

SANITATION IN UNSEWERED URBAN POOR AREAS

TECHNOLOGY SELECTION,
QUANTITATIVE MICROBIAL RISK ASSESSMENT
AND GREY WATER TREATMENT



ALEX YASONI KATUKIZA



ProQuest Number:28225874

All rights reserved

INFORMATION TO ALL USERS

The quality of this reproduction is dependent on the quality of the copy submitted.

In the unlikely event that the author did not send a complete manuscript and there are missing pages, these will be noted. Also, if material had to be removed, a note will indicate the deletion.



ProQuest 28225874

Published by ProQuest LLC (2020). Copyright of the Dissertation is held by the Author.

All Rights Reserved.

This work is protected against unauthorized copying under Title 17, United States Code
Microform Edition © ProQuest LLC.

ProQuest LLC
789 East Eisenhower Parkway
P.O. Box 1346
Ann Arbor, MI 48106 - 1346

**Sanitation in unsewered urban poor areas:
technology selection, quantitative microbial risk assessment
and grey water treatment**

PREVIEW

Alex Yasoni Katukiza

Thesis committee

Promotor

Prof. Dr P.N.L. Lens
Professor of Environmental Biotechnology
UNESCO-IHE, Delft

Co-promotor

Dr M. Ronteltap
Lecturer in Sanitary Engineering
UNESCO-IHE, Delft

Other members

Prof. Dr G. Zeeman, Wageningen University
Em. Prof. Dr W. Verstraete, Ghent University, Belgium
Prof. Dr P.D. Jenssen, Norwegian University of Life Sciences, Ås, Norway
Dr T.O. Okurut, National Environmental Management Authority, Kampala, Uganda

This research was conducted under the auspices of the Graduate School for Socio-Economic and Natural Sciences of the Environment (SENSE)

**Sanitation in unsewered urban poor areas:
technology selection, quantitative microbial risk assessment
and grey water treatment**

Thesis

submitted in fulfilment of the requirements of
the Academic Board of Wageningen University and
the Academic Board of the UNESCO-IHE Institute for Water Education
for the degree of doctor
to be defended in public
on Friday, 29 November 2013
at 4 p.m. in Delft, The Netherlands

by

Alex Yasoni KATUKIZA
born in Kabale, Uganda

CRC Press/Balkema is an imprint of the Taylor & Francis Group, an informa business

© 2013, Alex Yasoni Katukiza

All rights reserved. No part of this publication or the information contained herein may be reproduced, stored in a retrieval system, or transmitted in any form or by any means, electronic, mechanical, by photocopying, recording or otherwise, without written prior permission from the publishers.

Although all care is taken to ensure the integrity and quality of this publication and information herein, no responsibility is assumed by the publishers or the author for any damage to property or persons as a result of the operation or use of this publication and or the information contained herein.

Published by:

CRC Press/Balkema

PO Box 11320, 2301 EH Leiden, The Netherlands

e-mail: Pub.NL@taylorandfrancis.com

www.crcpress.com – www.taylorandfrancis.com

ISBN 978-1-138-01555-5 (Taylor & Francis Group)

ISBN 978-94-6173-769-4 (Wageningen University)

Dedication

This thesis is dedicated to my children as a motivation for them to strive and achieve what they want in life.

To my wife whose love and patience provided the strength I needed to progress.

To my parents who valued education and enabled me to reach where they could not reach.

PREVIEW

Acknowledgments

This research was funded by the Netherlands Ministry of Development Cooperation (DGIS) through the UNESCO-IHE Partnership Research Fund. It was carried out at UNESCO-IHE, Delft (The Netherlands) and Makerere University, School of Engineering (Uganda) in the framework of the research project 'Addressing the Sanitation Crisis in Unsewered Slum Areas of African Mega-cities' (SCUSA).

