Master Thesis
TVVR 19/5003

Onsite greywater treatment for reuse at Zandspruit informal settlement in Johannesburg

Tendai H Madzaramba

Division of Water Resources Engineering
Department of Building and Environmental Technology
Lund University

Onsite greywater treatment for reuse at Zandspruit informal settlement in Johannesburg

By:

Tendai Hardwork Madzaramba

Master Thesis

Division of Water Resources Engineering
Department of Building & Environmental Technology
Lund University
Box 118
221 00 Lund, Sweden

Water Resources Engineering
TVVR-19/5003
ISSN 1101-9824

Lund 2019
www.tvrl.lth.se

Master Thesis

Division of Water Resources Engineering
Department of Building & Environmental Technology
Lund University
Box 118
221 00 Lund, Sweden

English title:	Onsite greywater treatment for reuse at Zandspruit informal settlement in Johannesburg
Author:	Tendai Hardwork Madzaramba
Supervisor:	Miklas Scholz
Examiner:	Kamshat Tussupova
Language	English
Year:	2019
Keywords:	Greywater generation, greywater treatment, greywater reuse, wastewater reuse, informal settlements

Acknowledgements

This research has been produced during my scholarship period at Lund University, funded by the Svenska Institutet through the Swedish Institute Study Scholarships (SISS) in Category 1 for studies within Master's programme in Water Resources Engineering.

I am also grateful to the Swedish International Centre for Local Democracy (ICLD) for the grant to conduct fieldwork at Zandspruit informal settlement in Johannesburg South Africa.

I would like to extend my appreciation to Professor Miklas Scholz my Academic Supervisor and Guide throughout the course of this degree project. His assistance and encouragement is priceless. Besides, l will forever cherish the opportunity l had to conduct my fieldwork abroad under his watch.

I do wish to thank my Examiner Dr Kamshat Tussupova for her precious time.

I would also like to thank my External Supervisor Sam Van Staden and the Department of Civil Engineering Science at University of Johannesburg for taking me in. The experience was quite fascinating.

I am also thankful to my friends and family for their continuous support through the perilous journey of academic life.

Finally, Glory be to God Almighty my Creator and Keeper who makes all things possible. Indeed, the steps of the righteous are ordered by the Lord.

Abstract

The urban landscape in South Africa is marred by informal settlements. Nearly a quarter of its population lives in shacks and do not have access to sufficient clean water and improved sanitation. The aim of the present study was to ascertain household daily water consumption and quantify the amount of greywater generated at Zandspruit slums. Another objective was to assess perceptions and user acceptability towards treated greywater reuse in urban slums. Overly, the study endeavour to elucidate the potential benefits of greywater reuse in informal settlements. The author used a systematic literature review and administered a survey questionnaire to fulfil these objectives. The survey was conducted between the 1st of February and the 29th of March 2019.

Zandspruit settlement has the capacity to produce significant amount of greywater for reuse. Observed daily water consumption varies from 40 – 400 L/du.d. With a mean return factor of 0.62 a medium-sized family will produce an average of 121 litres per day. 83% of the residents accept reuse of treated greywater for non-potable purposes. A further 69% expressed willingness to reuse treated greywater for drinking and cooking. The implementation of onsite greywater treatment and reuse will certainly unlock socioeconomic benefits and enhance water availability to some of the poorest people in South Africa.

Table of Contents

List of Tables

List of Figures

Acronyms

BOD: Biochemical Oxygen Demand

COD: Chemical Oxygen Demand

EU: European Union

FAO: Food and Agriculture Organisation

GW: Greywater

HGW: High Strength Greywater

LEDC: Low Economically Developed Countries

LGW: Low Strength Greywater

MEDC: More Economically Developed Countries

SS: Suspended Solids

TSS: Total Suspended Solids

WHO: World Health Organisation

UN: United Nations

USEPA: United States Environmental Protection Agency

1. Background

Access to sufficient clean water and improved sanitation is the mark of global civilisation. It distinguishes the More Economically Developed Countries (MEDCs) and Low Economically Developed Countries (LEDCs), affluence and poverty, planned settlements and slums. In the developing world the development of water supply and sanitation services has not kept pace with urbanisation and population growth. In Sub-Saharan Africa for instance, 35% of the population do not have access to improved reliable drinking water sources and 695 million of a global 2.4 billion people living without improved sanitation facilities live in Sub-Saharan Africa (WHO, 2015). Consequently, water-related diseases are common with over 80% directly linked to poor water and sanitation conditions (UN, 2003).

In Africa, the widening gap between the urban areas and rural communities has resulted in high demographic growth in cities and towns. An increasing number of people are moving into urban areas in search of a better lifestyle and improved social amenities (Awumbila, 2017). Nonetheless, basic services such as housing and health facilities have been overwhelmed thus perpetuating a rapid increase in living costs (Awumbila, 2017). At the same time, income levels in most African countries remain depressed. This has fuelled rapid and unplanned urban growth as residents look for least-cost alternatives.

According to the UN 15 million South Africans live in shacks (Moyo, 2016). Although Johannesburg is the commercial hub of South Africa and probably one of the richest cities in Sub-Saharan Africa, it houses numerous slums.

29% of Johannesburg residents stay in informal dwellings (Beall *et al*, 2000). In Soweto for instance, only 46 per cent of the population live in ex-council houses but as many as 30 per cent live in tiny backyard structures and shacks (Beall *et al*, 2000).

The financially restrained metro municipality of Johannesburg is not only finding it difficult to keep up with the land and housing needs of a burgeoning population but still face the huge task of trying to improve access to clean water and sanitation services in slums. The much publicised water crisis in South Africa is not only affecting Cape Town. Johannesburg authorities have consistently requested residents to reduce their water consumption patterns as the city is at risk of running dry due to years of drought, inadequate infrastructure, and excessive water use (Brand, 2018).

The informal settlements are the hardest hit as many people have to walk a long way to the only available water tapes installed in their vicinity to get water. Women and children often bear the brunt of fetching water as their often queue daily for many hours.

As the impact of climate variability and anthropogenic activities worsen, water resources face enormous pressure, resulting in local authorities not prioritising low income communities in as far as water provision is concerned. There is therefore a need for urban planners and engineers to rethink urban water management with a focus on reuse, water-use efficiency and equitable distribution.

1.1 Problem formulation

Poor water and sanitation service provision characterises numerous communities in Johannesburg. In planned settlements, water and sanitation services are often poorly developed and maintenance works neglected, further paralysing service provision. At Zandspruit informal settlement, access to sufficient clean water and basic sanitation is limited. Households do not have piped water and are served by a public tap or standpipe and commune sanitation services. For most of the day there is no sufficient clean water for daily chores.

In Johannesburg informal settlements are densely populated and have no planned infrastructure hence the expansion of water infrastructure at Zandspruit is hindered. Nonetheless, a least-cost onsite greywater treatment system for reuse can be used to supplement freshwater supply at Zandspruit.

Greywater (GW) requires treatment to remove contaminants and pathogens. Typical raw grey water characteristics do not conform to effluent quality standards for reuse for instance USEPA (2004) and FAO (1985). Besides, storing grey water for 48 hours at 19 to 26 ºC severely deteriorates its quality (Dixon *et al.*, 1999); biological degradation produces malodorous compounds, causing an "aesthetic problem" (Kourik, 1991; Van der Ryn *et al*, 1995; Christova-Boal *et al.*, 1995; Dixon *et al.*, 1999) and result in pathogen growth (Christova-Boal *et al.*, 1995; Rose *et al.*, 1991).

Greywater treatment and reuse is a topical research thrust which has been covered by several authors. Most of the work focuses on planned settlements and the affluent society and to a lesser extent slums.

1.2 Research objectives

The main objectives of this degree project are:

i. To ascertain household water consumption per day and quantify the amount of greywater produced at Zandspruit slums.

ii. To assess perceptions and acceptability towards treated greywater reuse in urban slums.

The minor objectives of the study are:

iii. To elucidate the potential benefits of greywater reuse in informal settlements.

iv. To review suitable treatment train for onsite greywater treatment for reuse in slums.

1.3 Relevance of study

This study is significant because of the following aspects:

- Limited research on reuse of treated greywater in urban slums.
- Development of sustainable onsite greywater treatment technologies promotes a technological revolution and fosters socio-economic linkages in low income communities.
- It is an opportunity to break barriers, wastewater reuse is almost a taboo in most African societies.
- The threat of increased global water scarcity in this century and beyond requires participatory water management approaches.

1.4 Limitations

Zandspruit informal settlement is a haven of violence and lawlessness as such access to certain sections of the neighbourhood is restricted.

1.5 Study area

Zandspruit is an informal settlement located at 26.0102° S and 27.9410° E in Northern Johannesburg along Beyers Naude Drive in Honeydew. Honeydew is in Region C of the Johannesburg Metropolitan Municipality in Gauteng Province, South Africa.

The settlement has an estimated total area of 1 km^2 and a population of 65 000 people mostly children, teenagers and young adults (Impophomo, 2016). As such, the area is a haven for drug abuse, hooligans and gangsterism. Besides, the settlement is faced with a plethora of social ills such as alcoholism, teenage pregnancy, HIV/AIDS, rampant poverty and limited access to basic social amenities (Impophomo, 2016).

Figure 1: City of Johannesburg.

(Courtesy of Municipalities of South Africa, 2019)

1.6 Procedure

Recent studies have been used to comprehend the current research trajectory with reference to global water scarcity, onsite greywater treatment and suitability of alternate sources of freshwater in urban areas particularly in low income communities. The literature study was refined by the author using a survey administered at Zandspruit informal settlement. Data analysis was then undertaken using Microsoft Excel.

1.7 Adjustment of work plan

After commencing fieldwork in Johannesburg, the author had to readjust the objectives to suit the new reality. Initially the author intended to construct and make an evaluation of the performance of a simple greywater treatment model in terms of effluent quality and to quantify water use and greywater generation through field measurements at Zandspruit. The change in approach was necessitated by a rather slow flow of support materials and resources. Besides, the initial scope of the project demanded a lengthy period (at least a year of running tests) to realise conclusive results. The degree project study period is only twenty weeks.

1.8 Definition of terms

In this study the following definitions have been adopted:

Shack refers to a miniature dwelling typically made of metal or wood.

A **compound** is a yard or plot which houses at least two shacks and averages 200 m^2.

Household is a family of at least two members living in the same dwelling (shack).

Household size refers to the number of people living in the same dwelling.

Standpipe refers to an outdoor water tape.

A commune sanitation facility is a shared system for collection and disposal of human excreta.

Sewered settlement is a community with a network of conduits to carry off wastewater for disposal or stabilisation

In South Africa an **informal settlement** is an unplanned settlement on land which has not been surveyed or proclaimed as residential, consisting mainly of shacks (Graham, 2003). In South Africa informal settlements are typically identified on the basis of the following characteristics: illegality and informality; inappropriate locations; restricted public and private sector investment; poverty and vulnerability; and social stress (DHS, 2009).

Urban slum is defined by the Department of Housing as "erstwhile settlements that have degenerated to such an extent that there exists a need to rehabilitate them to acceptable levels" and as well as being "loosely used to refer to an informal settlement" (Department of Housing, KwaZulu-Natal, 2002). In this study the later has been adopted. Infact the author uses the terms slum, informal settlement, low income community and township interchangeably.

2. Greywater perspectives

As global water scarcity is anticipated to worsen in this century as a result of climate variability and high demographic growth water users are increasingly facing restrictions in water use. In South Africa, the dual effect of restrictions and intermittent water supply has led to use of alternate water sources particularly in affluent suburbs (Nel *et al*, 2017). The traditional alternate water sources include groundwater abstraction, rainwater harvesting, storm water use and greywater reuse. Residents utilise supplementary water for purposes where water quality is not normally prioritised such as gardening and toilet flushing (Nel *et al*, 2017; Botha, 2017; Mukheibir et al., 2014). The use of untreated water from alternate sources, for instance greywater, however contributes to environmental degradation and poses risk to human health (Nel *et al*, 2017; Govender *et al*, 2011, Carden *et al*., 2017).

Greywater reuse is a significant source of supplementary water that can be used in slums and help propel the vision of the South African government to provide basic water and sanitation services across the country. Nonetheless it requires treatment as it is most likely to have high faecal contaminants especially in households with children under the age of three. It is widely accepted that microbial population in standard greywater is minimal; nonetheless significant pathogen growth during storage has been reported (Christova-Boal *et al*., 1995; Rose *et al.*, 1991). Furthermore, microbial threshold for greywater is contested. Besides, knowledge of the pathogen content of greywater is limited (Khalaphallah R, 2012).

2.1 Domestic greywater generation

Greywater is the component of domestic wastewater that is generated from washing dishes, laundry and bathing (Ludwig, 1997; Eriksson *et al*, 2002). It constitutes up-to 75% of household wastewater generation depending on climatic pattern, physical location and affluence (Hernandez Leal *et al*., 2010). Typical domestic wastewater composition is shown in Figure 1 below. GW represents a potential supplementary water source that would otherwise be lost to the environment. The amount of greywater generated at a household, however varies due to size of the household, water-use patterns, climate variability and season of the year (Siang Oh *et al*, 2018; de Gois *et al*., 2015). Furthermore, greywater generation in slums varies considerably depending on access to freshwater supply.

