GREYWATER REUSE - AN ASSESSMENT OF HEALTH AND NUTRITIONAL QUALITY OF HOME GARDENS PRODUCE IN RURAL SOUTH AFRICA

Makgalake Pabalelo Radingoana

A thesis submitted to the Department of Earth Sciences, Faculty of Natural Sciences at the University of the Western Cape in fulfilment for the requirements for the degree of Doctor of Philosophy in Environmental and Water Sciences

Supervisor: Prof. Timothy Dube
Co-supervisor: Prof. Dominic Mazvimavi

November 2021

ABSTRACT

The majority of rural communities in sub-Saharan Africa are predominantly poor and depend largely on small-scale subsistence farming. To date, various farming mechanisms (e.g. organic farming, crop rotation, agroforestry and inter-cropping) have been introduced to improve food security and to avert hunger; however, water scarcity remains a challenge. The sub-Saharan African region is currently regarded as water stressed and this has had a significant impact on rural livelihoods. Despite being considered as a water-scarce region, the demand for water for agricultural purposes continues to increase exponentially, while, on the other hand, its supply keeps on diminishing, particularly for agricultural production. It is on this premise that alternative innovative technologies are being put in place to manage and spare freshwater. Such technologies include the re-use of greywater for agricultural purposes, which has received significant attention in recent years. However, the lack of public acceptance and of an educational awareness in certain areas still hinders the full adoption and utilization of this resource for agricultural purposes.

This study, therefore, aimed to assess the nutritional quality of vegetables irrigated with greywater in the rural areas of Limpopo, South Africa. More specifically, it sought to investigate the impact of greywater irrigation on the soil quality and home gardening produce, as well as its possible impact on human health. In order to achieve the main objective of the study, the literature was first reviewed on the progress, opportunities and challenges associated with the use of greywater in home gardening. Secondly, the quality of greywater from different sources (the kitchen, bathtub and laundry) was evaluated and furthermore, its possible impacts on trace elements in the soil was assessed. Lastly, the nutritional quality of home garden produce that has been irrigated with greywater was also assessed. For the literature review chapter, one-hundred-and-eighty-four (184) scientific journal articles were accessed and reviewed for the period between 1963 and 2019. In addition, the behavioral and adoption challenges and possible opportunities of re-using greywater, as well as case studies from developed and developing countries, were reviewed. Moreover, water quality indices, such as the salinity and sodium hazards, were used to access heavy metals in greywater in chapter 3. In chapter 4, the pollution levels in the soils irrigated with greywater were determined by using soil indices, such as the Index of Geo-accumulation (Igeo), the Contamination Factor (CF) and the modified Degree of Contamination (mCd). Furthermore, a non-carcinogenic risk assessment was determined by using indices for human health risk assessments (chapter 5), such as the Estimated Daily Intake (EDI), the Hazard Quotient (HQ) and the Target Hazard

Quotient (THQ). The microbial quality of vegetables was evaluated by means of laboratory analyses. The metals that were tested in the study included arsenic (As), copper (Cu), cadmium (Cd), chromium (Cr), manganese (Mn), zinc (Zn), lead (Pb), as well as magnesium iron (Mg^{2+}), sodium ions (Na^{2+}) and potassium iron (K^{2+}). The statistical analyses included the use of ANOVA, the Tukey test, Pearson's correlation coefficient and the T-test.

The key results from this study revealed that greywater has the potential to improve home gardening in water-limited environments. The quality of greywater was revealed to be within the acceptable standards, although continuous use, over long periods, can lead to high salt concentrations in the soil and it can consequently lead to high metal concentrations in the actual produce. It was revealed that the pH values of soil irrigated with greywater were within an acceptable range for agricultural practices. In addition, it was observed that the accumulation of the metals in the soils was not due to greywater irrigation, except for zinc. This was also supported by the ANOVA test, which revealed that these metals were significantly different from each other. It was observed that the metals were distinctly different at a depth of 30 cm, where F2.5727 = 48.93, $p<0.05$, whereas the metals were also significantly different at a depth of 60 cm, at F2.5727 = 1544.88, $p<0.05$. Furthermore, the Pearson's correlation test revealed that there were positive, but moderate, inter-metal relationships. It was found that microbial activities from bacteria that cause salmonella, E-coli bacterium and listeria were absent in the edible parts of the experimental vegetables. Although heavy metals were found in large quantities in some of the vegetables, the Estimated Daily Intake (EDI) indicated that some metals were within the acceptable limit for consumption. Even though the levels of some metals were high, this does not guarantee that there are possible or probable health risks. It is therefore recommended that greywater be used to supplement the freshwater for agricultural purposes during the dry season; however, this water should be used within 48 hours of being produced, in order to reduce the possibility of microbial activity. Consistent irrigation patterns should be minimized and supplementary irrigation, using freshwater, is recommended.

Keywords: crop production; greywater re-use; home gardening; heavy metals; microbial risks; rural area; soil quality

PREFACE

This research study was conducted in the Department of Earth Science, at the University of the Western Cape, South Africa, from March 2018 to September 2021, under the supervision of Prof. Timothy Dube and Prof. Dominic Mazvimavi.

I declare that the work presented in this thesis has never been submitted in any form to this, or any other, institution. This work represents my original work, except where other authors' views have been used, and due acknowledgements have been made in that regard.

Ms. Makgalake Pabalelo Radingoana **Signed date**: 24 November 2021

As the candidate's supervisor, I certify the aforementioned statement and have approved this thesis for submission.

Prof. Timothy Dube **Signed date**: 24.11.2021

Prof. Dominic Mazvimavi **Signed date:**

DECLARATION

Full names of student: **Makgalake Pabalelo Radingoana**

1. I fully understand what plagiarism is, and I am aware of the policy of the University of the Western Cape in this regard.

2. I declare that this thesis is my own original work. Where other people's work has been used (either from a printed source, the Internet, or any other source), this has been properly acknowledged and referenced, in accordance with the departmental requirements.

Signature: **Signed:** 24 November 2021

PUBLICATIONS AND MANUSCRIPTS

The following published papers and manuscripts under review have been produced from this study and have been worked on, together with my supervisors. My contribution was significant and, therefore, it is fitting that I am the first author in all cases, in the order that they are presented below:

Makgalake P. Radingoana, Timothy Dube and Dominic Mazvimavi. 2020a. Progress in greywater re-use for home gardening: Opportunities, perceptions and challenges. *Journal of Physics and Chemistry of the Earth*, 116: 102853. https://doi.org/10.1016/j.pce.2020.102853

Makgalake P. Radingoana, Timothy Dube and Dominic Mazvimavi. 2020b. An assessment of irrigation water quality and the potential for re-using greywater in home gardens in water-limited environments. *Journal of Physics and Chemistry of the Earth*, 116: 102857. https://doi.org/10.1016/j.pce.2020.102857

Makgalake P. Radingoana, Timothy Dube and Dominic Mazvimavi. 2021. Assessing soil contamination from greywater irrigation in small home gardening plots. *Journal of Physics and Chemistry of the Earth.* **Under review**, Manuscript number: **JPCE-D-21-00152**.

Makgalake P. Radingoana, Timothy Dube and Dominic Mazvimavi. 2021. Microbial and heavy metal contamination of vegetables irrigated with untreated greywater in rural home gardens. *Water SA*. **Under review**, Manuscript number: **12077**.

DEDICATION

This thesis is lovingly dedicated to my two beautiful daughters, **Mapeu Retang Radingoana** and **Lephepane Retlotlilwe Radingoana**. Their love has kept me going through the years and it has kept me afloat, even when it felt as though I was sinking.

ACKNOWLEDGEMENTS

I would like to thank the Almighty God for giving me the strength to make it through; even though it was not easy at times, He had it all planned. Thank you, Lord, for providing me with the wisdom, guidance and grace, to help me sail through. It is only You who made it possible for me to accomplish this task. Furthermore, I would like to express my sincere gratitude to my Supervisors, Prof. Timothy Dube and Prof. Dominic Mazvimavi. I would like to thank you for your mentorship, support, motivation, patience, understanding, kindness and critical insights during this study - may God bless you.

To the HCD Inter-bursary programme of the Council of Scientific and Industrial Research, thank you very much for the funding, for the opportunities that were granted to me through the programme and, most importantly, for the part you played in the successful completion of this study. To the Capricorn District Municipality (CDM) water testing laboratory at the University of Limpopo, I cannot thank you enough for assisting me with my sample testing. A special mention also goes to my friends for always believing in me - you guys have been excellent!

Nobody has been more important to me in the pursuit of this project than my children (Retang and Retlotlilwe Radingoana). I would like to thank them immeasurably, because I know that their love and guidance has been with me throughout. Most importantly, they have been strong, their strength has kept me going throughout the study and they are the reason that I am here. To everyone who acted as parents to my kids when I was tied up with both work and studies, God bless you. I would not have accomplished this task without your sacrifices. To my friends, for always believing in me, I really appreciate it, and say "Modimo a le direng ka go loka"! To my parents, thank you for everything. My unending appreciation is also directed towards my academic mentor, Professor Hasani Richard Chauke. He pushed me to greater academic heights and believed in me. Thank you for motivating me to be who I am today, for emphasizing the significance of being consistent in my studies and the importance of having a positive attitude, more especially when it came to the publications - "Ha khensa ngopfu!" To my previous supervisors, Dr Josephine Letsoalo and Dr Huruma Mollel, you are the reason that I am here; this one is for you too.

To all the doors that kept shut when I was knocking,

Thank you. For the stone that was rejected by the builder, is
Now a cornerstone ~ Psalms 118:22

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS

ALVs - African Leafy Vegetables

ANOVA - Analysis of Variance

CF - Contamination Factor

CH - Chlorine Hazard

EC - Electrical Conductivity

EDI - Estimated Daily Intake

EPA - Environmental Protection Agency

ES - Standard Error

FBS - Free Basic Service

HCL - Hydrochloric acid

$HCLO_4$ - Perchloric acid

HNO_3 - Nitric Acid

HQ - Hazard Quotient

ICP - Inductively Coupled Plasma

ICPE - Inductively Coupled Plasma Emission

ICP-MS - Inductively Coupled Plasma Mass Spectrometry

ICP-OES - Inductively Coupled Plasma Atomic Emission Spectroscopy

Igeo - Index of Geo-accumulation

ISO - International Organization of Standardization

KR - Kelly Ratio

MAR - Magnesium Adsorption Ratio

mCd - Modified Degree of Contamination

MSE - Mean Squared Error

NDP - National Development Plan

PTFE - Polytetrafluoroethylene

RfDo	-	Oral Reference Dose
SAR	-	Sodium Adsorption Ratio
SDGs	-	Sustainable Development Goals
SE	-	Standard Deviation
SSA	-	sub-Saharan Africa
SSP	-	Soluble Sodium Percentage
STA	-	Study Area
TDS	-	Total Dissolved Solids
THQ	-	Target Hazard Quotient
TWQR	-	Target Water Quality Range
UNDP	-	United Nations Development Plan

CHAPTER ONE

1 GENERAL INTRODUCTION

1.1 General Background of the Study

The growth in population and urbanisation will be two of the main challenges for global food security in the near future (Liu *et al*., 2021). City dwellers and the elderly population will probably account more than 75% and 20% of the population, respectively (Mosel *et al*., 2016). Moreover, it is estimated that, the world will be required to feed nine billion people by 2050 (Godfray *et al.,* 2010). Most developing countries are experiencing a rise in urbanization and are already experiencing food shortages (Ruel et al., 2017; Pawlak and Kolodziejczak, 2020). Most of the population in developing countries is based in the rural areas, and people survive on small-scale farms of 1 to 2 hectares of land, or less, with a limited knowledge of farming technology and investment (Das *et al.*, 2020). The production of food is mostly for subsistence consumption by the households (Das *et al.*, 2020), while the lack of water for agricultural activities remains a major threat to food security, poverty and sustainable development (Kahinda and Taigbenu, 2011). In sub-Saharan Africa, more than 60% of all households live in rural areas whereby rain-fed agriculture is their primary, and sometimes their only, source of livelihood (Faurès and Santini, 2008). While sub-Saharan Africa is one of the least urbanized regions in the world, Tostensen *et al.* (2001) argued that the region is experiencing rapid urbanisation. Because of poor access to water, agricultural productivity is often interrupted during the dry season, when many farmers must rely on the food stocks that they accumulated during the rainy season and/or on purchasing their food (Domenech, 2015).

1.2 Food Security in sub-Saharan Africa

The world is projected to have a population of approximately 9.8 billion people by 2050, and sustainable food systems will be required to ensure sustainable food production (UN, 2017). Well-functioning markets with dynamic linkages are required for complex global food chains, in order to assist with a safer and cheaper distribution of food, from production to consumption (Fan, 2017). In addition, these food systems need to take into account the complexity of food production, distribution and consumption (Nchanji and Lutomia, 2020). Unfortunately, dynamic linkages and well-functioning markets are not always accessible, due to inadequacies in the production, post-harvest marketing and consumption of food (Alexander *et al.*, 2017). According to Nchanji and Lutomia (2020), food and nutritional security is further threatened by this inadequacy. However, the other factors hampering the development of food systems in developing countries include, but are not limited to, pollution, the lack of water for irrigation, climate change pests and diseases (Pratt, 2015; Shimeles *et al*., 2018; Pais *et al*., 2020; GAIN, 2020; Gralak *et al*., 2020). The inefficiency of food systems has been exacerbated further by the rapid spread of the current coronavirus pandemic (Nchanji and Lutomia, 2020), and the progress that has been made in the reduction of hunger and poverty in sub-Saharan countries has been slowed down by pandemic-related food security challenges (Nchanji and Lutomia, 2020). It has been reported by Akinwotu (2020) that, about 22 million people in West Africa required food assistance before the pandemic, and among that number, 6 million of them are also facing severe food security during the current pandemic. Job losses, a reduced income, private transfer payments and border restrictions have accelerated the problem and the costs per household, which are now more food insecure, due to the reduced food trade (Foh *et al*., 2020).

In 2019, undernourishment in sub-Saharan Africa rose to 19.1% which is twice as much as the world average as compared to 17.6% in 2014 (FAO *et al*., 2020). The population of sub-Saharan Africa is projected to increase from 1.07 billion to 1.40 billion by 2030, with the possibility of reaching 3.78 billion by the end of the century (UN, 2019). The African population is dominated largely by the younger generation (Giller, 2020), which highlights the fact that, even though there is currently a reduction in the population growth, almost half of the projected increase will still take place in the near future (UN, 2017). Although Vollset *et al*. (2020) suggest that the sub-Saharan population will only reach 3.07 billion by the year 2100, this region is still at risk of experiencing food insecurity because of the population growth and the stagnant productivity in agriculture (van Ittersum *et al*., 2016). Malnutrition and undernutrition as well as obesity and micronutrient deficiencies need to be addressed, not only by increasing food production, but also by promoting access to affordable and nutritious food, as well as education on behavioral changes in people's diets (Giller, 2020). Agronomically, the lack of agricultural production in sub-Saharan Africa is a result of poor soil fertility (Sanchez and Swaminathan, 2005), due to the limited soil nutrients (Penning de Vries and Diteye, 1991), and the dry savannas in the Sahel also impact productivity; therefore, mineral fertilizers are required for augmenting production in African agricultural systems.

Rural communities are marginalised and entangled in a vicious cycle of poverty and inequality. Many rural households are still living way below the poverty datum line. Although South Africa is food secure on a national level, the same cannot be said for its rural households (Hart *et al*., 2009). In general, children (0-17 years) and women remain vulnerable. The Sustainable Development Goals (SDGs), specifically objective Number Two of the United Nations Development Plan (UNDP), aim to end hunger, achieve food security, improve nutrition and promote sustainable agriculture. These goals are supported by the National Development Plan (NDP), which aims to achieve an integrated and inclusive rural economy by improving people's livelihoods. The plan also highlights the fact that the integration of the country's rural areas can be achieved through successful job creation and poverty-alleviating projects. The use of irrigation systems to supplement dry land (rain-fed) agricultural production especially in small-scale farming areas, is seen as a potential force for combating poverty in rural areas in the future.

1.3 General Greywater Utilization and its Impacts on Home Gardening

Since the balance between freshwater demand and supply is dwindling (Seckler *et al*., 1999), there is a need for possible alternative water sources for irrigation. The use of greywater on site has been shown to conserve valuable potable water sources and it also decreases its discharge into the environment (Behzadian and Kapelan, 2015). The high volumes of greywater that are produced have led to the rapid development of its use in many countries worldwide (Boyjoo *et al*., 2013), such as Australia (Pham *et al*., 2011), the UK (Diaper *et al*., 2001), Germany (Nolde, 2000), Jordan (Faraqui and Al-Jayyousi, 2002) and Brazil (Ghisi and Ferreira, 2007). Since greywater is considered to be less contaminated, in comparison to black water (Boyjoo *et al*., 2013), it is considered to be a possible alternative for non-potable uses, such as toilet flushing, the irrigation of the landscapes and crop production (Finley *et al*., 2009). Unfortunately, the use of greywater is often associated with an increase in the environmental risks, through the pollution of the soil and water sources (Gross *et al*., 2005). Hazards caused by greywater can be either biological, chemical or physical in nature and can also present risks that can potentially cause harm (Vuppaladadiyam *et al*., 2019). Even though Finley *et al*. (2009) and Mohamed *et al*. (2013) reported on the quality of greywater, the assessment of exposure to it is a considerable process when re-using greywater for crop production (Ganoulis, 2012). Moreover, realistic guidelines should be established for the use of greywater, in order to can be able to assess the associated risks (Carr *et al*., 2004).

Greywater re-use has attracted global attention over the past decade, due to intensive agriculture, changes in people's lifestyles, water pollution and industrialization (Al Ghazawi *et al*., 2018). Use of greywater has also become one of the effective approaches for solving the problem of water scarcity for non-drinking/potable purposes (Ren *et al*., 2020; Manna, 2018). According to Mahmoudi *et al*. (2021), the application of safe and effective methods in the treatment of greywater renders it possible to use it for different purposes. Urban environments have been attracted by the fact that it can be applied for irrigation, as well as for expanding greenspaces (Tian *et al.*, 2020). There are some concerns associated with the re-use of greywater; these include, but are not limited to, possibility of health risks due to pathogens, and environmental risks, due to the alkalinity, salinity and micro-pollutants that are found in detergents (Maimon and Gross, 2018; Lubbe *et al*., 2016; Mohamed *et al*., 2013).

As in any other developing country, agriculture remains one of the key livelihood assets for the rural poor in South Africa. By 2001, 57% of the South African population had been urbanized (Collins, 2001) and this percentage has risen over the last decade, with the United Nations (2012) estimating that 67.9% of the South African population will be living in cities by 2025. This has resulted in urban areas experiencing a shortage of employment and housing, increased poverty, severe environmental problems and a lack of services, while the rural areas are left drained. One of the reasons for this drastic urbanization rate is the fact that rural areas are prone to chronic poverty. Large backlogs in service delivery only add to the problem (van Schalkwyk, 2015). Water shortages in South Africa are still a matter of foremost concern, especially in drought-prone areas. Those who are the most affected are the subsistence farmers who are unable to irrigate their crops or feed their livestock. The North-West, KwaZulu-Natal, Mpumalanga, Limpopo and the Free State Provinces always withstand the worst water crises and are, in most cases, the most severely affected by drought, with some of these areas often being declared as 'disaster-stricken'. Despite all the mechanisms that have been put in place by the South African government to provide Free Basic Service (FBS) delivery, most rural areas in South Africa are still experiencing the challenges of accessing water. Tissington *et al.* (2008) claims that this is due to some municipalities in South Africa providing FBS (mainly the free basic water and free basic sanitation) in an ad hoc manner, which, in most cases, do not comply with the national standards. The government has introduced some safety nets, such as school feeding schemes, social grants and gardening on the school premises, in order to provide the learners with fresh vegetables. These nets have been very helpful to some households, although most rural households tend to depend solely on social grants and, in most cases, they have large households consisting of unemployed members. Most cities in developing countries are characterised by two distinct set-ups, namely, the formally built ‘cement areas’, and the nearly-rural type of neighbourhoods, or the so-called peri-urban settlements in metropolitan areas. The latter are usually slums, in which the majority of the urban poor live and where there is a lack of every form of urban planning (Matsinhe et al., 2008). Although access to basic services is of the same order as other middle-income countries (World Bank, 2013), there are still a large number of households that do not have access to water, and these are concentrated in informal settlements in the cities and in peri-urban areas (NPC, 2012). Recently, the City of Cape Town publicly, and strongly, encouraged its inhabitants to rely on the re-use of greywater for garden food irrigation (City of Cape Town, 2019). This was a coping mechanism, following the 2015 to 2018 droughts in the area, which resulted in the high demand for freshwater (Hardie, 2021). However, according to Maimon and Gross (2018), there has been limited research to support this recommendation. This study is therefore limited to the application of greywater in home gardens in arid and semi-arid areas only. It focuses on the application of this resource, without prior treatment, and without knowing its impact on the soil and the agricultural crops.

1.4 Justification for the Study

This project intends to provide new insights into greywater use for home gardening, and it intends to promote small-scale entrepreneurship through greywater re-use for home gardening as a way of improving food security, particularly in rural households, where small-scale farming is still practised (Das *et al.*, 2020). The project will also contribute to knowledge generation and the results can be used by the government to assist communities in generating an extra income for households through the sale of surplus crops, etc., as it strongly encourages optimal nutrition (Taukobong, 2016; Borroway, 2016). An analysis of the greywater and soil samples, as well as the nutritional status of crops irrigated with greywater, will provide knowledge about the health and nutritional status of the produce and how irrigation with greywater affects the quality, nutritional status and growth of the crops. The research will also support the Sustainable Development Goals (SDGs), and the main aim of Objective Two is to end hunger and poverty. Chapter Six of the United Nations Development Plan (UNDP) also aims to achieve an integrated and inclusive rural economy by improving the rural livelihoods, and this study focuses on the improvement of lives in rural areas. The findings of the research will inform other researchers on the adoption the re-use of greywater, which has the potential to realistically improve food security, while promoting employment for the rural poor in the agricultural sector.

1.5 Aim and Objectives

The aim of the study is to assess the health and nutritional quality of the produce from home gardens irrigated with greywater in rural South Africa.

1.5.1 The objectives of this study are therefore, as follows:

a) to provide an insight into the progress, opportunities and challenges associated with the re-use of greywater for home gardening;

b) to evaluate the quality of greywater from different sources (the kitchen, laundry and bathtub) for irrigation;

c) to assess the impacts of greywater irrigation on the trace elements in soil for small-scale home gardening; and

d) to assess the nutritional quality of home garden produce that is irrigated with greywater, in order to improve food security.

1.5.2 The following research questions have been formulated to support the purpose of the study:

a) What are the insights into the progress, opportunities and challenges associated with the re-use of greywater for home gardening?

b) What is the quality of greywater from the different sources (the kitchen, laundry and bathtub) that is used for irrigation?

c) What are the impacts of greywater irrigation on the trace elements in the soil in rural home gardening?

d) What is the nutritional quality of the produce irrigated with greywater and can it be consumed?

1.6 Structure of the Thesis

This study was conducted to assess the nutritional and health quality of home garden produce that is irrigated with greywater in rural South Africa. Furthermore, it investigated the quality of greywater that is used for irrigation purposes and to determine its potential for the pollution of soils. The study followed an approach whereby the information derived from a succession of related, yet independent, research papers was compiled together to form the different chapters in this thesis. A total of six chapters were conceptualized and formed by stand-alone research articles that focused on each objective. All the articles that have been published, or which are under review, can be found from Chapters Two to Five. Chapters Two and Three have been published in the *Journal of Physics and Chemistry of the Earth*, Chapter Four is under review by the *Journal of Physics and Chemistry of the Earth,* and lastly, Chapter Five is under review by the *Journal of Water SA*. The stand-alone chapters address each objective individually and have been published in different accredited journals. Subsequently, the Introduction, Materials and Methods, Results and Discussion sections of each chapter are different, in the sense that they have their own style, according to the selected journal. Although attempts have been made to conform to the general style in the dissertation, there may be some overlapping and repetition in some of the sections.

Chapter One provides a general overview of the research background and problem, and it also outlines the aims and objectives, the study area, the structure of the dissertation, its scientific contribution and the ethical considerations.

Chapter Two reviews insights into the progress in greywater re-use for home gardening by looking at the opportunities, perceptions and challenges related to its use. Numerous published articles have been reviewed for this purpose. Certain keywords have been employed, in order to reach the specific results of this objective.

Chapter Three assesses the quality of greywater that is used for irrigation and the potential of re-using it in home gardens, in water-limited environments. The objective was to test its salinity and sodium hazards and the water quality indices were explored.

Chapter Four evaluates the impact of greywater on the trace elements in soils. The chapter follows up on Chapter Three by exploring the possibilities of how greywater can pollute the soil through the accumulation of heavy metals. This was tested with indices and substantiated with statistics.

Chapter Five focuses on the nutritional quality of the vegetables irrigated with greywater. It adds to the results obtained in Chapters Three and Four, by addressing the question of whether the metals tested in Chapter Three, and which accumulate in the soils in Chapter Four, can eventually be found in the edible parts of vegetables. The experiment was performed under normal weather conditions.

Chapter Six synthesises and consolidates the findings of the research, the discussions and the overall conclusions of the preceding chapters. It also makes recommendations for future research.

1.7 Ethical Considerations

This study required no ethical clearance.

CHAPTER TWO

2 PROGRESS IN GREYWATER RE-USE FOR HOME GARDENING: OPPORTUNITIES, PERCEPTIONS AND CHALLENGES

This chapter is based on:

Makgalake P. Radingoana, Timothy Dube and Dominic Mazvimavi 2020a. Progress in greywater re-use for home gardening: Opportunities, perceptions and challenges. *Journal of Physics and Chemistry of the Earth*, 116: 102853. https://doi.org/10.1016/j.pce.2020.102853

Abstract

Water is one of the most essential natural resources for sustaining livelihoods. Freshwater consumption and demand have spiralled over the years, due to population growth, as well as agricultural and industrial intensification. Innovative water conservation techniques (greywater re-use, rainwater harvesting, seawater desalination and groundwater extraction, etc.), especially in the face of climate change and climate variability, are central for the minimization of water shortages, hunger and poverty alleviation, as well as health challenges. Most water conservation methods remain ineffective and are adopted less frequently due to the associated costs, inaccessibility and the lack of technical expertise in addressing these water challenges, particularly in developing countries. Greywater re-use, which represents approximately 43-70% of the total domestic wastewater volume, remains an alternative and effective source of water that can help to reduce the pressure on freshwater for food production and poverty alleviation in third-world countries. Great research strides have been made in greywater re-use for agricultural use, but much remains unknown with regard to its adoption rate, especially in developing countries. This work provides a detailed review on greywater re-use in crop production, with a particular emphasis on the community perceptions, the challenges and opportunities and lessons learnt from other countries and the possible implications on food security. The study has demonstrated that greywater re-use is a common practice in both developed and developing nations and that it is used as a coping strategy. However, it was observed that some communities remain cautious and sceptic on its use for home gardening

purposes. The resource is regarded as unclean and unfit for the irrigation of food crops. Its limited adoption rate appears to be due to limited information on, or a lack of awareness of, programs and platforms on the potential for greywater re-use as a supplement for freshwater, especially in developing countries like South Africa. However, strategies that incentivise greywater use i.e. the installation of greywater systems, have seen a rise in its adoption in the developed world. It is necessary to find possible ways of using the strategies that have been used in developed countries, to adopt them in developing countries, and to promote greywater re-use for home gardening purposes.

Key words: Crop production; greywater re-use; innovative technologies; water scarcity

2.1 Introduction

Water is an essential natural resource that sustains the livelihoods of poor communities through agriculture. Currently, almost a quarter of humankind (±1.6 billion people) faces serious water shortages and this number is likely to double in the next decade (Roson and Damania, 2017). Of the 800 million people who reside in Africa, more than 300 million of them live in water-scarce environments (NEPAD, 2006) and more than 60% of the freshwater in South Africa is used for agricultural production with irrigation accounting for 50% of the entire water utilisation in the country (DAFF, 2014). Agriculture is the main consumer of freshwater, with an estimated withdrawal of 85-90% in Africa and Asia (Shiklomanov, 1999). Freshwater is regarded as any naturally occurring water that is not seawater, or brine water. It is estimated that an average individual in developed countries uses around 500-800 litres of water per day, compared to 60-150 litres per person per day in developing countries (UNESCO, 2000). Population growth and water use estimates and projections show that the international demand for freshwater has trebled since the 1950s and that its quantity and quality have deteriorated significantly (Gleick, 2003).

2.2 The Impact of Climate Change on Water Sources

The impacts of climate change, pollution and population growth, amongst others, contribute to the observed deterioration and vulnerability of water resources (Hanak and Lund, 2008; Raskin *et al*., 2009; Saloua *et al*., 2012). Daniel (2011) and Saloua *et al*. (2012) argue that climate change will affect water availability due to the temperature rise, as well as the variability and changes in the precipitation patterns. Therefore, water is very important as it influences ecological functions (Hurlimann *et al*., 2009a) and plays a major role in the development of socio-economic programs (Abdullaev *et al*., 2009; Allan, 2005). An increase in water scarcity is observed as a universal threat (Vörösmarty *et al*., 2010; Bakker, 2012) to livelihoods and socio-economic development. The efficient and sustainable use of water resources is critical for maintaining social and economic development, and it is necessary for environmental management (Xinchun *et al*., 2017), especially in developing countries like Africa. Although there are still uncertainties surrounding the prediction of rainfall, most climate models predict warmer and drier future conditions for most semi-arid areas, particularly in southern Africa (Kenabatho *et al*., 2012). It is estimated that about 250 million people in Africa could be exposed to greater risk of water stress by 2020 (IPCC, 2007b). Currently, Africa, which is largely dependent on agriculture, is widely recognised as one of the most vulnerable regions to climate change in the world, due to the widespread poverty, its limited coping capacity and its highly-variable climate (Madzwamuse, 2010; UNFCCC, 2007). Fabiya *et al*. (2007) stated that agriculture is an essential sector and the backbone of the rural populace in most developing countries (Todaro and Smith, 2000).

2.3 Greywater Re-use as a Potential Substitute for Freshwater

Robust innovative approaches are needed to attain both water and food security, particularly in sub-Saharan Africa (Finley *et al*., 2009; Hanjra and Qureshi, 2010; Rodda *et al*., 2011). These approaches include the re-use of greywater, namely, household wastewater, excluding toilet wastewater (black water), for irrigation (Pinto *et al*., 2010). Greywater is the most possible alternative for water scarcity and water conservation, and it can help to alleviate pressure on the potable water sources for home gardening purposes e.g. the irrigation of gardens, lawns, shrubs and trees, as well as dust control (Rodda *et al*., 2010). The use of greywater in agriculture fits in well with the concept of Ecological Sanitation (EcoSan), which seeks to prevent pollution and disease by managing human urine and faeces as a resource, rather than as waste, with the recovery and recycling of their nutrients (Winblad *et al*., 2004).

Greywater is already being used for crop irrigation, more widely so in arid regions, where its re-use reduces potable water use by up to 50% (Al-Hamaiedeh and Bino, 2010). Many cases of greywater re-use have been documented. For example, Godfrey *et al*. (2009) conducted a case study on the cost-benefit analysis of greywater re-use for flushing toilets and garden irrigation in Madhya Pradesh, India. The results revealed that the internal and external benefits of greywater re-use are substantially higher than the internal and external costs. Faraqui and Al-Jayyousi (2002) documented the use of greywater in Tufileh, Jordan, where it was used in urban agriculture to alleviate poverty. The project helped community members to gain valuable gardening, irrigation and food preservation skills, while generating an income from selling their surplus production. Al-Hamaiedeh and Bino (2010) assessed whether treated greywater had any effect on soils and plants. The results showed that the salinity, Sodium Adsorption Ratio (SAR) and organic content of the soil increased over time. Roman *et al*. (2007) assessed greywater re-use for vegetable irrigation in Lima, Peru, as a way of improving the urban environment and reducing poverty. It showed that there are less health problems associated with untreated greywater and its direct discharge into the environment and, on the other hand, the local people had access to fresh cheap food. In an African context, Madungwe and Sakuringwa (2007) evaluated greywater re-use as a water management strategy. The study revealed that the unavailability of appropriate technologies for the primary treatment of greywater before re-use is a possible constraint for its adoption as a potential resource. Hoko and Nhapi (2002) examined greywater re-use for home gardening in Harare, Zimbabwe, while Kulabako *et al*. (2011) also re-used it for irrigation in Kawaala, Uganda. In South Africa, greywater re-use, specifically for irrigation, is practised to a lesser extent than for other household uses, but it does occur in middle- and higher-income suburbs in times of drought. The practice is also common in the rural areas of the country; however, it is used cautiously for food production, as the water is, in most cases, regarded as being unclean and unfit for use in the irrigation of some food crops.

The active promotion of greywater use for irrigation in gardens and small-scale agriculture has the potential to not only maximise the use of the limited water supplies, but also to improve the food security of the rural poor (Rodda *et al*., 2010). The impact of greywater on the contamination of freshwater on plant development and soil properties, through its elevated amounts of metals, has been extensively studied; however, since greywater also contains macronutrients, particularly nitrogen and phosphorus, the availability of these nutrients in the right quantities may benefit plant growth. It is important to investigate the availability of trace elements in crops irrigated with greywater, in order to assess whether the crops are fit to be consumed or whether they pose a health threat to consumers. Although health risks of heavy metals in vegetables have been investigated (Yang *et al*., 2017; Kacholi and Sahu, 2018: Zhong *et al.,* 2018), the health risks of crops irrigated with greywater, and their ability to be consumed, have not been investigated. Therefore, a knowledge gap exists relating to the possible impacts of greywater on crop health. This implies that, if greywater has no impact on the crops, the rural communities in arid and semi-arid areas can re-use their greywater for small-scale farming, which will enhance their food security, at a household level. This will also encourage small-scale female entrepreneurs to sell their surplus produce during the dry and wet seasons and to continue with food production, even when there is no rainfall. By selling their surplus vegetables, more money will be generated for their basic needs, and bridge the societal gap of men being the common providers at home and it will contribute to employment.