I wish to express my sincere gratitude to my promotor Prof. Dr. ir. Piet Lens and supervisors Dr. ir. Mariska Rontelap, Prof. Dr. Frank Kansime and Dr. Charles Niwagaba for their strong scientific support, guidance and encouragement throughout the PhD research period. I will never forget the continuous critical comments from Prof. Dr. Piet Lens, that seemed to cause tough times but in the end enabled me to be critical, open minded and carryout multiple tasks with tight deadlines. I would like to thank Dr. Mariska again for her encouragement and scientific guidance during tough times and for the assistance in translating the summary into Dutch. I look forward to future research collaboration with my supervisors.

I would like to thank the SCUSA project manager Assoc. Prof. Dr. Jan Willem Foppen for his scientific support and assistance during the course of the research. Thanks to my colleagues Philip Nyenje and John. B. Isunju with whom I passed through the hard times and enjoyed good times during the course of this research. I thank Fred Kruis, Peter Heerings and Lyzette Robbemont of UNESCO-IHE for their assistance in obtaining research equipment and laboratory consumables and Jolanda Boots for her assistance in transferring funds and obtaining airtickets. Thanks go to Dr. Kulabako Robinah for assistance with laboratory equipment and encouragement. The support provided by John Omara and Rita Nakazibwe during analysis of samples and by Fred Mukasa during construction of the filtration systems for the grey water treatment is highly appreciated. The following carried out their MSc. research within the framework of this SCUSA project 1 and their contribution is appreciated: Albert Oleja, Hayeloum Temanu, Olivier Goldschmidt and Henrietta Osei-Tutu.

I thank my wife Joan and our beloved children Jethro Mugume and Ashley Abindabyamu for their love, support, prayers and also patience during my absence while abroad. To my parents and siblings, in-laws and close friends; thank you for your prayers, support and love.

Alex Y. KATUKIZA

Delft, 29 November 2013

PREVIEW

Abstract

The sanitation crisis in unsewered urban slums of cities in developing countries is one of the challenges that need to be addressed. It is caused by the high rate of urbanisation in developing countries and the increasing urban population with limited urban infrastructure. The major issues of concern are the collection, treatment and safe disposal of excreta, grey water and solid waste. The goal of this study was to contribute to the sanitation improvement in urban slums with focus on sanitation technologies.

A review of sanitation technology options for urban slums was made followed by a baseline study in the slum of Bwaise III in Kampala Uganda. The results from the situation assessment and analysis were used to develop a method for selection of sustainable sanitation technologies in urban slums. Quantitative microbial risk assessment was then carried out based on the sources and concentration of pathogens and indicator organisms in the slum environment. The risk of infection and the disease burden contribution from various exposure pathways were determined. The study then focused on grey water treatment using a low-cost media (sand, crushed lava rock) based systems at laboratory scale and household level in the study area.

The results showed that existing facilities in Bwaise III are unimproved and do not function as elements within a sanitation system. In addition, there is no system in place for grey water management. There was also wide spread viral and bacterial contamination in the area. The maximum concentration of human adenoviruses F and G (HAdV-F and G) rotavirus (RV) was 2.65×10^1 genomic copies per mL (gc mL⁻¹) and 1.87×10^2 gc mL⁻¹, respectively. The concentration of *Escherichia coli* and *Salmonella* spp. ranged from 3.77×10^4 cfu. (100 mL)⁻¹ to 2.05×10^7 cfu. (100 mL)⁻¹. The disease burden from each of the exposure routes in Bwaise III slum was 10^2 to 10^5 higher than the World Health Organisation (WHO) tolerable risk of 1×10^{-6} disability-adjusted life years (DALYs) per person per year. Grey water generated in Bwaise III amounted to 85% of the domestic water consumption and was highly polluted with a COD and TN concentration range of 3000-8000 mg.L⁻¹ and 30-50 mg.L⁻¹, respectively, and *Escherichia coli* (*E. coli*) concentration of up to 2.05×10^7 cfu. (100 mL)⁻¹. Grey water treatment with a crushed lava rock filter and using a two-step filtration process, resulted in the COD and TSS removal efficiencies of 88% and 90%, respectively, at a constant Hydraulic Loading rate (HLR) of 0.39 m.d⁻¹. In addition, the highest removal efficiencies of TP and TKN were 59.5% and 69%, respectively, at a HLR of 0.39 m.d⁻¹. A log removal of *E. coli*, *Salmonella* spp. and total coliforms of more than 3 (99.9%) was also achieved under household filter usage conditions.