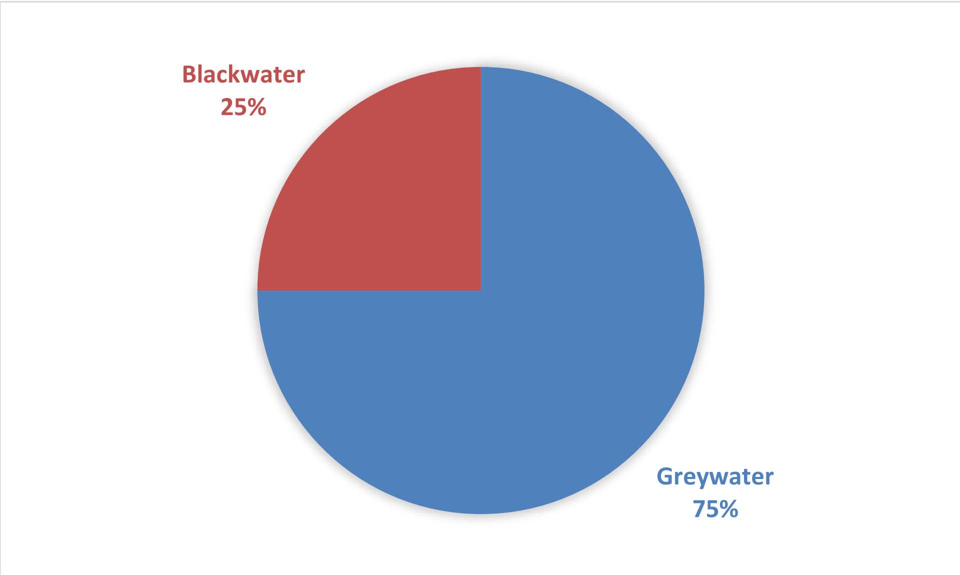

Figure 2: Typical household wastewater composition.

2.1.1 Greywater generation in informal settlements of South Africa.

The generation of sullage is dependent on level of service provision, environmental and health risk awareness of the residents (Carden *et al*, 2007). Carden *et al,* (2007) observed water consumption of between 20 - 200 litres per dwelling per day (L/du·d) and an average of 104 L/du·d. This translates to 6000 L per household per month of which greywater amounts to 4500 L/month, assuming a return factor of 75% (Hernandez Leal *et al.*, 2010; Eriksson *et al*, 2002).

In a similar study of greywater generation in four informal settlements in the Ekurhuleni Metropolitan Municipality in Gauteng, Mofokeng (2008), found out that the average volume of greywater produced varies from 7 to 173 litres per household per day and approximately 2 to 40 Lpcd.

Water consumption in low income communities in SA depends on the availability of stand pipes and likewise, the amount of GW generated.

2.2 Greywater characteristics

GW composition is highly varied and complex (Ghaitidak and Yadav, 2013). Studies show a considerable variation of GW constituents and moreso inconsistency in GW characterisation. The chemical and microbial constituents of greywater are influenced by several factors. Viz are source type, lifestyle, socio-cultural orientation of the residents and water availability and its consumption (Khalaphallah R, 2012; Ghaitidak and Yadav, 2013).

Besides, it has been observed by Carden *et al*, (2007) that GW generated in densely populated slums is heavily polluted than in low density settlements.

Carden *et al*, (2007), carried out an analysis of the greywater characteristics in densely populated low income areas in six SA provinces, including Gauteng. The sextet reported that raw GW is unsuitable for reuse as it is heavily polluted from the use of domestic chemicals and detergents which alters crop growth and distorts soil physical conditions when used for irrigation. Furthermore, the tested GW samples contained considerable microbial population (1 800 organisms/100 mL) indicating significant faecal contamination. Besides, contrary to established research Mofokeng (2008) reported the presence of E-Coli in laundry GW above set limits of wastewater or effluent in SA. Table 1 shows typical greywater characteristics.

GW contains significant amounts of readily biodegradable organic materials namely nitrates and phosphates and their derivatives, and microbes such as faecal coliforms and salmonella (Oteng-Peprah *et al*, 2018). Lately, pharmaceuticals and heavy metals have been detected (Oteng-Peprah *et al*, 2018; Eriksson *et al*, 2010; Aonghusa and Gray, 2002; Eriksson *et al*, 2003).
In terms of physical constituents, GW has significantly high temperatures ranging from 18-35°C and TSS of 190–537 mg/L (Oteng-Peprah *et al*, 2018; Jeppersen & Solley, 1994). Electrical conductivity (EC) of GW depends on the water source and is typically between 14 and 2000 μS/cm (Eriksson *et al*, 2002). Groundwater and old water conveyance systems produce GW with high EC values (Oteng-Peprah *et al*, 2018).

Table 1:Typical greywater characteristics

Parameter	Unit	Carden *et al*, (2007)	Eriksson, *et al*. (2002)	Källerfelt & Nordberg (2004)	Jepperson & Solley (1994)
pH	-	3.3 - 10.9	5.0 - 8.7	6.1 - 7.0	6.6-8.7
Conductivity	mS/cm	28 - 1 763	32 - 2 000	83 - 132	325-1140
COD	mg/L	32 - 11 451	13 - 549	530 - 3 520	100-633
Suspended solids	mg/L	-	6.4 - 330	69.0 - 1 420	45 - 330
TKN	mg/L	0.6 - 488.0	2.1 - 31.5	-	-
NH_3-N	mg/L	0.2 - 44.7	0.03 - 25.4	-	-
BOD_5	mg/L	-	-	-	9 - 290
Turbidity	NTU	-	-	-	22 - >200
Tot-N	mg/L	-	-	-	2.1-31.5
Tot-P	mg/L	-	-	-	0.6-87

2.3 Greywater reuse regulations

2.3.1 International standards and guidelines

The acceptance of treated greywater by residents is restricted by lack of relevant water quality standards for reuse (Lazarova *et al*., 2003). Li *et al*., (2009) observed that there is no internationally accepted wastewater reuse guidelines except national standards that are used to monitor quality. Such national guidelines consistently vary across states and between countries depending on need, intended use and social factors (Li *et al*., 2009; Pidou, 2006). Environmental Protection Agency of the US has stricter guidelines compared to the EU standards (Boyjoo *et al*, 2013). Most EU states use the European bathing water standards as GW guidelines (European Environment Agency, 2012).

The first widely recognised reuse guidelines for agricultural purposes were released by the Food and Agriculture Organisation (FAO) in 1985. These regulations were later corroborated by the World Health Organisation (WHO) in the year 2006. Li et al., (2009) however, observed that the regulations only consider microbiological constituents that is the number of Helminth eggs and E. coli, and is silent on physico-chemical parameters. Furthermore, the published guidelines are for recycled municipal wastewater and require revision to suit treated greywater.

2.3.2 South Africa greywater regulations

The South African government recognises the importance of GW reuse particularly for irrigation, toilet flushing and numerous other non-potable purposes. Nonetheless, GW reuse is not regulated and there is no piece of legislation that provides standards and guidelines of GW reuse and management in SA. The National Water Act of 1998 and the Water Services Act, No. 108 of 1997 do not specifically mention greywater and does not suggest explicit guidelines regarding GW reuse (Carden 2016). Mofokeng (2008) argues that GW is generally considered as sewage in South Africa and as such is regulated by general wastewater guidelines, however this is not adequate. Standards and guidelines of greywater reuse needs to be fully clarified.

The National Water Act as amended 2013 stipulates that GW for reuse shall conform to the National Health Act (No 61 of 2003), and users must minimize pondage and flow into neighbouring property (Government Gazette, 2017). Furthermore, the Draft National Sanitation Policy (GN 70 of 12 February 2016: Government Gazette No 39688) recommends the Minister to formulate regulations for reuse of liquids, solids and gaseous constituents of wastewater.

2.4 Implications of onsite greywater reuse

2.4.1 Water-use demand

Water scarcity is a global risk (WEF, 2014). South Africa receives mean annual rainfall of less than 500mm which results in high water stress with only 40% of its population having access to sufficient water required to maintain a healthy livelihood (Adewumi *et al*, 2010).

Onsite greywater treatment and reuse benefits users through water saving and increasing household water availability (Maimon & Gross, 2017). The UN in its 2017 Global Water Report recognises the importance of wastewater as an alternate water source which improves water availability, reduces pollution of water resources and curtails demand on investment in water infrastructure (UN 2017; Oviedo-Ocaña *et al*, 2017; Penn *et al*, 2017).

It is irrefutable that residents in low income communities are most certain to benefit as freshwater water availability is low. GW reuse supplements household water demand and provides an opportunity for low income families to grow crops at the homestead. Furthermore, Maimon and Gross (2017) argues that besides the financial benefit, GW reuse also contributes to a better environment. In slums the environment is often the sink for untreated wastewater.

The reuse of GW also reduces the domestic water budget. It is estimated that onsite GW treatment and reuse for toilet flushing reduces household consumption by 30% (Memon et al, 2015; Adel, 2012). This reduction when considered with other potential savings postpones expansion of municipal wastewater treatment infrastructure (Penn *et al*, 2017). Overly, onsite GW treatment and reuse propagates decentralised water management. Decentralised wastewater management is sustainable (Domènech *et al,* 2015; Opher *et al*, 2016) and has the potential to accelerate access to water and sanitation for all in developing countries (Bieker, *et al*., 2010; IDRC, 2010; Larsen & Maurer, 2011),

2.4.2 Social acceptability

Across the globe greywater reuse has become a common practice however, there are varied and sometimes conflicting perceptions with regard to onsite greywater treatment and reuse. The acceptance of GW reuse is influenced by several factors including engineering and environmental feasibility, intended use, the source of greywater and moreso public perception and support (Mashabela, 2015; Adewumi *et al*, 2010; Jeffrey & Jefferson, 2002).

Research indicates that non-potable GW reuse is widely accepted (Hurlimann & McKay 2007; Kantanoleon *et al.* 2007; Dolnicar & Schafer, 2006; Friedler *et al* 2006; Marks, 2004; Po *et al* 2004). The reuse of GW for outdoor use such as irrigation of golf courses and gardens has been embraced extensively particularly by high income city dwellers (Mashabela 2015, Carden *et al*, 2007). In a survey carried out at three institutions of higher learning in South Africa (University of Cape Town, University of the Witwatersrand and the University of Johannesburg) interviewees indicated notable bias towards reuse of greywater for toilet flushing as compared to irrigation citing health risks (Ilemobade *et al*, 2012).

The use of recycled water for indoor and personal use is still at minimal and somehow contentious especially for purposes that results in direct contact with the recycled water (Mashabela 2015; Jeffrey & Jefferson, 2002; Dolnicar & Schafer, 2006; Marks *et al.* 2006). Acceptance of treated GW reuse in the household decreases considerably as intended use changes from toilet flushing, laundry and bathroom to kitchen uses and drinking (Po *et al*, 2003).

The source of GW is also significant as the majority of urban residents prefer reusing their own greywater (Mashabela, 2015; Jeffrey & Jefferson, 2002) whilst those connected to commune sanitation systems prefer an anonymous and centralised system unlike a situation they are acquainted with most of the people involved (Po *et al*, 2003).

Public support and user involvement has been identified by Adewumi *et al* (2010) as a prerequisite to implementing successful GW reuse systems. Po *et al* (2003) argued that public perception and acceptance are the main ingredients for a successful reuse scheme. Residents often reject schemes if there are not involved at the onset of the project no matter the technical soundness of the system or intervention (Adewumi *et al*, 2010). Nonetheless, an understanding of the concept of personal decision making is complex and little known by planners, engineers and policy makers alike. Studies recognises that public acceptance of treated GW is influenced by socio-demographics, age, level of education, religion, water availability, cost, source of the influent, use of the effluent, environmental awareness, health risks and income (Boyjoo *et al*, 2013; Po *et al*., 2003; Friedler *et al*., 2006).

2.4.3 Public health impact

Greywater is traditionally considered a cleaner version of wastewater. Nonetheless, GW reuse might pose significant health risks, due to the presence of bacteria, viruses and other pathogenic microorganisms from faecal contamination, skin, mucus, and food preparation (Maimon & Gross, 2017). These microbes include Escherichia coli, Rotavirus, Legionella spp., and Pseudomonas aeruginosa (Benami *et al*, 2016). Moreover, storage of GW accelerates microbial growth and reduces its aesthetic quality (WERF, 2006; Yaka *et al*, 2006; Christova Boal *et al*, 1996). In the tropics and subtropics, pondage of greywater provide breeding grounds for mosquito and other vectors (Yaka *et al*, 2006).

Etchepare *et al* (2015) and Turner *et al* (2016) recognise the presence of micro-pollutants and heavy metals in GW as a source for secondary human health risks. In a similar study, Gerba and Smith (2005) assert that GW contains significant proportion of cadmium. Exposure to cadmium is associated with kidney failure as well as skeletal fractures in humans (Yaka *et al*, 2006; Gerba & Smith 1996).

Greywater disposal as a result of poor sanitation have been attributed to incidences of waterborne diseases in slums. In South Africa Mara (2001) reported that 43 000 people, die from diarrheal annually and children under the age of five are the most affected. In a related study, Stern (2004), also noted significant cases of diarrheal especially amongst children living in slums attributed to inadequate sanitation facilities.

Evaluation of simple low-cost, low tech greywater treatment systems using quantitative microbial risk assessments (QMRA) and epidemiological studies reveals that when used for irrigation effluent quality is within acceptable limits (Barker *et al*, 2013; Benami *et al*, 2016). Furthermore, direct epidemiological assessments suggest that GW reuse does not pose significant health threat if the greywater treatment process conforms to established guidelines (Maimon & Gross, 2017; Alfiya Y *et al*, 2017; O'Toole *et al*, 2012).

