned that main markets could be far from production. Instead, in the thesis it is mentioned as an advantage of the Tower system that it can be assembled on-site.

□ Comment rejected, the tower is designed with materials that may not be easily accessible for example in the case of fly ash/ sand.

With respect to table 7.3 which deals with costs it is necessary to relate the costs to a reference base, such as kilolitres of grey water or another service unit, which is not given in the table.

□ Comment accepted, the units have been added to the to the description check pg 134.

There is a variety of inconsistencies and/or mistakes in the text which could have been prevented by a more thorough preparation and rereading. Some examples; table 7.2 at page 134 and table 7.4 at page 136 are totally identical and one must be omitted.

□ Comment accepted, Table 7.4 on page 134 has been omitted.

Concluding remarks under chapter 4.5 on page 73 is given twice the same. On page 95 beetroot. Often sentences are incomplete, e.g. at 96 first sentence under table 5.5 or at page 92 chapter 5.4.3.

 Comment accepted, second concluding remarks on page 73 and the repetition on page 95 has been deleted.

“Generally…” the headlines of the chapters not always describe their contents. E.g. in case of headline chapter 5 “Reuse of grey water to retrench water needs” is indicated. However, the chapter deals with irrigation of plants using grey water. On page 122 it is stated that in chapter 6 grey “Water effluent… was evaluated for reuse in irrigation “however chapter 6 deals with Community based water monitoring etc. only.

 Comment accepted and the following changes have been made on to the chapter titles: Chapter 5 to Irrigation trial with the FLFT effluent and the evaluation of the impact on soil properties and Chapter 6 to A model paradigm for the roll-out of the FLFT into greywater treatment in communities.

Examiner 3: Djamel Turki

Recommendations

Repetition of paragraph 4.5 in thesis pg 71

 Comment accepted, the paragraph 4.5 has been deleted on chapter 4 page 71 concluding remarks.

Yours Faithfully

Nosiphiwe Ngqwala

G10n7601@ru.ac.za