These results show that grey water treatment using a two-step crushed lava rock filter at household level in an urban slum has the potential to reduce the grey water pollutant loads by 50 % to 85%. However, its impact on public health and the environment needs to be assessed after its wide application. The need for advanced removal of pathogens and micro-pollutants from grey water warrants further research. In addition, the management systems for other waste streams of excreta and solid waste need to be in place as well to achieve the desired health impacts in urban slums. Integration of quantitative microbial risk assessment (QMRA) in the selection process of sustainable sanitation technologies for urban slums is recommended for future studies aimed at providing a holistic approach for upgrading slum sanitation. This will help to further understand the health impacts and benefits of sanitation solutions and also provide support to local authorities in making decisions on the measures to reduce the disease burden and environmental pollution.

PREVIEW

Contents

ACKNOWLEDGMENTS	VI
ABSTRACT	VIII
CHAPTER 1: GENERAL INTRODUCTION	1
1.1 SANITATION IN URBAN SLUMS OF DEVELOPING COUNTRIES	2
1.2 RESEARCH SCOPE AND OBJECTIVES	3
1.3 THESIS OUTLINE	4
REFERENCES.....	4
CHAPTER 2: SANITATION TECHNOLOGY OPTIONS FOR URBAN SLUMS	7
2.1 INTRODUCTION	9
2.1.1 <i>Sanitation in slums</i>	9
2.1.2 <i>Public health and consequences of poor sanitation</i>	10
2.1.3 <i>Sustainable sanitation</i>	11
2.2 WASTE STREAMS IN URBAN SLUMS	12
2.2.1 <i>Excreta</i>	12
2.2.3 <i>Grey water</i>	15
2.2.4 <i>Solid Waste</i>	18
2.3 SANITATION SYSTEMS FOR URBAN SLUMS	19
2.3.1 <i>Introduction</i>	19
2.3.2 <i>Collection and treatment of sewage</i>	21
2.3.3 <i>Collection and treatment of faecal sludge</i>	22
2.3.4 <i>Collection and treatment of urine</i>	28
2.3.5 <i>Collection and treatment of solid waste and faecal sludge for resource recovery</i>	30
2.3.6 <i>Collection and treatment of grey water</i>	34
2.4 CONCLUSION	36
REFERENCES.....	37
CHAPTER 3: SELECTION OF SUSTAINABLE SANITATION TECHNOLOGIES FOR URBAN SLUMS	49
3.1 INTRODUCTION	51
3.1.1 <i>Sanitation in slum areas</i>	51
3.1.2 <i>Case study area: Bwaise III</i>	52
3.2 MATERIALS AND METHODS	54
3.2.1 <i>Sample size and selection</i>	54
3.2.2 <i>Questionnaires</i>	54
3.2.3 <i>Field investigations</i>	55
3.2.4 <i>Technology selection process scheme</i>	55
3.3 RESULTS.....	65
3.3.1 <i>Existing sanitation situation</i>	65
3.3.2 <i>Technology selection</i>	70
3.4 DISCUSSION	72
3.4.1 <i>Human excreta management</i>	72
3.4.2 <i>Water supply</i>	73
3.4.3 <i>Solid waste management</i>	73
3.4.4 <i>Ranking of the technologies using the sustainability criteria</i>	74
3.5 CONCLUSIONS	75
REFERENCES.....	76
CHAPTER 4: GENOMIC COPY CONCENTRATIONS OF SELECTED WATERBORNE VIRUSES IN A SLUM ENVIRONMENT IN KAMPALA, UGANDA	80
4.1 INTRODUCTION	82
4.2 MATERIALS AND METHODS.....	84
4.2.1 <i>Characterisation of the slum environment</i>	84
4.2.2 <i>Sample collection</i>	84
4.2.3 <i>Virus concentration by glass wool filtration</i>	87
4.2.4 <i>Nucleic acid extraction</i>	87
4.2.5 <i>Quantitative PCR (qPCR) and Reverse transcription-qPCR (RT-qPCR)</i>	89