2.4.4 Environmental risk

Environmental risk arises due to the presence of physiochemical pollutants such as sodium, pH, surfactants and micro pollutants in greywater which leads to pollution of water resources and the soil (Maimon & Gross, 2017).

According to WERF (2006) GW may contain inordinate amounts of salts, TSS, BOD and organic nutrients that can alter soil physical and chemical properties and harm crops. Besides, the prolonged use of GW for irrigation increases soil pH, salinity and sodicity (Roesner *et al*., 2006; Wielshafran *et al*., 2006). At the same time, irrigation with greywater accelerate the accumulation of heavy metals (zinc, lead and copper) in the soil reduces soil productivity and ultimately results in stunted growth and poor yields of crops (Rattan et al, 2005).

A high content of nitrogen and phosphorus in raw greywater results in eutrophication of surface water resources (DWAF, 1999). This inevitably upsets the aquatic ecosystem and livelihoods dependent on it.

3. Greywater treatment in informal settlements

Recent studies indicate the increased presents of contaminants in domestic GW moreso in non-sewered informal settlements. On the other hand, reuse of treated GW is gaining a lot interest across the globe due to its various benefits. Nonetheless, without proper treatment GW reuse might pose public health risks and environmental pollution (Maimon, 2014).

The treatment process of GW ranges from simple onsite systems common in developing countries to advanced designs used in the developed world. The choice of GW treatment system depend on the GW characteristics (Ghaitidak and Yadav, 2013), desired effluent quality and reuse guidelines.

Water scarcity is high in SA moreso in unplanned settlements (Mofokeng, 2008). Treatment and reuse of GW is arguably a sustainable source of freshwater particularly in settlements without piped. The potential health and environmental risks associated with GW reuse demands robust treatment systems. There is need to develop appropriate treatment systems as recent studies have indicated the presence of heavy metals and emerging contaminants that poses even greater risk to public health and the environment (Bakare *et al.*, 2019)

Literature reviewed shows that a number of treatment options have been developed and promoted extensively in developed countries such as the US, Japan and Australia.

The emphasis in the developed world has been the development of GW treatment systems mainly for irrigation purposes (Carden *et al*., 2007). In developing countries GW treatment and reuse is still in its infancy and confined to high income settlements. Most of these systems, however have not been implemented in informal settlements due to space limitations, cost and inherently because municipal authorities do not incorporate informal settlements in physical planning. Besides, Jefferson *et al* (2004) asserts that the variability of organic load particularly the high BOD: COD ratio complicates the selection of suitable GW treatment system in low income communities. The selected technology therefore, should produce treated GW that meets the following criteria for reuse, hygienic safety, aesthetics, environmental tolerance and economic feasibility (Nolde, 1999).

In South Africa, GW treatment in informal settlements is considered not feasible and the focus has been on reducing the impact of GW disposal on the environment and public health (Carden *et al*., 2007). Greywater management in non-sewered communities is mainly through onsite disposal in low-medium density areas (Carden *et al*., 2007; Mashabela, 2015; Mofokeng, 2008). Disposal of untreated GW however might result in pollution of surface water resources, unlined wells, aquifers and soil degradation. Besides, pondage of GW create a reproduction niche for mosquitoes putting community health at risk. It is thus imperative to rethink greywater management in urban slums with a focus on sustainable treatment and reuse.

3.1 Greywater treatment process

In planned settlements conventional GW treatment system include pre-treatment followed by primary treatment, secondary treatment and a post treatment. Septic tanks, filter bags and screen mesh are normally used as a pre-treatment to remove solid particles, oil and grease. Nonetheless, Wurochekke *et al*. (2016) observed that there is no standard global design for GW treatment. According to Edwin (2014) GW treatment system design depends on greywater source, quality and quantity, site condition and intended reuse. The treatment process should not use chemical additives and be eco-friendly (Harju, 2010; Wurochekke *et al*., 2016).

3.1.1 Physical treatment

Physical treatment involves the removal of suspended macro-solids from the fluid through filtration and sedimentation.

In greywater treatment process filtration is pre-treatment phase which precedes biological and chemical treatment. Moreover, filtration is also a used as post-treatment before disinfection of effluent (Boyjoo *et al*., 2013; Li *et al*., 2009).

Numerous filter media can be used for pre-treatment of greywater in low income communities. This include sand bed filtration (Chaillou *et al.*.2011); nylon sock type filtration (March et al., 2004); gravel filtration (Al-Hamaiedeh & Bino, 2010); volcanic turf (Albalawneh *et al*, 2017); peat (Mohamed et al, 2014) and charcoal (Dalahmeh, 2014).

The media can be used singly, as dual media or multi-media depending on greywater composition and desired effluent quality, amongst other factors.

The filter media traps SS and COD is removed by a biofilm layer that accumulates on the filter matrix (Boyjoo *et al*., 2013; Chaillou *et al.*,2011). Physical systems however, have a low removal efficiency for nutrients and pathogens as such filtration is often used when high water quality is not desired or if the greywater is of low strength (Boyjoo *et al*. 2013; Li *et al*., 2009; Chaillou *et al.*,2011). Furthermore, organic removal rates obtained by March *et al*., (2004) and Chaillou *et al.*, (2011), that is 45% and 30% respectively, do not meet reuse standards such as USEPA (2004), FAO (1985) and WHO (2006). Low organic removal rates restrict chemical disinfection and might result in disinfection by-products (chloramines, trihalomethanes) in effluent (Al-Jayyousi, 2003). Pidou (2006) reported improved pathogen removal using a sand filter combined with activated carbon and disinfection however, removal of residual SS solids remained low (48% removal).

Toilet flushing and restricted irrigation purposes do not demand high effluent quality as such gravity filtration can be used effectively (Al-Hamaiedeh & Bino, 2010). The effluent nonetheless, contains significant amounts of E. coli and Salmonella sp. (Mandal *et al*., 2011, Boyjoo *et al*., 2013)

3.1.2 Biological treatment

Biological treatment is a technique of wastewater treatment further classified as aerobic and anaerobic treatment. Research on biological treatment of greywater in informal settlements is scant and is not mentioned at all in the literature reviewed. Biological greywater treatment system however, has been implemented extensively in sewered and high income areas.

Biological treatment systems achieve high organic and nutrient removal even in high strength GW (Boyjoo *et al*., 2013; Li *et al*., 2009). However, coarse filtration is required as a pre-treatment step. Moreover, biological systems are associated with significant microbial growth hence often include a disinfection stage as post-treatment (Boyjoo *et al*., 2013).

Biological treatment systems include biological aerated filter (BAF), membrane bioreactor (MBR), sequencing batch reactor (SBR), up flow anaerobic sludge blanket (UASB), rotating biological contactor (RBC) and the fluidised bed reactor (FBR) (Boyjoo et al., 2013). Biological systems are synonymous with relatively high cost (MBR, FBR) and energy dependence (MBR, RBC, FBR, UASB) and as such do not fit well in the context of integrated greywater management for deprived urban settlements.

3.1.3 Chemical treatment

The use of chemicals or chemical processes for GW treatment for reuse is limited (Li *et al*., 2009). Recently the use of coagulation, photo-catalytic oxidation, ion exchange, natural zeolites and adsorption by granular activated carbon (GAC) has been reported (Lin *et al*., 2005; Sostar-Turk *et al*., 2005; Pidou *et al*., 2008; *Li et al*., 2009; Widiastuti *et al*., 2011; Boyjoo *et al*., 2013). Low strength greywater (LGW) and to some extent laundry GW can be treated using chemical processes. For high strength greywater (HGW), chemicals can only be used as a post- treatment (Boyjoo *et al*., 2013).

3.1.3.1 Coagulation / Flocculation

Coagulants neutralises colloidal charges and results attraction of colloid particles. The addition of polymers creates large flocs. The agglomeration of flocs into even larger flocs of significant mass is aided by slow mixing. Coagulation and flocculation builds up large flocs that are quick to settle, as such this process is normally followed by sedimentation.

The most utilised coagulants and flocculants are metal salts such as ferric sulphate, ferrous sulphate, ferric chloride and ferric chloride sulphate. Nonetheless, chemical coagulants and flocculants produce toxic by-products such as carcinogenic compounds (Wurochekke *et al*., 2016). The use of natural coagulants Moringa oleifera, Elephantorrhiza goetzei (E. goetzei) and Strychnos potatorum has been reported. These plants produce seeds with active coagulation properties (Deshmukh *et al*., 2013; Hamid *et al*., 2014; Wurochekke *et al*., 2016; Mbiza 2019).

In terms of removal efficiency, coagulation and flocculation process using synthetic coagulants achieves 85-89% and 64% BOD and COD removal respectively (Ghaitidak *et al*., 2013).

Moreover, Ghaitidak et al (2013) reported tot-N removal of up to 13% and >99% removal of TC and E. coli. Pidou *et al*. (2008) used aluminium salt as a coagulant and obtained removal rates of COD 63%, BOD 89%, turbidity 90%, tot-N 12 % and 95% tot-P. Besides, TC and E. coli in effluent were all less than 1/100mL. The authors achieved similar results with ferric salt.

In related study, Sostar-Turk et al. (2005) combined chemical coagulation, sand filter and GAC to treat LGW from laundry. Aluminium salt was added to GW which was then filtered through a sand bed and passed onto GAC for a further removal of organics. The authors reported removal rates of 93%, 95% and 86% for COD, BOD and SS respectively. More importantly, the scholars obtained 51% BOD removal and 100% removal of SS at coagulation stage.

3.1.3.2 Natural zeolites

Naturally occurring zeolites can be used to remove contaminants in GW through adsorption, and cation exchange (Widiastuti *et al*., 2008). Widiastuti *et al* (2008) also asserts that zeolites exist abundantly across the globe and requires low cost technology GW treatment systems to be utilised. Zeolites can remove inorganic contaminants and microorganisms from wastewater with up to 97% removal of ammonium (Widiastuti *et al*., 2011).

Depending on the strength of GW, type of zeolite, particle size, etc. removal rates of 100 % for BOD, E. coli, TC and faecal coliforms have been observed (Garcia *et al*., 1992; Nikashina *et al*., 1999; Bowman, 2003).

3.1.4 Post treatment

The effluent that is obtained using the treatment process highlighted above retains significant amounts of microorganisms. Disinfection is therefore required to eliminate pathogens and produce clean and aesthetically acceptable greywater for non-potable reuse (Al-Gheethi *et al*., 2015). Post-treatment technologies include chemical (chlorination and ozonation), filtration and solar disinfection (SODIS).

3.1.4.1 Chemical disinfection

Chlorine disinfection is the commonly used post-treatment for greywater in planned settlements (March *et al*. 2004; Friedler *et al*. 2005; Lin *et al*. 2005; Chaillou *et al*., 2011). The use of chlorine however, is reported to result in soil toxicity from carcinogenic chloroforms or other halogenated organics that has a detriment effect on plants and animals (Boyjoo *et al*., 2013). Besides, the use of chemical disinfection is associated with incidences of resistance and regrowth among pathogenic bacteria and increased TDS in effluent (Al-Gheethi *et al*., 2015). The nature and prolificacy of pathogens in greywater in densely populated settlements is varied and renders chemical disinfection less sustainable for onsite treatment.

3.1.4.2 SODIS

Transparent 2 litre polyethylene-terephthalate (PET) beverage bottles can be used as a solar reactor for water disinfection by exposure to the effect of solar and UV radiation for at least 6 hours, a technique referred to as SODIS (McGuigan *et al*., 2012). SODIS is a basic and least cost method of eliminating pathogens that have been used effectively across the globe.

In the United States EPA (2015) recognises SODIS as a tool to remove pathogenic bacteria from greywater generated in residential areas. According to the WHO (2002) and Gomez-Couso *et al* (2009) the dual effect of the temperature and UV, effectively destroys pathogenic bacteria. Indeed, it has been established by the work of Pansonato *et al* (2011) that SODIS has the capacity for TC and E. coli inactivation in pre-treated greywater by >2 $\log_{10}$.

McGuigan *et al* (2012) asserts that over 5 million people in LEDC use SODIS to treat drinking water. However, the treated water should be consumed or disposed away within 24 hours. In developing countries SODIS has been used to improve drinking water quality and prevent water-related diseases such as diarrhoeal and cholera (Clasen *et al*, 2007). Informal settlements are populated by people on the extreme end of socio-economic status the use of SODIS as a post-treatment is inevitable.

The efficiency of SODIS depends on length of exposure to sunlight, solar intensity and nature of pathogenic bacteria (McGuigan *et al*., 2012; Ubomba-Jaswa *et al*., 2009).

Solar water disinfection can be enhanced by painting solar reactors in black and putting them on reflective surfaces for maximum solar insolation (Mani *et al*., 2006; Kehoe *et al*., 2001).

4. Materials and Methodology

The problem was answered using a systemic literature review and fieldwork as shown in the flow chart below.

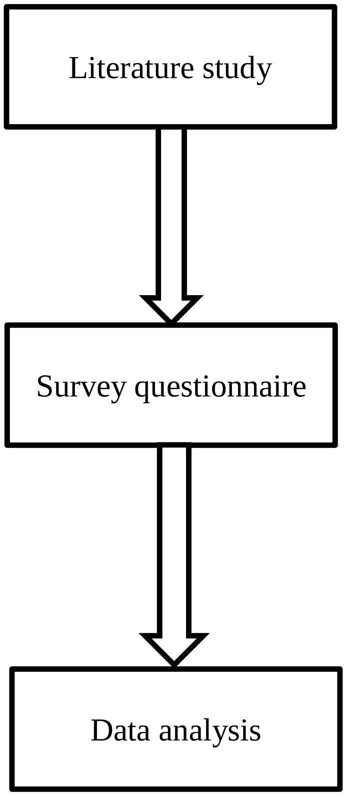

Figure 3: Methodology

4.1 Literature study

4.1.1 Review

The first part of the degree project is a literature study which outlines greywater perspectives, implications of reusing raw greywater and domestic greywater treatment train applicable to resource constrained urban dwellers living in densely populated settlements.

