SANITATION IN UNSEWERED URBAN POOR AREAS

TECHNOLOGY SELECTION, QUANTITATIVE MICROBIAL RISK ASSESSMENT AND GREY WATER TREATMENT

ALEX YASONI KATUKIZA

Sanitation in unsewered urban poor areas:

technology selection, quantitative microbial risk assessment and grey water treatment

Alex Yasoni Katukiza

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

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)

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

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.

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 Ronteltap, Prof. Dr. Frank Kansiime 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 transfering 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

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.

Contents

Chapter 1: General introduction

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.