The intention of this paper was to provide an overview of the importance of greywater re-use, as well as the perceptions, challenges and possible opportunities for its use as an alternative in crop production, in order to alleviate poverty. Poverty is understood to be a multidimensional phenomenon that causes deprivation and undermines people's well-being (Bebbington, 1999; Sen, 1981, 2000). With this as a background, it is therefore important to assess the impact greywater on the health and nutritional status of home garden produce in rural South Africa, as a way of increasing food security for the rural poor. Poverty alleviation refers to the ability of human beings to lead lives that have a reason and a value, and to enhance the substantive choices that they make (Sen, 1997), which can only be realised in the context of well-functioning institutions committed to social security (Nussbaum, 2000). In this review, the attention is focused mainly on the perceptions of, and the challenges faced by, communities on the re-use of greywater as a substitute for freshwater, especially for irrigation purposes. Informed by this background, this work sought to provide a detailed overview of the challenges faced by communities when re-using greywater for irrigation, as a water conservation method, which can be important for agriculture and for recharging of the water table, if it is well-managed.

2.4 Relevant Literature Search

In order to search for relevant research, specific keywords and phrases were used, such as "Africa", "climate change", "greywater", "greywater irrigation", "greywater management", "greywater recycling", "greywater re-use", "perceptions on greywater re-use", "South Africa" and "water sustainability". These keywords helped to narrow the scope and focus on specific articles that are linked to the aim of this work. The literature search included reviewed articles that published original research between the earliest years (from 1963) to 2019 (Figure 2.1). A total of 184 articles were reviewed. The relevant articles were initially identified by using targeted searches in the Science Direct, Jstor, Google Scholar, Proquest and Emerald Insight databases, to help explore the above keywords and phrases and to filter out the relevant literature.

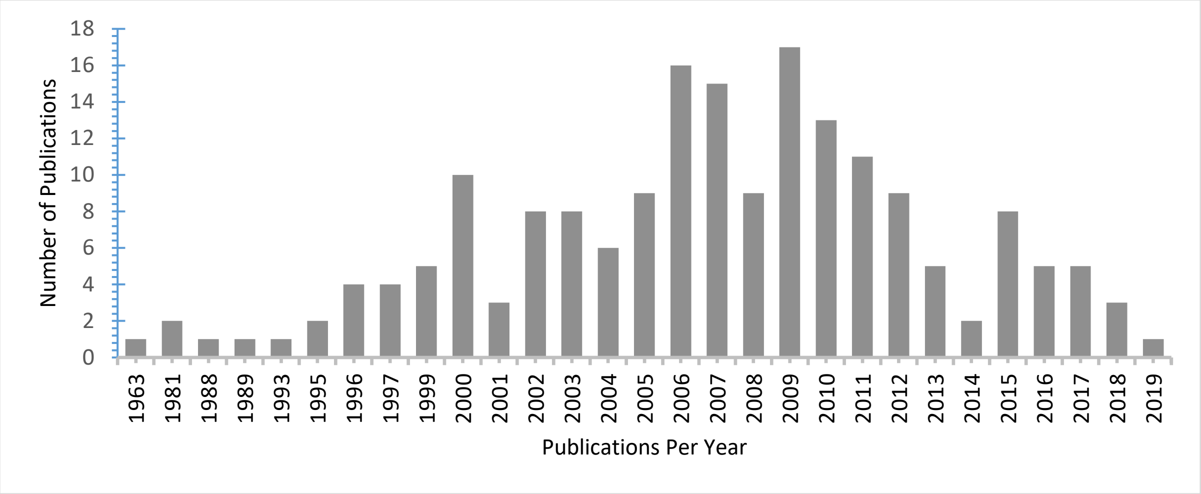

Figure 2.1 The temporal development of published articles in which greywater has been explored

The inclusion/exclusion criteria for the selection of articles involved the need for, or the use of, greywater/recycled water for agricultural purposes and it was necessary for them to have been published in a scientific journal. Additional articles were identified in relevant literature reviews, and backward reference list checking was used to include other articles (Gough *et al*., 2012). The review was guided by the potential of greywater in substituting freshwater in agriculture, as a way of working towards the Sustainable Development Goals, as well as Agenda 2063, which focused on both eradicating poverty and empowering the rural poor particularly women. The main target was peer-reviewed scientific journal articles. Case studies on greywater re-use in developed and developing countries were reviewed, in order to understand its behavioural and adoption challenges, as well as the possible opportunities.

2.5 General Perceptions on Greywater Re-use for Irrigation Purposes

In most cases, greywater re-use is typically restricted to irrigation (Wiel-Shafran *et al*., 2006; Howard *et al*., 2007; Travis *et al*., 2010; Tian *et al*., 2020), although other uses, such as the flushing of toilets, are more common (Jeppesen, 1996; Godfrey *et al*., 2009; March and Gual, 2009; Etchepare and van der Hoek, 2015). Ilemobade *et al*. (2012) reported that respondents at the University of Cape Town, Wits University and the University of Johannesburg preferred to re-use greywater for toilet flushing, rather than for garden irrigation, as they feared that it may lead to contracting diseases. Earlier studies on greywater re-use argued that, even though the practical part of water re-use can be fixed, eventually ‘the issue of public acceptance would be the one killing the proposal” (Dishman *et al.*, 1989). Numerous studies have explored the relationship between the background characteristics and the attitude of individuals towards re-using water. Studies, such as those of Po *et al*. (2005), Porter *et al*. (2005), Dolnicar *et al*. (2011) and Fielding *et al*. (2015), revealed that the youth and women, or certain ethnic or religious groups (Dolnicar *et al*. 2011, Hills *et al*. 2013, Aitken *et al*. 2014, Garcia-Cuerva, 2016), were less interested in the issue of water re-use. However, higher-income persons (Hills *et al*. 2002) and those who had obtained higher educational qualifications (Garcia-Cuerva, 2016) seemed to be more accepting of its re-use. Nonetheless, according to Friedler and Lahav (2006) and Smith *et al*. (2015), there was no clear relationship between the people's background characteristics and their perceptions. The general anxiety regarding water collection and water re-use is linked to various economic, health and environmental issues (Bruvold, 1988; Dillon, 2000; Higgins *et al*., 2002; Marks *et al*., 2006a). The perception of risk can play an important role in the public's acceptance and adoption of greywater re-use for crop production. Large-scale greywater potable water projects have been rejected on the basis of the perception of public risk (Ryan *et al*., 2009). Grey, or treated, greywater from individual households tends to be more acceptable than using greywater from other secondary sources (Ryan *et al*., 2009). When re-using water from their own house, people can determine the water sources that are to be used (e.g. laundry or shower water) and the type of crops to be irrigated e.g. for the lawn, the flowers or the vegetables (Ryan *et al*., 2009).

The quality of greywater depends upon its source (Jefferson *et al*., 1999; Eriksson *et al*., 2002). Different sources of greywater include water generated from the kitchen, laundry washing and bathing (Alsulaili and Hamoda, 2015). The characteristics of greywater are widely dependent on the number and age of household occupants, living habits, detergents used and living standards (Spychala *et al*., 2019). Some chemicals and salts in greywater are capable of causing serious long-term soil or crop damage (Ryan *et al*., 2009). Soils and plants are sometimes able to process these contaminants, but only within certain bounds, and their improper use can lead to environmental damage (Ryan *et al*., 2009). However, detergent manufacturers are now developing products that are environmentally-friendly and they are making them more relevant for irrigation purposes (Planet Ark, 2008). According to a study by Radingoana *et al*. (2020b), the pH of water sourced from various households was largely alkaline, ranging from 6.25 to 10.49 with an average of 8.71. In addition, kitchen water had high sodium hazard when compared to laundry water. Moreover, the chlorine hazard for the same waters revealed to be within the acceptable limits. Previous studies have concluded that many household residents find greywater to be an appropriate water source for the garden, while they regard the use of recycled water as inappropriate for other activities. Marks *et al*. (2006b, 2008) reported that over 90% of people in Australia viewed greywater as suitable for home gardening, while Po *et al*. (2003) summarised eight studies and found that only 6% of the respondents viewed recycled water as being inappropriate for home gardening, while the majority were against the idea.

A qualitative study by Browne *et al*. (2007) concluded that education and marketing information influence people's perceptions on greywater re-use. Having a limited knowledge about it, due to limited campaigns on its re-use, is also recognised as a major limiting factor (Barr, 2003; Syme *et al*., 2000); such campaigns therefore require careful designing, if the communication is to be successful (Reisch *et al*., 2008). While the focus on marketing and education is there to increase people's actual knowledge, their perceived knowledge can also influence their behaviour (Ryan *et al*., 2009). Their perceived knowledge may be unrelated (Knight, 2005) because they are capable of thinking that they know more, or less, than they do (Alba and Hutchinson, 2000). Many residents may be re-using household greywater because they are aware that its re-use is appropriate for a range of alternative options, such as wetlands, parks and their home gardens (Ryan *et al*., 2009). In Spain, the use of greywater is becoming extensive because local regulations oblige people to install re-use systems in new buildings (Domènech and Sauri, 2010). The available literature on the re-use of greywater focuses mainly on the technical aspects (Christova-Boal *et al*., 1996; Nolde, 2000; Kim *et al*., 2009), whereas cohesive analyses of the factors (institutional, economic, technological and social) that influence the possibility, and likelihood, of the success of such technologies, are rare. The perception of greywater users is an area that has been least explored, when it comes to greywater re-use (Domènech and Sauri, 2010). There is abundant literature on the perceptions of the general public towards water re-use (Hartley, 2006; Marks, 2006b; Toze, 2006; Dolnicar and Schäfer, 2009); however, this subject has been poorly documented (Domènech and Sauri, 2010).

According to Pinto *et al.* (2010), the fact that respondents have a view, proves that they are environmentally conscious. Furthermore, although they may want to re-use greywater to relieve the water stress, they are concerned about the long-term effects of this source on the soil and plants. Moreover, even though some respondents mentioned that greywater irrigation reduced the occurrence of weeds, it also affected some native Australian plants, such as Banksia. In addition, it has also been concluded that, despite the age and gender of the respondents, the quality of the water used was the most important aspect for them. Another study by Pinto and Maheshwari (2015) revealed that the re-use of greywater is against the cultural and religious teachings in the Middle East. Greywater (10%), rainwater (19%) and groundwater (71%) were combined and treated and used for toilet flushing at the Millennium Dome in the UK (Diaper *et al*., 2001; Hills *et al*., 2002). Almeida *et al.* (1999) also found that an average toilet uses 8.4 litres of potable water per flush and greywater re-use can save water for this purpose. Furthermore, it has been noted that greywater generation peaks in the mornings and evenings, due to the lifestyles of the residents (Butler *et al*., 1995; Almeida *et al*., 1999). The amount of greywater produced by household activities is dependent on the location and lifestyle of the people involved (Pinto and Maheshwari, 2015). It has been recorded that the 75% is produced in Denmark, 70-75% in Sweden and 50-80% in Jordan (Al-Jayyousi, 2003: Palmquist and Hanaeus, 2005: Eriksson *et al*., 2006). Moreover, developed nations produce higher volumes (in California, USA, it is 223 l), compared to developing nations (in Apecsy, West Africa, it is 4.5 l) (Sall and Takahashi, 2006).

2.6 The Importance of Greywater for Irrigation

In Africa, where the livelihoods of people are mostly sustained by subsistence farming, rapid population and urban growth is being experienced, which results in inadequate access to water. In this era of dwindling resources, it is becoming almost impossible to continue feeding families sustainably through subsistence farming. With only 64% of the African population having access to an improved water supply, the African continent has the lowest total water supply coverage (WHO *et al*., 2000). The problem of water supply is worse in rural areas, where it is impacted by an inadequate and unbalanced service delivery, the lack of infrastructure, poor topography, and in some instances, and the lack of competency among municipalities and service providers. Hindrances in the provision of an adequate, clean, safe and affordable water supply affects women, children, the elderly and people with disabilities, in particular, and it raises the issues of their personal safety, health and dignity. It also jeopardises the education of children and gender equity (WHO and UNICEF, 2006), human health and productivity, as well as inequalities between the urban rich and the rural poor. The rural poor pay more for these services, while they are the least likely to receive them. Irrigation using greywater is a commonly established practice in urban and peri-urban areas in Africa; however, this is not the same in rural areas. Although greywater irrigation can be a health risk for farmers and consumers, through the spread of diseases, such as cholera and typhoid, it also has nutrients for crop production and can reduce the need for chemical fertilizers, depending on the degree of dilution. It is a reliable source of water, which can increase agricultural productivity, and it can enhance plant growth through improved soil fertility, given that it contains acceptable quantities of nitrogen, phosphorus, potassium and organic matter. The re-use of greywater for food production in African countries is of paramount importance, as agriculture is the people's main source of livelihood, especially in arid and semi-arid countries.

Domestic greywater is currently commonly used in Australia for most daily non-potable activities in households (e.g. toilet flushing and garden irrigation), except for the washing of clothes washing, and it is also used for industrial and irrigation purposes (Pham *et al*., 2011). Irrigating home garden crops with greywater has several advantages (Holtzhausen, 2005; Al-Zu'bi and Al-Mohamadi, 2008). One apparent advantage is that it saves the use of the threatened freshwater resources (Schoen *et al*., 2017; Jeong *et al*., 2018). Jeppesen (1996) states that it can complement the irrigation sources and can lead to a reduction of about 30% in a household's potable water consumption while NASEM (2016) states that it can 19% in demands of freshwater. Several studies have shown that a further advantage of greywater irrigation is that it increases plant growth (Day *et al*., 1981; Rusan *et al*., 2007; Rodda *et al*., 2011) and crop yields (Salukazana *et al*., 2005; Misra *et al*., 2009), without any impact on the quality of the crop (Day *et al*., 1981; Zavadil, 2009). The organic matter that is available in greywater might contribute to the total loading of organic matter in the soil over time and, therefore, it may support crop production (Rusan *et al*., 2007; Rodda *et al*., 2011). However, some researchers, such as Maimon *et al*. (2010), Kuru and Luettgen (2012), Etchepare and van der Hoek (2015), do not condone the re-use of untreated (or inadequately-treated) greywater for either potable or non-potable uses. A study by Maimon *et al*. (2014) further encouraged a strong experience when using greywater for irrigation of home gardens.

The use of domestic greywater for irrigation is becoming increasingly common in both developed and developing countries, in order to cope with water scarcity. Wastewater and greywater recycling are emerging as an integral part of water demand management, for promoting the preservation of high-quality freshwater, for reducing pollutants in the environment and for reducing the overall supply costs (Al-Jayyousi, 2003; Glover *et al*., 2021). The recent technological developments and changes in attitude towards water re-use suggest that there is potential for the re-use of greywater in the developing world.

One commonly applied individual initiative for the re-use of wastewater is the recycling of greywater, specifically for irrigation (Travis *et al*., 2010). Furthermore, in the past, greywater re-use for irrigation was considered to be a means of water conservation, since it represents the largest potential source of water and saves costs in domestic residences (Al-Jayyousi, 2003), with a saving of up to 38% of water, when combined with a sensible garden design. Between 13-65% of the greywater obtained from domestic household activities has been used for irrigation in Los Angeles (Shaikh, 1993). In Brazil, water consumption has been reduced by 29-35% by using greywater for flushing toilets (Ghisi and Ferreira, 2007). Although 60% of the water in Malaysia is used for domestic activities, 30% of the water can be saved by using greywater for flushing toilets (Ismail *et al*., 2011). Greywater is a potentially re-usable water resource for the irrigation of household lawns and gardens (Al-Jayyousi, 2003) through the diversion of laundry effluent. According to Jeppesen, (1996), this is technically possible without treatment. However, the re-use of greywater for growing plants may affect the microbial activity in the rhizosphere, which degrades the surfactants and their use by plants for transpiration (Garland *et al*., 2000). Greywater also has the potential to increase soil alkalinity if it is applied in gardens over a long period of time. Greywater with pH values of higher than 8 can lead to an increase in the soil pH and a reduction in the availability of some micronutrients for plants. The WHO (2006) has set standards with regard to the value of microbiological parameters, due to irrigation with wastewater (Table 2.1). The Environmental Protection Agency (EPA) has already published guidelines on the re-use of treated domestic wastewater for a variety of purposes, namely, in agriculture (edible and non-edible crops), in urban areas, in areas with restricted access, for recreational purposes, in construction, industry and the environment, as well as groundwater recharge and indirect potable re-use. The EPA (2004) classifies agricultural re-use into two sub-types, namely, the re-use by crops that are not industrially processed, and crops that are industrially processed/non-comestible (non-edible).

Table 2.1 Microbial quality criteria required for accessible and restricted irrigation areas (WHO, 2006)

Parameters	Crops not industrially processed	Crops industrially processed Crops non-comestible
Helminths eggs (n/L)	< 1	< 1
E. coli (CFU/100 mL)	10^5	10^3

A study by Gorgich *et al*. (2020) in Portugal, baby carrots, grand rapid lettuce and gypsy red peppers where irrigated using greywater. Three sources of water were used namely tap water, untreated and treated graywater. These vegetable crops produced healthy fruits with exception of lettuce that was irrigated with tap water suffering from pest related weakness. Fecal coliforms were detected on lettuce and carrots in small numbers.

2.7 Impacts of Greywater on the Environment

With the accumulation of scientific data over the past few decades, a growing number of countries are setting guidelines and regulations for the use of greywater for irrigation (Maimon *et al*., 2017). Any use of greywater is likely to have an environmental impact, which may be positive and/or negative (Muanda and Lagardien, 2008). However, while most of the scientific research and legislation efforts have focused on the health risks of greywater, less consideration has been given to its environmental impacts (Cook, 2016; Gross *et al*., 2015). Greywater may contain plant macronutrients, particularly nitrogen and phosphorus. If these nutrients are present in the right quantities, greywater may act in the same manner as a fertiliser and benefit plant growth (Rodda *et al*., 2011). In the context of greywater disposal, these benefits do not typically apply, as the application rate is too high and the nutrients are condensed into one small area (Siggins *et al*., 2016). The environmental concerns surrounding greywater re-use are often related to the chemical contamination of freshwater and its impacts on plant development and soil properties (Misra and Sivongxay, 2009; Reichman and Wightwick, 2013; Rodda *et al*., 2011; Siggins *et al*., 2016).

A number of studies have investigated the impacts of untreated greywater usage on pathogens and the standard water quality parameters (e.g. chemical oxygen demand), with fewer studies looking at soil and plant health (Chaillou *et al*., 2011; Mandal *et al*., 2011; Pandey *et al*., 2011; Rodda *et al*., 2011). 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 (Pandey *et al*., 2011; Pinto *et al*., 2010). Very little research has been conducted on the impacts of greywater on trace elements in plants or soils (Misra *et al*., 2010; Rodda *et al*., 2011), as well as on soil ecotoxicology. Some studies have raised concerns that greywater irrigation might increase the soil salinity, sodicity and pH, thus affecting both plant health and the hydraulic properties of soil (Al-Hamaiedeh and Bino, 2010; Misra and Sivongxay, 2009; Pinto *et al*., 2010). Interestingly, only a few studies have explored the potential effects of greywater properties, other than the salinity and Sodium Adsorption

Ratio (SAR) on the wettability of soils, and their importance is still debated (Abu-Zreig *et al*., 2003; Travis *et al*., 2008; Wiel-Shafran *et al*., 2006).

Despite the widespread adoption of the re-use of greywater for irrigation, there is still limited research on the impacts of this greywater on the receiving environment (Donner *et al*., 2010; Stevens *et al*., 2011; Turner *et al*., 2013; Reichman and Wightwick, 2013). Research generally recommends that only treated greywater be used in gardens, as this reduces the risk of microbial contamination, in particular (Maimon *et al*., 2010). Thus far, studies have recommended greywater re-use for agricultural crop production, although only for certain water qualities (Finley *et al*., 2009; Misra *et al*., 2010; Pinto *et al*., 2010). The lack of the proper management of greywater in peri-urban and rural areas in developing countries has led to the indiscriminate discharge of greywater, which has contributed to public health concerns and threats. According to the British Columbian Ministry of Health (2017), greywater should be applied evenly, to prevent ponding, it should not be used on vegetables that are intended for raw consumption, and the immediate harvesting of fruits irrigated with greywater should be avoided until the soil and the fruits (if wetted unintentionally) have dried up. It is also advisable to irrigate alternately with potable and greywater where possible, in order to dilute the occurrence of heavy metals in the soil. It is also advisable to use underground irrigation when applying greywater, for aesthetic purposes.

Although most of the research focuses on reducing the possible health risks of re-using greywater, a publication by Turner *et al*. (2013) discusses the potential environmental risks of re-using it for irrigation, such as soil contamination, due to the excessive pollutants present in greywater. The study further states that irrigating with greywater has a limited influence on the soil environment, that it curbs the high volume of freshwater consumption for irrigation and that it also provides nutrients for the crops or plants (Turner *et al*. 2013). A study by Pinto *et al*. (2010) showed that the Electrical Conductivity (EC) (300 µS/cm) and soil pH (>7.0–8.0) were significantly elevated due to greywater irrigation, compared to potable and diluted greywater (1:1) treatments. However, in a study by Rusan *et al*. (2007), although there was an accumulation of pollutants in the soil, as a result of irrigating with greywater, they did not affect the soil pH. Despite the accumulation of heavy metals and the elevation of pH and EC in soils irrigated with greywater, Faruqui and Al-Jayyousi (2002) and Pinto *et al*. (2010) suggested that it does not pose any risks to soil health. On the contrary, Sharvelle *et al*. (2012) investigated the effects of greywater irrigation on landscapes, over the long term (more than five years) and observed that there was an accumulation of salts in the soil. The Electrical conductivity (EC) of soils irrigated with greywater was 557±238 µS cm^{-1} when compared to that irrigated with potable water (216±60 µS cm^{-1}) and therefore posing the risk of contaminating the groundwater. However, they suggested that the contamination of the water table could be minimised, if not avoided altogether, by using an effective greywater management system.

As much as greywater might contribute to soil pollution by adding pollutants such as heavy metals, the use of inorganic fertilisers can also add impurities to the soil (Schroeder and Ballassa, 1963; Carnelo *et al*., 1997). Agrochemicals, such as pesticides, fungicides and herbicides (Gimeno-Garcia *et al*., 1996; Nicholson *et al*., 2003), as well as the corrosion of metal objects, such as water pipes, taps and roof materials (Boller, 1997; Sörme and Lagerkvist, 2002), also play a major role in the contamination of soils. According to Mzini and Winter (2015), soil profile analyses after greywater application suggest that it contributes minimally to the concentration of heavy metals in the soil, and it therefore does not exclusively pollute the soil or pose an environmental risk within a time-frame of one year. The study further concluded that the concentration of nutrients and heavy metals found in the greywater samples were significantly lower, compared to the World Health Organization's health guidelines for the safe use of greywater (WHO, 2006). Moreover, they revealed that the nutrient and heavy metal concentrations in greywater were within the Target Water Quality Range (TWQR) permitted by the South African guidelines for irrigation (DWAF, 1996). However, it is strongly recommended that greywater should be diluted, in order to lower the salt content and to improve the quality of the irrigation water, so as to avoid long-term risks to the soil and the environment (Mzini and Winter, 2015) and to avoid the contamination of the groundwater.

Although the recharging of groundwater with greywater is frequently substantial, in most cases, this procedure is done in an uncontrolled manner. The prospective of tainting of groundwater remains a risk, even though the quality of greywater improves as it infiltrates underground and is stored for future use (Morel and Diener, 2006). The hydrology of an area, as well as the soil structure and greywater physiognomies, regulate the level of risk that is posed by greywater, mainly where groundwater is being used as a source for drinking water. The contamination of water by pathogens is therefore the main concern, if the recharged water is used for drinking (Aertgeerts and Angelakis, 2003). However, the contamination of groundwater with microbial pathogens from the infiltrating greywater is usually an issue where the water table is high.

Porous rocks and deeply-weathered soils do not serve as an effective blockade against microbials, which leaves the groundwater greatly exposed to their infiltration. Under these conditions, tainted discharges can potentially reach the groundwater quickly and can travel longer distances with the underground water, before the pathogens die off (Morel and Diener, 2006).

2.8 Behavioural Challenges on Greywater Re-use in Developed and Developing Countries

The traditional approach used to predict water consumption behaviour assumes that water usage can be explained by a person's individual attributes, such as his/her education, income and age (Ryan *et al*., 2009). Socio-demographic variables are, therefore, construed as indicators or proxies for a person's personal capabilities (Stern, 2000). A number of studies have investigated the socio-economic profile of general household water usage. Gregory and Di Leo (2003) measured the water consumption for a year in Shoalhaven, New South Wales, and found that, contrary to their expectations, the households that were proactively using less water had lower income and educational levels and were older. They noted that many residents were raised in an era of awareness and when the conservation of dam or tank water was a part of everyday life. Porter *et al*. (2005) reported that younger people are more likely to rate a water conservation proposal positively, while no significant differences were found across education categories. Po *et al*. (2003) predicted that the greatest opposition to water re-use schemes came from people aged 50 years and over, but they also noted that Jeffrey (2002) had found no significant variations across the gender, age or socio-economic groups. In a summary of ten empirical studies, Dolnicˇar and Saunders (2005) concluded that, the acceptance of recycled water is correlated with a high level of education, followed by the younger age category, while income and gender were only significant in one-third of the studies. Thus, generalising about the influence of socio-economic variables is mitigated by the specific context, with respect to its costs and benefits, and the characteristics of the population. The challenge of greywater re-use is not only limited to minimizing water usage and maximizing water re-use; there is also a need to find a balance between environmental sustainability, while simultaneously addressing the issues of user safety, economic viability, utilities and politics (Alkhatib *et al*., 2006; Chen *et al*., 2012; Harding, 2006). In some developing countries, city planners and administrators view greywater as a disposal problem. They are not concerned about its impact on, or threat to, the livelihoods or health of the stakeholders (Valipour and Singh, 2016). Politics and corruption play an important role in the decision to construct expensive treatment plants, which often fail to function properly, if at all, once they have been commissioned (Bhamoriya, 2004). Strong traditional water rights, the lack of urban planning and weak institutions are some of the constraints that hamper the improvement of greywater management in some urban and peri-urban areas (Huibers *et al*., 2004).

The use of interviews, questionnaires, focus group discussions, informal discussions, and extra similar and respectable social surveys to source data on the behavioural tenets of communities on the re-use of greywater is evident (Bruvold, 1998; Jeffrey, 2001; Dolnieara and Saunders, 2006; Marks, 2006b; Dolnicar and Saunders, 2006; Alhumoud and Madzakanda, 2010). These strategies have been used to assess the public's perceptions towards greywater re-use the world over and there is no doubt that societies back the idea of re-using water as a way of dealing with water scarcity and trying to reduce pollution (Oteng-Peprah *et al*., 2019). It has been shown that water conservation, environmental protection, a reduction in the water bill and health concerns are some of the substantial contributing factors as to why individuals accept the re-use of greywater (Hurlimann *et al*., 2009b; Oteng-Peprah *et al*., 2019). However, the transmission of knowledge cannot alter the lifestyle and behavioural patterns of people on its own (Gifford and Nilsson, 2014).

2.9 Lessons Learnt on Greywater Re-use for Irrigation Worldwide

Greywater re-use is widely practised worldwide, especially in developed nations, such as the United States of America, the United Kingdom, Australia, Japan and Germany (Oh *et al*., 2018). Some developing countries have begun to adopt greywater re-use to reduce freshwater consumption and to curb water shortages (Mah *et al*., 2009; Mandal *et al*., 2011). The United States, Japan and Australia have been at the forefront of greywater re-use. Home-owners in the Western United States and Australia have used their own initiative in response to water shortages by irrigating ornamental gardens with greywater (Domènech and Sauri, 2010). The widespread use of this resource has urged authorities to legalize greywater re-use and to develop guidelines for reducing the environmental and health risks that might be associated with the practice. There has been growing interest in the separation and re-use of greywater as a water-saving strategy, particularly in water-scarce regions (Busgang *et al.*, 2015). The views about greywater re-use have shifted in recent years, with developed countries, such as Australia, the USA and Japan, leading the way (Domènech and Saurí, 2010) with regard to its use in landscape irrigation (Casanova *et al*., 2001). The practice of re-using greywater is becoming more common, particularly in arid and semi-arid regions (Roesner *et al*., 2006; Wiel-

Shafran *et al*., 2006) and it has undergone a resurgence in Australian households. Both roof-harvested rainwater and greywater re-use are promising substitutes for high quality water in non-potable applications, such as toilet flushing and irrigation (Ghisi and Ferreira, 2007). Some studies on the physico-chemical (Friedler, 2004) and microbiological (Birks and Hills, 2007) characteristics of greywater have focused on Europe and shown that there is a knowledge gap, while few studies have been conducted in Asia, where perceptions on the use of greywater vary, depending on the lifestyle and culture of the inhabitants and the greywater sources (Friedler, 2004). Moreover, studies on greywater characterisation (Katukiza *et al*., 2015; Oteng-Peprah *et al*., 2018b), greywater generation and quality analysis (Qadir *et al*., 2009; Abedin and Rakib, 2013) are emerging in Africa and other developing nations. In addition, Carden *et al*. (2007a), Kulabako *et al*. (2011) and Kariuki *et al*. (2012) conducted studies that focused on the characteristics of greywater relative to its potential for re-use in the peri-urban areas of developing countries, while Carden *et al*. (2007b) and Armitage *et al*. (2009) have dealt with its management options. In South Africa and Kenya, greywater characteristics have been assessed by Carden *et al*. (2007b), Mungai (2008), Kraft (2009) and Raude *et al*. (2009); however, inadequate evidence was found on the precise pollutant load of greywater. Furthermore, changes in the quality of greywater along the tertiary drains of households are still under-investigated.

In Jordan and Tunisia, controlled greywater use is practised and has had a significantly positive impact on water budget of those countries. Apart from the Middle East and the North African region, other countries have employed a proactive policy of reclaiming greywater for productive use, including the USA (California and Arizona) and Australia (Redwood, 2008).

The USA has used treated greywater for toilet flushing and irrigation since 1925 (Christova-Boal, 1995). The first greywater recycling system was constructed in the Grand Canyon to reclaim greywater from tourist facilities (Oh *et al*., 2018). A major drought that hit California in May 1991 triggered the public’s interest in greywater re-use (Dixon *et al*., 1999), and this caused 11 counties in California to legalize greywater re-use in 1992. Apart from California, domestic greywater has also been re-used in Florida for more than 40 years (Parsons, 2009). South-eastern Australia has been hit by freshwater shortages, due to the impacts of population growth, urbanization and climate change (Ryan *et al*., 2009). This has led to Australians developing several approaches in order to reduce freshwater consumption, and one such approach is the recycling of greywater (Pham *et al*., 2011). The Australian Government has announced reimbursements of up to $500 for all households that install greywater re-use systems, which is a way of encouraging its citizens to adopt the idea (Domènech and Saurí, 2010). For a long time, Japan has also been following the tradition of greywater re-use, due to water shortages. In Tokyo, greywater re-use is compulsory for buildings with an area of over 30,000 m^2, or that have the potential to can re-use 100 m^3/day (CSBE, 2003). Greywater re-use is also practised increasingly in countries such as Germany and the UK, where water shortages are less critical but where environmental conservation is the main concern. In Spain, regulations relating to greywater re-use have been formulated in order to promote public awareness, and several localities have endorsed new policies and regulations that promote the installation of greywater re-use systems in new multi-storey buildings (Domènech and Saurí, 2010). Communities are often more interested in adopting systems that are encouraged by some sort of reimbursement. It is also of paramount importance that communities are first educated about certain issues, by means of workshops, in order for them to accept the idea. Since Africa is already a dry continent, some of the above lessons from developed countries can be adopted to address the issues of water scarcity within the drier parts of the continent.

2.10 Implications of Re-using Greywater on Food Security

More than 60% of the global population could suffer from water scarcity by 2025 or 2030 (Wallace, 2000; Rijsberman, 2006; Qadir *et al*., 2007). The agricultural sector uses 80% of the global water consumption for irrigation and this is a limiting factor in rural food production in many countries (Hanjra and Qureshi, 2010). The use of groundwater is increasing because of climate change, population growth and excessive water consumption, and irrigation is not exempted (Doll *et al*., 2012, Green *et al*., 2011), which puts greater pressure on the groundwater and freshwater resources. Furthermore, the construction and improvement of dams might influence the levels of underground freshwater. Thus, the use of conventional water is limited and difficult, from day to day (Valipour and Singh, 2016). Moreover, the price of clean water is too high (Dominguez, 2010) and it is not reasonable for most of the people residing in the rural areas of developing countries. Innovative approaches are therefore needed to attain both water and food security, particularly in sub-Saharan Africa (Finley *et al*., 2009; Hanjra and Qureshi, 2010; Rodda *et al*., 2011). One of the approaches that are used to reduce the pressure on urban water supplies include the re-use of domestic greywater (wastewater from bathtubs, showers, hand-wash basins, laundry and kitchen sinks) (Finley *et al*., 2009; Pinto *et al*., 2010) for irrigation (Pinto *et al*., 2010). Greywater is already used for the irrigation of crops, more widely so in arid regions, where its re-use reduces the potable water use by up to 50% (Al-Hamaiedeh and Bino, 2010).