4.2.6	<i>Determining virus concentrations</i>	89
4.2.7	<i>Inhibition and false negative tests</i>	90
4.2.8	<i>Quality Control</i>	90
4.3	RESULTS.....	90
4.3.1	<i>Characterisation of Bwaise III</i>	90
4.3.2	<i>Recovery of the bacteriophages</i>	91
4.3.3	<i>Sensitivity and efficiency of the HAdV-F and G and RV assays</i>	92
4.3.4	<i>PCR inhibition tests</i>	92
4.3.5	<i>Prevalence of viruses in Bwaise III slum</i>	92
4.3.6	<i>Temporal virus concentration variations</i>	95
4.3.7	<i>Genomic copy concentrations (GC) of HAdV-F and G, and RV</i>	96
4.4	DISCUSSION	97
4.4.1	<i>Virus recovery and PCR accuracy</i>	97
4.4.2	<i>Waterborne viral contamination in the Bwaise III slum</i>	97
4.4.3	<i>Possible interventions needed based on the findings</i>	99
4.5	CONCLUSIONS	99
	REFERENCES.....	100
CHAPTER 5: QUANTIFICATION OF MICROBIAL RISKS TO HUMAN HEALTH CAUSED BY WATERBORNE VIRUSES AND BACTERIA IN AN URBAN SLUM		106
5.1	INTRODUCTION	108
5.2	MATERIALS AND METHODS	109
5.2.1	<i>The study area</i>	109
5.2.2	<i>Hazard Identification</i>	109
5.2.3	<i>Exposure Assessment</i>	110
5.2.4	<i>Sample collection and analysis for detection of bacteria</i>	112
5.2.5	<i>Sample collection and analysis for detection of waterborne viruses</i>	113
5.2.6	<i>Dose-response models</i>	113
5.2.7	<i>Risk characterisation</i>	114
5.2.8	<i>Burden of the disease determination</i>	115
5.2.9	<i>Variability and uncertainty in the data</i>	117
5.3	RESULTS.....	119
5.3.1	<i>Sources of contamination and concentrations of bacteria and waterborne viruses</i>	119
5.3.2	<i>Risk of infection</i>	122
5.3.3	<i>Disease burden</i>	124
5.4	DISCUSSION	127
5.4.1	<i>Concentration of bacteria and waterborne viruses</i>	127
5.4.2	<i>Risk of infection</i>	128
5.4.3	<i>The disease burden in the Bwaise III slum</i>	129
5.4.4	<i>Intervention options to reduce the risk of infection and the disease burden in Bwaise III</i>	130
5.5	CONCLUSIONS	131
	REFERENCES.....	132
CHAPTER 6: GREY WATER CHARACTERISATION AND POLLUTANT LOADS IN AN URBAN SLUM		138
6.1	INTRODUCTION	140
6.2	MATERIALS AND METHODS	141
6.2.1	<i>Study Area</i>	141
6.2.2	<i>Selection of households</i>	141
6.2.3	<i>Selection of the tertiary drains</i>	141
6.2.4	<i>Collection of grey water samples</i>	143
6.2.5	<i>Analytical techniques</i>	143
6.2.6	<i>Pollutant loads</i>	144
6.2.7	<i>Statistical analysis</i>	144
6.3	RESULTS.....	145
6.3.1	<i>Quantity of grey water produced in Bwaise III</i>	145
6.3.2	<i>Physical and chemical characteristics of grey water in Bwaise III</i>	147
6.3.3	<i>Bacteriological quality of grey water</i>	153
6.3.4	<i>Specific pollutant loads originating from grey water</i>	155
6.3.5	<i>Variation of grey water quality in tertiary drains</i>	157
6.4	DISCUSSION	159