Furthermore, this section chronicles the potential risk and benefits of greywater reuse in urban slums according to recent studies. The following databases were used for the literature study; LUBSearch, Google Scholar, Scopus, Science Direct, Web of Science, JSTOR and Academic Search. Keywords such as greywater, greywater treatment, greywater reuse, urban water reuse, greywater treatment methods etc. were used in the search.

4.1.2 Structure of the questionnaire

A questionnaire was developed to evaluate socio-demographics, water use trends, water availability and greywater management at Zandspruit. Besides, the author also crafted questions with the intention to assess perceptions towards greywater reuse in the community. The author read the questions and respondent had to select a yes or no. About 10% of the questions were open ended. The questionnaire was administered in English.

4.2 Fieldwork

The second part of the degree project is two-fold. The initial part focuses on domestic water supply, water use trends and GW disposal practices at Zandspruit. The objective of this was to ascertain the extent of water scarcity and identify the most vulnerable members of the community. This then led to an assessment of user attitudes, perceptions and acceptability of reusing treated greywater and benefits of water reuse at Zandspruit informal settlement.

The fieldwork was carried out using a prewritten survey questionnaire that was administered in the community by the author between the 1st of February and the 29th of March 2019 inclusive of weekends. It was assumed that almost all family heads will be at home during the weekend.

The fieldwork involved a reconnaissance survey, identification of households to administer survey and conducting the survey with respondents. The purpose of the reconnaissance survey was to assess suitability of the study area for the intended research and familiarize with the neighbourhood. A random sample of 35 compounds was selected to conduct the survey. Each compound is served by one standpipe and in yard flush toilet. Besides, one compound consists of on average 8 families, making a total of 294 households covered by the survey. The sample selection was corroborated using the Cochran equation.

Each respondent had to respond to a set of prepared questions on general socio-demographics, water use and availability, access to sanitation facilities and perceptions on water reuse. See detailed questionnaire at Appendix 1. The survey was administered in English.

Cochran equation

$$N_o = \frac{Z^2 Pq}{e^2}$$

Where N_o is the sample size,

Z^2 is the abscissa of the normal curve that cuts off an area α at the tails;

(1 – α) equals the desired confidence level, e.g., 95%);

e is the desired level of precision,

P is the estimated proportion of an attribute that is present in the population, and q is 1-P.

The value for Z is found in statistical tables which contain the area under the normal curve. E.g. Z = 1.96 for 95 % level of confidence (Cochran, 1963).

In this case,

Z = 1.96

e = $\pm$ 4%

P = Proportion of in yard toilets in informal dwellings = 74% (StatsSA, 2016).

q = 16%

Thus $N_o = \frac{1.96^2(0.74\ x\ 0.16)}{0.04^2}$ = 284 housing units.

A sample selection of 35 compounds satisfies the desired sample size based on Cochran sampling technique.

4.3 Data Analysis

The collected data was compiled and analysed using Microsoft Excel spread sheet. Descriptive statistics (minimum, mean, maximum, SD, variance) were determined to summarise the results of the survey. The analysis was limited to descriptive statistics due to the nature of collected data and the scope of the present study. Besides, the collected data only represented a sample of the population.

Linear regression was used to describe the relationship between water use, greywater generation, units served by one standpipe and household size.

5. Results and Discussion

This chapter presents reflections from literature and findings from the survey conducted at Zandspruit informal settlement. The results were used to assess water use patterns and the potential for greywater generation at Zandspruit and ascertain perceptions and acceptability towards treated greywater reuse.

5.1 Greywater generation in informal slums of South Africa.

5.1.1 National context

The potential for greywater generation and reuse perceptions in sewered informal settlements in South Africa has not been comprehensively documented. Nonetheless, Carden *et al* (2007) assessed in detail water use trends and the potential for greywater generation in non-sewered of South Africa. The authors administered structured questionnaires in six provinces of South Africa including Gauteng. The on-site surveys were conducted at 39 sites over a period of one year.

In the study Carden *et al* (2007) estimated that the water consumption in non-sewered slums vary from 20 to 200 L/du.d. The consumption values obtained in this survey however vary significantly ranging from a minimum of 45 L/du.d to a maximum of 180 L/du.d as shown in Table 2 below. Nearly 85% of the 39 sites obtain water from off-site standpipes. Compounds with onsite water supply have high water consumption rates compared to households with offsite supply.

Carden *et al* (2007) and Graham (2003) argues that consumption in such areas is at least twice the water use of plots with offsite water supply.

Table 2: Greywater generation from selected informal settlements

	Settlement	Province	On-or off-site water	Average per capita water use (Lpcd)	Average household water use (L/du.d)	Average household greywater produced (L/du.d)
1	Clanwilliam	Western Cape	Off	25	65	50
2	Redhill		Off	18	75	60
3	Fairyland		Off	13	75	55
4	Kleinmond		Off	19	105	80
5	Sweet Home Farm		Off	13	70	55
6	Masiphumelele		Off	18	100	75
7	Khayelitsha		Off	15	55	40
8	Lingelethu		Off	11	65	40
9	Silverton	Eastern Cape	Off	22	70	55
10	Bongweni		Off	26	160	120
11	Orange Grove		Off	27	60	45
12	Phakamisa Park		Off	13	80	60
13	New Payne		On	17	80	60
14	Mputhi		Off	11	75	55
15	Mthento		Off	11	150	115
16	Mpathi		Off	25	100	75
17	Emahobeni		Off	12	45	35
18	Zolani	Kwazulu Natal	Off	27	85	65
19	Boboyi		Off	15	110	85
20	KwaShange		On	16	95	75
21	Emambedwini		On	11	80	60
22	Emaqedini		On	17	100	75
23	Cato Manor		Off	28	95	70
24	Leeufontein	Limpopo	Off	38	150	115
25	Manapyane		Off	20	150	115
26	Jane Furse		On	24	180	135
27	Doornkraal		Off	54	135	100
28	Mothlakaneng		Off	41	140	105
29	Seshego Zone 5		Off	27	115	85
30	New Pietersburg		Off	63	130	100
31	Mahwelereng		Off	34	145	110
32	Mashati		On	30	165	125
33	Winnie Park		Off	27	140	105
34	Tlhalampye		Off	27	130	100
35	Masakhane	Mpumalanga	Off	24	115	85
36	Doornkop		Off	22	120	90
37	Mayfield Ext	Gauteng	Off	21	95	70
38	Freedom Square		Off	42	110	80
39	Barcelona		Off	20	95	70
	Min			11	45	35
	Mean (all sites)			23	104	80
	Mean (off-site)			24	102	78
	Mean (on-site)			19	117	88
	Max			63	180	135

(*Source: Carden et al, 2007) (*Reproduced with permission from Kirsty Carden).

Carden *et al* (2007) adopted a 75% return factor, Census 2001 population data and an average household water consumption of 200 L/d to estimate the potential for greywater generation in urban slums. This corresponds to greywater generation of approximately 490 000 m^3/d which is enough to supply 50% of the daily water demand of Cape Town (Carden *et al*, 2007). The authors did not take actual measurements of water use and greywater generation.

5.1.2 Greywater generation in urban slums of Gauteng Province

In another related study, Mofokeng (2008) carried out an extensive analysis of the greywater situation in informal settlements of the Ekurhuleni metropolitan municipality - eastern region (Gauteng, South Africa). In this study the author selected four informal settlements in Gauteng namely Harry Gwala, Gugulethu, Mkhanca and Soul City for the survey. At all the sites water was obtained from standpipes except at Harry Gwala informal settlement (Table 3). Data collection involved the administration of a pre-designed questionnaire at 25 households of each study site. The survey was meant to assess water supply, wastewater management, water use and greywater disposal options.

Water fetched per household ranged from 3 - 205 L/du.d. The mean water use was 44 L/du.d. The study argued that the total water fetched per day is high when there is limited infrastructure at the compound. The maximum water fetched was observed at Gugulethu (Table 4).

This site only had one tap and residents collect water once per week to avoid queues (Mofokeng, 2008). Mkhanca had the lowest total amount of water collected per day (Table 5).

The author reported that the volume of greywater generated from informal settlements with an average of four members varies from 7 to 173 L/du.d. This translates to greywater generation of 2 - 40 Lpcd. The greywater return factor is widely distributed with some insurmountable maxima of 540% observed at Soul City (Table 6). Interestingly, at some households the greywater produced exceeds the total water fetched. 64% of the households at Gugulethu and Mkhanca informal settlements have a negative water balance whilst at Harry Gwala and Soul City the same has been noted at 44% and 56% units respectively. The collected data is based on estimates hence this disparity (Mofokeng, 2018). The detailed household water consumption and greywater generation values for the study sites are tabulated below.

The major source of greywater at all settlements understudy was laundry which contributes nearly 50% of greywater produced at Mkhanca and Soul City. Household cleaning has the least amount of greywater generate as most families normally prepare one meal per day.

Table 3: Harry Gwala water use and greywater generation

		Greywater generated						
Unit	Water fetched (L/d)	Dishes (L/d)	Bath (L/d)	Cleaning (L/d)	Laundry (L/d)	Total (L/d)	Return factor (%)	Water left (L/d)
1	*	10	10	0	7	27	*	*
2	10	6	20	0	4	30	300	-20
3	100	10	10	5	4	29	29	71
4	20	10	5	20	17	52	260	-32
5	100	4	8	3	33	48	48	52
6	25	5	10	0	11	26	104	-1
7	20	10	20	10	43	83	415	-63
8	20	5	5	0	9	19	95	1
9	100	50	20	10	6	86	86	14
10	40	4	10	20	4	38	95	2
11	20	8	8	0	6	22	110	-2
12	20	4	10	5	17	36	180	-16
13	40	15	10	5	9	39	97.5	1
14	50	4	10	5	3	22	44	28
15	*	10	20	0	3	33	*	*
16	100	15	10	5	7	37	37	63
17	60	2	10	0	6	18	30	42
18	29	18	18	0	14	50	172	-21
19	20	5	10	0	6	21	105	-1
20	20	2	4	5	7	18	90	2
21	45	10	0	5	43	58	129	-13
22	45	6	10	2.5	6	24.5	54	20.5
23	20	2	4	0	11	17	85	3
24	20	8	5	0	11	24	120	-4
25	5	2	5	0	3	10	200	-5
Min	5	2	0	0	3	10		
Mean	40	9	10	4	12	35		
Max	100	50	20	20	43	86		
Sum	929	225	252	101	290	868		
% of Total greywater		26	29	12	33	100		

*(Source: Mofokeng, 2008) (*Reproduced with permission from Nomvula Mofokeng).

Table 4: Gugulethu water use and greywater generation

		Greywater generated						
Unit	Water fetched (L/d)	Dishes (L/d)	Bath (L/d)	Cleaning (L/d)	Laundry (L/d)	Total (L/d)	Return factor (%)	Water left (L/d)
1	26	6	5	3	43	57	219	-31
2	96	6	5	1	21	33	34	63
3	29	10	10	1	9	30	103	-1
4	26	15	20	5	21	61	235	-35
5	30	45	20	15	33	113	377	-83
6	40	5	20	5	23	53	133	-13
7	205	15	20	5	23	63	31	142
8	22	10	20	10	7	47	214	-25
9	9	3	4	4	17	28	311	-19
10	25	10	20		21	51	204	-26
11	100	5	5		14	24	24	76
12	125	4	2	5	6	17	14	108
13	120	10	10	5	17	42	35	78
14	41	20	20	5	21	66	161	-25
15	29	10	20	5	4	39	134	-10
16	25	15	20		6	41	164	-16
17	100	10	20	5	14	49	49	51
18	80	10	10	10	14	44	55	36
19	50	20	20	5	14	59	118	-9
20	80	10	14	2.5	14	40.5	51	39.5
21	24	5	10		11	26	108	-2
22	60	10	20	5	11	46	77	14
23	11	5	20		6	31	282	-20
24	9	5	8	2	6	21	233	-12
25	9	10	20	5	16	51	567	-42
Min	9	3	2	1	4	17		
Mean	55	11	15	5	16	45		
Max	205	45	20	15	43	113		
Sum	1371	274	363	104	392	1133		
% of Total greywater		24	32	9	35	100		

*(Source: Mofokeng, 2008) (*Reproduced with permission from Nomvula Mofokeng).

Table 5: Mkhanca water use and greywater generation

		Greywater generated						
Unit	Water fetched (L/d)	Dishes (L/d)	Bath (L/d)	Cleaning (L/d)	Laundry (L/d)	Total (L/d)	Return factor (%)	Water left (L/d)
1	60	30	60		60	150	250	-90
2	20	2	5		3	10	50	10
3	10	2	4		2	8	80	2
4	3	2	5		3	10	333	-7
5	40	10	6		11	27	68	13
6	25	3.5	7		14	24.5	98	0.5
7	5	2	4		1	7	140	-2
8	9	10	10		9	29	322	-20
9	26	4	8		34	46	177	-20
10	100	9	10		11	30	30	70
11	11	4	7.5	2	6	19.5	177	-8.5
12	40	10	10		3	23	58	17
13	40	10	10		50	70	175	-30
14	20	10	10		50	70	350	-50
15	100	20	30	5	64	119	119	-19
16	11	10	20		14	44	400	-33
17	50	15	20		29	64	128	-14
18	14	1	6		29	36	257	-22
19	30	20	10	20	4	54	180	-24
20	80	18	12	5	26	61	76	19
21	40	10	20	10	17	57	143	-17
22	50	5	20	5	11	41	82	9
23	20	10	20		29	59	295	-39
24	80	9	20	4	17	50	63	30
25	11	4	20		17	41	373	-30
Min	3	1	4	2	1	7		
Mean	36	9	14	7	21	46		
Max	100	30	60	20	64	150		
Sum	895	231	355	51	514	1150		
% of Total greywater		20	31	4	45	100		

*(Source: Mofokeng, 2008) (*Reproduced with permission from Nomvula Mofokeng).