Therefore, greywater is a non-conventional water resource that can help to provide for a portion of the irrigation water and reduce the pressure on the conventional water resources, while at the same time improving food security. Re-using treated greywater for food production is less common than re-using treated greywater for municipal use, for example, in public parks, schools and golf courses (Megdal, 2007). However, the use of greywater for agriculture is common in some countries of the world, particularly where water is simply unavailable or where the economic encouragement for its re-use is considerable. It is estimated that 20 million farmers worldwide use untreated or partially-treated greywater for the irrigation of their crops or vegetables (WHO, 2008). Parts of South Africa receive less than the required 500 mm annual rainfall for rain-fed cropping (Schulze, 1997), and recycled greywater could, therefore, be used in these regions for the irrigation of crops, especially for small-scale implementation, such as household and community food gardens. Greywater could be particularly useful for the irrigation of subsistence crops, such as African Leafy Vegetables (ALVs), which are consumed across Africa (van Rensburg *et al*., 2007).

2.11 Conclusions and Future Recommendations

The re-use of greywater is likely to help address food insecurity in rural households and areas by employing female youth/women during the dry and wet seasons and thereby improving food production during the dry periods. It is also important to promote an awareness of greywater re-use for crop production and to transfer this knowledge, which will be bridging the gap between researchers and the actual beneficiaries of the research outputs. It is claimed that public understanding is a key factor with regard to the acceptance greywater re-use, and it has been contended that it is equal to, or even greater than having the technical knowledge. There is however considerable concern over the reactions of the public on the re-use of greywater for crop production, and the need for developmental research in the field is still vital. In addition, the level of acceptance is particularly dependent on whether the crop is meant to be eaten uncooked, or not. Developing countries can also adopt methods, such as the reimbursement of households who are interested in the re-use of their onsite greywater for certain purposes, as well as by encouraging the connection of sewage systems in households at no cost. Although simply the provision of information and public engagement activities cannot work on their own, there needs to be comprehensive thinking around the issue of the public awareness approaches that are used.

There is therefore an urgent need for water conservation technologies to also consider greywater re-use. In many countries, greywater has proved itself to be a useful substitute for freshwater, for non-potable uses, such as toilet flushing and irrigation. However, greywater has to be used with caution and extended periods of greywater re-use should be avoided. The environmental and health risks associated with greywater re-use through irrigation should also be taken into consideration. Furthermore, it is recommended that grey-water and potable water dilution rates (1:1) should be studied further. Governments should also promote water sustainability by educating the public about water re-use and by creating an awareness of its advantages. Other studies provide readily-available information that apply to African states where, in many instances, the easiest way of recycling and using greywater is plant irrigation, which is mainly done in water-scarce areas where irrigation water can be transported by hand into a garden by using a bucket.

Furthermore, implementing simple-installation, -maintenance, -operation and cost- and energy-effective greywater systems will benefit rural communities if they adopt these systems in their households. In addition, greywater re-use should be backed up by by-laws and legislation, in particular where the irrigation of food crops is concerned. The wider adoption of greywater re-use will be possible if municipalities are encouraged to have wastewater treatment plants, while also building the skills and knowledge of the people on greywater re-use in rural areas. An increase in awareness education, restructuring policies and laws, developing and encouraging technological innovations, while also enlightening local communities on the best practices of greywater treatment and re-use, are some of the most important steps for securing a water supply, while also achieving the sustainability of water resources in rural areas. Furthermore, continuous studies on greywater re-use for crop production can also help to shape the policies and legislation and to curb food and water insecurity.

CHAPTER THREE

3 AN ASSESSMENT OF IRRIGATION WATER QUALITY AND POTENTIAL OF RE-USING GREYWATER IN HOME GARDENS IN WATER-LIMITED ENVIRONMENTS

This chapter is based on:

Makgalake P. Radingoana, Timothy Dube and Dominic Mazvimavi, 2020**.** An assessment of irrigation water quality and the potential of re-using greywater in home gardens in water-limited environments. *Journal of Physics and Chemistry of the Earth*, 116: 102857. https://doi.org/10.1016/j.pce.2020.102857

Abstract

In this study, the quality of greywater for re-use in home gardening irrigation was evaluated, in the water-limited environments of the rural Limpopo Province, South Africa. To address this objective, the pH, Electrical Conductivity (EC), Potassium (K^+), Calcium (Ca^{2+}), Magnesium (Mg^{2+}) and Sodium (Na^+) were tested from the sampled household greywater e.g. from kitchens, bathtubs and the laundry. The hazards of greywater were determined by using water quality indices and the derived results were assessed for any differences, using the ANOVA and Tukey methods. The average pH values of Study Area 1 (STA1), Study Area 2 (STA2) and Study Area 3 (STA3) were found to be slightly alkaline (pH 8-9). Generally, most of the Sodium Adsorption Ratio (SAR) values where within the low category (1-10), indicating its acceptability for re-use. Most water quality parameters had a high Soluble Sodium Percentage (SSP), with an average of 68.09%, 79.42% and 92.30% in STA1, STA2 and STA3, respectively. Furthermore, the Kelley's Ratio (KR) indicated elevated levels of salt concentrations in the greywater, with the exception of the laundry water in STA1. On the contrary, residual chloride levels in all samples were found to be within the acceptable range (0-30 meq/L), with <4 meq/L having no restrictions. Therefore, this study concludes that untreated water can be used for home gardening irrigation with caution, unless it is diluted with freshwater.

Keywords: adaptation mechanisms; climate change; food security; greywater; home gardening; livelihoods; water scarcity; sub-Saharan Africa

3.1 Introduction

Most parts of sub-Saharan Africa (SSA) are characterized by erratic rainfall, high temperatures and the frequent occurrence of drought. This has led to severe water scarcity, food insecurity and malnutrition (Ogallo *et al*., 2002). Although the various national rates of poverty are on the decline, SSA remains the leading region in the world with the largest number of people living below the poverty line (Serdeczny *et al*., 2016; World Bank, 2015). For instance, studies conducted across the region have demonstrated that hunger is prevalent in 23.2% of sub-Saharan Africa (FAO *et al*., 2015; Burchi *et al*., 2018).

In addition, poor governance, weak adaptive mechanisms, the overreliance on rain-fed agriculture and the exponential population growth make it difficult to curb food insecurity across the region (Pereira *et al*., 2002). Most parts of the sub-Saharan African region receive an average of between 300 mm and 500 mm rainfall per year (Collins, 2011). This is further exacerbated by climate change, which has seen the drier areas becoming even drier across Africa (Arslan *et al*., 2015; Juana *et al*., 2013). The high temperatures and the lack of rainfall (IPCC, 2007a; 2011), as well as the inability of the continent to adapt to, or cope with, these changes, further complicates the situation, with the poor being the most affected (Benhin, 2008; Hellin *et al*., 2012).

Although sub-Saharan Africa forms part of the least-developed regions the world over, Tostensen *et al*. (2001) argues that the continent is also experiencing a rapid rate of expansion, which is disturbingly high. Nearly 1.3 billion of the world's population will be hosted by the continent by 2050 (Cobbinah *et al*., 2015; UNDESA/PD, 2012). According to Faurès and Santini (2008), above 60% of the households in sub-Saharan Africa live in rural areas and their main source of livelihood is agriculture, which is mainly rain-fed. During the dry season, food production is interrupted due to limited rainfall, and the communities tend to buy their food or stock feed (Domenech, 2015). SSA's urban population is estimated to be approximately 472 million and it is expected to double in the next 25 years (Saghir and Santoro, 2018). Therefore, urban areas are likely to be exposed to numerous socio-economic and environmental challenges, such as the lack of housing, pollution, the lack of sanitation infrastructure, the elevated incidence of poverty and, more importantly, food insecurity and malnutrition, among others (Tacoli, 2017). The projected increases in the rate of urbanization are exacerbated by the lingering poverty in rural areas, and the problem is further aggravated by huge bottlenecks in service delivery (van Schalkwyk, 2015). This has led to calls from across the globe to come up with ground-breaking methods to mitigate against the scourge of water scarcity and climate change and to help reduce poverty, principally in sub-Saharan Africa (Finley *et al*., 2009; Hanjra and Qureshi, 2010; Rodda *et al*., 2011).

Faced by the burden that the rising population is placing on the available water resources, developing countries in the sub-Saharan region have resorted to building dams, inter-catchment water transfers, rainwater harvesting and greywater re-use. Although such ground-breaking methods to alleviate water scarcity have been adopted, greywater re-use for agricultural purposes (Pinto *et al*., 2010) seems to be the most lucrative method for the poor, given the urgent need to reduce food insecurity and malnutrition. The re-use of greywater has become a common practice the world over, predominantly in regions that are facing water stress. However, its adoption across the sub-Saharan countries has been slow, due to the skepticism associated with its quality (Finley *et al*., 2009; Hanjra and Qureshi, 2010; Rodda *et al*., 2011). Various greywater studies in Europe have assessed the production of greywater by households. One of these studies was by Noutsopoulus *et al*. (2018) in Greece, which showed that households produced 98.4 liters of greywater per day, on average. Antonoupoulou *et al*. (2013) revealed that 82.6 liters of greywater were produced in Greece in a day, whereas in Holland it was estimated to be about 86 liters per household per day (Krozer *et al*. 2010). A similar trend was also reported in Denmark (Revitt *et al*. 2011). Greywater, which includes water from bathtubs, showers, hand-wash basins, laundry and kitchen sinks, can therefore help to supplement the limited rainwater for use in small-scale farming (Finley *et al*., 2009; Pinto *et al*., 2010). Greywater re-use has the potential to reduce the use of freshwater for agricultural purposes by almost 50% (Al-Hamaiedeh and Bino, 2010; Ghisi and Ferreira, 2007).

However, besides the associated benefits, the re-use of greywater might also bring about some public wellbeing, ecological or environmental challenges (Maimon *et al*., 2010). The elevated salinity, pH and bromine content found in greywater can adversely affect the quality of the soil, in the long term (Finley *et al*., 2009; Al-Hamaiedeh and Bino, 2010; Misra *et al*., 2010; Rodda *et al*., 2011). The over-use, or use, of greywater is hypothesized to have a side effect on the growth of certain plants and vegetables, and it can pollute the surface/groundwater if it is not properly regulated (Eriksson *et al*., 2002; Negahban-Azar *et al*., 2013). Information on the associated impacts of greywater re-use for home gardening irrigation is not well-documented, especially in developing countries. Therefore, it is upon this premise that this study sought to assess the quality of greywater and its potential for possible re-use for home gardening irrigation in water-limited environments.

3.2 Methodology

3.2.1 Study area description

Greywater sampling was conducted in three study sites, which included the Schoonoord, Malegale and Ga-Radingwana communities (Figure 3.1). These communities are located in the Sekhukhune district, southeast of the city of Polokwane in the Limpopo Province, South Africa. Geographically, the area is located at the coordinates of 24°23′27.52’ S and 29°50′06.83’ E. The district is situated in a semi-arid environment, with an average annual rainfall of ±560 mm and average summer temperatures of ± 23°C (Mpandeli *et al*., 2015; Stronkhorst *et al*., 2009; Sepuru and Dube, 2018). Subsistence, or smallholder, agriculture accounts for 70%, whilst the other 30% is accounted for by commercial agriculture (Siambi *et al*., 2007). Prior to the selection of specific households, a pilot study was conducted to assess if there were any differences in the use and quality of greywater within the households in these communities. It was observed that most households used more or less similar detergents for washing and bathing. The detergents included the Omo, Maq, Surf and Sunlight branded washing powders, Sunlight liquid or green bar, together with bleach for their dishes, as well as the Sunlight green bar, Protex and Lifebuoy branded bath soaps. Participating households were sampled using purposive sampling based on their willingness to participate, the number of years they have been reusing greywater and how long they have been in the area. The individuals within the households were however not directly involved in the research. Since these communities were small and used the same detergents, the results obtained for each household were not very different. Based on this information and the costs involved in water quality tests, a small, but representative, number of households were selected for sampling purposes, which consisted of 5 to 7 members each.

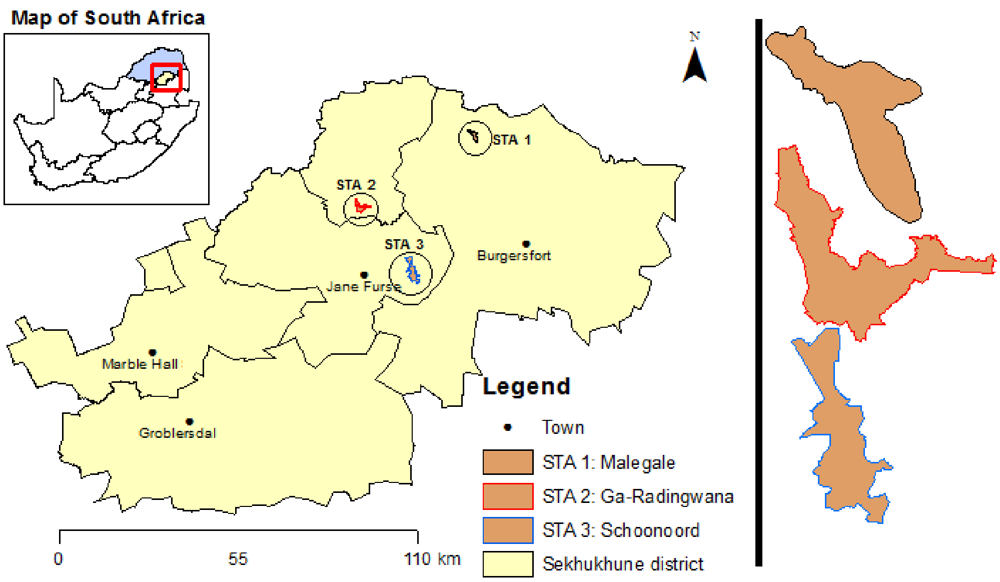

Figure 3.1 Location of the sampled study sites in Limpopo Province, South Africa

3.2.3 Greywater sampling

Before sampling, all plastic bottles were rinsed and sterilised to remove any impurities. The sterilised bottles were collected from the Capricorn District Municipality Water Laboratory. The bottles were labelled to indicate the type of greywater collected, the source and the study area. The greywater was stirred before sampling, to ensure that the water and constituents were properly mixed. Samples were collected from 100% greywater (bathtub, laundry and kitchen), as well as 50-50% (bathtub, laundry or kitchen water, mixed with potable water). The bottles were submerged into the centre of the greywater storage basins and buckets to obtain a sample of the greywater concentration. A total of six samples were collected and analysed from each site, which was a total of 18 samples for the three communities. Specifically, two samples (100% and 50-50%) per source of production (bathtub, laundry and kitchen) were collected from each site. The collected samples were stored in a cooler bag, with ice to keep them cold and to limit any possible microbial activity. They were then transported to the Capricorn District Municipality Water Testing Laboratory within 12 hrs and stored for further analysis.

Analyses were conducted within 48 hrs on the physical and aesthetic water quality components, namely pH, EC, Total Dissolved Solids (TDS) and Chloride (Cl^-), as well as on metals, namely, Potassium (K^+), Calcium (Ca^{2+}), Magnesium (Mg^{2+}) and Sodium (Na^+). These parameters were measured by using different equipment. For example, the pH was measured by using a pH model pH3 meter, while the Electrical Conductivity (EC) was measured by using a conductivity model COND61 meter. Inductively Coupled Plasma-Optical Emission

Spectrometer (ICP-OES), manufactured by Thermofischer Scientific was used to test the following metals: Potassium (K^+), Calcium (Ca^{2+}), Magnesium (Mg^{2+}) and Sodium (Na^{2+}). Samples were acidified with Hydrochloric acid (HCl) during sampling to preserve them from any chemical reactions during transportation and storage. The samples were filtered prior to testing, to remove any particles. A syringe micro-filter method was used for this purpose.

3.3 Evaluation Methods

3.3.1 Water quality indices

The three most significant quality measuring indices, namely, Sodium Adsorption Ratio (SAR), Soluble Sodium Percentage (SSP) and Kelley's Ratio (KR), were used to assess the greywater quality and to determine its appropriateness for agricultural use (Ishaku *et al*., 2011; Darwisha *et al*., 2011; Jang *et al*., 2012, Deshpande and Aher, 2012; Wang and Jiao, 2012). These indices are paramount for determining the concentrations of sodium in water. The indices are described, in detail, in the sections below:

3.3.1.1 Salinity Hazard

The EC and TDS values obtained from the analysed water samples were used to assess the salinity hazard. Four classes of EC limits were used, as defined by Richards (1954). These included low salinity (EC<250), medium salinity (250<EC<750), high salinity (750<EC<2250) and very high salinity (EC>2250), which were measured in microsiemens per centimetre.

3.3.1.2 Sodium Hazard

The sodium hazard was obtained by calculating the Sodium Adsorption Ratio, the Soluble Sodium Percentage and Kelley's Ratio.

3.3.2 Sodium Adsorption Ratio (SAR)

The Sodium Adsorption Ratio (SAR) is used to measure the relative concentration of sodium to calcium and magnesium in the water and soil (Aboukarima *et al*., 2018; DERM, 2009, Rashidi and Seilsepour, 2008). The ratio expresses the relative activity of sodium ions in the exchange reactions with the soil. The following Equation 3.1 by Richards (1954) was used:

$$SAR = \frac{Na^{+}}{\sqrt{\frac{(Ca^{2+} \ +(Mg^{2+})}{2}}} \qquad , \qquad \textbf{(3.1)}$$

where: sodium, calcium and magnesium concentrations are expressed in milli-equivalents/litre.

Since concentrations of ions in water samples are usually provided in milligrams per Litre (mg/L), the ions were converted into milli-equivalents per Litre (meq/L). This was done by dividing the concentration of Na^{+}, Ca^{2+} and Mg^{2+} by their equivalent weights, which are 22.90, 20.04 and 12.15, respectively. Equation 3.1 was used to calculate the SAR of each collected sample (Richards, 1954). Large concentrations of sodium in irrigation water increase the hazards to soils, as the accumulation of sodium ions reduces soil permeability (Hong *et al.*, 2009).

3.3.3 Soluble Sodium Percent (SSP)

The following Equation 3.2 was adopted from (Wilcox, 1955) for calculation of SSP:

$$SSP = \frac{(K^{+} \ +Na^{+})}{Ca^{2+}+Mg^{2+}+Na^{+}+K^{+}} \times 100 \qquad , \qquad \textbf{(3.2)}$$

where: potassium, sodium, calcium and magnesium concentrations are expressed in milli-equivalents/litre.

Water with a high SSP of greater than 60% affects the physical quality of soils (Khodapanah *et al.*, 2009). The ions were converted from milligrams per Litre (mg/L) to milli-equivalents per Litre (meq/L). This was prepared by dividing the concentrations of Na^{+}, Ca^{2+}, Mg^{2+} and K^{+} by their equivalent weights, which are 22.90, 20.04, 12.15 and 39.00, respectively.

3.3.4 Kelley's Ratio (KR)

The Equation 3.2 for calculating KR was sourced from (Kelley, 1963) as is shown below:

$$KR = \frac{Na^{+}}{Ca^{2+}+Mg^{2+}} \qquad , \qquad \textbf{(3.3)}$$

where: sodium, calcium and magnesium concentrations are expressed in milli-equivalents/litre.

Kelley's ratio (KR) indicates the balance among the Na^{+}, Ca^{2+} and Mg^{2+} ions in water. A Kelley's Ratio of >1 indicates an excess level of sodium in the water; therefore, the water samples with a KR of <1 are considered to be suitable for irrigation (Ibraheem and Khan, 2017).

Kelley (1963) suggests that the proportion of irrigation water should not exceed 1. The ions were converted from mg/L in milli-equivalents per litre (meq/L). This was done by dividing the concentration of Na^+, Ca^{2+} and Mg^{2+} by their equivalent weights, which are 22.90, 20.04 and 12.15, respectively.

3.3.5 Chloride Hazard

The chloride hazard was analysed by using the amount of residual chlorine found in the assessed sampled greywater.

3.3.6 Magnesium Adsorption Ratio (MAR)

The MAR was calculated by using the method proposed by Szabolcs and Darab (1964), for water use in agriculture. The MAR for this study was computed using Equation 3.4 as follows:

$$MAR = \frac{Mg^{2+}}{Ca^{2+} + Mg^{2+}} \times 100 \quad , \qquad \textbf{(3.4)}$$

where: magnesium and calcium concentrations are expressed in milli-equivalents/litre.

The ions were converted from mg/L into milli-equivalents per litre (meq/L) where the concentrations of Ca^{2+} and Mg^{2+} were divided by their equivalent weights, which are 20.04 and 12.15, respectively.

3.4 Statistical Analysis

An Analysis of Variance (ANOVA) was used to determine whether there were any significant differences in concentrations of the selected water quality parameters (K^+, Na^+, C^{2+} and Mg^{2+}). The significance level was set at 0.05.

The following Equation 3.5 was used to calculate ANOVA:

$$T = q\alpha(c, n-c)\sqrt{\frac{MSE}{n_i}} \quad , \qquad \textbf{(3.5)}$$

where: T is the Tukey criterion, qα (c, n-c) is the studentized range distribution, based on c and n-c df, c is the number of groups, n-c is the total sample size, MSE is the Mean Square Error (from the ANOVA table) and n_i is the sample size of the group with smallest number of observations.

3.5 Results

3.5.1 pH

In Study Area 1 (STA1), the combined pH values from the sampled greywater ranged from 5.20 to 10.02, with an average value of 8.03, depicting that the sampled greywater is faintly alkaline in nature. Fifty percent (50%) of the samples in STA1 were good for irrigation according to the South African Water Quality Guidelines for agricultural irrigation. The overall pH values for STA1 were within the irrigation water limits of 6.5 to 8.4 (DWAF, 1996). The values in Study Area 3 (STA2) ranged from 7.43 to 10.47, with an average of 8.73, which is alkaline/basic. Moreover, in Study Area 3 (STA3), 33% of the pH values were suitable for irrigation, with 77% of the samples being outside the limits (Bath 100%). The values ranged from 6.25 to 10.49, with an average of 8.71, which is alkaline.

3.5.2 Salinity hazard

The EC in sampled greywater ranged from 1.48 to 585mS/m (millisiemens per meter). According to van Rensburg *et al*. (2011), water used for irrigation with EC<400 is still considered to be safe. Most of these values (100%, 83% and 83% in STA1, STA2 and STA3, respectively) are within the limit, with the EC of laundry (50-50%) in STA3 being the lowest and with laundry (100%) in STA3 as the highest. The EC values of experimental samples for STA1 varied from 42.00-271 mS/m (mean value = 129mS/m), followed by STA2 with values ranging from 3.91-585 mS/m (mean value = 173 mS/m). The EC value of STA3 samples varied from 1.48-631 mS/m, with a mean value of 134 mS/m. The average values for EC in all study areas were within the limit, as specified in van Rensburg *et al*. (2011). The DWAF (1996) limit for TDS in irrigation water is ≤540 mg/L. Almost half (44%) of the samples were within the limit. The average TDS for STA1, STA2 and STA3 were 836.65 mg/L, 1124.26 mg/L and 869.73 mg/L, respectively, and they were all above the limit. Given the EC results, greywater can be applied on food crops.

3.5.3 Sodium Hazard

3.5.3.1 Sodium Adsorption Ratio (SAR)

Table 2 displays the SAR concentrations in the sampled water. In STA1, the values ranged from 2.33 to 51.11 meq/L, with a mean of 66.63 meq/L. The water from washing dishes contains high SAR values, probably due to the type of detergents used for washing their dishes. The SAR values for STA2 ranged from 1.56 to 37.13 meq/L, with a mean of 9.60 meq/L. The mean value of SAR in STA2 suggests that the hazard of using greywater in this study area is low; however, caution should be applied to sensitive crops. STA3 revealed a range of 10.31 to 90.45 meq/L, with a mean of 46.55 meq/L. Generally, most of the values are within the low sodium hazard category of Table 3.1 below. The SAR values recommended for irrigation are summarised in Table 3.1.

Table 3.1 The sodium hazard of water based on SAR* values (Fipps, 2003)

SAR* values	**Sodium hazard of water**	**Comments**
1-10	Low	Use on sodium sensitive crops such as avocados must be cautioned
10-18	Medium	Amendments (such as Gypsum) and leaching needed
18 - 26	High	Unsuitable for continuous use.
> 26	Very	High - generally unsuitable for use

*Sodium Adsorption Ratio

3.5.3.2 Soluble Sodium Percent (SSP)

In STA1, the SSP values ranged from 44.64 to 99.27%, with a mean of 68.09%. The samples with the highest percentages were from dish water, with laundry water having the lowest percentage. In STA2, the values range from 60.41 to 97.77%, with a mean of 79.42%. In STA3, the results surpassed the permitted values of SSP for irrigation, which is 60%. The values range from 77.69 to 99.18%, with a mean of 92.30%. Therefore, the results depict that, when using water that is high in SSP, continuous use should be avoided.

3.5.3.3 Kelley's Ratio (KR)

The results in Table 3.2 show that almost all the KR values were high, which indicates a high sodium concentration in the water, with the exception of laundry water in STA1. In STA1, the KR values ranged from 0.78 to 131.21 meq/L, with a mean of 34.00 meq/L. The KR values for STA1 were high, with the exception of laundry water. In STA2, the KR values ranged between 1.40 and 43.44 meq/L, with a mean of 12.90. In STA3, all the sample values ranged between 3.46 and 119.15 meq/L, with a mean of 38.73 meq/L. These results indicated that the greywater had excessive sodium levels. This water can only be used for irrigation or home gardening purposes, if leaching is allowed, and this can be done by alternating grey- and freshwater.

3.5.3.4 Chloride Hazard (CH)

Table 3.2 shows the amount of chloride in the water samples per study site. The results in Table 3.2 indicate that chloride concentration in all the water samples was within the acceptable limits, which made it suitable for irrigation or for home gardening. Most samples (56%, n =18) were below 2meq/L, which is regarded to be safe for all plants, followed by 22% of the samples, which were between 2 and 4meq/L and suitable for sensitive plants. In addition, the remaining 22% of the samples were found to be between 4 and 10meq/L, which can be used on moderate to tolerant plants. According to Alobaidy *et al*. (2010), the amount of Cl^- (meq/L) in irrigation water is considered to be safe for all plants when it is less than 2, it is safe for sensitive plants when it ranges between 2 and 4, and it is safe for moderate to tolerant plants when it is between 4 and 10.

3.5.3.5 Magnesium Adsorption Ratio (MAR)

Table 3.2 below reveals that 50% of the samples in STA1 and STA3 are within the acceptable MAR limits, while only 16% of the samples are within the limits in STA2. This means that greywater can be used on food crops, but it cannot be used for long periods without alternating it with freshwater. During the rainy season, the use of greywater can be supplemented by rainwater to stabilize the ions in the soils. The MAR negatively affects the soil when it surpasses 50% (Gupta and Gupta, 1987). If the value of the MAR is less than 50%, then the water is safe and suitable for irrigation (Khodapanah *et al*., 2009). However, elevated concentrations of Ca^{2+} and Mg^{2+} are sometimes required to hinder or neutralize the negative effects that might be brought about by excessive amounts of Na^+ in soils and water.

Table 3.2 Descriptive statistics of metal concentrations in sampled greywater

Water Quality Indices	Study Areas (STA)	Bath (100%)	Bath (50/50%)	Laundry (100%)	Laundry (50/50%)	Dish (100%)	Dish (50/50%)	Minimum	Maximum	Average
SAR (Meq/L)	STA1	2.33	2.90	2.93	2.79	51.11	27.51	2.33	51.11	14.96
	STA2	3.77	37.13	4.68	7.25	3.24	1.56	1.56	37.13	9.61
	STA3	76.21	11.00	16.85	74.29	10.31	90.45	10.31	90.45	46.52
SSP (Meq/L)	STA1	56.57	63.04	46.41	44.64	99.27	98.61	44.64	99.27	68.09
	STA2	95.73	97.77	60.41	73.61	87.06	61.93	60.41	97.77	79.42
	STA3	99.18	87.38	98.77	77.69	91.58	99.17	77.69	99.18	92.30
KR (Meq/L)	STA1	1.16	1.43	0.84	0.78	131.21	68.55	0.78	131.21	34.00
	STA2	22.16	43.44	1.40	2.48	6.39	1.56	1.40	43.44	12.91
	STA3	11.98	6.86	80.38	3.44	10.55	119.15	3.44	119.15	38.73
CH (Meq/L)	STA1	1.35	1.33	3.29	3.17	9.01	2.50	1.33	9.01	3.44
	STA2	1.30	1.66	4.84	7.57	0.27	0.24	0.24	4.84	2.66
	STA3	2.52	1.01	1.08	4.28	0.01	0.01	0.01	4.28	1.49
MAR (%)	STA1	31.64	37.47	63.94	61.82	68.33	45.96	31.64	68.33	51.53
	STA2	74.72	65.49	74.00	84.31	59.04	16.24	16.24	84.31	62.30
	STA3	65.27	45.33	42.97	57.50	46.31	61.12	42.97	65.27	53.08

3.5.4 Statistical analysis results

Overall, the one-way ANOVA results showed that the concentration of metals in greywater varied significantly across all study areas. In STA1, the ANOVA test revealed that the metals were different, where $F_{3.0984} = 13.66$, $p<0.05$. STA2 and STA 3 were also significantly different, with ANOVA revealing that $F_{3.0984} = 6.83$, $p<0.05$ and $F_{3.0984} = 22.74$, $p<0.05$. The Tukey HSD test was performed as one of the post-hoc tests to examine the mean differences. The test revealed that, across all study areas, 50% (3 out of 6) of the means per study area were different from one another.

3.6 Discussion

In this study, the quality of greywater was assessed for its potential re-use in home gardening irrigation in water-limited environments in the rural areas of the Limpopo Province of South Africa. Water quality results from all three monitoring sites showed that the pH was alkaline. The average pH was 8.03, 8.73 and 8.71 in STA1, STA2 and STA3, respectively. The recommended range of pH for agricultural water should be between 6.5 and 8.4. Therefore, our results indicated that greywater from the three sampled sites should be used with caution or be prioritized on crops that are salt-tolerant. Literature shows that the use of water with a pH value of below 6.5, or above 8.4, can result in a nutritional imbalance or it may contain toxic ions (Ayers and Westcot, 1985; Pescod, 1985), which can result in crops being stunted, due to nutrient deficiencies. For example, the study by Brown *et al*. (2008) has shown that acidic water can have a harmful effect on plant growth as it can contribute to nutritional problems in the soil. On the contrary, strongly acidic water, i.e. with a pH of less than 4, can lead to soil acidification, a condition that is very unfavourable for crop growth (Ourimbah, 2011). This water can be used effectively when it is alternated or diluted with freshwater, or when lime is added to the water to increase the pH and to minimise the impacts (Ourimbah, 2011).

Salinity tests revealed that the greywater from the three sites was fit for the irrigation of food crops. The EC results of all the study areas were shown to be within the 250 mS/m limit, as suggested by Agriculture and Food (2019), and they were classified as moderately salty. According to the South African Water Quality Guidelines, the recommended limit for TDS in irrigation water is 540 mg/L (DWAF, 1996). In general, 44% of the samples were within these limits. These results demonstrate the usability of greywater for the irrigation of food crops that are highly tolerant to salts. Elevated EC and TDS levels in water have the potential to reduce the productivity of the soil in the long term, more especially if it is uncontrolled (WHO, 2005).

Conversely, the EC of water used for agricultural purposes is within the limits of 75-225 mS/m and is tolerable for irrigation (Alobaidy *et al*., 2010). This is further supported by van Rensburg *et al*. (2011), who stated that soils are considered to be saline when they have an EC>400 mS/m, and irrigation water exceeding the limit will result in a decrease in the crop quality and yield.

Levels of sodium in water quality assessments were revealed to have a low SAR and to be suitable for irrigation. The levels of chloride in greywater are regarded as acceptable as they are within the limits depicted in literature (Alobaidy *et al*., 2010). However, other indices, such as SSP, KR and MAR, have revealed an elevated sodium content. An accumulation of sodium in the soil might influence changes in its physical properties due to irrigation or the application of water containing an SSP of greater than 60% (Halliwell *et al*., 2001). This can, however, be reduced by allowing the sodium to leach through the soil, and it can be achieved if greywater irrigation is discontinued during the rainy season, to allow the leaching of Na^+ to take place. If the levels of sodium are high in the soil, the infiltration of water will be reduced and runoff will be increased (Bauder *et al*., 2011). Alternatively, soils with a low SAR encourage infiltration, thus improving crop production.

3.6.1 Implications of greywater re-use for home gardening and policy implementations

These results imply that greywater can be a source of water for home gardening when there is a shortage of freshwater sources. However, this resource should not be used on rainy days, in order to allow leachate to take place. Since this water is mostly alkaline, it should not be used on crops that require an acidic pH to thrive/survive. It also implies that crop production does not have to be interrupted during the dry season. The policy direction in water-limited environments should be to focus on educating the public or raising their awareness on greywater re-use and its definition. The regulations should bear in mind the potential for actual compliance and implementation of greywater systems. Governments should also allow households that are willing to install these systems to have easy access to them and to subsidize them (Carden *et al*., 2018). It should be clearly stated that greywater should be used within <24 hours of production. In the case of irrigation, sub-surface irrigation should be used, or crops should be heavily mulched (Carden *et al*., 2018).

3.7 Conclusions

It is therefore concluded that the greywater from the three study sites was within the recommended standards for home gardening or irrigation purposes. All the key water quality parameters assessed in this work have been found to be slightly within acceptable concentrations. However, its use should be prioritized more on salt-tolerant crops, although the presence of Ca^{2+} and Mg^{2+} in greywater would help to neutralize the sodium concentrations. Furthermore, there is need for caution when this water is used, especially when it comes to prolonged irrigation, as the Na^{2+} concentration in greywater will have an impact on the plant and soil quality, in the long run. Overall, the findings of this study underscore the potential of greywater as an alternative source of water for home gardening or small-scale irrigation in the water-limited environments of the Limpopo Province, and in sub-Saharan Africa in general.