6.4.1	<i>Grey water production in Bwaise III</i>	159
6.4.2	<i>Biodegradability of grey water</i>	159
6.4.3	<i>Variation of the grey water quality from tertiary drains in Bwaise III</i>	160
6.4.4	<i>Grey water pollutant loads and its potential environmental impacts</i>	161
6.4.5	<i>Microorganism concentration and loads in grey water</i>	162
6.5	CONCLUSIONS	163
	REFERENCES	163
CHAPTER 7: GREY WATER TREATMENT IN URBAN SLUMS BY A FILTRATION SYSTEM: OPTIMISATION OF THE FILTRATION MEDIUM		169
7.1	INTRODUCTION	171
7.2	MATERIALS AND METHODS	172
7.2.1	<i>Study area and household selection</i>	172
7.2.2	<i>Grey water collection</i>	172
7.2.3	<i>Filter column set ups</i>	172
7.2.4	<i>Operating conditions</i>	173
7.2.5	<i>Characterization of the filter media</i>	174
7.2.6	<i>Analytical techniques</i>	177
7.3	RESULTS	177
7.3.1	<i>Characteristics of silica sand, crushed lava rock and granular activated carbon</i>	177
7.3.2	<i>Characteristics of the non-settled grey water and the filter influent (settled grey water mixture)</i>	177
7.3.3	<i>COD, TOC, DOC and TSS removal by filter columns</i>	181
7.3.4	<i>Nutrient removal by filter columns</i>	187
7.3.5	<i>E. coli, Salmonella spp. and total coliforms removal</i>	190
7.4	DISCUSSION	192
7.4.2	<i>Grey water characteristics</i>	192
7.4.3	<i>The role of pre-treatment</i>	193
7.4.4	<i>Performance of the filter columns in parallel and in series</i>	193
7.5	CONCLUSIONS	195
	REFERENCES	195
CHAPTER 8: A TWO-STEP CRUSHED LAVA ROCK FILTER UNIT FOR GREY WATER TREATMENT AT HOUSEHOLD LEVEL IN AN URBAN SLUM		199
8.1	INTRODUCTION	201
8.2	MATERIALS AND METHODS	202
8.2.1	<i>Study area</i>	202
8.2.2	<i>Household selection</i>	202
8.2.3	<i>Design and implementation of the crushed lava rock filter in Bwaise III</i>	203
8.2.4	<i>Characterization of the crushed lava rock</i>	206
8.2.5	<i>Sampling strategy</i>	208
8.2.6	<i>Analytical techniques</i>	208
8.3	RESULTS	209
8.3.1	<i>Physical and chemical characteristics of the crushed lava rock</i>	209
8.3.2	<i>Characteristics of raw and pre-treated grey water</i>	212
8.3.3	<i>Pollutant removal from grey water by the crushed lava rock filter</i>	214
8.4	DISCUSSION	221
8.5	CONCLUSIONS	224
	REFERENCES	225
CHAPTER 9: GENERAL DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS		231
9.1	INTRODUCTION	232
9.2	SELECTION OF SUSTAINABLE SANITATION TECHNOLOGIES	234
9.3	QUANTIFICATION OF MICROBIAL RISKS IN BWAISE III	235
9.4	GREY WATER POLLUTION LOAD BWAISE III	238
9.5	DECENTRALISED GREY WATER TREATMENT WITH A LOW-TECHNOLOGY SYSTEM	239
9.6	CONCLUSIONS	244
9.7	RECOMMENDATIONS FOR FURTHER RESEARCH	244
	REFERENCES	245
SUMMARY		249

SAMENVATTING	251
CURRICULUM VITAE.....	253
LIST OF SCIENTIFIC PUBLICATIONS.....	254

PREVIEW

PREVIEW

Chapter 1: General introduction

PREVIEW

1.1 Sanitation in urban slums of developing countries

The rates of urbanisation and urban slum growth in developing countries especially in sub-Saharan Africa, South America and Asia are estimated to be increasing and higher than the rate of urban infrastructure and services provision (Isunju et al., 2011; WHO and UNICEF, 2012). Urban slums are characterised by high population density, population dynamics, poor urban infrastructure and lack of legal status (Katukiza et al., 2010). These factors make the provision of sustainable sanitation services difficult, which has also led to the increase in the urban population without access to improved sanitation in major urban centres in developing countries (Cairncross, 2006; WHO and UNICEF, 2012). In addition, the funds budgeted for the water and sanitation sector for example are mainly spent on water supply infrastructure, which has further weakened the sanitation sub-sector leading to the sanitation targets not met by most developing countries (Moe and Rheingans, 2006; Joyce et al., 2010).