Table 6: Soul City water use and greywater generation

		Greywater generation						
Unit	Water fetched (L/d)	Dishes (L/d)	Bath (L/d)	Cleaning (L/d)	Laundry (L/d)	Total (L/d)	Return factor (%)	Water left (L/d)
1	17	6	6		9	21	124	-4
2	20		10		6	16	80	4
3	20	8	8	5	14	35	175	-15
4	40	5	8		14	27	68	13
5	25	4	8	2	43	57	228	-32
6	40	4	5	5	11	25	63	15
7	20	5	9	5	9	28	140	-8
8	100	30	12	4	111	157	157	-57
9	10	9	5	3	3	20	200	-10
10	60	10	10	2.5	11	33.5	56	26.5
11	20	4	8	5	9	26	130	-6
12	40	30	5	10	34	79	198	-39
13	40	30	30	10	103	173	433	-133
14	60	9	14		11	34	57	26
15	40	30	10		34	74	185	-34
16	75	10	10	10		30	40	45
17	40	15	10	5	26	56	140	-16
18	40	20	20	5	40	85	213	-45
19	90	10	20		60	90	100	0
20	75	30	50	10	75	165	220	-90
21	40	15	10	5	9	39	98	1
22	40	10	8	5	11	34	85	6
23	40	8	5	5	14	32	80	8
24	10	20	10	10	14	54	540	-44
25	60	10	5	5	1	21	35	39
Min	10	4	5	2	1	16		
Mean	42	14	12	6	28	56		
Max	100	30	50	10	111	173		
Sum	1062	332	296	112	672	1412		
% of Total greywater		24	21	8	48	100		

*(Source: Mofokeng, 2008) (*Reproduced with permission from Nomvula Mofokeng).

5.2 Findings: Zandspruit case study

5.2.1 Housing

The housing units at Zandspruit informal settlement are not uniformly planned and seem to have no predetermined layout. The units are clustered and each compound (yard or plot) averages 200 m^2. The number of households per compound varies considerably with an observed mean of 8 units. Most of the dwellings are made of metal sheets and are colloquially referred to as shacks. The shacks are closely packed on all sides. A typical dwelling at Zandspruit is shown below. A single family is housed in a one-room shack which is subdivided into miniature compartments by curtain sheets for convenience.

Figure 4: A shack at Zandspruit

5.2.2 Demographic information

Total interviewees were 35 persons each representing a compound of at least 8 families. All the respondents were adults with at least a basic level of education. Almost 50% of the respondents attained secondary education. Figure 5 shows the level of education of respondents. Nearly 40% of the interviewees are unemployed and 20% are self-employed (Figure 6).

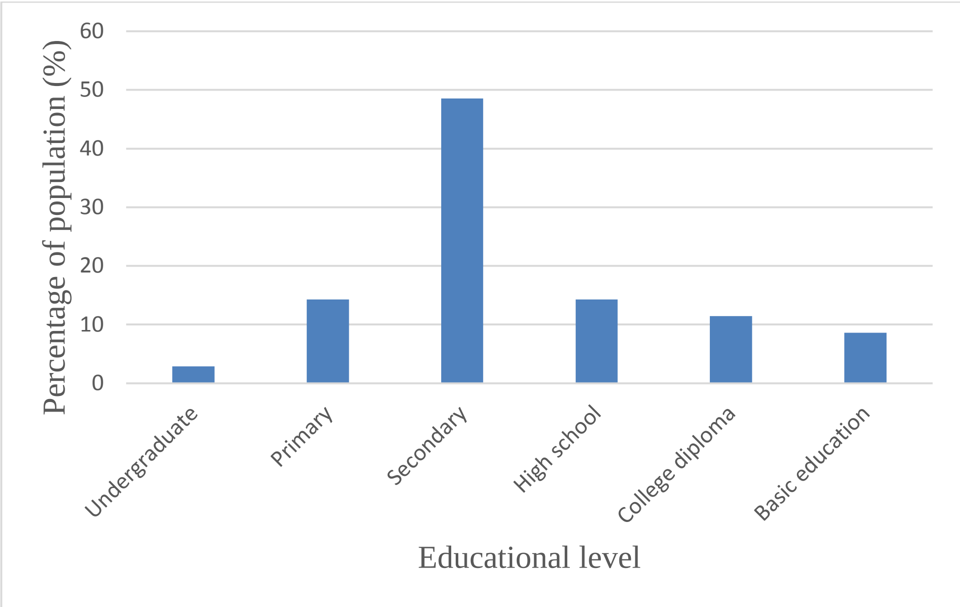

Figure 5: Educational level of respondents

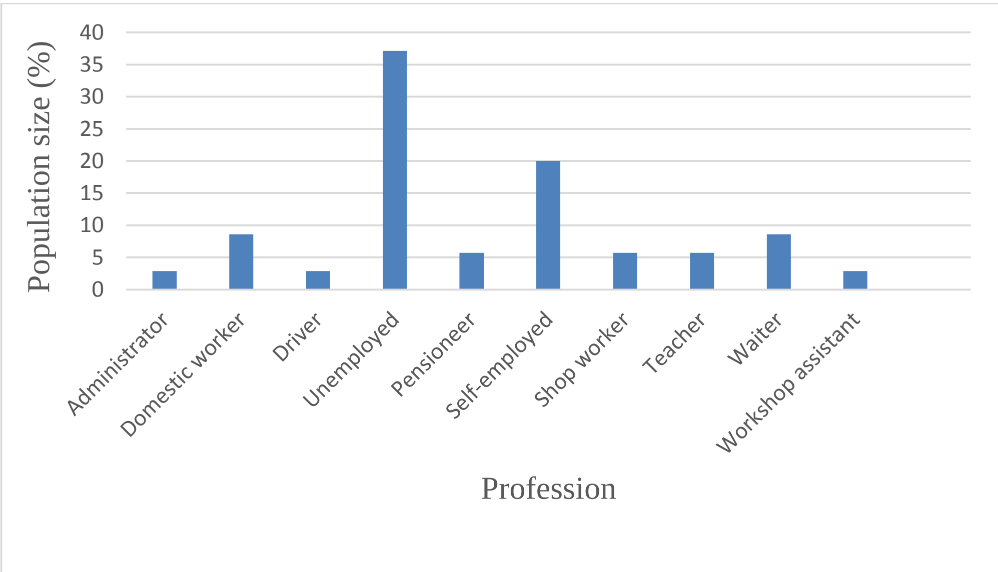

Figure 6: Profession of respondents

The age distribution of respondents varied from 19 - 76 years of which 71% were women as depicted by Figures 7 and 8. Approximately 51% (approximately 29,5 million) of the South African population is female (Stats SA, 2018). Nonetheless, at Zandspruit, the majority (38%) of the population is aged 20-40. Children under the age of 12 makes up 17% whilst toddlers, teenagers and the elderly contributes 17, 14 and 3% respectively as shown in Figures 9 and 10.

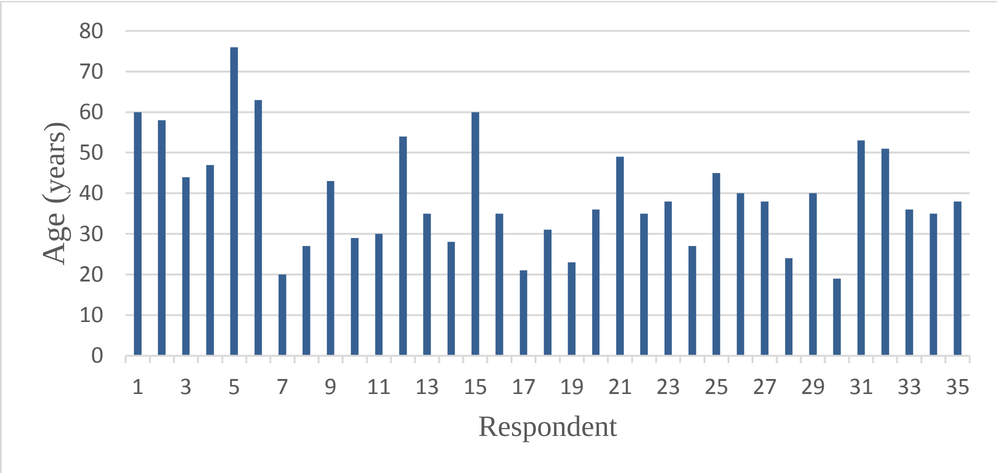

Figure 7: Age distribution of respondents.

An average family at the compound is made up of 5 members although households with 10 or more persons (Figure 11) have been observed at Zandspruit. Life expectancy at birth as of 2018 is estimated at 61,1 years for males and 67,3 years for females (Stats SA, 2018).

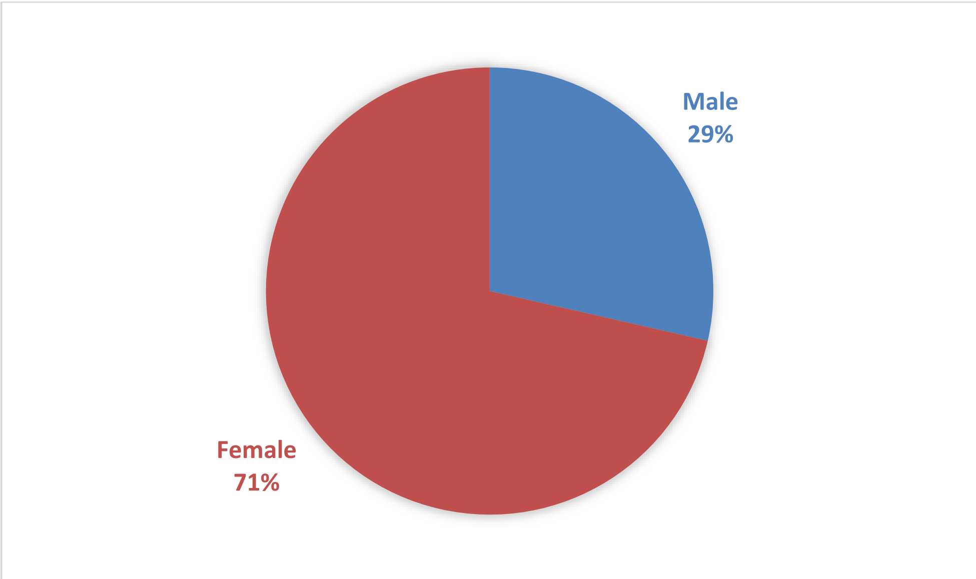

Figure 8: Gender parity.

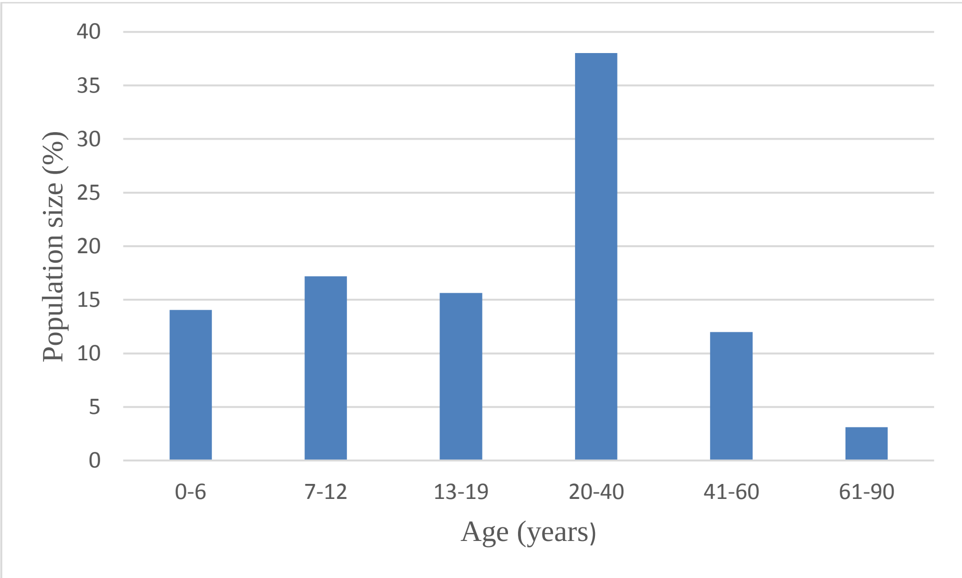

Figure 9: Sample age distribution.