CHAPTER FOUR

4 AN ASSESSMENT OF SOIL CONTAMINATION FROM GREYWATER IRRIGATION IN SMALL HOME GARDENING PLOTS

This chapter is based on:

Makgalake P. Radingoana, Timothy Dube and Dominic Mazvimavi 2021. Assessing soil contamination from greywater irrigation in small home gardening plots. **Under review**, Manuscript number: **JPCE-D-21-00152**.

Abstract

Africa has been identified as one of the most vulnerable continents in the world, because of its projected population growth and the impacts of climate change. Sub-Saharan Africa is currently projected to have a steady annual population increase of 2.7%, which will possibly double by 2050 and which will have a negative impact on the existing water resources. Water scarcity has become a worldwide problem and greywater re-use has been extensively adopted to circumvent the impacts of food security. Although greywater re-use seems to be fit for supplementing potable water in home gardening, it still possesses some characteristics that might have a negative impact on the soils and irrigated produce, if they are not monitored well. In this study, the impacts of greywater re-use on the soils in home gardening vegetable production were assessed. Four households, located in the Dihlabaneng village within the Makhuduthamaga Municipality of the Limpopo Province, South Africa, were purposefully selected to participate in this particular study. A total of eight soil samples were collected (two per household) consisting of 2 samples each for kitchen-, laundry-, bath irrigated greywater and lastly clean water irrigated soil to serve as a control site. The soil samples were collected from depths of 30 cm and 60 cm, stored in Ziplock polythene bags and labelled for further laboratory analysis. These depths were selected because some of the selected crops had taproots that extended to a depth of 60 cm. Heavy metals, such as arsenic (As), chromium (Cr), copper (Cu), manganese (Mn), lead (Pb) and zinc (Zn) were tested from each collected soil sample in the area that were irrigated with greywater (i.e. kitchen, bathtub and laundry) and control site resulting in 48 tests. The intra- and inter-variations in heavy metals across the two soil depths were statistically evaluated. The Analysis of Variance, Pearson's correlation, the index of geo-accumulation, the contamination factors and the modified degree of contamination were used to assess the heavy metal contamination levels in the area under study. The results revealed that the pH of all the sampled soils was within the optimal range for agricultural soils (5.5 to 7.5). The Analysis of Variance displayed that the highest percentages of metals (62% and 95%) in both the 30 cm and 60 cm soil depths were significantly different. There was a strong positive relationship between the metals at both soil depths, with the exception of Zn, at a depth of 30 cm. This shows that greywater was not the only cause of metal accumulation in the soils. The pollution indices revealed that As was the highest contaminant amongst all the other metals. Generally, the soils were moderately contaminated. It can therefore be concluded that greywater use over a long period is likely to contribute to metal accumulation in soils. However, crop rotation and other farming practices, such as intercropping, can be encouraged to reduce certain metal concentrations in the soils.

Keywords: greywater; home gardening; irrigated soils; rural area; trace elements

4.1 Introduction

Globally, the challenges associated with climate change, for example, the lack of proper infrastructure to trap and supply the water (Adams *et al*., 2019; Dos Santos *et al*., 2017), as well as water supply problems due to limited financial resources, especially in developing countries, are of major concern, as they have an impact on the already scarce water resources (IPCC, 2018; Ripple et al., 2019; Radingoana *et al*., 2020a; World Economic Forum, 2020; Pinto *et al*., 2010; Godfrey *et al*., 2009; Abusam, 2008; Jury and Vaux, 2007; Jenerette and Larsen, 2006; Lundqvist *et al*., 2005). Furthermore, pressure is being exerted on the water resources by pollution, leakages and population growth (Reichman and Wightwick, 2013). According to the full CMIP5 model ensemble (Sillmann *et al*., 2013), extreme precipitation is projected on the Horn of Africa with tropical eastern Africa predicted to experience precipitation increase of 5-75%. However, on the contrary, regional models project that there will be no change in rainfall; instead, the eastern region is drying up (Laprise *et al*., 2013). Vizy and Cook (2012) projected that the number of dry days in the eastern region of Africa will increase. The developing world is currently experiencing an increase in the population, with most of the people having poor access to clean water. Since African livelihoods are typically focused on subsistence agriculture, it will become almost impossible for these farmers to continue feeding their households sustainably, without being able to irrigate their fields (Radingoana *et al*., 2020a).

Water scarcity has become a worldwide problem (Godfrey *et al*., 2009); therefore, the re-use of greywater for irrigation purposes has been widely adopted throughout the world as a way of combatting this scarcity, as well as for improving food security (Maimon *et al*., 2010; Turner *et al*., 2013; Zhu *et al*., 2015; Turner *et al*., 2016). Even though greywater re-use is fit for substituting potable water in subsistence irrigation, this water still contains a lot of pollutants (Stevens *et al*., 2011; Mohamed *et al*., 2013; Turner *et al*., 2013; Albalawneh *et al*., 2016; Turner *et al*., 2016). Re-using greywater for irrigation purposes requires an understanding of the potential impacts that this practice can have on the environment (Travis *et al*., 2010). Although greywater irrigation on a larger scale is preceded by treatment measures (Travis *et al*., 2010), this might not be the case with irrigation at a household level (Wiel-Shafran *et al*., 2006).

As a result of the increased awareness of the problem of water scarcity, greywater re-use technology is currently considered to be of significant importance and a lucrative alternative (Travis *et al*., 2010). It is seen to be a potential substitute for the freshwater supply when the water demand increases (Lambert and Lee, 2018; Oteng-Peprah *et al*., 2018b; Atanasova *et al*., 2017; Zhu *et al*., 2015; Maimon *et al*., 2010). However, its sustainability still remains questionable, because it is linked to fears of environmental pollution (Wiel-Shafran *et al*., 2006). Maimon *et al*. (2010) recommends that greywater be treated before garden irrigation, as this reduces the risk of microbial contamination. Nevertheless, as the water shortages increase, untreated irrigation greywater is allowed in some countries (Maimon and Gross, 2018; Newcomer *et al*., 2017; Maimon *et al*., 2010).

During the severe drought conditions in the City of Cape Town, South Africa, between 2015 and 2018, residents were forced to rely on alternative water sources for irrigating their vegetable gardens. Rainwater, groundwater and domestic greywater were among the sources used (Hardie *et al*., 2021). Since the abstraction of groundwater is costly and requires the installation of boreholes, the reliability of this method was not a guaranteed solution for some residents. In addition, given the erratic nature of the South African rainfall, the storage capacity required for rainwater to last longer affects the availability of potable water for irrigation. Therefore, in such incidences, people were forced to use the readily available sources, such as greywater, and this was publicly emphasized by the City of Cape Town (City of Cape Town, 2019). However, although this water is regarded as the most potentially reusable source, the literature is still limited regarding its impact on soil when it is used for irrigation purposes

(Yashni *et al*., 2020). This is supported by Travis *et al*. (2010) and Turner *et al*. (2016) who stated that the impact of micro-pollutants in greywater and their environmental impact on the soil, groundwater and surface water (Erikson and Donner, 2009) has still not been established. It is therefore assumed by Turner *et al*. (2016) that most organic micro-pollutants can be treated, and their impact minimized through appropriate treatment systems. Unfortunately, this is not possible for the rural South African populace, where wastewater systems are lacking, and service delivery is still hindered by the lack of proper infrastructure, finance, vandalism and corruption. In addition, even though numerous techniques can be put in place to help reclaim greywater for use in non-potable cases (Zipf *et al*., 2016; Abed *et al*., 2017; Prodanovic *et al*., 2020), this remains impossible in developing and under-developed countries, due to the associated costs. Despite some metals that are found in greywater being essential for plant growth, their availability in large quantities can have an impact on the health of the soil (Shaikh and Ahammed, 2020). The availability of sodium (Na) in greywater has the potential of causing a Na build-up, which, in turn, is likely to cause the deterioration of the soil structure, which affects plant growth (Oteng-Pephra *et al*., 2018a)

Soil metals can be deposited through geogenic and anthropogenic activities. However, geogenic activities that contribute to the contamination of soils only amount to 20% of the total pollutants (Ludden *et al*., 2015). On the other hand, anthropogenic activities that lead to soil contamination include acid mine drainage, irrigation water, the application of fertilizers and pesticides, as well as some urban activities, etc. (González *et al*., 2011; Wuana and Okieimen, 2011). These contributions to soil pollution are of primary concern as they are the only ones that are regarded as true legal contaminants (Gàlan *et al*., 2019). However, the distinction of whether the cause of the pollution is anthropogenic or geogenic still lacks enough research evidence (Galán *et al*., 2014; Petrick *et al*., 2018). Furthermore, geogenic elements hardly exceed the threshold (González *et al*., 2011) and if they do surpass it, the risk of toxicity is still low, because of their low availability (Romero *et al*., 2012; Galán *et al*., 2014; Romero-Baena *et al*., 2018).

Most studies on untreated greywater tend to focus on traditional parameters, such as plant yield, pH and conductivity, as well as major nutrients, such as nitrogen, phosphorus, potassium, magnesium and calcium (Maimon and Gross, 2018; Lubbe et al., 2016; Pandey *et al*., 2011; Pinto *et al*., 2010). It is on this premise that the current study aimed to assess the impact of greywater irrigation on trace elements in soils, as there is little research on the metal elements

(Rodda *et al*., 2011; Misra *et al*., 2010). This study hypothesizes that the irrigation of soils with greywater has a minimal impact on the soil, particularly during the dry season, as rainfall reduces the accumulation of metals in soils during the rainy season. In addition, untreated greywater has been proven to be an available source that can be used for small-scale farming, which usually takes place in rural areas and informal settlements, where the available potable water does not meet all the household needs. Moreover, this will improve food security for the poor by providing a year-round harvest of vegetables and it will promote the independence of female and child-headed households.

4.2 Materials and Methods

4.2.1 Study area

This study was conducted in the Dihlabaneng village, which is located in the Makhuduthamaga Municipality of the Limpopo Province, South Africa (Figure 4.1). Villagers from this area frequently use greywater for home gardening purposes and the area is easily-accessible, hence the choice of this particular area. For the purposes of this particular study, four households were randomly selected. Their selection was based on their use of greywater to irrigate their crops, as well as the absence of a borehole in the yard. The selected households have also been re-using greywater for irrigation since they relocated to the area. Two soil samples were collected from each household, where different greywater sources were used to irrigate their crops. This means that, from Household 1, soil samples were collected from an area that was irrigated with kitchen greywater, from Household 2, soil samples were collected from an area that was irrigated with bath greywater, from Household 3, soil samples were collected from an area irrigated with laundry greywater, and lastly, the potable water of Household 4 was the control. The soil samples were collected from depths of 0-30 cm and 30-60 cm. This village is made up of virtually 209 265 hectares (ha) and is under the leadership of traditional authorities (MLM IDP, 2019/20). High poverty levels, municipal backlogs in service delivery, dispersed settlements and subsistence agriculture are some of its physiognomies (MLM IDP, 2019/20). The area is characterized by a hot climate, with average summer temperatures of 23°C (a maximum of 28°C and a minimum of 18°C). In winter, the average temperature is 13.5°C, with a maximum of 20°C and a minimum of 7°C (MLM IDP, 2019/20).

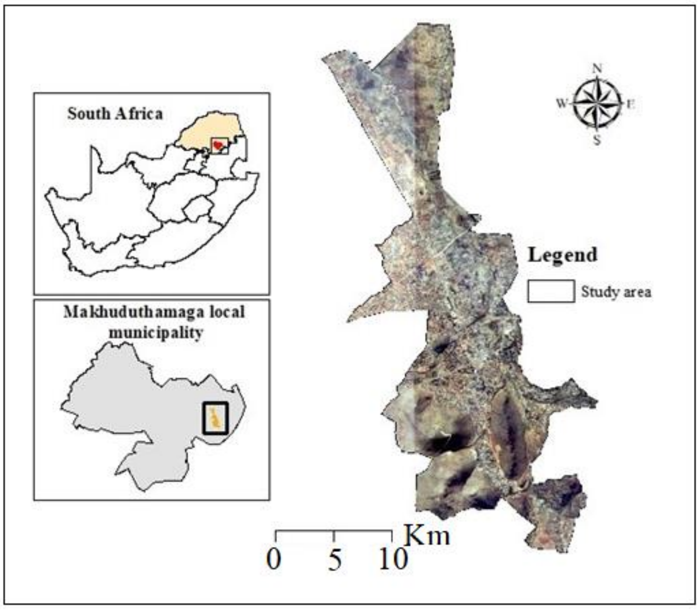

Figure 4.1 The Makhuduthamaga village in the Limpopo Province, South Africa

A total of eight soil samples were homogeneously collected from the four sites at depths of 0–30 cm and 30–60 cm. Each soil sample was tested for six different heavy metals which might be present in the soils. The total tests performed on the soils equalled 48 (8 samples x 6 metals). Sample 1 included soil obtained from area irrigated with kitchen water, Sample 2 from an area irrigated with bath water, Sample 3 from an area irrigated with laundry water and Sample 4 from an area irrigated with potable water, which served as the control site. The V method was used to collect the samples, whereby a spade was used to make a V-shaped cut of about 60 cm on the ground. Foreign materials, such as pebbles, twigs, litter and roots, were removed from the sample and the topsoil was cleared before sampling. The collected samples were thoroughly mixed. The soils were sieved through a 5 mm and 2 mm sieve to remove any coarse materials or any other remaining plant materials. The samples were stored in ziplock polythene bags, labelled and then sent to the Limpopo Agro-Food Technology Station at the University of Limpopo for metal (i.e. As, Cr, Cu, Mn, Pb and Zn) testing. The metals were prepared by using the microwave digester for an Inductively Coupled Plasma Emission (ICPE) spectrometry analysis. The soil was extracted in an acid solution with PerkinElmer Titan MPS in a standard 75 mL digester vessel, according to the EPA method 3051A. A total of 3.5-4.0 g of the sample was weighed into the digestion vessel. The amount of organic material did not exceed 250 mg. Ten milligrams (10 mg) of nitric acid (HNO_3) was added to the mixture and stirred carefully with a clean polytetrafluoroethylene (PTFE) bar. The vessel was closed, after waiting for at least 10 minutes.

4.2.2 Data analysis

4.2.2.1 Analysis of Variance test technique (ANOVA)

An analysis for the statistical significance of differences among the means of the samples obtained at 30 cm and 60 cm was performed, using the add-in Data Analysis Toolpak on the Excel Stats software. The tests were confirmed at a significance level of 0.05. A Pearson's correlation test was used to measure the strength of the relationship between the relative movements of the metals in the soils. An Analysis of Variance (ANOVA) test technique and two tailed post-hoc corrected two sample T-test assuming equal variances was used to evaluate the differences in soil metals between the different soil depths. In addition, the Bonferroni post-hoc correction was used to adjust the significance level to avoid errors when performing many corrections. The correction was done by using following Equation 4.1 below:

$$BC = \frac{SL}{NC} \quad , \qquad \textbf{(4.1)}$$

Where BC is the Bonferroni correction, SL is the significant level used, and NC is the number of comparisons

4.2.2.2 Pollution levels

There are numerous indices or techniques that can be applied when assessing the metal pollution of soils. For this study, the geo-accumulation index, contamination factor and modified degree of contamination were used to evaluate the levels of pollution. The background values determined by Herselman (2007) were used. Since Herselman (2007) did not calculate the value for As, Rudnick and Gao's (2003) As value in the upper continental crust was used. Manganese (Mn) has not been included in the calculation of pollution levels, as there were no background reference values from either Herselman (2007) or Rudnick and Gao (2003).

a. Index of geo-accumulation (Igeo)

The Index of geo-accumulation (Igeo) (Müller, 1969) was used to assess the contamination of soils, in comparison with their geochemical background values. The below Equation 4.2 was used to assess the contamination level of the soils:

$$Igeo = Log_2 \frac{C_i}{1.5(B_i)} \quad , \qquad \textbf{(4.2)}$$

Where C_i is the concentration of element *i* in the soil, 1.5 is a constant used in minimising the possible disparities in the background value owed to lithologic discrepancies (Stoffers *et al*, 1986), and Bi is the geochemical background concentration of element *i*

According to Müller (1969), the Igeo value is assessed based on seven classes, which consist of the following ranges: <0, 0-1, 1-2, 2-3,3-4, 4-5 and ≥5. These ranges are interpreted as follows: uncontaminated, uncontaminated to moderately contaminated, moderately contaminated, moderately to heavily contaminated, heavily contaminated, heavily to extremely contaminated and extremely contaminated, respectively.

b. *Contamination Factor (CF)*

The Contamination Factor (CF) is advantageous when monitoring the pollution of soil over time. This is calculated as a relation of the assessed metal with the background value of that specific metal (Varol, 2011). It is calculated by using the formula 4.3 below:

$$CF = \frac{C_{heavy\ metal}}{C_{background}} , \qquad \textbf{(4.3)}$$

Where $C_{\text{heavy metal}}$ is the value of the analysed heavy metal, and $C_{\text{background}}$ is the background value of that particular metal

The degree of contamination can be categorized according to their values from 1 to 6, as follows: "if CF < 1, low pollution; 1 < CF < 3, moderate pollution; 3 < CF < 6, considerable pollution; CF > 6, very high pollution" (Hakanson, 1979).

c. *Modified degree of contamination (mCd)*

Abrahim (2005) modified Hakanson's (1979) degree of contamination equation. This modified equation allows for the calculation of many elements, without having an upper limit. The reason for calculating the degree of contamination is to assess the overall degree of contamination in the surface layers of the sampling site. mCd is therefore the sum of the CF divided by the total number of elements assessed. The degrees of contamination used are interpreted as follows: mCd < 1.5 = nil to very low degree of contamination, 1.5 ≤ mCd < 2 = low degree of contamination, 2 ≤ mCd < 4 = moderate degree of contamination, 4 ≤ mCd < 8 = high degree of contamination, 8 ≤ mCd < 16 = very high degree of contamination, 16 ≤ mCd

< 32 = extremely high degree of contamination and mCd ≥ 32 = ultra-high degree of contamination.

The following formula was used to calculate mCd:

$$mCd = \frac{\sum_{i=1}^{i=n} C_f^i}{n} \quad , \qquad \textbf{(4.4)}$$

Where n is the number of analysed metals, i is the i^{th} element, and Cf is the contamination factor

4.3 Results and Discussion

4.3.1 pH in water

The pH of the soils (n = 8) varied between 5.92 and 7.64, with a median value of 6.88 (Figure 4.2). The optimal range for agricultural pH is 5.5 to 7.5 (Oshunsanya, 2018). According to Figure 4.2, the pH values of the soils are within the optimal range for crop production, with the exception of soil irrigated with laundry water at a depth of 30 cm. It has been revealed from the study that the pH levels of the tested soil samples were within the recommended range required for agricultural crops.

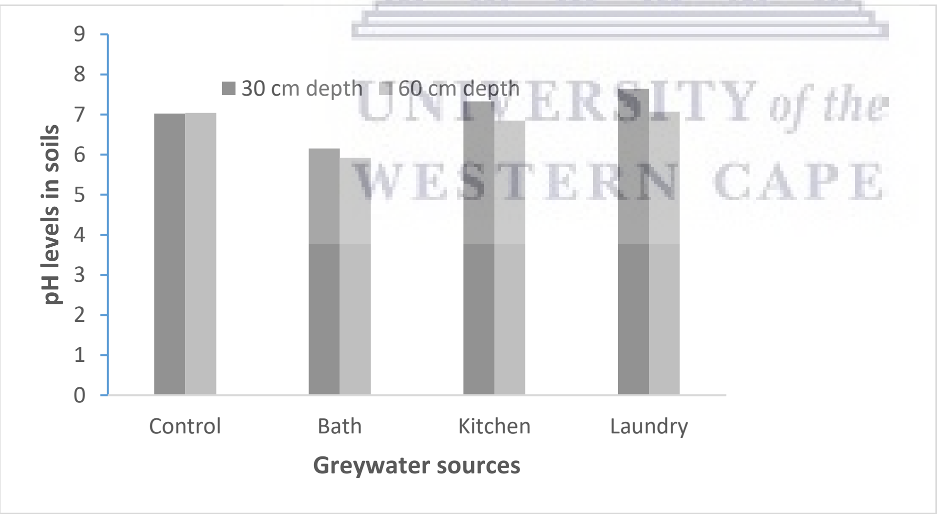

Figure 4.2 Levels of pH in the tested samples

Even though laundry detergent manufacturers are moving towards producing detergents that are environmentally friendly, the use of other detergents, such as bleach and fabric softeners, can alter the pH and total productivity of the soil. The safety of agricultural products is usually of concern where agricultural soils have been exposed to some sort of pollution (Xue *et al*., 2014; Sarwar *et al*., 2017). The duration of irrigation with greywater, without enough time for percolation or supplementation with freshwater irrigation, can affect the pH of an area, rendering it less productive for the production of certain crops.

4.3.2 Metal distribution (descriptive analysis)

The results of metal distribution in soil at 30 cm and 60 cm depths are shown in Table 4.1. From the data, the dominant metals in milligrams per kilogram (mg/kg) were As (40.65; 45.50), and Cu (30.30; 34.79) at both the 30 cm and 60 cm soil depths, respectively. At both depths, the order of the concentration, according to the mean values, was As > Cu > Cr > Mn > Pb > Zn. In the 30 cm depth zone, soils irrigated with greywater obtained from bathing contained the lowest concentrations of metals, excluding Zn, where soils irrigated with laundry water had the lowest concentrations, when compared to soils irrigated with water obtained from other sources. Bath and laundry greywater had the lowest metal concentrations of Mn and Pb at a depth of 30 cm depth, and of As, Cr, Cu, and Zn at a depth of 60 cm, respectively (Table 4.1).

The other metals exhibited relatively low concentrations of less than 16 mg/kg at both soil depths. As and Cu exhibited the highest dispersion in terms of the Standard Deviation (SD) and Standard Error (SE) in both soil depths (Table 4.1). The metals are seen to be lower at a depth of 30 cm, compared to the control, whereas it is the opposite at a depth of 60 cm. The standard deviation of the results at the 30cm depth was affected by outliers and the soil samples varied greatly from the mean. On the contrary, the standard deviation of metals at a 60 cm depth did not have high variations from the mean, compared to those at a 30 cm depth. According to Errikson *et al*. (2002), domestic greywater stands at a 50-80% production rate and might increase considerably with urbanization, population growth and increasing sanitation measures (Eman *et al*., 2014; Alobaidy *et al.*, 2010; Qadir *et al*., 2009). This will be the future of crop production in the coming years. Therefore, the management and treatment of this greywater is of importance, in order to help regulate the deposit of metals in the soil and, consequently, in the water systems.

Table 4.1 Statistical distribution of metals at the tested soil depths

	Greywater metals (Mg/Kg)					
	As	**Cr**	**Cu**	**Mn**	**Pb**	**Zn**
Control (30 cm)	43.5	14.28	32.78	14	9.51	3.77
Bath (30 cm)	33.63	7.95	23.5	8.16	6.38	10.4
Kitchen (30 cm)	42.1	13.48	30.98	10.9	8.76	4.07
Laundry (30 cm)	43.38	14.63	33.93	14	10.38	3.99
Min (30 cm)	33.63	7.95	23.5	8.16	6.38	3.77
Mean (30 cm)	40.65	12.59	30.30	11.77	8.76	5.56
Max (30 cm)	43.5	14.63	33.93	14	10.38	10.4
Standard Deviation	4.72	3.13	4.69	2.81	1.72	3.23
Standard Error	2.36	1.56	2.35	1.41	0.86	1.62
	As	**Cr**	**Cu**	**Mn**	**Pb**	**Zn**
Control (60 cm)	45.93	15.43	35.18	14.68	10.1	4.09
Bath (60 cm)	46.08	15.23	34.43	12.63	9.88	3.98
Kitchen (60 cm)	46.3	15.78	35.63	14.1	10.78	4.19
Laundry (60 cm)	44	14.55	33.93	13.63	10.4	3.94
Min (60 cm)	44	14.55	33.93	12.63	9.88	3.94
Mean (60 cm)	45.58	15.25	34.79	13.76	10.29	4.05
Max (60 cm)	46.3	15.78	35.63	14.68	10.78	4.19
Standard Deviation	1.06	0.52	0.76	0.87	0.39	0.11
Standard Error	0.53	0.26	0.38	0.43	0.20	0.06

Bath water was revealed to have the lowest metals discharged into the soils at a depth of 30 cm (Table 4.1). According to Jefferson *et al*. (2004), greywater generated from bathing is considered less polluted, when compared to other sources of domestic greywater. Nevertheless, greywater generated from bathing has a high electrical conductivity on the soil, when irrigating food crops, as it contains high sodium ions (Holgate *et al*., 2011). Even though the organic matter found in greywater can contribute to the building of organic matter in soil over time (Rusan *et al*., 2007), the sources of untreated domestic water still contribute to the health of soils irrigated with this water (Mzini, 2013). Mzini (2013) has also highlighted some of the possible pollutants caused by greywater irrigation and their effect on soils, in the short term (see Table 4.2).

Table 4.2 Effects of domestic greywater generating appliances on soils

Greywater source	Pollutants	Effects on the soil	Reference
Kitchen sink	Grease and oil	Reduction in soil water capillary rise	Travis *et al*., 2008
Washing machine	Surfactants and salts	Modest influence on soil water retention and evapotranspiration	Misra *et al*., 2009
Bathtub	Microorganisms, such as E. Coli	High electrical Conductivity (EC)	Holgate *et al*., 2011

4.3.3 Pearson's co-relation co-efficient matrix

This study hypothesized that a significant negative correlation would be indicative of greywater as a source of contamination; on the contrary, a positive correlation therefore signifies that greywater is a non-constituent of metals in the soil. The correlation matrix for soils at a depth of 30 cm revealed strong positive inter-metal relationships (Table 4.3). A strong positive relationship was observed between all metals against each other, except for Zn. The relationship of the Zn metal against the others displays a strong negative relationship (Table 4.3). Table 4.3 reveals that greywater is not a constituent in the availability of the metals in the soils, with the exception of Zn, which can be viewed as greywater being the cause of its availability in the soils. Wu *et al*. (2011) supports this assertion by stating that the main source of heavy metal pollution is solid waste, waste gas and the discharge of industrial wastewater.

However, there are also agricultural activities that contribute to the accumulation of metals in soils, such as fertilizers use, irrigation, as well as the production of livestock manure (Shi *et al.*, 2019). The bioavailability of heavy metal movement is dependent on the physical and chemical properties of soils, as well as the adsorption-desorption characteristics of the soil, environmental factors, metal properties, etc. Even though greywater re-use for irrigation is not always the only source that leads to the concentration of metals in soils (Turner *et al.*, 2016), these waters are prone to leaching. Therefore, it is important to use models for assessing the ability of greywater to increase leaching (Gardner *et al.*, 2002).

Table 4.3 Pearson's co-relation co-efficient (r) matrix for metals found in soils at a depth of 30 cm

	As	**Cr**	**Cu**	**Mn**	**Pb**	**Zn**
As	1					
Cr	0.99	1				
Cu	0.99	0.99	1			
Mn	0.92	0.92	0.95	1		
Pb	0.96	0.97	0.99	0.966	1	
Zn	-0.99	-0.99	-0.97	-0.87	-0.93	1

Table 4.4 below reveals the relationships of analysed metals at a soil depth of 60 cm. The following metals have a strong positive relationship with each other (Cr-As), (Cu-As), (Cu-Cr), (Zn-As), (Zn-Cr) and (Zn-Cu). With metals found at a depth of 30 cm (Table 4.3), it has been observed that Zn has a strong positive relationship with all the other metals at a soil depth of 60 cm (Table 4.4) as compared to Table 4.3. Therefore, it can be argued that accumulation of metals in the 60 cm soil depth are not caused by greywater irrigation with the exception of Zn-As relation.

Table 4.4 Pearson's co-relation co-efficient (r) matrix for metals found in soils at a depth of 60 cm

	As	**Cr**	**Cu**	**Mn**	**Pb**	**Zn**
As	1					
Cr	0.93	1				
Cu	0.79	0.95	1			
Mn	0.07	0.34	0.59	1		

Pb	-0.07	0.267	0.44	0.43	1	
Zn	0.71	0.914	0.99	0.61	0.59	1

4.3.4 Analysis of Variance (ANOVA)

Generally, the one-way ANOVA outcomes express that the concentration of metals in soils irrigated with greywater varied significantly across both soil depths. At a 30 cm depth, the ANOVA test revealed that the metals were significantly different, where $F_{2.5727} = 48.93$, $p<0.05$. In addition, the means of the metals at the 60 cm depth were proved to be significantly different with ANOVA, revealing that $F_{2.5727} = 1544.88$, $p<0.05$. The significance level was adjusted using the Bonferroni post-hoc correction (Equation 1) before performing the two-tailed post-hoc corrected T-test. This was done in order to avoid associated errors when performing many corrections. The corrected significance level was 0.007. Furthermore, a two-tailed post-hoc corrected sample T-test assuming equal variances revealed that, at the 30 cm depth, most (62%) of the metal concentrations were different from the rest of the percentages (38%), showing no discrepancies. On the other hand, at the 60 cm depth, 95% of the metal concentrations were generally significantly different, with only 5% (Cr-Mn) displaying no form differences.

4.3.5 Index of geo-accumulation (Igeo)

The values of the Igeo results have been presented in Table 4.5 below. This study revealed that As moderately (Igeo 1-2) contaminates the soil, while all the other metals (Cr, Cu, Pb and Zn) fall within the uncontaminated to moderately contaminated (Igeo 0-1) groups.

Table 4.5 Index of geo-accumulation for elements at both soil depths

	Igeo					
	Source	***As***	***Cr***	***Cu***	***Pb***	***Zn***
30 cm	**Control**	1,82	0,04	0,22	0,09	0,02
	Bath	1,4	0,02	0,16	0,06	0,05
	Kitchen	1,76	0,04	0,21	0,08	0,02
	Laundry	1,81	0,04	0,23	0,09	0,02
60 cm	**Control**	1,92	0,04	0,24	0,09	0,02
	Bath	1,93	0,04	0,23	0,09	0,02
	Kitchen	0,94	0,04	0,24	0,09	0,02
	Laundry	1,84	0,04	0,23	0,09	0,02

The results concur with those of Ahamad *et al*. (2020), which revealed that As has moderately contaminated the Weihe River in China. The average contamination of metals from all sources, at both soil depths, followed the same order of As > Cu > Pb > Cr >Zn. From Table 4.5, it can be seen that the concentration of metals was higher at the 60 cm depth, compared to the metals at the 30 cm depth.

4.3.5.1 Contamination Factor (CF)

The average concentrations of As, Cr, Cu, Pb and Zn in all the sources at a 30 cm soil depth were 8.48, 0.18, 0.80, 0.40 and 0.13 respectively. At a 60 cm depth, the average concentrations of As, Cr, Cu, Pb and Zn were 9.53, 0.20, 0.98, 0.50 and 0.10, respectively.

Table 4.6 Contamination factor analysis for the soils at both depths

				CF		
	Source	***As***	***Cr***	***Cu***	***Pb***	***Zn***
30 cm	**Control**	9,1	0,2	1,1	0,4	0,1
	Bath	7,0	0,1	0,8	0,3	0,2
	Kitchen	8,8	0,2	1,1	0,4	0,1
	Laundry	9,0	0,2	0,2	0,5	0,1
60 cm	**Control**	9,6	0,2	1,3	0,5	0,1
	Bath	9,6	0,2	0,2	0,5	0,1
	Kitchen	9,7	0,2	1,2	0,5	0,1
	Laundry	9,2	0,2	1,2	0,5	0,1

The average pollution level of metals from all sources at both soil depths in Table 4.6 above followed the same order of As > Cu > Pb > Cr >Zn as in Table 4.5. Among all the heavy metals, at the 30cm soil depth, Zn (control, kitchen and laundry) and Cr (bath) had the lowest pollution factor, while As had the highest contamination factor from all the sources. According to Kabata-Pendias (2010), the high value of CF reflects pollution through anthropogenic activities, while the lower values confirm natural contamination.

4.3.5.2 Modified degree of contamination (mCd)

The mCd values were calculated for the contamination of soils by all metals per source of greywater. Amongst all the sources of greywater at both soil depths, bath water had a low degree of contamination ($1.5 \leq mCd \leq 2$) at the 30cm depth, and all other greywater sources had a moderate degree of contamination ($2 \leq mCd \leq 4$) (Table 4.7).

Table 4.7 Modified degree of contamination analysis for the soils at both depths

		CF					***mCd***
	Source	***As***	***Cr***	***Cu***	***Pb***	***Zn***	
30 cm	**Control**	9,1	0,2	1,1	0,4	0,1	2,2
	Bath	7,0	0,1	0,8	0,3	0,2	1,7
	Kitchen	8,8	0,2	1,1	0,4	0,1	2,1
	Laundry	9,0	0,2	0,2	0,5	0,1	2,0
60 cm	**Control**	9,6	0,2	1,3	0,5	0,1	2,3
	Bath	9,6	0,2	0,2	0,5	0,1	2,1
	Kitchen	9,7	0,2	1,2	0,5	0,1	2,3
	Laundry	9,2	0,2	1,2	0,5	0,1	2,2

Even though soil irrigated with greywater might show the minimal availability of metals, the use of greywater over time will increase the metal concentration, which poses a moderate risk to the ecosystem (Turner *et al.*, 2016). However, the environmental impact of greywater will vary with the location or households, given the variations in the composition of the water (Turner *et al.*, 2016). It is therefore of paramount importance that irrigation with greywater be managed. The metals present in the water should be considered as potential contaminants, and the amount, as well as the frequency, of greywater irrigation should be controlled. This will allow the users to save their water and continue with agricultural production, while also minimizing the environmental impacts.