Generally, inadequate collection and treatment of the waste streams (excreta, grey water and solid waste) and safe disposal or reuse of the end products is a threat to the environment and a risk to public health. In urban slums, soil and water sources (such as boreholes, shallow wells, springs and streams) are contaminated with pathogens (bacteria, viruses), nutrients (NO_3^- , PO_4^{3-} , NH_4^+) and micro-pollutants (Howard et al., 2003; Katukiza et al., 2013; Nyenje et al., 2013). In particular pit latrines in slums contaminate ground water sources (Graham and Polizzotto, 2013; Nyenje et al., 2013), which may have negative health impacts on the slum dwellers. Moreover, high child mortality rate and loss of working days as a result of morbidity in urban poor areas are attributed to inadequate sanitation and poor hygiene practices (Genser et al., 2008; Rutstein, 2000). Provision of adequate and improved sanitation in slums is thus driven by the need to improve the quality of life by protecting the exposed population from infectious diseases, to reduce deterioration of water sources, to protect the ecosystem downstream the urban slums and to recover waste for economic benefits in the form of renewable energy, reclaimed water and recyclable solid materials.

The dominant type of sanitation facilities in urban slums in developing countries is mainly pit latrines used for excreta disposal (Thye et al., 2011; Howard et al., 2003). They require low capital and operating costs, are non-waterborne and can be easily built and maintained locally. Pit latrines are usually elevated in high water table areas (Katukiza et al., 2010). The high filling rate due to higher user-load and disposal of non-biodegradable solids in the pit latrine chamber is a challenge to the sustainability of pit latrines in urban slums. In addition, there is lack of access for pit emptying with cesspool emptiers whose cost may not be affordable by the slum dweller. Manual pit latrine emptying from the chamber to the adjacent excavated hole is therefore commonly practiced because it is the cheapest option, despite its negative health and environmental consequences. Alternative options in form of Vacutug MK1, Vacutug MK 2 and the MAPET have been used in some parts of Africa and Asia (Thye et al., 2011). Sanitation technology innovations in form of urine diversion dehydrating toilet

(UDDT), community sanitation blocks, Sulabh flush compost toilet and biogas toilets have also been implemented in Asia and Africa with the aim of improving sanitation in slums. They provide additional benefits in form of biogas and manure or soil conditioner. However, there are still questions on the categorisation of sanitation facilities as improved and unimproved by the Joint Monitoring Program (JMP) of UNICEF and the World Health Organization (WHO) based on technology approach rather than function based approach (Kvarnström et al., 2011). Moreover, this categorisation by UNICEF and WHO needs to include sanitation technologies for management of solid waste and grey water as well.

Simplified sewerage has been implemented for off-site treatment of combined sewage and grey water in South Africa, Sri Lanka, Brazil and other countries in the same regions (Mara, 2003; Paterson et al., 2007). Although it is considered cheaper based on the economies of scale (Paterson et al., 2007), its feasibility in densely populated urban slums is hampered by limited space, low affordability for waterborne systems and lack of reliable piped water supply. Off-site treatment of excreta and grey water does not offer opportunities for source separation of the waste and resource (in form of nutrients and energy) recovery. It is therefore critical to be able select appropriate technologies for a given geographical location or practical situation and to make technologies function within a system and acceptable by the beneficiaries. In addition, sustainability of sanitation systems is affected by inter-linked technical and non-technical factors including institutional arrangements for up-scaling and replication by practitioners (Jenkins and Sugden, 2006).

1.2 Research scope and objectives

This study was carried out in the framework of the interdisciplinary research project SCUSA (Sanitation Crisis in Unsewered Slum Areas in African mega-cities). It was comprised of three PhD sub-projects of Sanitation technologies (this research), hydrology and socio-economic aspects of sanitation in urban slums. The aim of the SCUSA project was to contribute to sanitation improvement in urban slums by integrating the technical, socio-economic and hydrological aspects of sanitation in slums. The study area of the SCUSA project was Bwaise III in Kampala (Uganda).