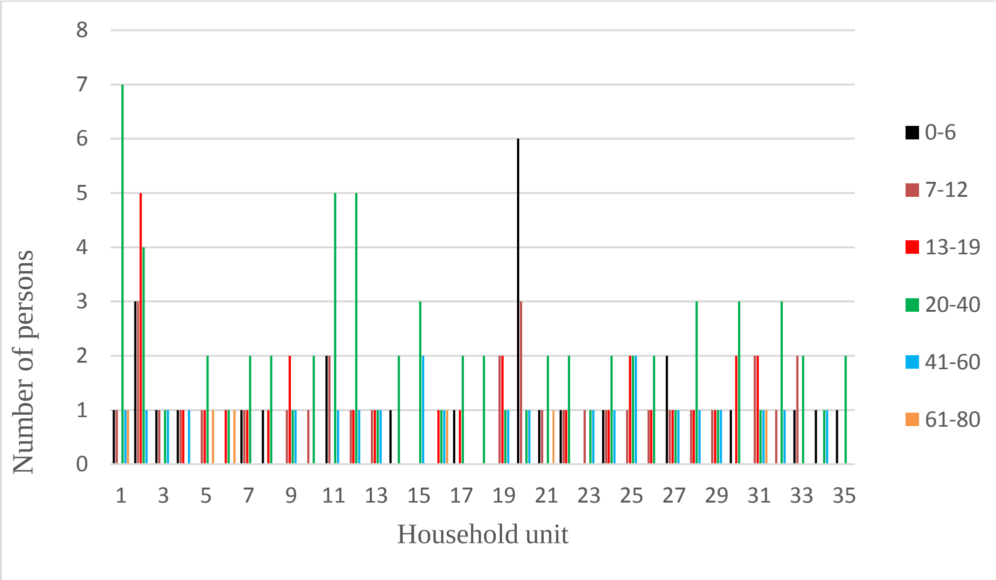

Figure 10: Number of persons per household per age distribution.

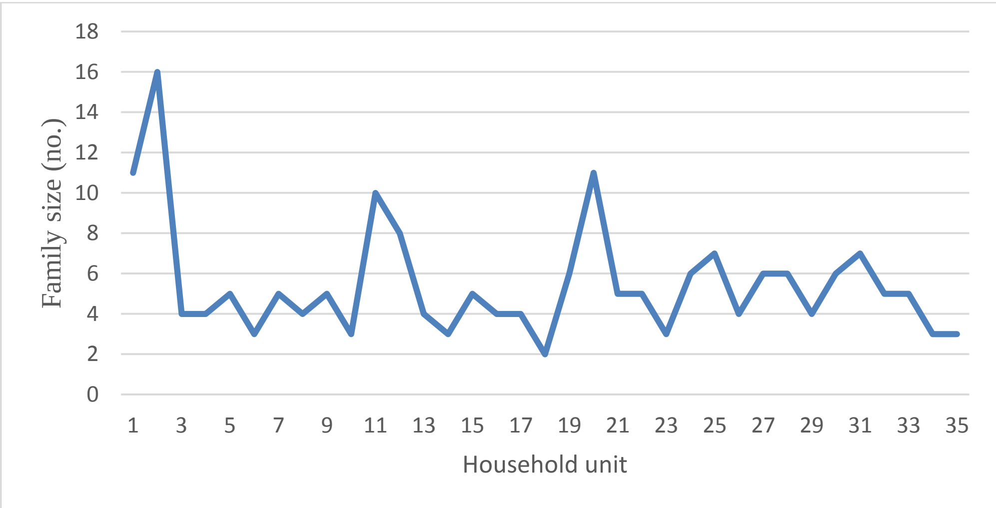

Figure 11: Family size per household.

5.2.3 Overview of water supply and sanitation

The housing units at Zandspruit are not served with indoor piped water. Municipal water supply is obtained from a standpipe installed at the compound (Figure 12). Water supply from the Municipality is intermittent. Respondents living on the upper part of the settlement (Greater Zandspruit) mentioned that supply is only available during the night and early in the morning (10 pm - 4 am). In essence, residents have no running water for almost 18 hours daily. In the lower part of Zandspruit weekends are completely dry.

Figure 12: Standpipe.

Each compound is served by one standpipe. A typical compound at Zandspruit consists an average of 8 families. The number of households served by one standpipe is shown in Figure 13 below. Visual inspection shows that many of standpipes are in derelict state and some have been cut off from supply completely.

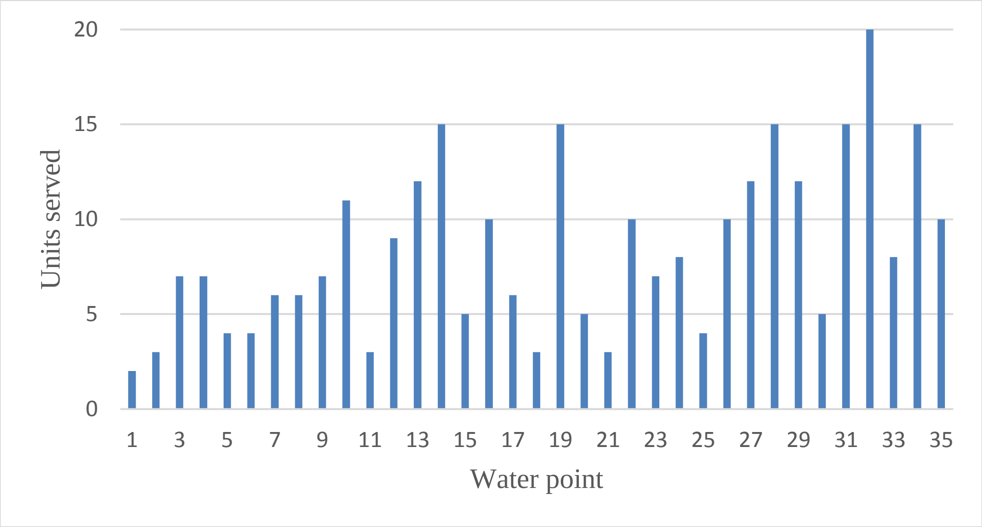

Figure 13: Number of households served by one standpipe.

The residents without functional standpipes obtain water from a local church yard and have to traverse considerable distances of between 400 m and 2000 m to get water. Respondents mentioned that they spent on average 40 minutes collecting water during peak hours.

Figure 14 below shows a commune cistern flush toilet facility used at Zandspruit informal settlement. All the compounds assessed had a commune sanitation facility.

The facility is however more of a pour-flush toilet as water is not available consistently. Residents use buckets to flush the system and washing hands after using the toilet. The commune toilet facility serves on average 8 households. Unlike water sources there is no alternate safe onsite sanitation systems at Zandspruit.

Figure 14: Cistern-flush toilet at Zandspruit.

Observations indicated that toilets are not properly cleaned probably as a result of water shortage. This poses serious health risk to children as they often use the toilet without adult supervision and on bare feet.

5.2.4 Water availability, adequacy and reliability

Nearly all the residents at Zandspruit do not have access to municipal water supply on demand. As shown in Figure 15, 68% of the population experience water unavailability daily whilst 17% do not have access to water supply at least once per week during the dry season. Between 6 and 9% reported water unavailability at least once monthly and for a prolonged time during the dry season. Furthermore 83% of the respondents said the water supply at Zandspruit is not reliable at all. The infamous rationing system is not consistent as most times the taps will be dry for most of the day. The flow pressure also is not uniform and residents living on the upper part of the settlement are the worst affected. Besides, standpipes in the same line may not have flow at the same time.

Considering the amount of water supply received at any particular time 66% of the residents at Zandspruit indicate that the water is not adequate for their daily household chores. The respondents would want to use more water. The community do not have access to alternate water sources within the compound. Members of the community depend on the local church standpipe to supplement daily requirements. This standpipe is however, an illegal connection (Mzwakhe, 2019).

5.2.5 Water consumption and greywater generation at Zandspruit

The daily water consumption per dwelling and the potential for greywater generation at Zandspruit is shown in Table 7 and 8 below. The values shown are estimates that were given by respondents and water users. The household daily water consumption varies from a minimum value of 40 L/du.d to a maximum 400 L /du.d. The daily water consumption pattern at Zandspruit is slightly on the higher side compared to the values reported by Carden *et al* (2007) of between 20 - 200 litres per dwelling per day (L/du·d). Minimum, maximum and average water consumption per capita values were 7, 120 and 42 Lpcd. The obtained daily water consumption values per dwelling and per capita water consumption however, are within the range postulated by other studies for residents without indoor piped water as illustrated in Table 9 and Table 10.

Family size and per capita water consumption at the study area is significantly high. The dual effect of these two factors is a correspondingly high household water demand observed, with a mean of 207 L/du.d. Even though the per capita water consumption at Zandspruit is above observed values at informal settlements it is still below the national average. In South Africa the mean per capita water consumption is 233 Lpcd (Table 11). Gauteng province has the highest per capita water consumption at 305 Lpcd (Mofokeng 2008; DWAF, 2017).

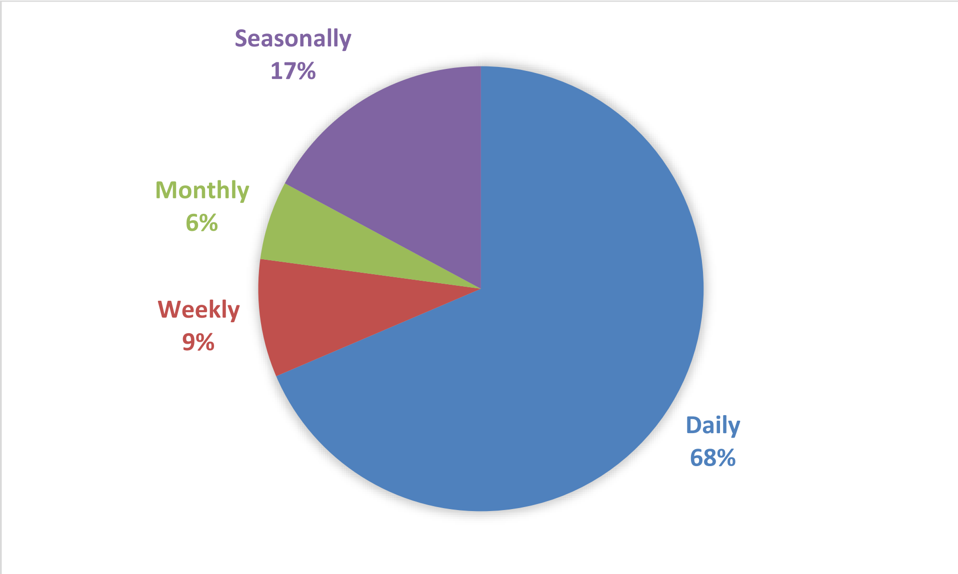

Figure 15: Water unavailability at Zandspruit.

Zandspruit has considerable potential to generate significant amount of greywater. The return factor ranges from 0.35 to 0.89 which translate to a maximum total household greywater generation of 312 L/du.d. Carden et al (2007) estimated that the average water consumption in non-sewered areas of South Africa is 104 L/du.d. This value was obtained using a small sample size and without measurements (Carden et al, 2007). In this study the average water consumption is 207 L/du.d and the corresponding greywater generation is 121 L/du.d. This figure is similar to actual measurements obtained by Stephenson *et al* (2006) and comparable to other studies as shown in Table 9.

Table 7: Household water use and greywater production.

Household unit	Family size	Daily water consumption (L/d)	Water consumption Lpcd	Household cleaning (L/d)	Washing dishes (L/d)	Bathing (L/d)	Laundry (L/week)	Laundry (L/d)	Total Household GW (L/d)	Return factor
1	11	380	35	25	10	220	400	57.14	312.14	0.82
2	16	400	25	35	10	170	500	71.43	286.43	0.72
3	4	80	20	20	10	20	80	11.43	61.43	0.77
4	4	120	30	15	10	20	80	11.43	56.43	0.47
5	5	300	60	20	15	40	200	28.57	103.57	0.35
6	3	80	27	10	10	20	140	20.00	60.00	0.75
7	5	60	12	10	15	20	40	5.71	50.71	0.85
8	4	60	15	15	10	20	40	5.71	50.71	0.85
9	5	200	40	10	15	60	115	16.43	101.43	0.51
10	3	120	40	5	5	40	120	17.14	67.14	0.56
11	10	180	18	5	3	60	160	22.86	90.86	0.50
12	8	200	25	10	20	80	130	18.57	128.57	0.64
13	4	120	30	10	5	40	50	7.14	62.14	0.52
14	3	150	50	5	5	60	100	14.29	84.29	0.56
15	5	340	68	20	20	100	200	28.57	168.57	0.50
16	4	400	100	20	10	120	350	50.00	200.00	0.50
17	4	200	50	25	10	60	140	20.00	115.00	0.58
18	2	40	20	4	2	10	80	11.43	27.43	0.69
19	6	240	40	10	10	120	100	14.29	154.29	0.64
20	11	82	7	15	5	20	120	17.14	57.14	0.70
21	5	240	48	20	40	60	100	14.29	134.29	0.56
22	5	40	8	12	8	10	40	5.71	35.71	0.89
23	3	120	40	20	20	30	120	17.14	87.14	0.73
24	6	140	23	20	10	40	80	11.43	81.43	0.58
25	7	380	54	15	15	175	400	57.14	262.14	0.69
26	4	400	100	20	40	80	160	22.86	162.86	0.41
27	6	240	40	2	4	120	200	28.57	154.57	0.64
28	6	200	33	20	20	120	80	11.43	171.43	0.86
29	4	260	65	5	30	120	155	22.14	177.14	0.68
30	6	145	24	20	5	20	280	40.00	85.00	0.59
31	7	320	46	10	40	140	390	55.71	245.71	0.77
32	5	280	56	12	60	25	148	21.14	118.14	0.42
33	5	200	40	20	20	25	135	19.29	84.29	0.42
34	3	160	53	20	20	40	100	14.29	94.29	0.59
35	3	360	120	15	30	75	240	34.29	154.29	0.43

Sewered areas receive consistent water supply that promotes high water use per capita. Due to erratic municipal water supply Zandspruit residents have adopted a stringent consumption pattern as shown by low values for different water uses in Table 7 above.