4.4 Conclusions

The pH levels of the soils were within the standard range in agricultural soils (5.5 to 7.5). Heavy metals concentrations were revealed to be significantly different from each other, even when the availability of these heavy metals in the soils was not due to irrigation with greywater. The manifestation of these metals can be from geogenic activities, rather than anthropogenic activities. However, the results also revealed that greywater did not contribute to the concentration of metals in the soils at both depths, with the exception of Zinc, at a 30 cm depth. Therefore, there might be high chances that most of metals in the soils are as a result of geogenic or mining activities taking place in the Sekhukhune district or the province. This thus implies that, should there be continuous irrigation with greywater (particularly laundry greywater), while also alternating it with freshwater, probable future heavy metals accumulation in the soil might be avoided all together. The ANOVA results revealed that the accumulation of metals in the soil was not due to irrigation with greywater. The post-hoc correction t-test also displayed that the concentrations of metals in the soils were very different from one another.

Pearson's correlation coefficient revealed that, at a 30 cm soil depth, the positive inter-metals relationship exposed greywater as not contributing to the availability of metals in the soils, with the exclusion of Zn. However, at a 60 cm soil depth, Zn had a positive relationship with the other metals. It was also disclosed that greywater is not the only cause of the accumulation of these metals in the soils. The pollution indices were used and Igeo showed that the soils generally fell into the moderately contaminated group (Igeo 1-2). In addition, the CF showed that the metals followed the pollution order of As ≥ Cu ≥ Pb ≥ Cr ≥ Zn, with As being the highest pollutant through anthropogenic activities. Moreover, mCd showed a generally moderate contamination level ($2 \leq mCd \leq 4$).

The order of the heavy metals at both depths was similar. The order of magnitude and the concentration of heavy metals in the soil was dependent on the type of greywater used, as well as the type of detergents used in the water. From the results, it can be concluded that greywater should be alternated with freshwater to allow percolation and to avoid the accumulation of heavy metals in the soils. Moreover, sustainable farming practices, such as rotational and mixed crop farming, should be encouraged, to allow certain metals to be absorbed by certain crops as a way of reducing their abundance. However, future studies should focus on the nutritional qualities of crops irrigated with greywater to see if there is any movement of metals from the soil to the crops.

CHAPTER FIVE

5 MICROBIAL AND HEAVY METAL CONTAMINATION OF VEGETABLES IRRIGATED WITH UNTREATED GREYWATER IN RURAL HOME GARDENS

This chapter is based on:

Makgalake P. Radingoana, Timothy Dube and Dominic Mazvimavi. 2021. Microbial and heavy metal contamination of vegetables irrigated with untreated greywater in rural home gardens. *Water SA*. **Under review**.

Abstract

The sustenance of rural livelihoods across Africa relies on the availability of water resources. Over the years, freshwater sources have been deteriorating and alternative methods have been sought. Greywater re-use is one of the technologies that has been proven to be of value for the improvement of food security. The aim of this study was to assess the presence of heavy metals and microbial activity in vegetables irrigated with untreated greywater. Four common vegetables (sweet pepper, tomato, Swiss chard and lettuce) were planted, irrigated with greywater and taken for laboratory analysis to determine the concentrations of heavy metals, such as Arsenic (As), Copper (Cu), Cadmium (Cd), Magnesium (Mn), Lead (Pb) and Zinc (Zn), and to identify any microbial risks (i.e *Escherichia coli* (E-coli), *Lysteria monocytogenes* (Lysteria) and *Salmonella enterica* (Salmonella spp)). These metals have a detrimental effect on the health of humans when consumed in large quantities, while these microbes also cause food-borne diseases. The experiment was conducted from February to May 2021. The data were analysed by using the statistical analysis and indices, such as the Estimated Daily Intake, Hazard Quotient and Target Hazard Quotient, and they were then computed. The indices revealed that the heavy metals present in the edible parts of the vegetables surpassed the maximum daily limits for heavy metals to be ingested through food, which might or might not have a non-carcinogenic effect on human health considering that the vegetables are either cooked or eaten raw. Although some metals present in some of these vegetables were within the permissible limits, their HQ and THQ were still above the permissible unit of 1. Even though Cd and As had the overall lowest EDI values, their values were still higher than the acceptable limits of 3 and 0.13 mg/kg/day respectively in their dry basis as compared to their wet basis. All the vegetables tested negative for salmonella, listeria and E-coli. It was concluded that, since the HQ and THQ limit of 1 does not elucidate the received value as a probability of health risk, there might still be a chance that these greywaters can be used. Therefore, it is recommended that greywater be alternated with freshwater, to reduce the accumulation of metals in vegetables, and that there must be a good drainage area to reduce the possibility of food-borne bacteria being present on the edible parts of the vegetables.

Keywords: Heavy metals; irrigation; home gardening; greywater; microbial risks; rural

5.1 Introduction

The decrease in the availability of potable water is perceived as being a global systematic risk (Disha *et al*., 2020). In addition, the decrease in water supply for agricultural purposes has led to a steadily-intensifying demand for water in recent years (Finley *et al*., 2009). Therefore, according to Marinoski *et al*. (2018), it is important to develop alternative strategies in the management of potable water and for the recycling of greywater. These innovations can largely contribute to water stress alleviation, while also saving huge amounts of financial resources that are being dedicated to the management of water resources (Chirisa *et al*., 2017). Given the available alternative water sources, such as rainwater harvesting and the desalination of seawater, greywater re-use still serves as the cheapest and most readily-available form of water for supplementing potable water for home gardening irrigation purposes. According to Shaikh and Ahammed (2020), greywater can be described as a water produced from bathtubs, showers, basins, laundry machines and sinks, with the exclusion of toilet water. The pollution capacity of this water is dependent on a few things, such as the source type, the quality of the water supply, the household size, the ages of the household members and their living standards, to name a few (Porob *et al*., 2020). This water is produced in large quantities and is locally available to sustain the purposes of garden irrigation and toilet flushing (Ghaitidak and Yadav, 2013). Greywater amounts to between 50-80% of all effluent produced at a household level (Al-Gheethi *et al*., 2019; Al-Hamaiedeh and Bino, 2010). According to Oteng-Peprah et al. (2018a) approximately 89% of domestic water demand is converted into greywater in some of the developing countries. Greywater has evidently been used in the agricultural sector in cities such as Berlin, London, Milan and Paris (Norton-Brandão *et al*., 2013). Approximately 260 000 hectares of vegetables have been irrigated with mostly untreated water in Mexico, while 26% of the vegetables produced in Pakistan are irrigated with this water, thus improving food security and reducing the use of potable water for irrigation purposes (Pedredo *et al*., 2010). Finley *et al*. (2009) noted the greatest threat of greywater re-use was the contamination of vegetables with microbials, such as E-Coli, Listeria, Salmonella and Campylobacter. These microbials can cause food-borne illnesses that can have an impact on mortality. Children, pregnant women, the elderly and those with weakened immune systems are the most vulnerable to illnesses caused by these microbes. Although certain techniques have been used in recovering greywater for non-portable use (Zipf *et al*., 2016; Abed *et al*., 2017; Prodanovic *et al*., 2020), developing and underdeveloped countries cannot afford to implement these techniques. The sustainment of life and the promotion of good health are related to the consumption of safe and nutritious food (Zamuz *et al*., 2021). Approximately 600 million people fall ill the world over, due to consumption of contaminated food, while 42 000 die annually, for the same reason (Zamuz *et al*., 2021). Some of the common bacteria causing food-borne illnesses include E-coli, listeriosis, salmonella and campylobacter. These bacteria can cause severe symptoms in people who are considered to be at-risk groups, such as infants, the elderly, pregnant women and patients living with HIV and aids, as well as cancer (Li, 2017). Negative impacts associated with greywater re-use such as microbial risks and unpleasant odours can be posed to users (Etchepare and van der Hoek, 2015; Shi *et al*., 2018) due to the high availability of organic matter, suspended solids, sulphates and faecal contamination (Vuppaladadiyam *et al*., 2019) present in untreated greywater. Although the re-use of untreated greywater is not recommended (Goncąlves *et al*., 2021), the rural poor continue to use it, as they still lack services, such as proper water and sanitation. It is on this premise that the study therefore seeks to assess the availability of heavy metals and microbials in vegetables irrigated with greywater.

5.2 Materials and Methods

5.2.1 Experimental design

A trial was conducted between February and May 2021 as a pot-based experiment under open field conditions. Sixteen (16) brown pots (1.5 litre) with a mixture of half-potting mix and half fertiliser (seedlings food) were used (Figure 5.1A). The seedlings-nutrient ratio was 6:2:5(13), which consisted of 60 g/kg of Sodium (N), 20 g/kg of Phosphorus (P) and 50 g/kg of Potassium (K). Prior to being filled with soil, a layer of kitchen paper towel was placed at the bottom of each pot to prevent the soil from escaping through the drainage holes. The pots were labelled according to the vegetables planted and the irrigation water used e.g. Spinach-bath (Figure

5.1B). The pots were free draining, in order to reduce the potential accumulation of salts during the experiment. Sweet pepper (*California wonder*), tomato (*Cherry little wonder*), Swiss Chard (*Fordhook giant*) and lettuce (*Mixed salad*) seeds were planted into a total of 16 pots (four pots per vegetable). When the vegetables were big enough and the roots protruded through the holes, they were moved to an area that had enough soil for the roots to penetrate through (Figure 5.1C and 5.1D).

Figure 5.1 Experimental set-up of vegetables (A - preparation, B - labelled pots with seeds planted, C and D - spinach and flowering tomatoes put in soil due to long roots)

These vegetables were chosen because they are common vegetables grown in home gardens. Immediately after planting, the pots were irrigated with municipal tap water until the soil was thoroughly saturated and the excess water was draining from the holes. Thereafter, the plants were irrigated with 500 ml of experiment-specific water daily, which drained freely. Greywater collected from the kitchen, laundry and bathtubs was used. This was sought from a volunteer’s home in the Dihlabaneng village, which consisted of four adults and four children (10 years to 14 years), and the experiment was conducted in the same household.

5.3 Laboratory Analysis

5.3.1 Microbial analysis

After all the vegetables had germinated and/or flowered and produced fruit, they were harvested and sent for laboratory analysis at two different laboratories of the Agricultural

Research Council (ARC) in Irene and Arcadia, South Africa. The vegetables were analysed for the presence of microbial risks and heavy metals. The microbials that were analysed were *Escherichia coli* (E-coli), *Lysteria monocytogenes* (Lysteria) and *Salmonella enterica* (Salmonella spp). The testing for microbials in vegetables was conducted by following the methods of the International Organisation of Standardisation (ISO). These methods give guidance on the standard procedures to be followed and the general requirements and guidance with regard to microbial examinations that are applicable to products required for human consumption, animal feeding and environmental samples in the area of food production and handling. These can also be referred to as reference methods for the microbiological regulation of food. The standards are of paramount importance for assuring food safety and quality. Moreover, they are important for laboratory accreditation, in accordance with the ISO 17025 (David, 2020). The microbial risks, as well as E-coli and coliforms, in the vegetables were tested using ISO standard 4832. This standard gives general guidelines for the enumeration of coliforms by using the technique of counting colonies after incubation on a solid medium at 30^0C or 37^0C. The inoculation of a selective Agar medium (Paul played medium method) was used. In addition to the used technique for the initial suspension of the test samples, the plates were incubated aerobically at 30^0C for 24 hours. The counting and calculation of organisms was done per cfu /g. *Listeria monogytogenes* detection by using a detection method following the ISO standard 11290 Part 1. This standard specifies a standard horizontal method for the detection of *L. monocytogenes* and *Listeria* spp. The principles of the method were carried out in three stages, namely, the enrichment in the selected liquid medium, streaking out and recognition. The confirmation was done only when the presumptive positive was detected. Salmonella spp detection was done according to the ISO standard 6579, which specifies a horizontal method for its detection. The principles of the method were carried out following four stages, namely, the pre-enrichment of a non-selective liquid medium, the enrichment in a selective liquid medium, followed by streaking out and recognition. The confirmation was also only done when the presumptive positive was detected.

5.3.2 Heavy metal analysis

The heavy metals that were analysed on the vegetables were Arsenic (As), Copper (Cu), Cadmium (Cd), Magnesium (Mn), Lead (Pb) and Zinc (Zn). The sample was weighed and recorded and then oven-dried for 48 hours in a 50^0C oven. They were then milled into a fine powder, by using a mortar and pestle. Microwave digestion was used for ICP-OES and ICP-MS. A 0.5 g of the sample was weighed into polymeric vessels and 9 ml of HNO_3 was added.

The samples were left overnight and the following day, 2 ml of $HClO_4$ was added and sealed. The vessels were shaken and heated in a microwave at 180^0C for 15 minutes, then left to cool to room temperature for 20 minutes and transferred into a 50 ml volumetric flask (EPA, 2020). Copper was determined by using the ICP-OES Agilent 725 (700 series), which is a multi-element instrument. The instrument used is an Agilent 725 (700 Series) simultaneous instrument, where all the elements (all the wavelengths) are determined simultaneously. Thus, several of the elements may be determined at more than one wavelength, which allows for the confirmation of the values, with no increase in the analysis time or consumption of the digest solution. The Cu element was measured at two appropriate emission wavelengths, which were chosen for their high sensitivity and for their lack of spectral interferences (Agilent Technologies, 2010). The remaining metals were determined by using ICP-MS and diluted with 10 times Indium, which is a standard solution (Agilent Technologies, 2008).

5.4 Non-carcinogenic Risk Assessment

5.4.1 Human health risk assessment

The heavy metal concentrations in vegetables were tested to evaluate the health risks that can be associated with the consumption of vegetables irrigated with untreated greywater. An assessment of human risk was done according to several indices. The non-carcinogenic method for human health risk assessment, as labelled by Muhammed *et al*. (2011), was used in this study. For the assessment of risks associated with the consumption of vegetables irrigated with greywater, the following equations have been used:

5.4.1.1 Estimated Daily Intake (EDI)

The EDI of heavy metals in vegetables was calculated by using the average concentration of metals, the consumption rate of the vegetables and the individuals' body weight. The following formula 5.1 was used in calculating EDI (Chen *et al*., 2011):

$$EDI = \frac{F_{IR}\, x\, C_{metal}}{BW} \quad , \qquad \textbf{(5.1)}$$

Where, F_{IR} is the food ingestion rate of an adult averaged at $342gd^{-1}$ (Tariq, 2021), C_{metal} is the heavy metal in the vegetable (mg/kg^{-1}) and BW Is the body weight (kg) of an adult assumed at 70kg (Hawrami *et al*., 2019).

5.4.1.2 Hazard Quotient (HQ)

The HQ for non-carcinogenic risk was calculated by using formula 5.2 below:

$$HQ = \frac{EDI}{RfD_O} \quad , \qquad \textbf{(5.2)}$$

Where, EF is the exposure frequency of the metal ingestion, based on 365 days per year, and ED is the exposure duration set at 70 years, according to USEPA (1991), and AT is the average time for the non-carcinogens calculated as (EF x ED). RfD_o is the oral reference dose of a particular metal. If the HQ is <1, it is commonly viewed as being safe from the risk of non-carcinogenic effects, while it is presumed that there is a possibility for non-carcinogenic effects if the HQ is > 1, with an increasing possibility as the value increases (Antoine *et al*., 2017; Chen *et al*., 2011). The RfD_o values of the assessed metals are represented in Table 5.1 below:

Table 5.1 RfD_o values used to characterize the HQ and THQ

Heavy Metal	**RfD oral value**	**Reference**
Arsenic (As)	0.0003	DEA, 2010; USEPA, 2010
Cadmium (Cd)	0.0005	DEA, 2010; USEPA IRIS, 2011
Copper (Cu)	0.037	DEA, 2010
Lead (Pb)	0.0036	Luo *et al*., 2012
Zinc (Zn)	0.3	DEA, 2010
Manganese (Mn)	0.024	DEA, 2010

5.4.1.3 Target Hazard Quotient (THQ)

The THQ was evaluated using the following formula 5.3 as in FAO/WHO (2011):

$$THQ = \frac{EF \ x \ ED \ x \ F_{IR} \ x \ C_{metal}}{RfD \ x \ BW \ x \ AT} \quad , \qquad \textbf{(5.3)}$$

Where the values used are the same as those in the previous equations.

5.4.2 Statistical analysis

A statistical analysis was performed by using the add-in Data Analysis Toolpak software on Excel Stats. The One-way Analysis of Variance (ANOVA) was used to determine whether there were any significant differences in concentrations of the metals in the vegetables. The significance level was set at 0.05. In addition, the Tukey post-hoc test, which is based on the studentized range distribution, was used. The following equation 5.4 was used:

$$T = q\alpha(c, n-c)\sqrt{\frac{MSE}{n_i}} \quad , \qquad \textbf{(5.4)}$$

where: T is the Tukey criterion, qα (c, n-c) is the studentized range distribution, based on c and n-c df, c is the number of groups, n-c is the total sample size, MSE is the Mean Square Error (from the ANOVA table) and n_i is the sample size of the group with smallest number of observations.

5.5 Results

5.5.1 Microbiological activity in the edible parts of the vegetable

The germination rates of the vegetables were different, with those watered with bath greywater and clean water germinating first in all the vegetables, excluding the lettuce in clean water. For those watered with kitchen greywater, germination was positive for spinach and tomatoes only, while those watered with laundry greywater did not germinate at all. Out of all the 16 samples, only nine samples survived. Greywater from the bathtub germinated all the vegetables, kitchen water germinated spinach and tomato, whereas clean water germinated spinach, tomato and peppers, while plants irrigated with laundry water did not germinate. This may be owing to kitchen water having too much oil and detergent in it, while the laundry water had fabric softener, clothing whiteners and harsh chemicals to remove tough stains.

The Salmonella spp, Listeria and E-Coli detection tests revealed that, there was no presence of these bacteria in the fresh samples. All samples tested negative for the bacteria. The E-coli count for all samples was <10 cfu/g. The highest sample with a coliform count was green pepper bath with 9800000 cfu/g, followed by green pepper clean at 500000 cfu/g and spinach clean at 28000 cfu/g, while tomato clean had the lowest count at <10 cfu/g. The coliform count was in the following order (highest to lowest): green pepper-bath, green pepper-clean, spinach-clean, spinach-kitchen, spinach-bath, tomato-bath, tomato-kitchen, lettuce-bath, tomato-clean.

5.5.2 Heavy metal presence in the edible parts of the vegetables

The vegetables were analysed, based on their wetness and dryness. The flowering vegetables were analysed on their wet basis, while the leafy vegetables were dried before analysis, to compare the presence of metals in the fresh and dry states. According to the overall analysis, the fresh samples had a lower presence of metals, while the leafy vegetables contained higher values of the same metals. This might be because the leafy vegetables have a higher surface area for water retention and possible contamination, compared to peppers and tomatoes. The peppers that were used were sweet peppers and the tomatoes that were used were cherry tomatoes, which are both smaller, which might also possibly contribute to the amount of heavy metals present.

According to the maximum acceptable daily intake of heavy metals in vegetables (Table 5.2), the EDI values revealed that all leafy samples had higher levels of heavy metals than the acceptable limits. Although Cd and As had the lowest levels of heavy metals in their group, they were still above the recommended limit of 3 and 0.13 mg/kg/day, respectively. When the flowering vegetables were tested on their wet or fresh basis, it was revealed that some of the samples were within the acceptable daily limit intake.

Table 5.2 Estimated Daily Intake (EDI) values in mg/kg^{-1} for adults in vegetables irrigated with untreated greywater

Pathway	**Analysis basis**	**Greywater Source**	**Estimated Daily Intake (EDI) values for heavy metals (mg/kg/day) in vegetables**					
			Mn	Zn	Cu	Cd	Pb	As
Ingestion	Dry Basis	Spinach-clean	7294.4	721.6	68.9	0.3	23.4	0.9
		Lettuce-bath	1146.2	514.5	47.8	0.1	18.5	1.8
		Spinach-bath	3807.4	549.6	72.3	0.2	23.8	1.4
		Spinach-kitchen	5789.6	1036.7	71.3	0.3	29.6	1.8
	Wet Basis	Tomato-clean	6.6	**9.5**	4.0	**0.01**	0.3	**0.04**
		Pepper-bath	23.8	**13.0**	3.9	**0.01**	0.3	**0.03**
		Tomato-bath	10.3	**7.5**	**2.6**	**0.01**	0.3	**0.04**
		Tomato-kitchen	8.8	**9.5**	**2.4**	**0.01**	0.3	**0.04**
Maximum Acceptable Daily Intake (*Shaheen et al., 2016; **Zheng et al., 2007; ***Basha et al., 2014)			5 *	65***	3**	0.07*	0.21*	0.13*

According to Table 5.2 above, the Zn, Cd and As levels in the tomatoes and peppers were all within the acceptable daily limits of 65, 0.07 and 0.13 mg/kg/day, respectively. It was revealed that the tomato-bath and tomato-kitchen also met the acceptable limits of Cu (3), with 2.6 and 2.4 mg/kg/day, respectively.

Given that the HQ values (Table 5.3) were greater than one (>1) in both analysis basis, the consumption of these vegetables might have some sort of impact as a health hazard. A higher HQ suggests a higher chance of possible non-carcinogenic effects.

Table 5.3 Hazard Quotient (HQ) values in mg/kg^{-1} for adults in vegetables irrigated with untreated greywater

Pathway	**Analysis basis**	**Greywater Source**	**Hazard Quotient (HQ) values for heavy metals (mg/kg/day) in vegetables**					
			Mn	Zn	Cu	Cd	Pb	As
Ingestion	Dry Basis	Spinach-clean	387266.7	2405.3	1940.5	600	6500	3000
		Lettuce-bath	47758.3	1715	1291.9	600	5166.7	6000
		Spinach-bath	158641.7	1832	1954.1	400	6611.1	4666.7
		Spinach-kitchen	241233.3	3455.7	1927	800	8222.2	6000
	Wet Basis	Tomato-clean	275	31.7	108.1	40	83.3	133.3
		Pepper-bath	991.7	43.3	105.4	20	83.3	100
		Tomato-bath	429.2	25	70.3	20	83.3	133.3
		Tomato-kitchen	366.7	31.7	64.9	40	83.3	133.3

The THQ results (Table 5.4) revealed that all samples that were analysed in their fresh state did not show a possibility of causing any carcinogenic health effects. However, it was revealed that all the leafy samples complied with the non-carcinogenic effect where the THQ is less than one, compared to all the other metals.

Table 5.4 Target Hazard Quotient (THQ) values in mg/kg-1 for adults in vegetables irrigated with untreated greywater

Pathway	**Analysis basis**	**Greywater Source**	**Target Hazard Quotient (THQ) values for heavy metals (mg/kg/day) in vegetables**					
			Mn	Zn	Cu	Cd	Pb	As
Ingestion	Dry Basis	Spinach-clean	303.9	2.4	1.9	**0.7**	6.5	3.3
		Lettuce-bath	47.8	1.7	1.3	**0.7**	5.2	5.9
		Spinach-bath	158.6	1.8	1.9	**0.4**	6.6	4.6
		Spinach-kitchen	241.2	3.5	1.9	**0.7**	8.2	5.9
	Wet Basis	Tomato-clean	**0.3**	**0.03**	**0.1**	**0.03**	**0.09**	**0.02**
		Pepper-bath	**0.9**	**0.04**	**0.1**	**0.02**	**0.1**	**0.1**
		Tomato-bath	**0.4**	**0.03**	**0.07**	**0.02**	**0.08**	**0.1**
		Tomato-kitchen	**0.4**	**0.03**	**0.06**	**0.03**	**0.07**	**0.02**

All the dry basis metals have a THQ value that is >1, with Mn having the highest value of all the samples. Although some samples have a THQ that is way >1, this does not in any way suggest that it is a statistically probable that adverse non-carcinogenic health effects will or might occur (Antoine *et al*., 2017).

5.5.3 Analysis of Variance

Normally, the conclusions of a one-way ANOVA indicate that the concentration of heavy metals in vegetables irrigated with greywater varied significantly across the edible parts of the vegetables that were dried before being tested. The ANOVA test revealed that these heavy metals were significantly different across the vegetables, where F2.7729 = 10.87, $p<0.05$. In addition, the means of the heavy metals in the wet/fresh state were correspondingly verified to be significantly different, with ANOVA revealing that F2.7728 = 10.90, $p<0.05$. The Tukey Honest Significant Difference test was performed as one of the post-hoc tests to examine the actual difference in means between the heavy metals present in the edible part of the vegetables. The mean of Mn, compared to all other metals in the vegetables that have been dried before testing, proved to be significantly different at alpha (α) = 0.05. It was also shown that the difference between these means was greater than the Tukey criterion. However, the means of other metals against each other was proved to be not significantly different from each other, as the difference in these means was less than in the Tukey criterion, which is 501.12. For heavy metals analysed in their fresh state, the means of Mn and Zn were revealed to be significantly different from the means of Cd, Pb and As at $\alpha = 0.05$, T=1.53. On the contrary, when other means were compared to each other, they all proved to be not significantly different, as the differences between their means did not surpass the Tukey criterion, which is 1.53.

5.6 Discussion

The microbial results from this study do not agree with those of Akoachere *et al*. (2018), which revealed that lettuce had the most coliforms and green peppers had the least. Although there was no positive detection of bacteria in the fresh samples, it is important that these vegetables be thoroughly washed before cooking. Although coliforms will not likely cause a disease, their presence in the fresh samples confirms the possibility of the disease-causing bacteria in the irrigation water. Given that the food chain is the main pathway leading to the exposure of humans to health risks (Tewari and Pande, 2013), it is important to assess the level of exposure. The EDI results agreed with those of Wachirawongsakorn, (2015), which revealed that the EDI of Pb and Cd surpassed that of the RfD. Manganese and Zn had the highest concentration in their dried basis, compared to other metals. However, it has also been revealed by Chen *et al*. (2014) that Pb and Cd were more likely to accumulate in leafy vegetables, compared to fruity vegetables. In addition, some leafy vegetables, such as *C. sativum* and *B. campitata,* have a higher chance of accumulating heavy metals, compared to bulb- and tuber-type vegetables (Mahmood and Malik, 2014). Moreover, Harmanescu *et al*. (2011) reported that Pb and Cd is found to be highly concentrated in lettuce.

Given that the HQ is only a ratio of an estimated exposure to a hazardous substance and the level at which adverse carcinogenic effects can or cannot occur, it does not in any way explain that there is a probability of risk and furthermore the results must not be taken as a likelihood to proportion of possible risk (USEPA-NATA, 2017). Moreover, even if the THQ surpasses the given unit of 1, this does not mean or equate the results to a certainty of adverse effects. However, they can be used to approximate the possible accumulative risks associated with the potential toxins. Even though the ingestion route of these metals is similar, they do not target the same areas/organs, and most certainly not at the same pace (Antoine *et al*., 2017).

In addition, these results concur with those of Onyele and Anyanwu (2018), which revealed the HQ for all metals is greater than one. These results make rural people more vulnerable to diseases through the consumption of vegetables irrigated with untreated greywater, as they navigate the barriers to accessing clean or potable water. Ekere *et al*. (2014) recorded that the HQ was greater than one for some of the assessed metals. This is usually due to the high EDI values in the metals involved in a particular study. Therefore, this might result in long-term health effects, as consumers use greywater to irrigate their crops in order to improve their food security.

5.7 Conclusions

The study has revealed that there was no presence of microbial activity in the edible parts of the vegetables that can lead to food-borne illnesses. Although there were coliforms present in the samples, these do not cause disease, but rather, they give a heads-up that there is a possibility of disease-causing bacteria in the water or soil. Traces of heavy metals were present in some of these vegetables and this might lead to the possibility of non-carcinogenic health effects. Given that rural households are vulnerable to inconsistencies in service delivery, particularly clean water and proper sanitation, the technologies required for the treatment of greywater before use remain a necessity. It is therefore encouraged to alternate greywater with potable water for irrigation when it is available, in order to reduce the amounts of heavy metals that might be present in the vegetables. The study therefore recommends that the municipalities should do their utmost to make sure that clean water, as a basic need, is available to all its citizens, in particular those living in rural areas.

CHAPTER SIX

6 SYNTHESIS, CONCLUSIONS AND RECOMMENDATIONS

6.1 Synthesis

6.1.1 Progress, opportunities and challenges associated with the re-use of greywater for home gardening

The results of this study have demonstrated that the use of greywater has the potential to improve food security in arid and semi-arid rural areas. The use of this water can successfully supplement potable water during the dry season, in order to maximize food production and, in turn, it encourages the conservation of freshwater (Friedrich *et al*., 2020; Jeong *et al*., 2018; Masmoudi Jabri *et al*., 2020; Memon *et al*., 2007). The general perceptions of authors, as presented in the literature, is that the use of greywater for toilet flushing is preferred, rather than for garden irrigation, as people fear contracting diseases. Moreover, people with a higher income and educational qualifications are more accepting of the re-use of greywater. The challenges that hinder acceptance of its re-use are deemed to be their lack of knowledge and the lack of information campaigns, regarding this matter (Amaris *et al*., 2021a, 2021b, 2020). The lack of legislation has also surfaced as being one of the challenges facing the re-use of greywater, as well as the lack of environmental consciousness. Literature states that greywater irrigation increases plant growth and crop yield without impacting the actual crop, which was not the case with the current study. There is disagreement in the literature when it comes to the re-use of greywater in its untreated form. However, although use of untreated greywater has the potential to contaminate the groundwater, effective greywater management systems can be used to minimize this, and even to avoid it altogether. Although significant research strides have been undertaken with regard to greywater, very few researchers have assessed the impacts of greywater on soil quality and home gardening produce.

6.1.2 The quality of greywater from different sources (kitchen, laundry and bathtub) for irrigation

Salinity hazard coupled with sodium and chloride hazards in assessing the quality of greywater in this study has revealed that the electrical conductivity of greywater is within the required limits. The overall sodium absorption ratio of the assessed water was within a low sodium hazard range, which means that the use of greywater on sodium-sensitive crops should be cautioned. The soluble sodium percentage was elevated in some study areas, revealing that its continuous use should be avoided. This could be due to variations in the composition of household, in the detergent types, as well as in the different diets. It was also revealed that the use of greywater should be prioritized on salt-tolerant crops. Even though the salinity assessment and the overall Sodium Adsorption Ratio were within the required limits, the use of greywater should be regulated, due to its possible impacts on the soil in the long run. The priority should be to alternate greywater irrigation with potable water irrigation, when it is available.

6.1.3 Impacts of greywater irrigation on soil trace elements for small-scale home gardening

It has been shown that arsenic and copper are the dominant metals in the soils. The different sources of greywater constitute different pollutants and thus a different accumulation of metals. The metals were revealed to have a strong and positive relationship with each other in the soil, except for zinc, which displayed a strong negative relationship. The pollution indices revealed that arsenic contaminates the soils moderately, while the other metals showed a low to moderate contamination of the soil. It was shown that the high contamination factor values of arsenic in the soil were due to anthropogenic sources, compared to zinc. Furthermore, the pH of soils irrigated with greywater were within the acceptable range for agricultural production. The dominance of copper and arsenic as carcinogenic metals requires further assessment, with respect to how greywater irrigation can affect the health of consumers. Although greywater is used as an alternative, its possible health impacts through the absorption of metals and bacteria by irrigated plants, should be of great importance and should be evaluated thoroughly to avoid jeopardizing human health (Winward *et al.*, 2008b).

6.1.4 The nutritional quality of home garden produce irrigated with greywater for improving food security

Vegetables produced with greywater irrigation did not contain any E-coli-, listeria- or salmonella-causing bacteria. However, irrigation with greywater derived from laundry washing significantly impacted the growth of the vegetables. All the experimental vegetables irrigated from this source did not grow/germinate, compared to those irrigated with grey bathwater, which germinated all the seeds right through to maturity. All the tested metals were found to have exceeded the estimated daily intake values in the selected vegetables, with the exception of the flowering vegetables that were tested in their fresh state. The hazard quotient and the target hazard quotient of the metals were all above the limit of 1, but this did not reveal that there was a probability of a health hazard, or that they cause non-carcinogenic health effects. Because of the lack of germination when using laundry water, this water must not be used for irrigation, as it is deemed to be stronger in detergents and might contaminate the soil and vegetables quicker, in the long run (Alsulaili and Hamoda, 2015). Further research is required to assess if these vegetables are likely to cause any major illnesses, such as cancer.

6.2 Conclusion

This study has concluded that greywater is a good substitute for freshwater in this era of climate change; however, it should be used with caution on crops that require acidic conditions to thrive. The greywater that was tested in this study was shown to be within the recommended standards for irrigation. However, the main target for greywater irrigation should be salt-tolerant crops. Its prolonged use, without alternation, is discouraged, as elevated sodium concentrations can impact the soil and the quality of the crops. The greywater tested in this study was revealed to be within the low category (1-10), in relation to the SAR values in the study area. Greywater-irrigated soils have been shown to be within the normal pH range required for agricultural soils. In addition, some of the metals found in the soils in the study area might be geogenic, and not anthropogenic, in nature. Furthermore, The ANOVA results showed that the accumulation of some of the metals in the soils was not due to greywater irrigation. Metals at a 30 cm depth revealed a positive inter-metal relationship, compared to those at a 60 cm depth. The pollution indices that were used revealed that the vegetables were moderately contaminated (Igeo 1-2). The contamination factor revealed that the metals were abundant in the order As ≥ Cu ≥ Pb ≥ Cr ≥ Zn, while the mCd revealed moderate contamination (2 ≤ mCd ≤4). There was no presence of microbial activity in the vegetables and they were free of listeria, salmonella and E-coli. Leafy vegetables are seen to be prone to the accumulation of metals, and high quantities of heavy metals were available in some vegetables. The indices showed that the accumulated metals in the edible parts of the vegetables surpassed the stipulated requirements. However, these indices do not particularly project that there is or is no probability of any adverse effects. In addition, these somehow suggest that it is statistically probable that adverse non-carcinogenic health effects might occur. The effects will therefore be possible in instances where proper food preparation methods such as washing, and well-cooked vegetables are not followed. It is therefore encouraged to consume vegetables irrigated with greywater after they are cooked and not in their raw state. The results of this study provide a useful insight into greywater re-use for home gardening purposes. However, these results have to be treated with care, as the poor germination rate of selected crops led to a reduced number of samples in the analysis; some of the experimental vegetables for the study did not germinate at all, while others only bore small fruit.