The specific objectives of this study based on the aim of the SCUSA research project were:

- To assess the sanitation situation in an urban slum of Bwaise III in Kampala (Uganda) and develop a method for selection of sustainable sanitation technologies.
- To provide an insight of the magnitude of microbial risks to public health caused by pathogens through various exposure pathways in typical urban slums such as Bwaise III in Kampala (Uganda).

- To design, implement and evaluate the performance of a grey water treatment technology (prototype) in an urban slum.

1.3 Thesis outline

The thesis consists of nine chapters. This first chapter gives a brief introduction of the study. Chapter 2 is based on literature review of technologies for urban slums and Chapter 3 presents a method for Selection of sustainable sanitation technologies for urban slums based on a baseline study in Bwaise III in Kampala (Uganda). Chapter 4 shows the results of genomic copy concentrations of selected waterborne viruses, while in Chapter 5 the magnitude of microbial risks from waterborne pathogens in a typical urban slum of Bwaise III in Kampala (Uganda) are presented. Chapters 6, 7 and 8, respectively, deal with the grey water characterisation and pollutant loads, laboratory-scale grey water treatment with a filter system and application of a two-step crushed lava rock filter system for grey water treatment at household level in the study area. The last chapter consists of general discussion, conclusions and recommendations for future research.

References

- Cairncross S., 2006. Sanitation and water supply: practical lessons from the decade. UNDP – World Bank Water and Sanitation Program, The International Bank for Reconstruction and Development/The World Bank, Washington DC.
- Carden, K., Armitage, N., Winter, K., Sichone, O., Rivett, U., Kahonde, J., 2007. The use and disposal of grey water in the non-sewered areas of South Africa: Part 1- Quantifying the grey water generated and assessing its quality. *Water SA* 33(4), 425-432.
- Genser, B., Strina, ., dos Santos, L.A., Teles, C.A., Prado, M.S., Cairncross, S., Barreto, M.L., 2008. Impact of a city-wide sanitation intervention in a large urban centre on social, environmental and behavioural determinants of childhood diarrhoea: analysis of two cohort studies. *International Journal of Epidemiology* 37(4), 831 - 840.
- Graham. J.P., Polizzotto, M.L., 2013. Pit latrines and their impacts on groundwater quality: a systematic review. *Environmental Health Perspectives* 121(5), 521-30.
- Holm-Nielsen B, Al Seadi T, Oleskowicz-Popiel P. The future of anaerobic digestion and biogas utilization. *Bioresource Technology* 100 (22), 5478-5484
- Howard, G., Pedley, S., Barret, M., Nalubega, M., Johal, K., 2003. Risk factors contributing to microbiological contamination of shallow groundwater in Kampala, Uganda. *Water Research* 37, 3421–9.
- Isunju, J.B., Schwartz, K., Schouten, M.A., Johnson, W.P., van Dijk, M.P., 2011. Socio-economic aspects of improved sanitation in slums: A review. *Public Health* 125, 368-376.