Table 8: Mean values of household water use and greywater production

Household unit	Family size	Daily water consumption (L/d)	Water consumption Lpcd	Household cleaning (L/d)	Washing dishes (L/d)	Bathing (L/d)	Laundry (L/week)	Laundry (L/d)	Total Household GW (L/d)	Return factor
Min	2.00	40.00	7.45	2.00	2.00	10.00	40.00	5.71	27.43	0.35
Mean	5.49	206.77	41.80	16.89	18.69	65.29	141.86	20.27	121.12	0.62
Max	16.00	400.00	120.00	35.00	60.00	220.00	500.00	71.43	312.14	0.89
SD	2.83	113.43	25.69	7.24	12.94	53.48	115.75	16.54	71.88	0.15
Mode	4.00	200	40	20	10	20	80	11.43	50.71	0.77

The standard deviation (SD) for the water use is low which shows that the data obtained is aligned with the mean. The same is true considering the SD for family size, and total greywater generation. The mode of return factor of 0.77 is comparable to greywater generation factors obtained from literature.

Table 9: Greywater generation in low income communities.

Location	Water consumption (L/du.d)	Average water consumption (L/du.d)	Grey water generation (L/du.d)	Return factor	Reference
South Africa	20-200	153	133	0.87	Stephenson *et al*. (2006)
Mali	30-120	50	30	0.60	Alderlieste and Langeveld, 2005
Ghana			32	0.89	Oteng-Peprah *et al*, 2018.
Uganda	60-160	118	99	0.85	Katukiza *et al*, 2015
South Africa	40-400	207	121	0.62	This study

Greywater sources at Zandspruit include water from bathing, household cleaning, washing dishes and laundry. The contribution of each purpose (source) to total household greywater is as shown in Figure 16 below. Interviewees indicated that due to limited supply, water use for laundry and washing basins is evidently low as users resort to washing clothes only once per week. Basins are cleaned once per day in most households. This practice most likely produces greywater with a high contaminant load that may pose health risk especially in households with infants and young children if reused without proper treatment.

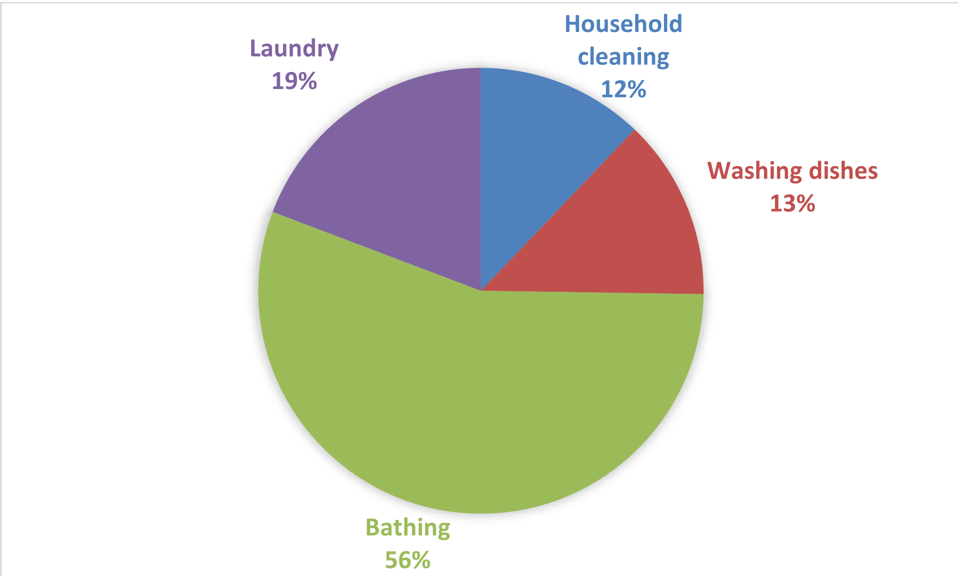

Figure 16: Greywater sources at Zandspruit.

After washing clothes, the collected wastewater is stored in large basins and is later reused for toilet flushing. Respondents however, are not comfortable to reuse raw greywater after prolonged storage due to offensive odours, health and environmental risk.

23% cited discomfort due to pungent smell, whilst 43% and 26% were worried about potential health risk and environmental pollution respectively (Figure 17).

The portion of household greywater that is not reused is disposed away into drains and onto the open surface. In certain areas of the community wastewater could be seen strewn on the streets and in depressions.

Accumulation of greywater in miniature ponds results in further deterioration in quality which will likely result in contamination of groundwater resources. Besides, depressions filled with murky waters are breeding sites for mosquitoes and house flies.

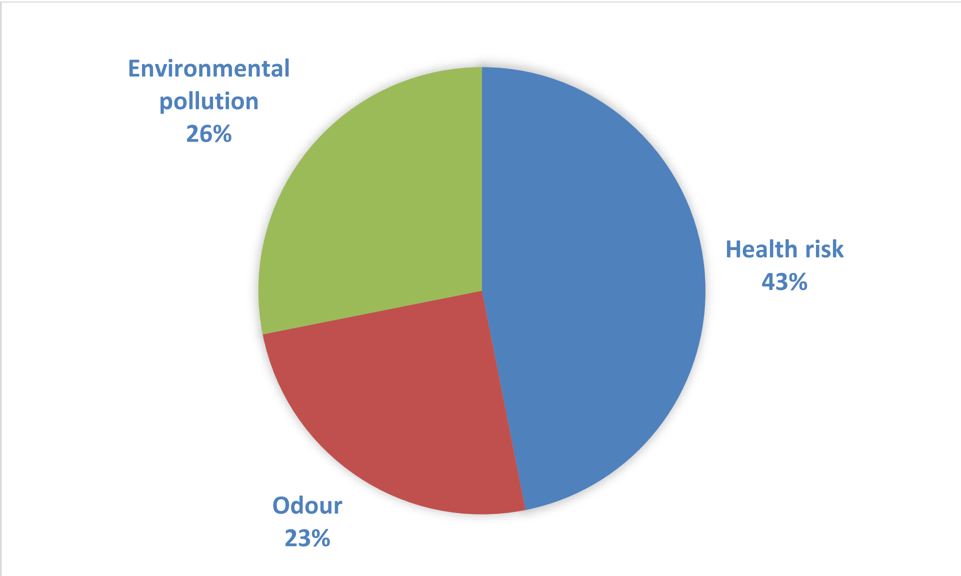

Figure 17: Likely effects of greywater storage and user perceptions.

The water quality at Zandspruit is commendable. 96% of the residents concur that the water is of good quality. Less than 2% of the respondents reported issues of water-borne diseases.

Table 10: Typical domestic water consumption and greywater generation

Type of water consumption	Typical water consumption (L/c.d)	Range (L/c.d)	Greywater generation (L/c.d)
Standpipe within 200m	25	10 - 50	
Yard connection	55	50-100	30-60
Yard connection with dry sanitation	55	30-60	
Yard connection with Low Flow On Site Sanitation System (LOFLOS)	55	45-75	
Yard connection with full-flush sanitation	55	60-100	

[Adapted from Council for Scientific and Industrial Research (CSIR, 2001)]

Table 11: Water consumption in South Africa

Province	**Consumption (Lpcd)**
Eastern Cape	200
Free State	209
Gauteng	305
Limpopo	182
KwaZulu Natal	225
North West	186
Northern Cape	238
Western Cape	201
Mpumalanga	205
National average	233

(Adapted from DWAF, 2017)

5.2.6 Greywater acceptability at Zandspruit informal settlement

Greywater reuse is not a new phenomenon at Zandspruit. Due to water unavailability most of the day, 74% of the population utilize raw greywater regularly without treatment for toilet flushing as shown in Figure 18 below. The rest is disposed away in drains or onto the surface.

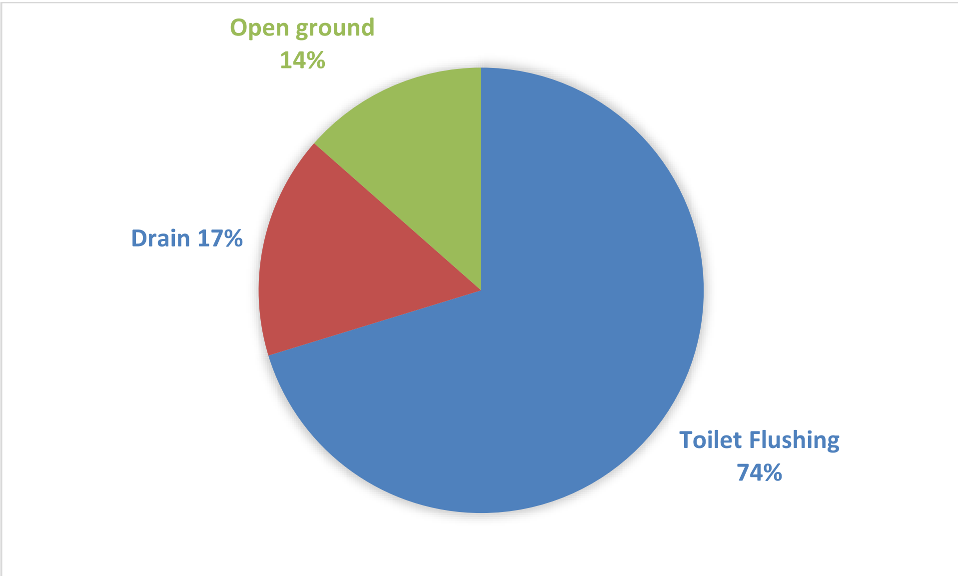

Figure 18: Greywater disposal options at Zandspruit

As depicted in Figure 19 below, 83% of the population accept reuse of treated greywater. 17% indicated that they are not comfortable reusing greywater. The major reason cited is the perceived quality of the recycled water. Residents consider onsite systems as less efficient producing effluent of low quality.

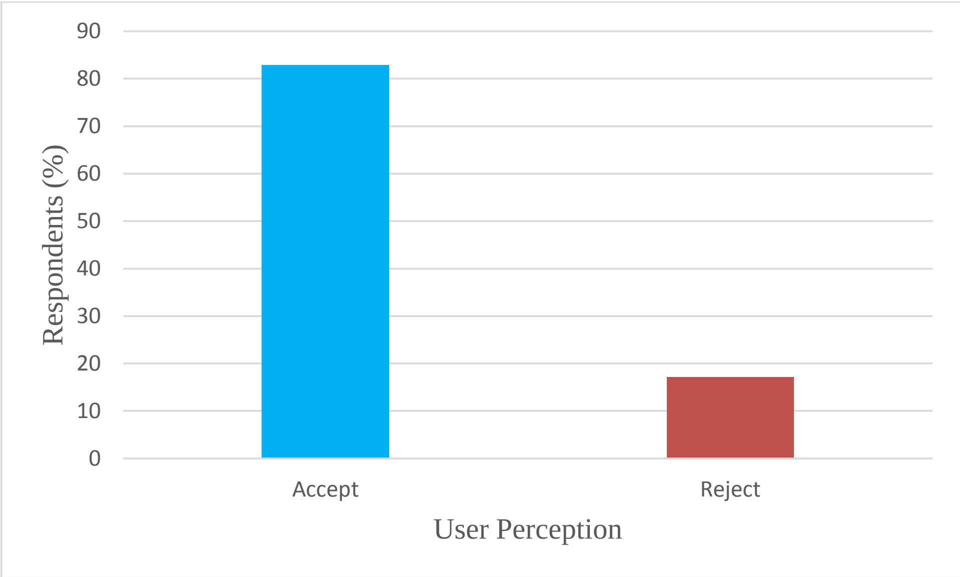

Figure 19: Greywater reuse perceptions.

For specific purposes almost all the respondents accept reuse of treated greywater for non-potable uses such as toilet flushing (97%) and gardening (94%). Figure 20 below shows that 71% of the residents would use treated greywater for laundry and personal hygiene. Conversely, nearly 30% of the population do not accept reuse of treated greywater for bathing and laundry.

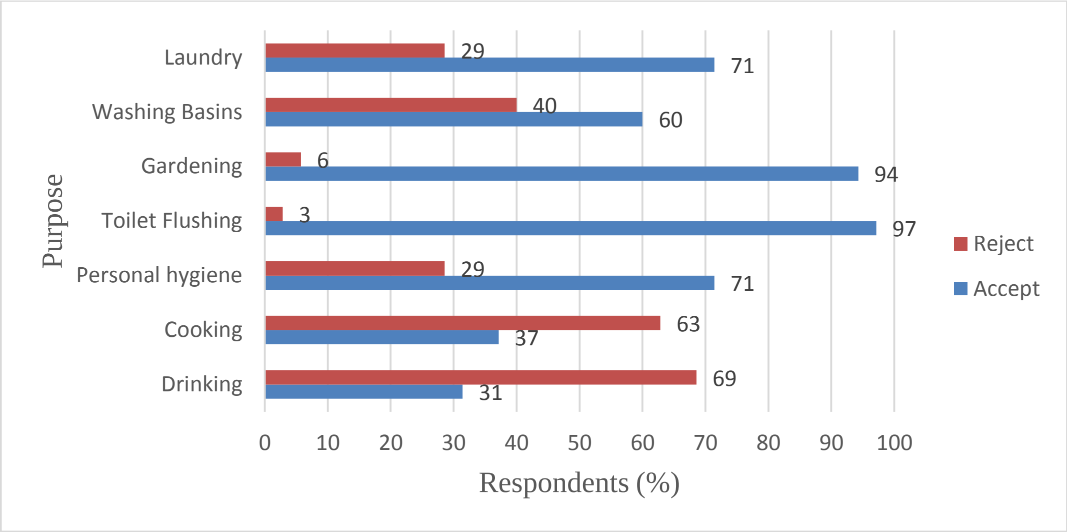

Figure 20: Acceptance of greywater for different purposes.