6.3 Recommendations

This study recommends that greywater be used within 24 hours of production, which will limit any microbial activity from taking place. Since the re-use of greywater is regarded as a possible water conservation strategy, policies, legislation and awareness can be structured for agricultural purposes and shaped by the existing literature. The dilution of greywater and potable water (1:1) should be studied further, as well as the impact of greywater on the edible parts of vegetables. Households willing to re-use greywater should be given incentives in the form of simple cost- and energy-effective systems that are easy to maintain and operate.

REFERENCES

Abdullaev, I., Kazbekov, J., Manthritilake, H. and Jumaboev, K. 2009. Participatory water management at the main canal: A case from South Ferghana canal in Uzbekistan. *Agricultural Water Management* 96(2): 317-329. https://doi.org/10.1016/j.agwat.2008.08.013

Abed, S.N., Almuktar, S.A. and Scholz, M., 2017. Treatment of contaminated greywater using pelletised mine water sludge. *J. Environ. Manag.* 197: 10-23. https://doi.org/10.1016/j.jenvman.2017.03.021

Abedin, S.B. and Rakib, Z.B. 2013. Generation and quality analysis of greywater at Dhaka City. *Environmental Research, Engineering and Management* 2(64): 29-41. https://doi.org/10.5755/j01.erem.64.2.3992

Aboukarima, A.M., Al-Sulaiman, M.A. and El-Mazarky, M.S.A. 2018. Effect of SAR and EC of the applied water on infiltration in a sandy-loam soil. *Water SA* 44(1): 105-110. https://doi.org/10.4314/wsa.v44i1.12

Abrahim, G.M.S. 2005. Holocene sediments of Tamaki Estuary: Characterisation and impact of recent human activity on an urban estuary in Auckland, New Zealand. Ph.D. thesis, University of Auckland, Auckland, New Zealand, 361. https://doi.org/10.5176/2251-2012_qqe17.13

Abusam, A. 2008. Re-use of greywater in Kuwait. *International Journal of Environmental Studies* 65: 103-108. https://doi.org/10.1080/00207230701868204

Abu-Zreig, M., Rudra, R.P. and Dickinson, W.T. 2003. Effect of application of surfactants on hydraulic properties of soils. *Biosystems Engineering* 84: 363-372. https://doi.org/10.1016/s1537-5110(02)00244-1

Adams, E.A., Sambu, D. and Smiley, S.L. 2019. Urban water supply in sub-Saharan Africa: historical and emerging policies and institutional arrangements. *International Journal of Water Resources Development* 35(2): 240-263. https://doi.org/10.1080/07900627.2017.1423282

ADEQ, 2011. Using Greywater at Home. Arizona Department of Environmental Quality's Guide to Complying with the Type 1 General Permit. Arizona Department of Environmental Quality, Arizona.

Aertgeerts, A. and Angelakis, A. 2003. State of the Art Report: Health Risks in Aquifer Recharge using Reclaimed water. EUR/03/5041122, WHO Regional Office of Europe Copenhagen.

Agilent Technologies. 2008. Agilent 7500 Series ICP-MS: Hardware manual. https://www.concordia.ca/content/dam/artsci/research/cbams/docs/7500ceICP-MShardwaremanualen.pdf [Accessed 23 August 2021].

Agilent Technologies. 2010. Agilent 700 Series ICP Optical Emission Spectrometers: User's guide. http://photos.labwrench.com/equipmentManuals/7566-3082.pdf [Accessed 23 August 2021].

Agriculture and Food. 2019. Water salinity and plant irrigation. Department of Primary Industries and Regional Development. Government of Western Australia.

Ahamad, M.I., Song, J., Sun, H., Wang, X. and Mehmood, M.J. 2020. Contamination Level, Ecological Risk and Source Identification of Heavy Metals in the Hyporheic Zone of the Weihe River, China. *International Journal of Environmental Research and Public Health 17*: 1070. https://doi.org/10.3390/ijerph17031070

Aitken, V., Bell, S., Hills, S. and Rees, L. 2014. Public acceptability of indirect potable water re-use in the south-east of England. *Water Science and Technology: Water Supply* 14(5): 875-885. https://doi.org/10.2166/ws.2014.051

Akinwotu, E. 2020. West Africa facing a food crisis as coronavirus spreads. https://www.theguardian.com/global-development/2020/may/15/west-africa-facing-food-crisis-as-coronavirus-spreads. Accessed 15 August 2021.

Akoachere, J.T.H., Tatsinkou, B.F. and Nkengfack, J.M. 2018. Bacterial and parasitic contaminants of salad vegetables sold in markets in Fako Division, Cameroon and evaluation of hygiene and handling practices of vendors. *BMC Res Notes* 11: 100. https://doi.org/10.1186/s13104-018-3175-2

Alba, J.W. and Hutchinson, J.W. 2000. Knowledge Calibration: What Consumers Know and What They Think They Know. *Journal of Consumer Research* 27(2): 123-156.

Albalawneh, A., Chang, T. and Chou, C. 2016. Impacts on soil quality from long-term irrigation with treated greywater. *Paddy Water Environ*. 14(2): 289-297. https://doi.org/10.1086/314317

Alexander, P., Brown, C., Arneth, A., Finnigan, J., Moran, D. and Rounsevell, M.D. 2017. Losses, inefficiencies and waste in the global food system. *Agric. Syst.* 153, 190–200. https://doi.org/10.1016/j.agsy.2017.01.014.

Al-Ghazawi, A. Z., Qasaimeha, A. and Bani-Melhem, K. 2018. Ablution gray water qualitative assessment and treatment by submerged membrane bioreactor: a case study in Jordan. *Desalination and Water Treatment* 127: 213–221. https://doi:10.5004/dwt.2018.22790

Al-Gheethi, A.A.S., Noman, E.A., Radin Mohamed, R.M.S., Bala, J.D. and Mohd Kassim, A.H. 2019. Qualitative Characterization of Household Greywater in Developing Countries: A Comprehensive Review. *Water Science and Technology Library*. Springer, Cham, pp. 1–31 https://doi.org/10.1007/978-3-319-90269-2_1

Al-Hamaiedeh, H. and Bino, M. 2010. Effect of treated greywater re-use in irrigation on soil and plants. *Desalination* 256: 115-119. https://doi.org/10.1016/j.desal.2010.02.004

Alhumoud, J.M. and Madzikanda, D. 2010. Public perceptions on water re-use options: the case of Sulaibiya Wastewater Treatment Plant in Kuwait. *International Business and Economics Research Journal* 9: 141-158. https://doi.org/10.19030/iber.v9i1.515

Al-Jayyousi, O. 2003. Greywater re-use: towards sustainable water management. *Desalination* 156: 181-192. https://doi.org/10.1016/s0011-9164(03)00340-0

Alkhatib, R., Roesner, L. and Marjoram, C. 2006. An overview of greywater collection and treatment systems. In: World Environmental and Water Resource Congress 2006 at Examining the Confluence of Environmental and Water Concerns. ASCE, 1-10. https://doi.org/10.1061/40856(200)363

Allan, J.A. 2005. Water in the environment/socio-economic development discourse: Sustainability, changing management paradigms and policy responses in a global system. Government and Opposition 40(2): 181-199. https://doi.org/10.1111/j.1477-7053.2005.00149.x

Almeida, M.C., Butler, D. and Friendler, E. 1999. At source domestic wastewater quality. Urban Water J. 1,49–55.

Alsulaili, A.D. and Hamoda, M.F. 2015. Quantification and Characterization of greywater from schools. *Water Sci. Technol*. 72, 1973–1980.

Alobaidy, A.H.M.J, Al-Sameraiy, M.A., Kadhem, A.J. and Majeed, A.A. 2010. Evaluation of treated municipal wastewater quality for irrigation. *Journal of Environmental Protection* 1: 216-225. https://doi.org/10.4236/jep.2010.13026

Al-Zu'bi, Y. and Al-Mohamadi, I.F. 2008. Effect of greywater on soil chemical composition and yield of tomato plant. *Journal of Food Agriculture and Environment* 6(2): 408-410.

Amaris, G., Dawson, R., Gironás, J., Hess, S. and Ortúzar, J. de D. 2020. Understanding the preferences for different types of urban greywater uses and the impact of qualitative attributes. *Water Res*. 184: 116007. https://doi.org/10.1016/j.watres.2020.116007

Amaris, G., Gironás, J., Hess, S. and Ortúzar, J. de D. 2021a. Capturing and analysing heterogeneity in residential greywater reuse preferences using a latent class model. *J. Environ.Manag*.279:11673. https://doi.org/10.1016/j.jenvman.2020.111673.

Amaris, G., Hess, S., Gironás, J. and Ortúzar, J. de D. 2021b. Using hybrid choice models to capture the impact of attitudes on residential greywater reuse preferences. *Resour. Conserv. Recycl.* 164: 105171. https://doi.org/10.1016/j.resconrec.2020.105171.

Antoine, J.M.R, Hoo Fung, L.A. and Grant, C.N. 2017. Assessment of the potential health risks associated with aluminium, arsenic, cadmium and lead content in selected fruits and vegetables grown in Jamaica. *Toxicology Reports* 4: 181-187. https://doi.org/10.1016/j.toxrep.2017.03.006

Antonopoulou, G., Kirkou, A. and Stasinakis, A.S. 2013. Quantitative and qualitative greywater characterization in Greek households and investigation of their treatment using physicochemical methods. *Science of the Total Environment* 454-455: 426-432. https://doi.org/10.1016/j.scitotenv.2013.03.045

Armitage, N.P., Winter K., Spiegel, A. and Kruger, E. 2009. Community focused greywater management in two informal settlements in South Africa. *Water Science and Technology* 59(12): 2341-2350. https://doi.org/10.2166/wst.2009.294

Arslan, A., McCarthy, N., Leslie Lipper, L., Asfaw, S., Cattaneo, A. and Kokwe, M. 2015. Climate smart Agriculture? Assessing the adaptation implications in Zambia. *Journal of Agricultural Economics* 66(3): 753-780. https://doi.org/10.1111/1477-9552.12107

Atanasova, N., Dalmau, M., Comas, J., Poch, M., Rodriguez-Roda, I. and Buttiglieri, G., 2017. Optimized MBR for greywater re-use systems in hotel facilities. *Journal of Environmental Management* 193: 503-511. https://doi.org/10.1016/j.jenvman.2017.02.041

Ayers, R.S. and Westcot, D.W. 1985. “Water Quality for Agriculture,” Irrigation and Drainage Paper No. 29, FAO, Rome.

Bakker, K. 2012. Water security: research challenges and opportunities. *Science* 337(6097): 914-915. https://doi.org/10.1126/science.1226337

Barr, S. 2003. Strategies for sustainability: citizens and responsible behaviour. *Area* 35(3): 227-240. https://doi.org/10.1111/1475-4762.00172

Basha, A.M., Yasovardhan, N., Satyanarayana, S.V., Reddy, G.V.S. and Vinod Kumar, A. 2014. Trace metals in vegetables and fruits cultivated around the surroundings of Tummalapalle Uranium Mining Site, Andhra Pradesh, India. *Toxicology Reports* 1: 505-512. https://doi.org/10.1016/j.toxrep.2014.07.011

Bauder, T.A., Waskom, R.M., Sutherland, P.L. and Davis, J.G. 2011. Irrigation Water Quality Criteria: Fact Sheet No. 0.506. Colorado State University.

Bebbington, A. 1999. Capitals and capabilities: A framework for analyzing peasant viability, rural livelihoods and poverty. *World Development* 27(12): 2021-2044. https://doi.org/10.1016/s0305-750x(99)00104-7

Behzadian, K. and Kapelan, Z. 2015. Advantages of integrated and sustainability-based assessment for metabolism based strategic planning of urban water systems. *Science of the Total Environment* 527-528:220-231.

Bell, S. 2015. Renegotiating urban water. *Progress in Planning* 96: 1-28.

Benhin, J.K.A. 2008. South African crop farming and climate change: An economic assessment of impacts. *Global Environmental Change* 18(4): 666-678. https://doi.org/10.1016/j.gloenvcha.2008.06.003

Bhamoriya, V. 2004. Wastewater Irrigation in Vadodara, Gujarat, India: Economic catalyst for marginalised communities. In: Scott CA, Faruqui NI and Raschid-Sally L (eds), Wastewater use in irrigated agriculture: confronting the livelihood and environmental realities. IWMI / IDRC-CRDI / CABI, Wallingford, UK. https://doi.org/10.1079/9780851998237.0127

Birks, R. and Hills, S. 2007. Characterization of indicator organisms and pathogens in domestic greywater for recycling. *Environmental Monitoring and Assessment* 129: 61–69. https://doi.org/10.1007/s10661-006-9427-y

Boller, M. 1997. Tracking heavy metals reveals sustainability deficit of urban drainage systems. *Water Science and Technology* 35(9): 77-87. https://doi.org/10.2166/wst.1997.0332

Boyjoo, Y., Pareek, V.K. and Ang, M. 2013. A review of greywater characteristics and treatment processes. *Water Science & Technology* 67, 1403-1424.

Brown, T.T., Koenig, R.T., Huggins, D.R., Harsh, J.B. and Rossi, R.E. 2008. Lime effects on soil acidity, crop yield, and aluminium chemistry in direct-seeded cropping systems. *Soil Science Society of America Journal 72*: 634-640. https://doi.org/10.2136/sssaj2007.0061

Browne, A.L., Tucker, D.I., Johnston, C.S. and Leviston, Z. 2007. Sustainable Water Use at a Household Level: A Scoping Report, CSIRO Water for a Healthy Country Flagship Program, Perth.

Bruvold, W.H. 1988. Public opinion on water re-use options. *Journal of the Water Pollution Control Federation* 60: 45-50.

Borroway, R. 2016. Empowering women, strengthening children: a multi-level analysis of gender inequality and child malnutrition in developing countries. Advances in Gender Research, Gender and Food: From Production to Consumption and After. Emerald Group Publishing Limited, Bingley.

Busgang, A., Ovadia, O., Friedler, E. and Gross, A. 2015. Epidemiological study for the assessment of health risks associated with greywater re-use for irrigation in arid regions. *Science of the Total Environment* 538: 230-239. https://doi.org/10.1016/j.scitotenv.2015.08.009

Burch, F., Scarlato, M. and d'Agostino, G. 2018. Addressing Food Insecurity in Sub-Saharan Africa: The Role of Cash Transfers. *Poverty & Public Policy* 10: 4.

Butler, D., Friendler, E. and Gatt, K. 1995. Characterizing the quantity and quality of domestic wastewater inflows. *Water Sci Technol*. 31,13–24

Carden, K., Armitage, N., Sichone, O. and Winter, K. 2007b. The use and disposal of greywater in the non-sewered areas of South Africa: Part 2 - Greywater management options. *Water SA* 33(4): 433-442. https://doi.org/10.4314/wsa.v33i4.52936

Carden, K., Armitage, N., Vinter, K., Sichone, O., Rivett, U. and Kahonde, J. 2007a. The use and disposal of greywater in the non-sewered areas of South Africa: paper l-quantifying the greywater generated and assessing its quality. *Water South Africa* 33: 425-432. https://doi.org/10.4314/wsa.v33i4.52937

Carden, K., Fischer-Jeffes, L., Young, C., Barnes, J. and Winter, K. 2018. Guidelines for Greywater use and management in South Africa. Water Research Commission Report TT746/17. Pretoria, South Africa.

Carnelo, L.G.L., Deminguez, S.R. and Marban, L. 1997. Heavy metals input with phosphate fertilizers used in Argentina. *Science of the Total Environment* 204(3): 245-250. https://doi.org/10.1016/s0048-9697(97)00187-3

Carr R. M., Blumenthal U. J. and Mara D. D. 2004. Guidelines for the safe use of wastewater in agriculture: revisting WHO guidelines. *Water Science and Technology* 50 (2): 31-38.

Casanova, L.M., Little, V., Frye, R.J. and Gerba, C.P. 2001. A survey of the microbial quality of recycled household greywater. Journal of the American Water Resources Association 37(5): 1313-1319. https://doi.org/10.1111/j.1752-1688.2001.tb03641.x

Center for the Study of the Built Environment (CSBE). 2003. Greywater Re-use in Other Countries and its Applicability to Jordan. Funded by the Ministry of Planning, Kingdom of Jordan.

Chaillou, K., Gerente, C., Andres, Y. and Wolbert, D., 2011. Bathroom greywater characterization and potential treatments for re-use. *Water Air Soil Pollution* 215: 31-42. https://doi.org/10.1007/s11270-010-0454-5

Chen, C., Qian, Y., Chen, Q. and Li, C. 2011. Assessment of daily intake of toxic elements due to consumption of vegetables, fruits, meat, and seafood by inhabitants of Xiamen, China. *J. Food Sci.* 76: 181-188.

Chen, Z., Ngo, H.H. and Guo, W. 2012. A critical review on sustainability assessment of recycled water schemes. *Science of the Total Environment* 42: 13-31. https://doi.org/10.1016/j.scitotenv.2012.03.055

Cheng, Y., Wu, P., Shao, Y. and Ying, Y. 2014. Health risk assessment of heavy metals in vegetables grown around battery production area. *Scientia Agricola* 71(2): 126-132. https://doi.org/10.1590/s0103-90162014000200006

Chirisa, I., Bandauko, E., Matamanda, A. and Mandisvika, G. 2017. Decentralized domestic wastewater systems in developing countries: the case study of Harare (Zimbabwe). *Appl. Water Sci.* 7: 1069-1078. https://doi.org/10.1007/s13201-016-0377-4

Christova-Boal, D. 1995. Installation and Evaluation of Domestic Greywater Re-use Systems. Victoria University of Technology.

Christova-Boal, D., Eden, R.E. and McFarlane, S. 1996. An investigation into greywater re-use for urban residential properties. Desalination 106: 391-397. https://doi.org/10.1016/s0011-9164(96)00134-8

City of Cape Town, 2019. Safe use of greywater booklet. https://resource.capetown.gov.za/documentcentre/Documents/Graphics%20and%20educational%20material/Safe%20Use%20of%20Greywater%20booklet.pdf [Accessed 16 April 2021].

Cobbinah, P.B., Erdiaw-Kwasie, M.O. and Amoateng, P. 2015. Rethinking sustainable development within the framework of poverty and urbanisation in developing countries. *Environmental Development* 13: 18-32. https://doi.org/10.1016/j.envdev.2014.11.001

Collins, J. 2001. Urbanisation. http://www.bcb.uwc.ac.za/envfacts/facts/urbanisation.htm Accessed 12 August 2020.

Collins, J.M. 2011. Temperature variability over Africa. *Journal of Climate* 24: 3649-3666.

Cook, C. 2016. Regulating the risks of domestic greywater re-use: a comparison of England and California. *Built Environment* 42: 230-242. https://doi.org/10.2148/benv.42.2.230

Daniel, E. 2011. Vulnerability assessment of surface water supply systems due to climate change and other impacts in Addis Ababa, Ethiopia. Department of Earth Sciences, Aquatic Climatology. Uppsala University, Villavägen 16, SE 752 36 Uppsala, Sweden.

Darwisha, T., Atallahb, T., Francisb, R., Sabb, C., Jomaaa, I., Shaabana, A., Sakkac, H. and Zdrulic, P. 2011. Observations on soil and groundwater contamination with nitrate: A case study from Lebanon-East Mediterranean. *Agricultural Water Management* 99: 74-84. https://doi.org/10.1016/j.agwat.2011.07.016

Das, K., Gerbens-Leenes, P.W. and Nonhebel, S. 2020. The water footprint of food and cooking fuel: A case study of self-sufficient rural India. *Journal of Cleaner Production* 281: 125255. https://doi.org/10.1016/j.jclepro.2020.125255.

David, T. 2020. The new ISO standards and what it means for food microbiologists. https://www.newfoodmagazine.com/article/118962/microbiology-2/ [Accessed: 23 August 2021].

Day, A.D., McFadyen, J.A., Tucker, T.C. and Cluff, C.B. 1981. Effects of municipal waste water on the yield and quality of cotton. *Journal of Environmental Quality* 10: 47-49.

Department of Agriculture Forestry and Fisheries (DAFF)., 2014. Abstract of Agricultural Statistics. Department of Water Affairs, Pretoria, South Africa. http://www.nda.agric.za/docs/statsinfo/Ab2012.pdf. [Accessed: 23 November 2021].

Department of Cooperative Governance and Traditional Affairs (COGTA)., 2009. The state of Local Government in South Africa. Overview report. National State of Local Government Assessments. http://pmg-assets.s3-website-eu-west-1.amazonaws.com/docs/091017tas.pdf [Accessed: 10 March 2020].

Department of Environment and Resource Management (DERM). 2009. Available online at http://www.derm.qld.gov.au. [Accessed: 22 June 2019].

Department of Environmental Affairs (DEA). 2010. The Framework for the Management of Contaminated Land, South Africa. http://sawic.environment.gov.za/documents/562.pdf [Accessed: 10 August 2021].

Department of Water Affair and Forestry (DWAF). 1996. Water Quality Guidelines-Agricultural: Irrigation. DWAF, South Africa.

Deshpande, S.M. and Aher, K.R. 2012. Evaluation of groundwater quality and its suitability for drinking and agriculture use in parts of Vaijapur, District Aurangabad, MS, India. *Journal of Chemical Science* 2(1): 25-31.

Diaper, C., Dixon, A., Butler, D., Fewkes, A. and Parsons, S.A., et al. 2001. Small scale water recycling systems-risk assessment and modelling. *Water, Science and Technology* 43(10):83-90.

Dillon, P. 2000. Water reuse in Australia: current status, projections and research. Proc. Water Recycling Australia 2000, Adelaide, 19-20 Oct 2000 (ed. P.J. Dillon) 99-104.

Disha, A.S., Al Harun, Md.A.Y., Akter, S., Billah, S.M. and Abdullah-Al-Noman M.D. 2020. Re-using greywater for cultivation of Capsicum frutescens and Calendula officinalis. *Journal of Environmental Management* 272: 111088. https://doi.org/10.1016/j.jenvman.2020.111088

Dishman, C.M., Sherrard, J.H. and Rebhun, M. 1989. Gaining support for direct potable water re-use. *Journal of Professional Issues in Engineering* 115(2): 154-161. https://doi.org/10.1061/(asce)1052-3928(1989)115:2(154)

Dixon, A.M., Butler, D. and Fewkes, A. 1999. Guidelines for greywater re-use: health issues. *Water and Environment Journal* 13(5): 322-326. https://doi.org/10.1111/j.1747-6593.1999.tb01056.x

Doll, P., Hoffmann-Dobrev, H., Portmann, F.T., Siebert, S., Eicker, A., Rodell, M., Strassberg, G. and Scanlon, B.R. 2012. Impact of water withdrawals from groundwater and surface water on continental water storage variations. *Journal of Geodynamics* 59-60: 143-156. https://doi.org/10.1016/j.jog.2011.05.001

Dolnicˇar, S. and Saunders, C. 2005. Marketing recycled water: review of past studies and research agenda. In: Khan, S.J., Schäfer, A.I. and Muston, M.H. (Eds.), Integrated Concepts in Water Recycling. University of Wollongong, Wollongong, 181-192.

Dolnicar, S. and Schafer, A.I. 2009. Desalinated versus recycled water: public perceptions and profiles of the accepters. *Journal of Environmental Management* 90: 888-900. https://doi.org/10.1016/j.jenvman.2008.02.003

Dolnicar, S., Hurlimann, A. and Grun, B. 2011. What affects public acceptance of recycled and desalinated water? *Water Research* 45(2): 933-943. https://doi.org/10.1016/j.watres.2010.09.030

Dolnieara, S. and Saunders, C. 2006. Recycled water for consumer markets – a marketing research review and agenda. *Desalination* 187: 203-214. https://doi.org/10.1016/j.desal.2005.04.080

Domenech, L. 2015. Improving irrigation access to combat food insecurity and undernutrition: a review. *Global Food Security* 6: 24-33. https://doi.org/10.1016/j.gfs.2015.09.001

Domenech, L. and Saurí, D. 2010. Socio-technical transitions in water scarcity contexts: Public acceptance of greywater re-use technologies in the Metropolitan Area of Barcelona. *Resources, Conservation and Recycling* 55: 53-62. https://doi.org/10.1016/j.resconrec.2010.07.001

Dominguez, F. 2010. Water scarcity: can virtual water operators help? *Utilities Policy* 18(3): 129-134. https://doi.org/10.1016/j.jup.2010.02.001

Donner, E., Eriksson, E., Revitt, D.M., Scholes, L., Holten Lützhøft, H.C. and Ledin, A. 2010. Presence and fate of priority substances in domestic greywater treatment and re-use systems. *Science of the Total Environment* 408: 2444-2451. https://doi.org/10.1016/j.scitotenv.2010.02.033

Dos Santos, S., Adams, E.A., Neville, G., Wada, Y., de Sherbinin, A., Bernhardt, E.M. and Adamo, S.B. 2017. Urban growth and water access in sub-Saharan Africa: Progress, challenges, and emerging research directions. *Science of the Total Environment* 607: 497-508. https://doi.org/10.1016/j.scitotenv.2017.06.157

Ekere, N.R., Ihedioha, J.F., Eze, I.S. and Agbazue, V.E. 2014. Health risk assessment in relation to heavy metals in water sources in rural regions of South East Nigeria. *International Journal of Physical Sciences* 9(6): 109-116. https://doi.org/10.5897/ijps2014.4125

Eman, S.A., Al Obaidy, A.H.M. and Al Mendilawi, H.R. 2014. Environmental assessment of wastewater treatment plants (WWIPs) for old Rustamiya project. *Int. J. Sci. Eng. Technol. Res.* (IJSETR) 3(12): 3455-3459.

Environmental Protection Agency (EPA). 2004. Guidelines for water re-use. Washington, DC: U.S. Environmental Protection Agency.

EPA. 2020. Microwave-assisted acid digestion of siliceous and organically-based matrices. EPA 3052 Method. https://www.epa.gov/sites/default/files/2015-12/documents/3052.pdf [Accessed: 23 August 2021].

Eriksson, E. and Donner, E., 2009. Metals in greywater: Sources, presence and removal efficiencies. *Desalination* 248(1-3): 271-278. https://doi.org/10.1016/j.desal.2008.05.065

Eriksson, E., Auffarth, K., Henze, M. and Ledin, A. 2002. Characteristics of grey wastewater. *Urban Water* 4: 85-104. https://doi.org/10.1016/s1462-0758(01)00064-4

Eriksson, E., Baun, A., Henze, M. and Ledin, A. 2006. Phytotoxicity of grey wastewater evaluated by toxicity tests. *Urban Water J*. 3,13–20.

Etchepare, R. and van der Hoek, J.P. 2015. Health risk assessment of organic micro-pollutants in greywater for potable re-use. *Water Resources* 72: 186-198. https://doi.org/10.1016/j.watres.2014.10.048

Fabiya. E.F., Danladi, B.B., Akande, K.E. and Mahmood, Y. 2007. Role of women in agricultural development and their constraints: A case study of Biliri local government area, Gombe state, Nigeria. *Pakistan Journal of Nutrition* 6(6): 676-680. https://doi.org/10.3923/pjn.2007.676.680

Fan, S. 2017. The importance of tracking global food system sustainability. https://www.ifpri.org/blog/importance-tracking-global-food-system-sustainability. [Accessed: 15 August 2021].

FAO, IFAD, UNICEF, WFP and WHO. 2020. The state of food security and nutrition in the world. Transforming food systems to deliver affordable healthy diets for all. FAO, Rome.

FAO, IFAD AND WFP. 2015. The state of food insecurity in the world 2015. Meeting the 2015 international hunger targets: Taking stock of uneven progress. Rome: Food and Agriculture Organization

FAO. 2004. Drought Impact Mitigation and Prevention in the Limpopo River Basin: A Situation Analysis. Land and Water Discussion Paper; Food and Agricultural Organization (FAO): Rome, Italy.

FAO/WHO. 2011. Joint FAO/WHO food standards programme Codex Committee on Contaminants in foods, in: Food CF/5 INF/1. Fifth Session. The Hague, The Netherlands. http://www.fao.org/input/download/report/758/REP11_CFe.pdf [Accessed: 10 June 2020]

Faraqui, N. and Al-Jayyousi, O. 2002. Greywater re-use in urban agriculture for poverty alleviation. *Water International* 27(3): 387-94. https://doi.org/10.1080/02508060208687018

Faurès, J. and Santini, G. 2008. Water and the rural poor interventions for improving livelihoods in sub-Saharan Africa. FAO. Rome: FAO/IFAD.

Fielding, K.S., Gardner, J., Leviston, Z. and Price, J. 2015. Comparing public perceptions of alternative water sources for potable use: The vase of rainwater, stormwater, desalinated water and recycled water. *Water Resources Management* 29(12): 4501-4518. https://doi.org/10.1007/s11269-015-1072-1

Finley, S., Barrington, S. and Lyew, D. 2009. Re-use of domestic greywater for the irrigation of food crops. *Water, Air and Soil Pollution* 199: 235-245. https://doi.org/10.1007/s11270-008-9874-x

Fipps, G. 2003. “Irrigation Water Quality Standards and Salinity Management strategies,” Texas Agricultural Extension Service, Texas A and M University System, College Station, TX (USA). B-1667 4-03, 1-19.

Foh, N., M´egret, P. and Said, J. 2020. A different approach to strengthening african food systems. Retrieved from. https://institute.global/advisory/different-approach-strengthening-african-food-systems. [Accessed: 15 August 2021].

Food and Agricultural Organization (FAO). 2004. Drought Impact Mitigation and Prevention in the Limpopo River Basin: A Situation Analysis. Land and Water Discussion Paper; FAO: Rome, Italy.

Friedler, E. 2004. Quality of individual domestic greywater streams and its implication for on-site treatment and re-use possibilities. *Environmental Technology* 25(9): 997-1008. https://doi.org/10.1080/09593330.2004.9619393

Friedler, E. and Lahav, O. 2006. Centralised urban wastewater re-use: what is the public attitude? *Water Science and Technology* 54(6): 423-430. https://doi.org/10.2166/wst.2006.605

Friedrich, J., Poganietz, W.R. and Lehn, H. 2020. Life-cycle assessment of system alternatives for the Water-Energy-Waste Nexus in the urban building stock. *Resour. Conserv. Recycl*. 158: 104808. https://doi.org/10.1016/j.resconrec.2020.104808.

GAIN. 2020. Impacts of COVID-19 on small- and medium-sized enterprises in the food system: results of an online survey. https://www.gainhealth.org/sites/default/files/publications/documents/impacts-of-covid-19-on-small-and-medium-sized-enterprises-in-the-food-system.pdf. [Accessed: 14 August 2021].

Gàlan, E. Romero-Baena, A.J., Aparicio, P. and Gonzalez, I., 2019. A methodological approach for the evaluation of soil pollution by potentially toxic trace elements. *Journal of Geochemical Exploration* 203: 93-107. https://doi.org/10.1016/j.gexplo.2019.04.005

Galán, E., González, I., Romero, A. and Aparicio P., 2014. A methodological approach to estimate the geogenic contribution in soils potentially polluted by trace elements. Application to a case study. *Journal of Soils and Sediments* 14(4): 810-818. https://doi.org/10.1007/s11368-013-0784-1

Ganoulis, J. 2012. Risk analysis of wastewater reuse in agriculture. *International Journal of Recycling of Organic Waste in Agriculture* 1:13.

Garcia-Cuerva, L., Berglund, E.Z. and Binder, A.R. 2016. Public perceptions of water shortages, conservation behaviours, and support for water re-use in the U.S. *Resources, Conservation and Recycling* 113: 106-115. https://doi.org/10.1016/j.resconrec.2016.06.006

Gardner, T., Hyde, R., Miller, G. and Vieritz, A. 2002. A healthy home: a step towards greening paradise. 4th Queensland Environmental Engineering Conference. Brisbane Environmental Engineering Society.

Garland, J.I., Levine, L.H., Yorio, N.C., Adams, J.I. and Cook, K.I. 2000. Greywater processing in recirculating hydroponic systems: phytotoxicity, surfactant degradation, and bacterial dynamics. *Water Resources* 34: 3075-3086. https://doi.org/10.1016/s0043-1354(00)00085-3

Ghaitidak, D.M. and Yadav, K.D. 2013. Characteristics and treatment of greywater—a review.*Environmental Science and Pollution Research* 20 (5) (2013) 2795–2809 https:// doi.org/10.1007/s11356-013-1533-0

Ghisi, E. and Ferreira, D.F. 2007. Potential for potable water savings by using rainwater and greywater in a multi-storey residential building in southern Brazil. *Build Environment* 42: 2512-2522. https://doi.org/10.1016/j.buildenv.2006.07.019

Gifford, R. and Nilsson, A. 2014. Personal and social factors that influence pro-environmental concern and behaviour: a review. *International Journal of Psychology* 49: 141-157.