- Jenkins, M.W., Sugden, S., 2006. Rethinking sanitation. Lessons and innovation for sustainability and success in the New Millennium. UNDP - sanitation thematic paper.
- Jingura, R.M, Matengaifa, R., 2009. Optimisation of biogas production by anaerobic digestion for sustainable energy development in Zimbabwe. *Renewable and Sustainable Energy Reviews* 13, 1116-1120.
- Joyce, J., Granit, J., Frot, E., Hall, D., Haarmeyer, D., Lindström A., 2010. The Impact of the Global Financial Crisis on Financial Flows to the Water Sector in Sub-Saharan Africa. Stockholm, SIWI.
- Katukiza, A.Y., Ronteltap, M., Niwagaba, C., Kansiime, F., Lens, P.N.L., 2010. Selection of sustainable sanitation technologies for urban slums - A case of Bwaise III in Kampala, Uganda, *Science of the Total Environment* 409(1), 52-62.
- Katukiza, A.Y., Temanu H, Chung JW, Foppen JWA, Lens PNL., 2013. Genomic copy concentrations of selected waterborne viruses in a slum environment in Kampala, Uganda. *Journal of Water and Health* 11(2), 358-369.
- Kulabako, N. R., Ssonko, N.K.M, Kinobe, J., 2011. Greywater Characteristics and Reuse in Tower Gardens in Peri-Urban Areas – Experiences of Kawaala, Kampala, Uganda. *The Open Environmental Engineering Journal* 4, 147-154.
- Kvarnström, E., McConville, J., Bracken, P., Johansson, M., Fogde, M., 2011. The sanitation ladder – a need for a revamp?. *Journal of Sanitation and Hygiene for Development* 1(1), 3-12.
- Mara, D.D., 2003. Water, sanitation and hygiene for the health of developing nations. *Public Health* 117(6), 452-456.
- Moe, C.L, Rheingans, R.D., 2006. Global challenges in water, sanitation and health, *Journal of Water and Health Suppl* (04), 41-57.
- Morel, A., Diener, S., 2006. Greywater Management in Low and Middle-Income Countries. Review of different treatment systems for households or neighbourhoods.
http://www.eawag.ch/forschung/sandec/publikationen/ewm/dl/GW_management.pdf [Accessed on 3rd January, 2013].
- Nyenje, P.M., Foppen, J.W., Kulabako, R., Muwanga, A., Uhlenbrook, S., 2013. Nutrient pollution in shallow aquifers underlying pit latrines and domestic solid waste dumps in urban slums. *Journal of Environmental Management* 122, 15-24.
- Okot-Okumu, J., Nyenje, R., 2011. Municipal solid waste management under decentralisation in Uganda. *Habitat International* 35, 537-543.
- Paterson, C., Mara, D., Cutis, T., 2007. Pro-poor sanitation technologies. *Geoforum* 38(5), 901-907.
- Rutstein, S.O., 2000. Factors associated with trends in infant and child mortality in developing countries during the 1990s. *Bulletin of the World Health Organization*. 78(10), ISSN 0042-9686.
- Sall, O., Takahashi, Y., 2006. Physical, chemical and biological characteristics of stored greywater from unsewered suburban Dakar in Senegal. *Urban Water Journal* 3(3), 153-164.

Thye, Y.P., Templeton, M.R., Ali, M., 2011. A Critical Review of Technologies for Pit Latrine Emptying in Developing Countries, *Critical Reviews in Environmental Science and Technology* 41(20), 1793-1819.

UN, 2007. United Nations Millennium Development Goals Report. UN Statistics Division.

WHO and UNICEF., 2012. Progress on drinking water and sanitation. Joint Monitoring Program Report (JMP). 1211 Geneva 27, Switzerland.

PREVIEW

Chapter 2: Sanitation technology options for urban slums

PREVIEW

This chapter is based on:

Katukiza, A.Y., Rontelap, M., Niwagaba, C.B., Foppen, J.W.A., Kansime, F., Lens, P.N.L., 2012. Sustainable sanitation technology options for urban slums. *Biotechnology Advances* 30, 964-978.

Abstract

Poor sanitation in urban slums results in increased prevalence of diseases and pollution of the environment. Excreta, grey water and solid wastes are the major contributors to the pollution load into the slum environment and pose risk on public health. The high rates of urbanization and population growth, poor accessibility and lack of legal status in urban slums make it difficult to improve their level of sanitation. New approaches may help to achieve the sanitation target of the Millennium Development Goal (MDG) 7; ensuring environmental sustainability. This paper reviews the characteristics of waste streams and the potential treatment processes and technologies that can be adopted and applied in urban slums in a sustainable way. Resource recovery oriented technologies minimise health risks and negative environmental impacts. In particular, there has been increasing recognition of the potential of anaerobic co-digestion for treatment of excreta and organic solid waste for energy recovery as an alternative to composting. Soil and sand filters coupled with a tertiary treatment step are suitable for removal of organic matter, pathogens, nutrients and micro-pollutants from grey water.