Giller, K.E. 2020. The Food Security Conundrum of sub-Saharan Africa. *Global Food Security* 26: 100431. https://doi.org/10.1016/j.gfs.2020.100431

Gimeno-Garcia, E., Andreu, V. and Boluda, R. 1996. Heavy metals incidence in the application of inorganic fertilizers and pesticides to rice farming. *Environmental Pollution* 92(1): 19-25. https://doi.org/10.1016/0269-7491(95)00090-9

Gleick, P.H. 2003. Global freshwater resources: soft-path solutions for the 21st century. *Science* 302(28): 1524-1528. https://doi.org/10.1126/science.1089967

Glover, C.M., Liu, Y. and Liu, J. 2021. Assessing the risk from trace organic contaminants released via greywater irrigation to the aquatic environment. *Water Research* 205: 117664.

Godfray, H.C.J., Beddingtonian, J.R., Crute I.R., Haddad, L., Lawrence, D., Muir, J.F., Pretty, J., Robinson, S., Thomas, S.M. and Toulmin, C. 2010. Food Security: The Challenge of Feeding 9 Billion People. *Science* 327 (5967): 812-818. DOI:10.1126/science.1185383

Godfrey, S. Labhasetwar, P. and Wate, S. 2009. Greywater re-use in residential schools in Madhya Pradesh, India. A case study of cost-benefit analysis. *Resources, Conservation and Recycling* 53: 287-293. https://doi.org/10.1016/j.resconrec.2009.01.001

Gonçąlves, R.F., de Oliveira Vaz, L., Peres, M. and Merlo, S.S. 2021. Microbiological risk from non-potable re-use of greywater treated by anaerobic filters associated to vertical constructed wetlands. *Journal of Water Process Engineering* 39: 101751. https://doi.org/10.1016/j.jwpe.2020.101751

Gonzalez, I., Galán, E. and Romero, A. 2011. Assessing soil quality in areas affected by sulfide mining. Application to soils in the Iberian Pyrite Belt (SW Spain). *Journal of Minerals* 1(1): 73-108. https://doi.org/10.3390/min1010073

Gough, D., Oliver, S. and Thomas, J. 2012. An introduction to systematic Reviews. SAGE Publications, London.

Gorgich, M., Mata, T.M., Martins, A, Caetano, N.S and Formigo, N. 2020. Application of domestic greywater for irrigating agricultural products: A brief study. *International Conference on Energy and Environment Research, ICEER2019, 22–25 July, University of Aveiro, Portugal*. Energy Reports 6: 811–817.

Gralak, S., Spajic, L., Blom, I., Omrani, O., Bredhauer, J., Uakkas, S., Juliette, M., Abubakr, O., Iturregui, R., Ezzine, T., Lujain, A. and Sudhvir, S. 2020. COVID-19 and the future of food systems at the UNFCCC. *Comment* 4 (8), 309–311.

Green, T.R., Taniguchi, M., Kooi, H., Gurdak, J.J., Allen, D.M., Hiscock, K.M., Treidel, H. and Aureli, A. 2011. Beneath the surface of global change: impacts of climate change on groundwater. *Journal of Hydrology* 405(3-4): 532-560. https://doi.org/10.1016/j.jhydrol.2011.05.002

Gregory, G.D. and Di Leo, M. 2003. Repeated behavior and environmental psychology: The role of personal involvement and habit formation in explaining water consumption. *Journal of Applied Social Psychology* 33: 1261-1296. https://doi.org/10.1111/j.1559-1816.2003.tb01949.x

Gross, A., Azulai, N., Oron, G., Ronen, Z., Arnold, M. and Nejidat, A. 2005. Environmental impact and health risks associated with greywater irrigation: a case study. *Water Sci. Technol*. 52, 161–169.

Gross, A., Kaplan, D. and Baker, K., 2007. Removal of chemical and microbiological contaminants from domestic greywater using a recycled vertical flow bioreactor (RVFB). *Ecol. Eng.* 31(2): 107-14. https://doi.org/10.1016/j.ecoleng.2007.06.006

Gross, A., Maimon, A., Alfiya, Y. and Friedler, E. 2015. Greywater Re-use. CRC Press, Boca Raton, FL.

Gupta, S.K. and Gupta, I.C. 1987. Management of saline soils and waters. Oxford and IBH Publishing Company, New Delhi.

Hakanson, L. 1979. An ecological risk index for aquatic. Pollution control: A sedimentological approach. *Water Research* 14: 975-1001. https://doi.org/10.1016/0043-1354(80)90143-8

Halliwell, D.J., Barlow, K.M. and Nash, D.M. 2001. A review of the effects of wastewater sodium on soil physical properties and their implications for irrigation systems. *Australian Journal of Soil Research* 39(6): 1259-1267. https://doi.org/10.1071/sr00047

Hanak, E. and Lund, J. 2008. Adapting California’s Water Management to Climate Change. Published by PPIC (Public Policy institute of California) study-Preparing California for a Changing Climate. *Reference guide* 4: 1-49. DOI:10.1007/s10584-011-0241-3

Hanjra, M.A. and Qureshi, M.E. 2010. Global water crisis and future food security in an era of climate change. *Food Policy* 35: 365-377. https://doi.org/10.1016/j.foodpol.2010.05.006

Hardie, A.G., Madubela, N., Clarke, C.E. and Lategan, E.L. 2021. Impact of powdered and liquid laundry detergent greywater on soil degradation. *Journal of Hydrology* 595: 126059. https://doi.org/10.1016/j.foodpol.2010.05.006

Harding, R. 2006. Ecologically sustainable development: Origins, implementation and challenges. *Desalination* 187(1-3): 229-239. https://doi.org/10.1016/j.desal.2005.04.082

Harmanescu, M., Alda, L.M., Bordean, D.M., Gogoasa, I. and Gergen, I. 2011. Heavy metals health risk assessment for population via consumption of vegetables grown in old mining area; a case study: Banat County, Romania. *Chem Central J* 5: 64. https://doi.org/10.1186/1752-153x-5-64

Hart, T., Altman, M. and Jacobs, P. 2009. Food security in South Africa. Human Sciences Research Council, Centre for Poverty, Employment and Growth. Pretoria.

Hartley, T.W. 2006. Public perception and participation in water re-use. *Desalination* 187(1-3): 115-126.

Hawrami, K.A., Crout, N.M., Shaw, G. and Bailey, E.H. 2019. Assessment of potentially toxic elements in vegetables cultivated in urban and peri-urban sites in Kurdistan region of

Iraq and implications for human health. Enviro. Geochem. *Health* 1: 27. https://doi.org/10.1007/s10653-019-00426-z

Hellin, J., Shiferaw, B., Cairns, J.E., Reynolds, M., Ortiz-Monasterio, I., Banziger, M., Sonder, K. and la Rovere, R. 2012. Climate change and food security in the developing world: potential of maize and wheat research to expand options for adaptation and mitigation. *Journal of Development and Agricultural Economics* 4(12): 311-321.

Herselman, J.E. 2007. The concentration of selected trace metals in South African soils. Ph.D. Thesis. University of Stellenbosch.

Higgins, J., Warnken, J., Sherman, P.P. and Teasdale, P.R. 2002. Surveys of users and providers of recycled water: quality concerns and directions of applied research. *Water Resources* 36: 5045-5056. https://doi.org/10.1016/s0043-1354(02)00158-6

Hills, S., Birks, R. and McKenzie, B. 2002. The Millennium Dome 'Water-cycle' experiment: to evaluate water efficiency and customer perception at a recycling scheme for 6 million visitors. *Water Science and Technology* 46(6): 233-240. https://doi.org/10.2166/wst.2002.0684

Hills, S., Lambert, C., Aitken, T. and Bell, S.J. 2013. Investigating attitudes to "planned" indirect potable re-use in London using quantitative on-line surveys. In: (Proceedings) 9th IWA International Conference on Re-use, Windhoek.

Hoko, Z. and Nhapi, I. 2002. A cleaner production approach to urban water management: potential for application in Harare, Zimbabwe. In 3rd Waternet/Warfsa Symposium, Dar-es Salaam, Tanzania.

Holgate, L.C., Aitkenhead-Peterson, J.A. and Gentry, T.J. 2011. Irrigation water chemistry: impact on microbial community composition and biogeochemical leaching under perennial ryegrass (Lolium perenne [L]). *ISRN Ecology* 1-9. https://doi.org/10.5402/2011/797910

Holtzhausen, L. 2005. Greywater recycling: From grey to green: Re-using greywater for food. The Water Wheel June/July 10-12.

Hong, C.Y., Chao, Y.Y., Yang, M.Y, Cho, S.C. and Huei, K.C. 2009. Sodium but not chloride or osmosis stress is involved in NaCl- induced expression of glutathione reductase in roots of rice seedlings. *Journal of Plant Pathology* 166: 1598-1606. https://doi.org/10.1016/j.jplph.2009.04.001

Howard, E., Misra, R., Loch, R. and Le, M.N. 2007. Laundry Greywater Potential Impact on Toowoomba Soils - Final Report. University of Southern Queensland, National Centre for Engineering in Agriculture, Toowoomba, Australia. http://eprints.usq.edu.au/641/ [Accessed: 10 November 2018].

Huibers, F.P., Moscoso, O., Durân, A. and van Lier, J.B. 2004. The use of wastewater in Cochabama, Bolivia: a degrading environment. In: Wastewater Use in Irrigated Agriculture (ed. by Scott, C., Faruqui, N.I. and Rashid, I.). CAB International, Wallingford, UK. https://doi.org/10.1079/9780851998237.0135

Hurlimann, A., Dolnicar, S. and Meyer, P. 2009a. Understanding behaviour to inform water supply management in developed nations - A review of literature, conceptual model and research agenda. *Journal of Environmental Management* 91(1): 47-56. https://doi.org/10.1016/j.jenvman.2009.07.014

Hurlimann, A., Hemphill, E., McKay, J. and Geursen, G. 2009b. Establishing components of community satisfaction with recycled water use through a structural equation model. *Journal of Environmental Management* 88: 1221-1232. https://doi.org/10.1016/j.jenvman.2007.06.002

Ibraheem, M.A. and Khan, S.M. 2017. Suitability Assessment of Groundwater for Irrigation Purpose in Veppanthattai Block, Perambalur District, Tamil Nadu. *World Scientific News* 81(2): 81-93.

Ilemobade, A.A., Olanrewaju O.O. and Griffioen M.L. 2012. Greywater re-use for toilet flushing in high-density urban buildings in South Africa: a pilot study. WRC Report No. 1821/1/11. Water Research Commission, Pretoria. https://doi.org/10.4314/wsa.v39i3.2

Intergovernmental Panel on Climate Change (IPCC). 2011. Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation, a Special Report on Working Group I and Working Group II of the Intergovernmental Panel on Climate Change. http://www.ipcc.ch/ipccreports/ar4-syr.htm [Accessed: 26 February 2019].

IPCC. 2007a. Fourth Assessment Report: Climate Change (AR4). In: Chapter 8: Agriculture.

IPCC. 2007b. Climate Change 2007: Impacts, Adaptation and Vulnerability, Working Group II Contribution to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, United Kingdom.

IPCC. 2020. History of the IPCC [WWW Document]. https://www.ipcc.ch/about /history/. [Accessed: 23 November 2021].

Ishaku, J.M., Ahmed, A.S. and Abubakar, M.A. 2011. Assessment of groundwater quality using chemical indices and GIS mapping in Jada area, North-eastern Nigeria. *Journal of Earth Sciences and Geotechnical Engineering* 1(1): 35-60. https://doi.org/10.1016/j.jhydrol.2011.10.032

Ismail, Z., Ellias, S., Tajuddin, R.M., Atan, I., Ashaari, Y., Endut, I.R. and Baki, A. 2011. Alternative Water Resources for Sustainable Buildings. In Proceedings of the 3rd AUN/SEED-Net Regional Conference on Global Environment, AUN/SEED-Net, Mid Valley, MY, USA, 21–22 February 2011

Jang, C., Chen, S. and Kuo, Y. 2012. Establishing an irrigation management plan of sustainable groundwater based on spatial variability of water quality and quantity. *Journal of Hydrology* 414–415: 201–210. https://doi.org/10.1016/j.jhydrol.2011.10.032

Jefferson, B., Laine, A., Parsons, S., Stephenson, T. and Judd, S. 1999. Technologies for domestic wastewater recycling. *Urban Water* 1: 285-292. https://doi.org/10.1016/s1462-0758(00)00030-3

Jefferson, B., Palmer, A., Jeffrey, P., Stuetz, R. and Judd, S. 2004. Greywater characterization and its impact on the selection and operation of technologies for urban use. *Water Science Technology* 50(2): 157-164. https://doi.org/10.2166/wst.2004.0113

Jeffrey, P. 2001. Understanding public receptivity issues regarding ‘in-house’ water recycling. Results from a UK survey. *Water Supply* 3(3): 109–116 https://doi.org/10.2166/ws.2003.0015

Jeffrey, P. 2002. Public attitudes to in-house water recycling in England and Wales. *Water and Environmental Management* 16(3): 214-217.

Jenerette, G.D. and Larsen, L.A., 2006. Global perspective on changing sustainable urban water supplies. *Global and Planetary Change* 50: 202-211. https://doi.org/10.1016/j.gloplacha.2006.01.004

Jeong, H., Broesike, O.A., Drew, B. and Crittenden, J.C. 2018. Life cycle assessment of small-scale greywater reclamation systems combined with conventional centralized water systems for the City of Atlanta. Georgia. *Journal of Cleaner Production* 174, 333–342. https://doi.org/10.1016/j.jclepro.2017.10.193.

Jeppesen, B. 1996. Domestic greywater re-use: Australia's challenge for the future. *Desalination* 106(1-3): 311-315. https://doi.org/10.1016/s0011-9164(96)00124-5

Juan, J.S., Kahaka, Z. and Okurut, F.N. 2013. Farmers' perceptions and adaptations to climate change in sub-Sahara Africa: a synthesis of empirical studies and implications for public policy in African agriculture. *Journal of Agricultural Sciences* 5(4): 121-135. https://doi.org/10.5539/jas.v5n4p121

Jury, W.A. and Vaux Jr., H.J. 2007. The emerging global water crisis: managing scarcity and conflict between water users. *Advances in Agronomy* 95: 1-76. https://doi.org/10.1016/s0065-2113(07)95001-4

Kabata-Pendias A. 2010. Trace elements in soils and plants. 4th Ed. Boka Raton: CRC Press.

Kacholi, D.S. and Sahu, M. 2018. Levels and health risk assessment of heavy metals in soil, water and vegetables of Dar es Salaam, Tanzania. *Journal of Chemistry* 1-9. https://doi.org/10.1155/2018/1402674

Kahinda, J.M. and Taigbenu, A.E. 2011. Rainwater harvesting in South Africa: challenges and opportunities. *Physics and Chemistry of the Earth* 36:968-976. https://doi.org/10.1016/j.pce.2011.08.011

Kariuki, F.W., Nga´nga´, V.G. and Kotut, K. 2012. Hydro-chemical characteristics, plant nutrients and metals in household greywater and soils in Homa Bay Town. *Open Environment and Engineering Journal* 5: 103-109. https://doi.org/10.2174/1874829501205010103

Katukiza, A.Y., Ronteltap, M. and Niwagaba, C.B. 2015. Greywater characterisation and pollutant loads in an urban slum. *International Journal of Environmental Science and Technology* 12: 423-436. https://doi.org/10.1007/s13762-013-0451-5

Kelley, W.P. 1963. Use of saline irrigation water. *Soil Science* 95: 355-391. https://doi.org/10.1097/00010694-196306000-00003

Kenabatho, P.K., Parida, B.P. and Moalafhi, D.B. 2012. The value of large-scale climate variables in climate change assessment: the case of Botswana rainfall. *Physics and Chemistry of the Earth* 50-52: 64-71. https://doi.org/10.1016/j.pce.2012.08.006

Khodapanah, L., Sulaiman, W.N.A. and Khodapanah, D.N. 2009. Groundwater quality assessment for different purposes in Eshtehard District, Tehran, Iran. European Journal of Scientific Research 36(4): 543-553.

Kim, K.R., Owens, G. and Naidu, R. 2009. Effect of root-induced chemical changes on dynamics and plant uptake of heavy metals in rhizosphere soils. Pedosphere 20: 49-54. https://doi.org/10.1016/s1002-0160(10)60039-2

Knight, A.J. 2005. Differential effects of perceived and objective knowledge measures on perceptions of biotechnology. *AgBioForum* 8(4): 221-227.

Kraft, L. 2009. Characterisation of greywater from peri-urban areas in Nakuru, Kenya. Diploma thesis, University of Applied Sciences Weihenstefan, Germany (Fachhochschule Weihenstephan Abteilung Triesdorf).

Krozer, Y., Hophmayer-Tokich, S., van Meerendonk, H., Tijsma, S. and Vos, E. 2010. Innovations in the water chain – experiences in The Netherlands. *Journal of Cleaner Production* 18: 439-446. https://doi.org/10.1016/j.jclepro.2009.11.013

Kulabako, N.R., Ssonko, N.K.M. and Kinobe, J. 2011. Greywater characteristics and re-use in tower gardens in peri-urban areas. Experiences of Kawaala, Kampala, Uganda. *The Open Environment Engineering* Journal 4: 147-154. https://doi.org/10.2174/1874829501104010147

Kuru, B. and Luettgen, M. 2012. Is grey-water re-use ready for prime time? https://www.us.kohler.com/webassets/kpna/pressreleases/2012/KOHLERGRAYWATER_111412.pdf. [Accessed: 3 December 2018].

Lambert, L.A. and Lee, J. 2018. Nudging greywater acceptability in a Muslim country: Comparisons of different greywater re-use framings in Qatar. *Environmental Science and Policy* 89: 93-99. https://doi.org/10.1016/j.envsci.2018.07.015

Laprise, R., Herna´ndez-Dı´az, L., Tete, K. et al. 2013. Climate projections over CORDEX Africa domain using the fifth-generation Canadian Regional Climate Model (CRCM5). *Clim Dyn* 41:3219–3246. doi:10.1007/s00382-012-1651-2

Li, K.L. 2017. Inhibition of Listeria monocytogenes growth and biofilm production by nisin and phenolic compounds. University of Alberta, Canada.

Limpopo Economic Development, Environment and Tourism (LEDET). 2015. Limpopo Environmental Outlook Report. Chapter 1: Climate Change for Limpopo Province, South Africa.

Liu, X., Xu, Y., Engel, B.A., Sun, S., Zhao, X., Wu, P. and Wang, Y. 2021. The impact of urbanization and aging on food security in developing countries: The view from Northwest China. *Journal of Cleaner Production* 292: 126067 https://doi.org/10.1016/j.jclepro.2021.1260670959-6526/

Lubbe E., Rodda N. and Sershen. 2016. Effects of greywater irrigation on germination, growth and photosynthetic characteristics in selected African leafy vegetables. *Water SA* 42(2) 203 – 212.

Ludden, J., Peach, D. and Flight, D. 2015. Geochemically-based solutions for urban society: London, A Case Study. *Elements* 11(4): 253-258. https://doi.org/10.2113/gselements.11.4.253

Lundqvist, J., Tortajada, C., Varis, O. and Biswas, A. 2005. Water management in megacities. *Ambio* 3: 267-268. https://doi.org/10.1579/0044-7447-34.3.267

Luo, X.S., Ding, J. and Xu, B. 2012. Incorporating bio-accessibility into human health risk assessments of heavy metals in urban park soils. *Sci. Total Environ.* 424: 88-96. https://doi.org/10.1016/j.scitotenv.2012.02.053

Madungwe, E. and Sakuringwa, S. 2007. Greywater re-use: a strategy for water demand management in Harare? *Physics and Chemistry of the Earth* 32(15-18): 1231-1236. https://doi.org/10.1016/j.pce.2007.07.015

Madzwamuse, M. 2010. Climate Governance in Africa: Adaptation Strategies and Institutions. Heinrich Böll Stiftung (HBS).

Mah, D.Y.S., Bong, C.H.J., Putuhena, F.J. and Said, S. 2009. A conceptual modelling of ecological greywater recycling system in Kuching city, Sarawak, Malaysia. *Resources, Conservation and Recycling* 53: 113-121. https://doi.org/10.1016/j.resconrec.2008.07.008

Mahmood, A. and Malik, R.N. 2014. Human health risk assessment of heavy metals via consumption of contaminated vegetables collected from different irrigation sources in Lahore, Pakistan. *Arab J Chem* 7: 91–99. https://doi.org/10.1016/j.arabjc.2013.07.002

Mahmoudi, A., Mousavi, S.A.and Darvishi, P. 2021. Greywater as a sustainable source for development of green roofs: Characteristics, treatment technologies, reuse, case studies and future developments. *Journal of Environmental Management* 295: 112991.

Maimon, A. and Gross, A. 2018. Greywater: Limitations and perspective. *Current Opinion in Environmental Science and Health* 2: 1-6. https://doi.org/10.1016/j.coesh.2017.11.005

Maimon, A., Friedler, E. and Gross, A. 2014. Parameters affecting greywater quality and its safety for re-use. *Science of the Total Environment* 487: 20-25.

Maimon, A., Gross, A. and Arye, G. 2017. Greywater-induced soil hydrophobicity. *Chemosphere* 184: 1012-1019. https://doi.org/10.1016/j.scitotenv.2014.03.133

Maimon, A., Tal, A., Friedler, E. and Gross, A. 2010. Safe on-site re-use of greywater for irrigation-a critical review of current guidelines. *Environmental Science and Technology* 44: 3213-3220. https://doi.org/10.1021/es902646g

Makhuduthamaga Local Municipality IDP, 2019/20. MLM first draft 2019/20 IDP/budget. http://www.makhuduthamaga.gov.za/documents/MLM%20%20DRAFT%202019-20%20IDP.docx%20final.pdf [Accessed: 10 March 2020].

Mandal, D., Labhasetwar, P., Dhone, S., Dubey, A.S., Shinde, G. and Wate, S. 2011. Water conservation due to greywater treatment and re-use in urban setting with specific context to developing countries. *Resour. Conserv. Recycl.* 55: 356-361. https://doi.org/10.1016/j.resconrec.2010.11.001

Manna, S. 2018. Treatment of graywater for reusing in non-potable purpose to conserve water in India. *Int. J. Appl. Environ. Sci*. 13, 703–716.

March, J.G. and Gual, M. 2009. Studies on chlorination of greywater. *Desalination* 249(1): 317-322. https://doi.org/10.1016/j.desal.2009.09.005

Marinoski, A.K., Rupp, R.F. and Ghisi, E. 2018. Environmental benefit analysis of strategies for portable water savings in residential buildings. *Journal of Environmental Management* 206: 20-39. https://doi.org/10.1016/j.jenvman.2017.10.004

Marks J.S. 2006. Taking the public seriously: The case of potable and non-potable re-use. *Desalination* 187: 137-147. https://doi.org/10.1016/j.desal.2005.04.074

Marks, J.S., Martin, B. and Zadoroznyj, M. 2006. Comparing attitudes to recycled water: the difference between generalized and salient options, ISA Conference, Durban, South Africa.

Marks, J.S., Martin, B. and Zadoroznyj, M. 2008. How Australians order acceptance of recycled water: National baseline data. *Journal of Sociology* 44(1): 83-99. https://doi.org/10.1177/1440783307085844

Masmoudi Jabri, K., Nolde, E., Ciroth, A. and Bousselmi, L. 2020. Life cycle assessment of a decentralized greywater treatment alternative for non-potable reuse application. *Int. J. Environ. Sci. Technol.* 17: 433-444. https://doi.org/10.1007/s13762-019-02511-3.

Matsinhe, N.P., Juizo, D., Rietveld, L.C. and Persson, K.M. 2008. Water services with independent providers in peri-urban Maputo: challenges and opportunities for long-term development. *Water SA* 4(3): 411-420. https://doi.org/10.4314/wsa.v34i3.180636

Megdal, S.B. 2007. Municipal Water Re-use in Tucson, Arizona. Wastewater Re-use - Risk Assessment, Decision-Making and Environmental Security; Zaidi, M.K., Ed.; Springer, AK/Nato Publishing Unit: Dordrecht, The Netherlands, 81–90. https://doi.org/10.1007/978-1-4020-6027-4_9

Memon, F.A., Zheng, Z., Butler, D., Shirley-Smith, C., Lui, S., Makropoulos, C. and Avery, L. 2007. Life cycle impact assessment of greywater recycling technologies for new developments. *Environ. Monit. Assess.* 129, 27–35. https://doi.org/10.1007/s10661-006-9422-3

Ministry of Health of the British Columbia. 2017. Health information: greywater re-use. https://www2.gov.bc.ca/assets/gov/environment/waste-management/sewage/onsite-sewerage-systems/what_is_grey_water.pdf [Accessed: 06 June 2018].

Misra, R.K., Patel, J.H. and Baxi, V.R. 2009. Removal of pollutants by tomato plants during re-use of laundry greywater for irrigation. In: International Conference on Food Security and Environmental Sustainability (FSES), 17–19 December 2009, Kharagpur, India.

Misra, R.K., Patel, J.H. and Baxi, V.R. 2010. Re-use potential of laundry greywater for irrigation based on growth, water and nutrient use of tomato. *Journal of Hydrology* 386(1): 95-102. https://doi.org/10.1016/j.jhydrol.2010.03.010

Misra, R.K. and Sivongxay, A. 2009. Reuse of laundry greywater as affected by its interaction with saturated soil. *Journal of Hydrology* 366, 55–61.

Mohamed, R.M.S.R., Kassim, A.H.M., Anda, M. and Dallas, S., 2013. A monitoring of environmental effects from household greywater re-use for garden irrigation. *Environ. Monit. Assess*. 185(10): 8473–8488. https://doi.org/10.1007/s10661-013-3189-0

Morel A. and Diener S. 2006. Greywater Management in Low and Middle-Income Countries, Review of different treatment systems for households or neighbourhoods. Swiss Federal Institute of Aquatic Science and Technology (Eawag). Dubendorf, Switzerland.

Mosel, I., Lucci, B., Doczi, J., Cummings, C., Bahadur, C., et al. 2016. Urbanisation: consequences and opportunities for the Netherlands' Directorate General for International Cooperation. Overseas Development Institute, London.

Mpandeli, S., Nesamvuni, E. and Maponya, P. 2015. Adapting to the impacts of drought by smallholder farmers in Sekhukhune District in the Limpopo Province, South Africa. *Journal of Agricultural Sciences* 7(2): 115. https://doi.org/10.5539/jas.v7n2p115

Muanda, C. and Lagardien, A. 2008. Investigating Greywater Disposal Options in an Informal Settlement. Water Institution of Southern Africa, Biennial Conference, Sun City, South Africa.

Muhammad, S., Shah, M.T. and Khan, S. 2011. Health risk assessment of heavy metals and their source apportionment in drinking water of Kohistan region, North Pakistan. Microchemical Journal 98(2): 334-343. https://doi.org/10.1016/j.microc.2011.03.003

Muller, G. 1969. Index of geo-accumulation in sediments of the Rhine River. *GeoJournal* 2: 108-118.

Mungai, G. 2008. Impacts of long-term greywater disposal on soil properties and re-use in urban agriculture in an informal settlement - a case study of Waruku, Nairobi. MSc thesis MWI 2008/10, UNESCO-IHE Institute for Water Education, Delft, The Netherlands.

Mzini, L.L. 2013. The effects of greywater irrigation on vegetable crops and soil. MSc dissertation, University of Cape Town. https://open.uct.ac.za/bitstream/handle/11427/6609/thesis_sci_2013_mzini_loyiso.pdf [Accessed: 16 April 2021].

Mzini, L.l. and Winter, K. 2015. Analysis of grey-water used for irrigating vegetables and possible effects on soils in the vicinity of Umtata Dam, Eastern Cape. Water South Africa 41: 115-120. https://doi.org/10.4314/wsa.v41i1.14

National Academies of Sciences, Engineering, and Medicine (NASEM). 2016. Using Graywater and Stormwater to Enhance Local Water Supplies: An Assessment of Risks, Costs, and Benefits. The National Academies Press, Washington, DC.

National Planning Commission (NPC). 2012. National Development Plan 2030: Our Future - make it work. Sherino Printers. South Africa.

Nchanji, E.B. and Lutomia, C.K. 2020. Regional impact of COVID-19 on the production and food security of common bean smallholder farmers in Sub-Saharan Africa: Implication for SDG's. *Global Food Security* 29: 100524.

Negahban-Azar, M., Sharvelle, S.E., Qian, Y. and Shogbon, A. 2013. Leachability of chemical constituents in soil–plant systems irrigated with synthetic greywater. *Environmental Science Process Impacts* 15: 760–72. https://doi.org/10.1039/c3em30685b

New Partnership for Africa's Development (NEPAD). 2006. Water in Africa: management options to enhance survival and growth. Addis Ababa, UN. ECA. https://hdl.handle.net/10855/25038 [Accessed: 16 September 2020]

New, M. 2002. Climate change and water resources in the south Western Cape, South Africa. *South African Journal of Science* 98: 369-376.

Newcomer, E., Boyd, C., Nyirenda, L., Opong, E., Marquez, S. and Holm, R. 2017. Reducing the burden of rural water supply through greywater re-use: a case study from northern Malawi. *Water Science and Technology: Water Supply* 17(4): 1088-1096. https://doi.org/10.2166/ws.2017.004

Nicholson, F.A., Smith, S.R., Alloway, B.J., Carlton-Smith, C. and Chambers, B.J. 2003. An inventory of heavy metals inputs to agricultural soils in England and Wales. *Science of* *the Total Environment* 311(1–3): 205-219. https://doi.org/10.1016/s0048-9697(03)00139-6

Nolde, E. 2000. Greywater re-use systems for toilet flushing in multi-storey buildings-over ten years' experience in Berlin. *Urban Water* 1: 275-284. https://doi.org/10.1016/s1462-0758(01)00002-4

Norton-Brandao, D., Scherrenberg, S.M. and van Lier, J.B. 2013. Reclamation of used urban waters for irrigation purposes-A review of treatment technologies. *Journal of Environmental Management* 122: 85-98. https://doi.org/10.1016/j.jenvman.2013.03.012

Noutsopoulus, C., Andreadakis, A., Kouris, N., Charchousi, D., Mendrinou, P., Galani, A. and Mantziaras, I. 2018. Greywater characteristics and loadings-physicochemical treatment to promote re-use. *Journal of Environmental Management* 216: 337-346. https://doi.org/10.1016/j.jenvman.2017.05.094

Nussbaum, M. 2000. Women and Human Development: The Capabilities Approach. Cambridge University Press, Cambridge.

Ogallo, L., Stuth, J., Galu, G., Rutachokozibwa, V., Maunder, N., Ottichilo, W., Kasana, D., Wheeler, R. and Tesfayohannes, M. 2002. Factors affecting food availability and access. Greater Horn of Africa Food Security Bulletin, Issue No 7: 1-7. https://fews.net/sites/default/files/documents/reports/East_200211en.pdf [Accessed: 26 July 2021].

Oh, K.S., Leong, J.Y.C., Poh, P.E., Chong, M.N. and Lau, E.V. 2018. A review of greywater recycling related issues: Challenges and future prospects in Malaysia. *Journal of Cleaner Production* 171: 17-29. https://doi.org/10.1016/j.jclepro.2017.09.267

Onyele, O.G. and Anyanwu, E.D. 2018. Human health risk assessment of some heavy metals in a rural spring, South-eastern Nigeria. *African Journal of Environment and Natural Science Research* 1(1): 15-23.

Oshunsanya, S.O. 2018. Introductory Chapter: Relevance of Soil pH to Agriculture. https://www.intechopen.com/books/soil-ph-for-nutrient-availability-and-crop-performance/introductory-chapter-relevance-of-soil-ph-to-agriculture [Accessed: 17 February 2021].

Oteng-Peprah, M., Acheampong, M.A. and de Vries, N.K. 2018b. Greywater characteristics, treatment systems, re-use strategies and user perception—a review. *Water, Air and Soil Pollution* 229(8): 255. https://doi.org/10.1007/s11270-018-3909-8

Oteng-Peprah, M., Acheampong, M.A. and de Vries, N.K. 2019. Predicting greywater re-use for potable and non-potable purposes in a developing country – a theory of planned behaviour approach. *Desalination and Water Treatment* 142: 56-64. https://doi.org/10.5004/dwt.2019.23414

Oteng-Peprah, M., de Vries, N.K. and Acheampong, M.A. 2018a. Greywater characterization and generation rates in a peri urban municipality of a developing country. *Journal of Environmental Management 206*: 498-506. https://doi.org/10.1016/j.jenvman.2017.10.068

Ourimbah, V.B. 2011. Irrigation Water quality: factsheet. Department of Primary Industries. NWS Government.

Pais, G., Jayaram, K. and Van Wemelen, A. 2020. Safeguarding Africa's food systems through and beyond the crisis. McKinsey & Company. https://www.mckinsey.com/featured-insights/middle-east-and-africa/safeguarding-africas-food-systems-through-and-beyond-the-crisis. [Accessed: 15 August 2021].

Palmquist, H. and Hanaeus, J. 2005. Hazardous substances in separately collected grey and black water from ordinary Swedish households. *Sci Total Environ*. 348,151–163.

Pandey, A., Singh, M., Srivastava, R.K. and Vasudevan, P. 2011. Pollutant removal potential, growth and nutritional characteristics of short rotation woody crops in greywater vegetation filter system. *Journal of Scientific and Industrial Research* 70: 610-615.

Parsons, L.R. 2009. Reclaimed Water for Homeowner Irrigation. The Institute of Food and Agricultural Sciences (IFAS), University of Florida.

Pawlak, K. and Kołodziejczak, M. 2020. The Role of Agriculture in Ensuring Food Security in Developing Countries: Considerations in the Context of the Problem of Sustainable Food Production. *Sustainability* 12: 5488. https://doi.org/10.3390/su12135488

Pedredo, F., Kalavrouziotis, I., Alarćon, J.J., Koukoulakis, P. and Asano, T. 2010. Use of treated municipal wastewater in irrigated agriculture—review of some practices in

Spain and Greece. *Agric. Water Manag.* 97: 1233–1241. https://doi.org/10.1016/j.agwat.2010.03.003

Penning de Vries F.W.T. and Djitèye M.A. 1991. La productivité des pâturages sahéliens: une étude des sols, des végétations et de l'exploitation de cette ressource naturelle. (The productivity of Sahelian rangelands, a study of soils, vegetations, and exploitation of this natural resource), *Agric. Res. Rep.* 918.

Pereira, L.S., Cordery, I. and Lacovides, L. 2002. Coping with water scarcity. International Hydrological Programme. Technical Documents in Hydrology No. 58. UNESCO, Paris. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.127.8374&rep=rep1&type=pdf [Accessed: 16 September 2020]

Pescod, M.B. 1985. "Wastewater Treatment and Use in Agriculture," FAO Irrigation and Drainage Paper No. 47, FAO, Rome.

Petrik, A., Thiombanea, M., Limaa, A., Albanesea, S., Buscherb, S.T. and de Vivo, B. 2018. Soil contamination compositional index: A new approach to quantify contamination demonstrated by assessing compositional source patterns of potentially toxic elements in the Campania Region (Italy). *Applied Geochemistry* 96: 264-276. https://doi.org/10.1016/j.apgeochem.2018.07.014

Pham, T.T.N., Ngo, H.H., Guo, W.S., Dang, H.P.D., Mainali, B., Johnston, A. and Listowski, A. 2011. Responses from general community to the possible use of recycled water from washing machines: a case study in Sydney, Australia. *Resources, Conservation and Recycling* 55: 535-40. https://doi.org/10.1016/j.resconrec.2011.01.004

Pinto, U. and Maheshwari, B.L. 2010. Reuse of greywater for irrigation around homes in Australia: understanding community views, issues and practices. Urban Water Journal 7(2): 141-153.

Pinto, U., Maheshwari, B. and Grewal, H. 2010. Effects of greywater irrigation on plant growth, water use and soil properties. *Resources, Conservation and Recycling* 54: 429-435. https://doi.org/10.1016/j.resconrec.2009.09.007

Pinto, U. and Maheshwari, B.L. 2015. Sustainable graywater reuse for residential landscape irrigation – a critical review. *Chinese Journal of Population Resources and Environment* 13(3), 250-264

Planet Ark. 2008. Garden Safe Laundry Powders. http://products.planetark.org/paproducts/greywater.cfm [Accessed: 26 June 2018].

Po, M., Kaercher, J.D. and Nancarrow, B.E. 2003. Literature review of factors influencing public perceptions of water re-use. CSIRO Land and Water Technical Report 54/03. https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.197.423&rep=rep1&type=pdf [Accessed: 20 July 2021].

Po, M., Nancarrow, B., Leviston, Z., Porter, N., Syme, G. and Kaercher, J. 2005. Predicting Community Behavior in Relation to Wastewater Re-use: What Drives Decisions to Accept or Reject? CSIRO Land and Water, Melbourne.

Porob, S., Craddock, H.A., Motro, Y., Sagi, O., Gdalevich, M., Ezery, Z., Davidovitch, N., Porter, N.B., Leviston, Z., Nancarrow, B.E., Po, M. and Syme, G.J. 2005. Interpreting householder preferences to evaluate water supply systems: an attitudinal model, CSIRO: Water for a healthy country national research flagship. Land and Water: Perth.

Porter, N.B., Leviston, Z., Nancarrow, B.E., Po, M. and Syme, G.J. 2005. Interpreting householder preferences to evaluate water supply systems: an attitudinal model, CSIRO: Water for a healthy country national research flagship. Land and Water: Perth.

Pratt, A.N. 2015. The challenge of increasing agricultural productivity in Africa south of the Sahara. IFPRI. https://www.ifpri.org/blog/challenge-increasing-agricultural-productivity-africa-south-sahara. [Accessed: 16 August 2021].

Prodanovic, V., Hatt, B., McCarthy, D. and Deletic, A. 2020. Green wall height and design optimisation for effective greywater pollution treatment and re-use. *J. Environ. Manag.* 261: 110173. https://doi.org/10.1016/j.jenvman.2020.110173

Qadir, M., Sharma, B.R., Bruggeman, A., Choukr-Allah, R. and Karajeh, F. 2007. Non-conventional water resources and opportunities for water augmentation to achieve food security in water scarce countries. *Agriculture and Water Management* 87(1): 2-22. https://doi.org/10.1016/j.agwat.2006.03.018

Qadir, M., Wichelns, D., Raschid, I., McCornik,P.G., Drechsel, P., Bahri, A. and Minhas, P.S., 2009. The challenges of wastewater irrigation in developing countries. *Agric. Water Manage.* 97(4): 561-568. https://doi.org/10.1016/j.agwat.2008.11.004

Queensl, H. 2003. Department of Local Government, Planning, Sport, Recreation and Plumbing and Wastewater Code, Report. Government Printer. Pretoria.

Radingoana, M.P., Dube, T. and Mazvimavi, D. 2020a. Progress in greywater re-use for home gardening: opportunities, perceptions and challenges. *Physics and Chemistry of the Earth* 116: 102853. https://doi.org/10.1016/j.pce.2020.102853

Radingoana, M.P., Dube, T. and Mazvimavi, D. 2020b. An assessment of irrigation water quality and potential of reusing greywater in home gardens in water-limited environments. *Physics and Chemistry of the Earth* 116: 105827. https://doi.org/10.1016/j.pce.2020.102857

Rashidi, M. and Seilsepour, M. 2008. Modelling of soil exchangeable sodium percentage based on soil sodium adsorption ratio. *Journal of Agricultural and Biological Sciences* 3: 22-26.

Raskin, P., Hansen, E., Zhu, Z. and Stavisky, D. 2009. Simulation of water supply and demand in the Aral Sea region. *Water International* 17(2): 55-67.

Raude, J., Mutua, B., Chemelil, M. and Sleytr, K. 2009. Characterisation of urban and peri-urban greywater of Nakuru municipality, Kenya. 34th WEDC Conference in Addis Ababa, Ethiopia.

Redwood, M. 2008. Greywater irrigation: Challenges and opportunities. In CAB Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources; CAB International: London, UK, 2008; No. 063. https://doi.org/10.1079/pavsnnr20083063

Reichman, S.M. and Wightwick, A.M. 2013. Impacts of standard and 'low environmental impact' greywater irrigation on soil and plant nutrients and ecology. *Applied Soil Ecology* 72: 195-202. https://doi.org/10.1016/j.apsoil.2013.07.012

Reisch, L.A., Spash, C.L. and Bietz, S. 2008. Sustainable consumption and mass communication: A German experiment. Canberra, Australia: Commonwealth Scientific and Industrial Research Organisation (CSIRO), Socio-Economic and Environment in Discussion (SEED) Working Papers.

Ren, X., Zhang, Y. and Chen, H. 2020. Graywater treatment technologies and reuse of reclaimed water for toilet flushing. *Environ. Sci. Pollut. Control Ser*. 27, 34653–34663.

Revitt D.M., Eriksson, E. and Donner, E. 2011. The implications of household greywater treatment and re-use for municipal wastewater flows and micropollutant Loads. *Water Research* 45: 1549-1560. https://doi.org/10.1016/j.watres.2010.11.027

Richards, L.A. (Eds). 1954. Diagnosis and improvements of saline and alkali soils. US laboratory staff. United States Department of Agriculture Handbook 60.

Rijsberman, F.R. 2006. Water scarcity: Fact or fiction? *Agricultural Water Management* 80(1-3): 5-22. https://doi.org/10.1016/j.agwat.2005.07.001

Ripple, W.J., Wolf, C., Newsome, T.M., Barnard, P. and Moomaw, W.R. 2019. World scientists' warning of a climate emergency. BioScience biz. https://doi.org/10.1093/biosci/biz088, 088.

Rodda, N. Carden, K. and Armitage, N. 2010. Guidelines for sustainable use of greywater in small-scale agriculture and gardens in South Africa. *Technical Report*. https://doi.org/10.4314/wsa.v37i5.10

Rodda, N., Salukazana, L., Jackson, S. and Smith, M. 2011. Use of domestic greywater for small-scale irrigation of food crops: Effects on plants and soil. *Physics and Chemistry of the Earth* 36: 1051–1062. https://doi.org/10.1016/j.pce.2011.08.002

Roesner, L., Qian, Y., Criswell, M., Stromberger, M. and Klein, S. 2006. Long-term Effects of Landscape Irrigation Using Household Greywater – Literature Review and Synthesis. Water Environment Research Foundation (WERF) and Soap Detergent Association (SDA), Washington, DC, USA. https://doi.org/10.1061/40792(173)119

Roman, A., Winker, M., Tettenborn, F. and Otterpohl, R. 2007. Informal settlements and wastewater re-use: improve of urban environment and alleviate poverty in Lima, Peru. 2nd SWITCH scientific meeting, Dan Panorama Hotel, Tel-Aviv, Israel.

Romero, A., González, I. and Galán, E. 2012. Trace elements absorption by citrus in a heavily polluted mining site. *Journal of Geochemical Exploration* 113: 76-85.

Romero-Baena, A.J., González, I. and Galán, E. 2018. Soil pollution by mining activities in Andalusia (South Spain)—the role of Mineralogy and Geochemistry in three case studies. *Journal of Soils Sediments* 18: 22-31. https://doi.org/10.1007/s11368-017-1898-7

Ronen, Z. and Moran-Gilad, J. 2020. Quantification and characterization of antimicrobial resistance in greywater discharged to the environment. *Water* 12: 1460. https://doi.org/10.3390/w12051460

Roson, R. and Damania, R. 2017. The macroeconomic impact of future water scarcity. An assessment of alternative scenarios. *Journal of Policy Modelling*, https://doi.org/10.1016/j.jpolmod.2017.10.003.

Rudnick, R.L. and Gao, S., 2003. Composition of the Continental Crust. *Treatise on Geochemistry* 3: 1-64. https://doi.org/10.1016/b0-08-043751-6/03016-4

Ruel, M.T., Garrett, J., Yosef, S. and Olivier, M. 2017. Urbanization, Food Security and Nutrition. In: de Pee S., Taren D., Bloem M. (eds) Nutrition and Health in a Developing World. *Nutrition and Health. Humana Press, Cham* 705-735. https://doi.org/10.1007/978-3-319-43739-2_32

Rusan, M.J.M., Hinnawi, S. and Rousan, L. 2007. Long term effect of wastewater irrigation of forage crops on soil and plant quality parameters. *Desalination* 215: 143-152. https://doi.org/10.1016/j.desal.2006.10.032

Ryan, A.M., Spash, C.L. and Measham, T.G. 2009. Socio-economic and psychological predictors of domestic greywater and rainwater collection: evidence from Australia. *Journal of Hydrology* 379(1): 164-171. https://doi.org/10.1016/j.jhydrol.2009.10.002

Saghir, J. and Santoro, J. 2018. Urbanisation in sub-Saharan Africa: meeting challenges by bridging stakeholders. Center for Strategic and International Studies. Washington DC.

Sall, O. and Takahashi, Y. 2006. Physical, chemical and biological characteristics of stored greywater from unsewered suburban Dakar in Senegal. *Urban Water J.* 3,153–164.

Saloua, R., Barbara, R., Mohammed, M., Abdelaziz, B. and Mohammed, Y.K. 2012. Climate change impacts on water supply and demand in Rheraya Watershed (Morocco), with potential adaptation strategies. *Water* 4(1): 28-44. https://doi.org/10.3390/w4010028

Salukazana, L., Jackson, S., Rodda, N., Smith, M., Gounden, T., Mcloed, N. and Buckley, C. 2005. Re-use of greywater for agricultural irrigation. Paper presented at the 3rd

International Conference of Ecological Sanitation, 23-26 May 2005, Durban, South Africa.

Sanchez P.A. and Swaminathan, M.S. 2005. Cutting World Hunger in Half. *Science* 307 (5708): 357-359 DOI:10.1126/science.1109057

Sarwar, N., Imran, M. and Shaheen, M.R. 2017. Phytoremediation strategies for soils contaminated with heavy metals: modifications and future perspectives. *Chemosphere* 171: 710-721. https://doi.org/10.1016/j.chemosphere.2016.12.116

Schoerder, H. and Balassa, J.J. 1963. Cadmium: Uptake by vegetables from superphosphate in soil. *Science* 140 (3568): 819-820.

Schulze, R.E. 1997. South African Atlas of Agrohydrology and Climatology. WRC Report no. TT82/96. Water Research Commission, Pretoria.

Seckler, D., Barker., R. and Amarasinghe, A. 1999. Water Scarcity in the Twenty-first Century. *International Journal of Water Resources Development* 15(1-2): 29-42.

Sen, A. 1981. Poverty and Famines: An Essay on Entitlement and Deprivation. Oxford University Press, Oxford.

Sen, A. 1997. Editorial: Human capital and human capability. *World Development* 25(12): 1959-1961. https://doi.org/10.1016/s0305-750x(97)10014-6

Sen, A.K. 2000. Consequential evaluation and practical reason. *Journal of Philosophy* 97: 9.

Sepuru, T.K. and Dube, T. 2018. Understanding the spatial distribution of eroded areas in the former rural homelands of South Africa: Comparative evidence from two new non-commercial multispectral sensors. *International Journal of Applied Earth Observation and Geoinformation* 69: 119-132. https://doi.org/10.1016/j.jag.2018.02.020

Serdeczny, O., Adams, S., Baarsch, F., Coumou, D., Robinson, A. and Hare, W. 2016. Climate change impacts in sub-Saharan Africa: from physical changes to their social repercussions. *Regional Environmental Change* 15(18): 1-19. https://doi.org/10.1007/s10113-015-0910-2

Shaheen, N., Irfan, N.M., Khan, I.N., Islam, S., Islam, M.S. and Ahmed, M.K. 2016. Presence of heavy metals in fruits and vegetables: Health risk implications in Bangladesh. *Chemosphere* 152: 431-438. https://doi.org/10.1016/j.chemosphere.2016.02.060

Shaikh, I.N. and Ahammed, M.M. 2020. Quantity and quality characteristics of greywater: a review. *J. Environ. Manag.* 261: 110266. https://doi.org/10.1016/j.jenvman.2020.110266

Sharvelle, S., Roesner, L., Qian, Y., Stomberger, M. and Azar, M.N. 2012. Long-term study on landscape irrigation using household greywater – Experimental study. The Urban Water Centre, Colorado State University. http://www.aciscience.org/docs/graywater%20report%202012.pdf [Accessed: 6 June 2018].

Schoen, M.E., Xue, X., Wood, A., Hawkins, T.R., Garland, J. and Ashbolt, N.J. 2017. Cost, energy, global warming, eutrophication and local human health impacts of community water and sanitation service options. *Water Research* 109, 186–195.

Shi, K.W., Wang, C.W. and Jiang, S.C. 2018. Quantitative microbial risk assessment of Greywater on-site re-use. *Sci Total Enviro* 635: 1507–1519, https://doi.org/10.1016/j.scitotenv.2018.04.197.

Shi, T.R., M.J. and Wu, F.Y. 2019. Mass balance-based inventory of heavy metals inputs to and outputs from agricultural soils in Zhejiang Province, China. *Sci. Total Environ*. 649: 1269-1280. https://doi.org/10.1016/j.scitotenv.2018.08.414

Shiklomanov, I.A. 1999. World water resources: modern assessment and outlook for the 21st century. Summary of world water resources at the beginning of the 21st century, prepared in the framework of the IHP UNESCO. Federal Service of Russia for Hydrometeorology and Environmental Monitoring. State Hydrological Institute. St. Petersburg.

Shimeles, A., Verdier-Chouchane, A. and Boly, A. 2018. Introduction: understanding the challenges of the agricultural sector in sub-saharan Africa. In: Shimeless, A., Verdier-Chouchane, A., Boly, A. (Eds.), Building a Resilient and Sustainable Agriculture in Sub-saharan Africa. Palgrave MacMillan, Cham, Switzerland, pp. 1–12.

Siambi, M., Simalenga, T., Mpandeli, N.S., Liphadzi, K., Mailula, N., Mkhari, J. and Ramugondo, R., 2007. Increased food security and income in the Limpopo Basin through integrated crop, water and soil fertility options and public-private partnerships. In: Proceedings of the CGIAR Challenge Program on Water and Food. Addis Ababa, Ethiopia.

Siggins, A. Burton, V., Ross, C., Lowe, H. and Horswell, J. 2016. Effects of long-term greywater disposal on soil: A case study. *Science of the Total Environment* 557-558: 627-635. https://doi.org/10.1016/j.scitotenv.2016.03.084

Sillmann, J., Kharin, V.V., Zweiers, F.W., Zhang, X. and Bronaugh, D. 2013. Climate extreme indices in the CMIP5 multi-model ensemble. Part 2: future climate projections. *J Geophys Res Atmos* 118(6):1–55.

Smith, H.M., Rutter, P. and Jeffrey, P. 2015. Public perceptions of recycled water: A survey of visitors to the London 2012 Olympic Park. *Journal of Water Re-use and Desalination* 5(2): 189-195. https://doi.org/10.2166/wrd.2014.146

Sörme, L. and Lagerkvist, R. 2002. Sources of heavy metals in urban wastewater in Stockholm. *Science of the Total Environment* 298(1-3): 131-145. https://doi.org/10.1016/s0048-9697(02)00197-3\

Spychala, M., Niec, J., Zawadzki, P., Matz, R. and Nguyen, T.H. 2019. Removal of volatile solids from greywater using sand filters. *Appl. Sci.* 770, 2–13.

Stern, P.C. 2000. Toward a coherent theory of environmentally-significant behaviour. *Journal of Social Issues* 56: 407-424. https://doi.org/10.1111/0022-4537.00175

Stevens, D., Dillon, P., Page, D., Warne, M. and Ying, G.G. 2011. Assessing environmental risks of laundry detergents in greywater used for irrigation. *Journal of Water Re-use and Desalination* 1(2): 61-77. https://doi.org/10.2166/wrd.2011.027

Stoffers, P., Glasby, G.P., Wilson, C.J., Davis, K.R. and Watter, P., 1986. Heavy metal pollution in Wellington Harbour. New Zealand.

Stronkhorst, L., Trytsman, G., Breytenbach, F., Matlou, M., Kidson, M., Lotter, L. and Pollard, C. 2009. Report: Local Level Land Degradation Assessment in the Mphanama Village, Agricultural Research Council – Institute for Soil, Climate and Water Report No: GW/ A/2009/69 Project No: GW/56/017.

Syme, G.J., Nancarrow, B.E. and Seligman, C. 2000. The evaluation of information campaigns to promote voluntary household water conservation. *Evaluation Review* 24(6): 530-578. https://doi.org/10.1177/0193841x0002400601

Szabolc, I. and Darab, C. 1964. The Influence of Irrigation Water of High Sodium Carbonate Content of Soils, Proceedings of 8th International Congress of ISSS 2: 803-812.

Tacoli, C. 2017. Food (in) security in rapidly urbanising, lo-income contexts. *International Journal of Environmental Research and Public Health* 14(12): 1554. https://doi.org/10.3390/ijerph14121554

Tariq, F.S. 2021. Heavy metals concentration in vegetables irrigated with municipal wastewater and their human daily intake in Erbil city. *Environmental Nanotechnology, Monitoring and Management* 16: 100475. https://doi.org/10.1016/j.enmm.2021.100475

Taukobong, H.F.G., Kincaid, M.M., Levy, J.K., Bloom, S.S., Platt, J.L., Henry, S.K. and Darmstadt, G.L. 2016. Does addressing gender inequalities and empowering women and girls improve health and development programme outcomes? *Health Policy Plann.* 31, 1492–1514. https://doi.org/10.1093/heapol/czw074.

Tewari, G. and Pande, C. 2013. Health risk assessment of heavy metals in seasonal vegetables from north-west Himalaya. *Afr J Agric Res* 8(23): 3019-24.

Tian, Y., Wu, H., Zhang, G., Wang, L., Zheng, D. and Li, S. 2020. Perceptions of ecosystem services, disservices and willingness-to-pay for urban green space conservation. *J Environ Manage.* 260:110140. DOI:10.1016/j.jenvman.2020.110140.

Tissington, K., Dettmann, M., Langford, M., Dugard, J. and Conteh, S. 2008. Water Services Fault Lines, An Assessment of South Africa's Water and Sanitation Provision across 15 Municipalities, Executive Summary, Centre for Applied Legal Studies (CALS), Johannesburg, Centre on Housing Rights and Evictions (COHRE), Geneva and Norwegian Centre for Human Rights (NCHR), Oslo.

Todaro, M.P. and Smith, S.C. 2000. Intermediate Microeconomics, 9th Edition. Alan, USA.

Tostensen, A., Tvedten, I. and Vaa, M. 2001. Associational life in African cities – popular responses to the urban crisis. Stockholm: Elanders Gotab. https://doi.org/10.2307/1514989

Toze, S. 2006. Water re-use and health risks – real vs. perceived. *Desalination* 187: 41-51. https://doi.org/10.1016/j.desal.2005.04.066

Travis, M.J., Weisbrod, N. and Gross, A. 2008. Accumulation of oil and grease in soils irrigated with greywater and their potential role in soil water repellency *Science of the Total Environment* 394: 68-74. https://doi.org/10.1016/j.scitotenv.2008.01.004

Travis, M.J., Wiel-Shafran, A., Weisbrod, N., Adar, E. and Gross, A. 2010. Greywater re-use for irrigation: Effect on soil properties. *Science of the Total Environment* 408(12): 2501-2508. https://doi.org/10.1016/j.scitotenv.2010.03.005

Turner, R.D.R, Warne, M.S.J., Dawes, L.A., Vardy, S. and Will, G.D. 2016. Irrigated greywater in an urban sub-division as a potential source of metals to soil, groundwater and surface water. *J. Environ. Manag.* 183: 806–817. https://doi.org/10.1016/j.scitotenv.2019.03.073

Turner, R.D.R., Will, G.D., Dawes, L.A., Gardner, E.A. and Lyons, D.J. 2013. Phosphorus as a limiting factor on sustainable greywater irrigation. *Science of the Total Environment* 456-457: 287-298. https://doi.org/10.1016/j.scitotenv.2013.02.061

U.S. Environmental Protection Agency. 1991. Human Health Evaluation Manual, Supplemental Guidance: Standard Default Exposure Factors; USEPA: Washington, DC, USA.

U.S. Environmental Protection Agency. 2010. Recommended Use of BW3/4 as the Default Method in Derivation of the Oral Reference Dose.

United Nations (UN). 2012. South Africa: Demographic profile 1950–2025. http://esa.un.org/unup/unup/p2k0data.asp [Accessed: 11 November 2018].

UN. 2017. Habitat III- New Urban Agenda. http://habitat3.org/ [Accessed: 01 September 2021]

UNDESA/PD. 2012. World urbanisation prospects: The 2011 Revision. New York: United Nations.

United Nations Educational, Scientific and Cultural Organisation (UNESCO), 2000. Water use in the world. Present situation/future needs. www.unesco.org/science/waterday2000/water_use_in_the_world.htm. [Accessed: 17 June 2018].

United Nations Framework Convention on Climate Change (UNFCCC). 2007. Climate Change: Impacts, Vulnerabilities and Adaptations in Developing Countries. UNFCCC. 2009. Least Developed Countries under the UNFCCC.

USEPA IRIS (US Environmental Protection Agency)'s Integrated Risk Information System 2011. Environmental Protection Agency Region I, Washington DC 20460. http://www.epa.gov/iris/ [Accessed: 5 July 2021].

USEPA-NATA. 2017. U.S. Environmental Protection Agency National Air Toxics Assessment (NATA). Glossary of Terms. https://www.epa.gov/national-airtoxics-assessment/nata-glossary-terms [Accessed: 11 August 2021].

Valipour, M. and Singh, V.P. 2016. Global Experiences on Wastewater Irrigation: Challenges and Prospects. In: Maheshwari B., Thoradeniya B. and Singh V.P. (eds) Balanced Urban Development: Options and Strategies for Liveable Cities. Water Science and Technology Library,72. Springer, Cham. https://doi.org/10.1007/978-3-319-28112-418

van Ittersum, M.K., van Bussel, L.G.J., Wolf, J., Grassini, P., van Wart, J., Guilpart, N., Claessens, L., de Groot, H., Wiebe, K., et al. 2016. Can sub-Saharan Africa feed itself? Proceedings of the National Academy of Sciences of the United States of America. https://doi.org/10.1073/pnas.1610359113

Van Rensburg, L.D., de Clercq, W.P., Barnard, J.H. and du Preez, C.C. 2011. Salinity guidelines for irrigation: case studies from Water Research Commission projects along the Lower Vaal, Riet, Berg and Breede Rivers. *Water SA* 37(5): 739-750. https://doi.org/10.4314/wsa.v37i5.11

Van Rensburg, W.J., van Averbeke, W., Slabbert, R., Faber, M., van Jaarsveld, P., van Heerden, I., Wenhold, F. and Oelofse, A. 2007. African leafy vegetables in South Africa. *Water SA* 33: 317-326. https://doi.org/10.4314/wsa.v33i3.180589

van Schalkwyk, B., Schoeman, C. and Cilliers, J. 2014. The interface between rural communities in South Africa and their urban counterparts: the significance for sustainable rural community development in the Vaalharts area. *Transactions on Ecology and the Environment* 191: 453-462. https://doi.org/10.2495/sc140381

Van Schalkwyk, B.B. 2015. Challenges in realising sustainable community development in rural South Africa. Agriculture, Forestry and Fisheries. Special Issue: Planning for Sustainable Communities: Green-Spaces in Rural Areas 4(4-1): 73-79. https://doi.org/10.11648/j.aff.s.2015040401.19

Varol, M. 2011. Assessment of heavy metal contamination in sediments of the Tigris River (Turkey) using pollution indices and multivariate statistical techniques. *Journal of Hazardous Materials* 195: 355-364. https://doi.org/10.1016/j.jhazmat.2011.08.05.1

Vizy, E.K. and Cook, K.H. 2012. Mid-twenty-first-century changes in extreme events over Northern and Tropical Africa. *Journal of Climate Change* 25: 5748-5767. https://doi.org/10.1175/jcli-d-11-00693.1

Vollset, S.E., Goren, E., Yuan, C.W., Cao, J., Smith, A.E., Hsiao, T., Bisignano, C., Azhar, G.S., Castro, E., Chalek, J., Dolgert, A.J., Frank, T., Fukutaki, K., Hay, S.I., Lozano, R., Mokdad, A.H., Nandakumar, V., Pierce, M., Pletcher, M., Robalik, T., Steuben, K.M., Wunrow, H.Y., Zlavog, B.S. and Murray, C.J.L. 2020. Fertility, mortality, migration, and population scenarios for 195 countries and territories from 2017 to 2100: a forecasting analysis for the Global Burden of Disease Study. Lancet. https://doi.org/10.1016/S0140-6736(20)30677-2.

Vörösmarty, C.J., McIntyre, P.B., Gessner, M.O., Dudgeon, D., Prusevich, A., Green, P. and Davies, P.M. 2010. Global threats to human water security and river biodiversity. *Nature* 467(7315): 555–561. https://doi.org/10.1038/nature09440

Vuppaladadiyam, A.K., Merayo, N., Prinsen, P., Luque, R., Blanco, A. and Zhao, M. 2019. A review on greywater re-use: quality, risks, barriers and global scenarios. *Rev Environ Sci Biotechnol*. 18 (1): 77–99. https://doi.org/10.1007/s11157- 018-9487-9.

Wachirawongsakorn, P. 2015. health risk assessment via consumption of PB and CD contaminated vegetables collected from fresh markets in the lower north of Thailand. Human and Ecological Risk Assessment 22: 3 https://doi.org/10.1080/10807039.2015.1095631

Wallace, J.S. 2000. Increasing agricultural water use efficiency to meet future food production. Elsevier Science B.V, NPP.

Wang, Y. and Jiao, J.J. 2012. Origin of groundwater salinity and hydro geochemical processes in the confined quaternary aquifer of the Pearl River Delta, China. *Journal of Hydrology* 438-439: 112–124. https://doi.org/10.1016/j.jhydrol.2012.03.008

WHO (World Health Organization) and UNICEF (United Nations Children’s Fund). 2006. Meeting the MDG drinking water and sanitation target: the urban and rural challenge of the decade. WHO/UNICEF, Geneva and New York, 41.

WHO (World Health Organization), UNICEF (United Nations Children's Fund) and WSSCC (Water Supply and Sanitation Collaborative Council). 2000. Global Water Supply and Sanitation Assessment 2000 Report, WHO/UNICEF, Geneva and New York, 80.

WHO. 2005. "A Regional Overview of Wastewater Management and Re-use in the Eastern Mediterranean Region," World Health Organization, Regional Office for the Eastern Mediterranean Regional, California Environmental Health Association.

WHO. 2006. Guidelines for the Safe use of Wastewater, Excreta and Greywater. Volume 2: Waste Water in Agriculture. WHO, Geneva, 177-182.

WHO. 2008. Using Human Waste Safely for Livelihoods, Food Production and Health: Information Kit on the 3rd Edition of the Guidelines for the Safe Use of Wastewater, Excreta and Greywater in Agriculture and Aquaculture; WHO, FAO: New York, NY, USA.

Wiel-Shafran, A., Ronen, Z., Weisbrod, N., Adar, E. and Gross, A. 2006. Potential changes in soil properties following irrigation with surfactant-rich greywater. *Ecological Engineering* 26(4): 348-354. https://doi.org/10.1016/j.ecoleng.2005.12.008

Wilcox, L.V. 1955. Classification and use of irrigation waters. US Department of Agriculture Circular 969, Washington, DC, p 19.

Winblad, U., Simpson-Hebert, M. and Calvert, P. 2004. Ecological sanitation revised and enlarged edition. Stockholm Environment Institute, Stockholm.

Winward, G.P., Avery, A.M., Frazer-Williams, 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 re-use. *Ecological Engineering* 32(2): 187-197. https://doi.org/10.1016/j.ecoleng.2007.11.001

Winward, G.P., Avery, L.M., Stephenson, T. and Jefferson, B. 2008b. Chlorine disinfection of grey water for reuse: effect of organics and particles. *Water Res.* 42: 483–491.

World Bank. 2013. Development indicators database; analysis by authors.

World Bank. 2015. Regional dashboard: poverty and equity, sub-Saharan Africa.

World Economic Forum (WEF). 2020. The Global Risks Report 2020. World Economic Forum.

Wu, S., Zhou, S. and Li, X., 2011. Determining the anthropogenic contribution of heavy metal accumulations around a typical industrial town: Xushe, China. *J. Geochem. Explor*. 110: 92-97. https://doi.org/10.1016/j.gexplo.2011.04.002

Wuana, R.A. and Okieimen, F.E. 2011. Heavy metals in contaminated soils: a review of sources, chemistry, risks and best available strategies for remediation. ISRN Ecology. https://doi.org/10.5402/2011/402647

Xinchun, C., Mengyang, W., Xiangping, G., Yalian, Z., Wu Nan, G. and Weiguanga, W. 2017. Assessing water scarcity in agricultural production system based on the generalized water resources and water footprint framework. *Science of the Total Environment* 609: 587-597. https://doi.org/10.1016/j.scitotenv.2017.07.191

Xue, X., Zhao, Y. and Zhao, X. 2014. Sources of heavy metal pollution in agricultural soils of a rapidly industrializing area in the Yangtze Delta of China. *Ecotoxicol. Environ. Saf*. 108: 161-167. https://doi.org/10.1016/j.ecoenv.2014.07.001

Yang, J., Lv, F., Zhou, J., Song, Y.Y. and Li, F. 2017. Health risk assessment of vegetables grown in contaminated soil in Daye City of Hubei Province, China. *Sustainability* 9: 1-14. https://doi.org/10.3390/su9112141

Yashni, G., Mohammed, R.M.S.R., Al-Gheethi, A. and Arifin, S.N.H. 2020. Discharge quality of bathroom greywater effects on soil and treatment by solar water distillation. *Materials Today: Proceedings* 31(1): A98-A105 https://doi.org/10.1016/j.matpr.2020.12.1082.

Zamuz, S., Munekata, P.E.S., Dzuvor, K.O., Zhang, W., Sant'Ana, A.S. and Lorenzo, J.M. 2021. The role of phenolic compounds against Listeria monocytogenes in food. A Review. *Trends in Food Science and Technology* 110: 385-92. https://doi.org/10.1016/j.tifs.2021.01.068

Zavadil, J. 2009. The effect of municipal wastewater irrigation on the yield and quality of vegetables and crops. *Soil and Water Research* 4(3): 91-103. https://doi.org/10.17221/40/2008-swr

Zheng, N., Wang, Q., Zhang, X., Zheng, D., Zhang, Z. and Zhang, S. 2007. Population health risk due to dietary intake of heavy metals in the industrial area of Huludao city, China. *Sci Total Environ*. 387: 96-104. https://doi.org/10.1016/j.scitotenv.2007.07.044

Zhong, T., Xue, D., Zhao, L. and Zhang, X. 2018. Concentration of heavy metals in vegetables and potential health risk assessment in China. *Environmental Geochemistry and Health* 40: 313-322. https://doi.org/10.1007/s10653-017-9909-6

Zhu, N., Wang, C., Yip, A.C.K. and Tsang, D.C.W. 2015. Highly effective degradation of sodium dodecylbenzene sulphonate and synthetic greywater by Fenton-like reaction over zerovalent iron-based catalyst. *Journal of Environmental Technology* 6(11): 1423-1432. https://doi.org/10.1080/09593330.2014.992481

Zipf, M.S., Pinheiro, I.G. and Conegero, M.G. 2016. Simplified greywater treatment systems: slow filters of sand and slate waste followed by granular activated carbon. *J. Environ. Manag*. 17: 119-127. https://doi.org/10.1016/j.jenvman.2016.03.035