Greywater is not normally used for potable uses. At Zandspruit respondents indicated that if the greywater is properly treated they are willing to reuse it basically for all household chores including cooking and drinking. 69% of the residents accept the use of treated greywater for drinking whilst 63% will use it for cooking purposes. A significant proportion, that is 37 and 31% respectively, of the respondents however, reject the use of treated greywater for either cooking or drinking. Similarly, 40% of the respondents do not accept the use of treated greywater to clean kitchen utensils. A corresponding 60% have no objection in this regard.

5.3 Discussion

5.3.1 Potential for greywater generation at Zandspruit.

The vast majority of households at Zandspruit do not have access to sufficient domestic water supply. Water availability is not consistent nonetheless; the potential for greywater generation is considerable especially for families with at least five members. This study revealed that the mean return factor is 0.62 with an observed maximum of 0.89. The amount of greywater produced daily is significantly high with a mean of 121 L/du.d.

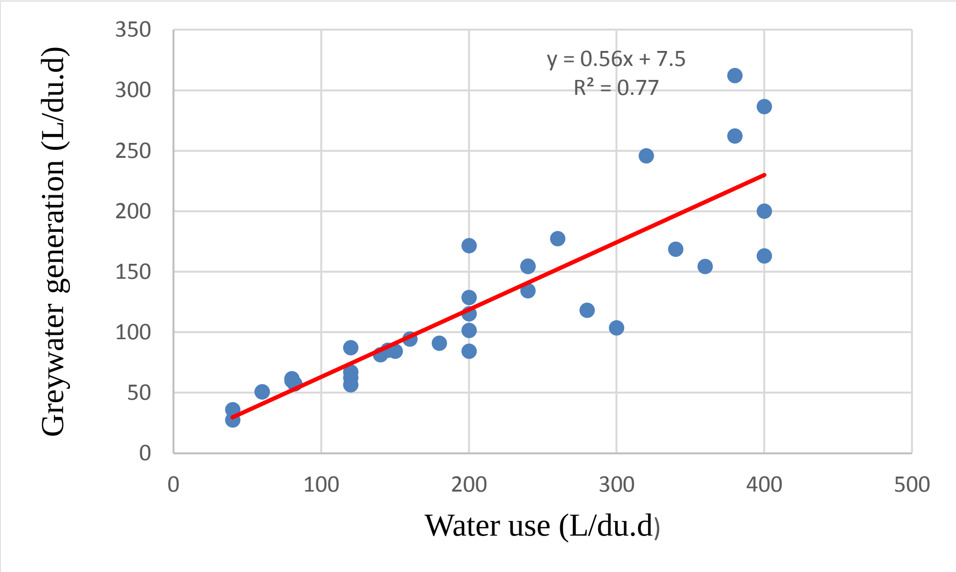

Figure 21: Correlation between water use and greywater generation

It is also important to consider the family size and water use per capita. Zandspruit, and indeed the majority of urban slums, have high settlement densities (Carden *et al.,* 2007). The observed water use per capita in this study ranges from 7 – 120 Lpcd with an observed mean of 42 Lpcd.

As shown by Figure 21 above there is a strong correlation between water use and greywater generation at Zandspruit. The increase in water use results in more greywater generation. Figure 22 however shows that the water use per capita reduces with an increasing household size. As the household size increases the number of families served by one standpipe however decreases (Figure 23).

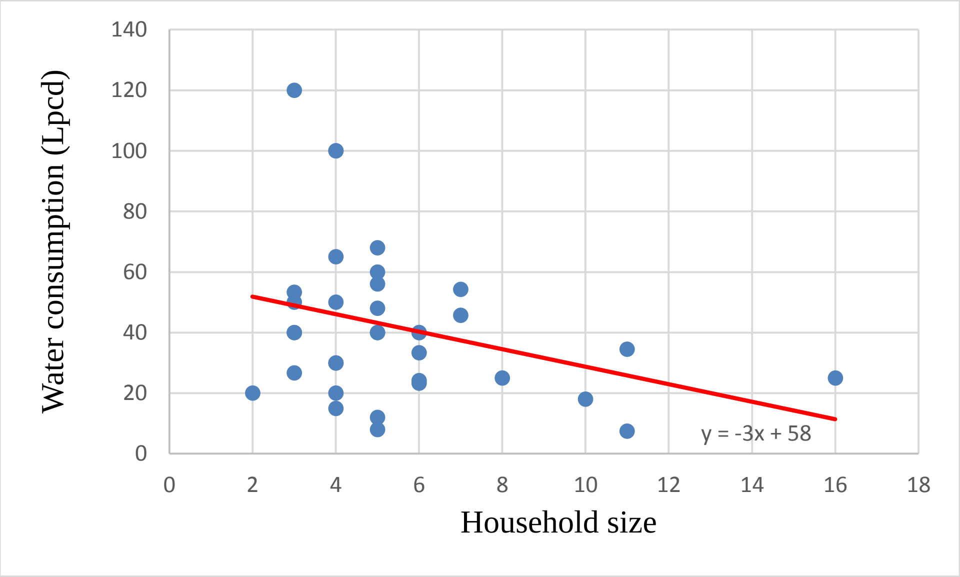

Figure 22: Relationship between water consumption and household size

The amount of greywater generated is enough to meet the basic needs of a medium-sized family of five considering that in South Africa the minimum amount of water recommended per capita is 25 Lpcd (DWAF, 2003). It is undeniable that onsite greywater generation and reuse will play a key role to alleviate water supply shortage prevalent in urban slums. Greywater reuse is certainly a low cost alternative suitable to low income communities.

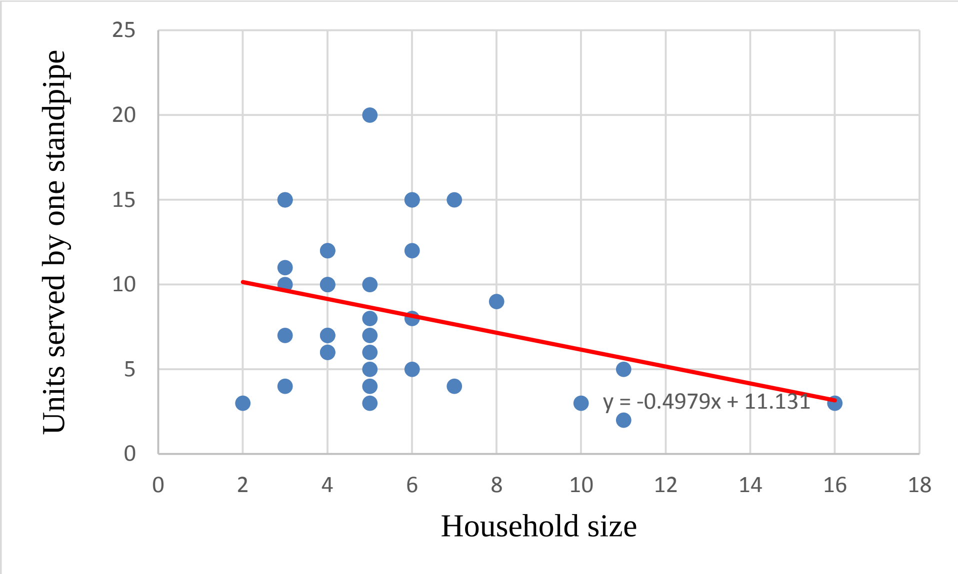

Figure 23: Correlation of household units served by a standpipe and family size

5.3.2 Greywater reuse: User perceptions and acceptability.

According to the results obtained from this study, there is a significant inclination towards greywater reuse in the study area. The same is corroborated by the work of Bakare *et al* (2016). Even without some form of treatment residents are already reusing household greywater for toilet flushing extensively. Toilet flushing typically consumes 20-40% of domestic water supply it is thus an important saving indeed (Ilemobade *et al*, 2012; Jefferson et al. 2004; Toze 2005). Furthermore, the population at Zandspruit expressed willingness to reuse treated greywater for potable purposes as well as uses which involve contact of treated effluent with humans.

Zandspruit residents recognise the significance of greywater as a sustainable source of water supply. Discussions with respondents revealed that they are concerned about the need to reduce environmental pollution and avoid disposal of wastewater close to sensitive areas. Hartley (2006) asserts that people tend to accept greywater reuse that promotes water conservation at a low cost and reduces environmental and health risks.

In a pilot study into public attitudes and perceptions towards greywater reuse in a low cost housing development in Durban, South Africa Bakare *et al* (2016) reported that over 70% of 346 respondents at Umhlabeni informal settlement in South Africa are willing to reuse greywater for toilet flushing and irrigation (Table 12). At the same time 65% of the population at Umhlabeni accepts reuse of greywater even when there is no drought or significant water scarcity. Bakare *et al* (2016) also argued that acceptance of greywater reuse depends on age and gender. The authors reported that the age bracket of 20–29 years and women showed greater willingness towards the reuse of greywater at Umhlabeni informal settlement. Indeed, literature suggests greywater reuse is acceptable in urban slums.

Table 12: Acceptance of greywater for specific reuse applications.

n =346	*Response*				
Items	*Strongly disagree*	*Agree*	*Not sure*	*Agree*	*Strongly agree*
I am willing to use greywater for toilet flushing	*6.1*	*10.1*	*8.1*	*28.3*	*47*
I am willing to use greywater for garden purposes	*5.8*	*12.5*	*11.6*	*32.5*	*37.7*
I am willing to use greywater from other building for toilet flushing or for garden purposes	*9.9*	*7.8*	*11.6*	*34.9*	*35.8*
I am only prepared to use greywater for either of the identified applications only during drought or water scarcity	*19.9*	*4.6*	*9.8*	*36.7*	*28.8*
I am willing to have a dual water distribution system installed where I currently reside	*4.9*	*4.9*	*10.1*	*31.8*	*48.3*

(Source: Bakare et al 2016) (Reproduced with permission from Babatunde F Bakare).

In the current study, acceptance of greywater reuse is influenced by gender parity of respondents of which the majority were women (71%) and have at least a basic form of education. Besides, most families at Zandspruit are led by women a scenario that reflects the norm in most urban slums of Johannesburg. Women often bear the brunt of water unavailability in the household. It is considered a woman's responsibility to ensure that there is enough water for daily household chores at Zandspruit. Interestingly women support the use of treated greywater to supplement freshwater supply and probably as a remedy to their daily struggles. Respondents are more concerned about improving water availability other than the associated health risk of wastewater reuse.

A portion of the community (17%) are content with their way of life and do not accept reuse of greywater for any purpose. 40% of those that accept greywater reuse reject the use of treated greywater for purposes that result in dermal contact with recycled water and potable uses such as drinking and cooking. This is common in a typical African setting where consumer perception is influenced mainly by tradition and other factors such as socio-cultural norms and religion. Tradition and social norms however changes with time. Another reason is probably poor knowledge dissemination in informal settlements. This sentiment was raised by respondents who cited lack of public awareness and education on greywater management alternatives.

A small section of the community (5%) attributed they disdain for wastewater reuse due to the ‘yuck factor’. The respondents generally dislike water reuse from sources other than their own. On the other hand, the elderly considers greywater as dirt wastewater and shun reuse. Moreover, it is a common practice in African families to throw away all unused water from the previous day in the morning as it is considered unsafe for potable purposes.

As the 21st century progresses, water scarcity is likely to worsen as a result of global population expansion and climate change. Greywater reuse will inevitably become a sustainable source of water supply useful to the community. The promotion of greywater treatment technologies through pilot trials will certainly change attitudes and perceptions as noted by Shafiuzzaman *et al* (2018).

The authors observed that perceptions and user acceptability can be enhanced by introducing efficient greywater treatment options in the community. Once the residents observe tangible benefits from the intervention they are better able to support the idea and embrace it.

5.3.3 Socioeconomic impact of onsite greywater treatment and reuse.

Although municipal water supply in informal settlements is free in South Africa, reuse of greywater is of socioeconomic value. Wastewater reuse reduces domestic water demand. When demand is reduced the cost of water supply to the community is also minimised. Besides, low water demand optimises the performance of infrastructure as most slums are often overcrowded beyond the capacity of the installed water and sewage system.

The implementation of low cost treatment systems in the community will certainly foster vital socioeconomic linkages through provision of raw materials and sundry services for a small fee. If the effluent is used to irrigate gardens the food grown will definitely supplement household nutrition. Surplus food can also be sold to neighbours and increase family income. People living in slums hardly have enough food. The opportunity to grow food in small gardens will enhance family diet and food sufficiency.

Women and children are the most affected by water scarcity. At Zandspruit women spent considerable time collecting water from public standpipes and often have to walk long distances to get to the water point.

Respondents concurred that during peak hours they spent at least an hour waiting in a queue to get water. Besides, women and children often walk nearly 2 km to collect water especially during the dry season when the municipal water supply is severely rationed. Reuse of greywater at the homestead reduces freshwater demand and takes away the burden of fetching water from elsewhere by the women. As most families at Zandspruit are headed by women there will be better able to attend to other responsibilities in the home.

5.3.4 Feasibility of onsite greywater treatment in slums.

5.3.4.1 Greywater reuse in slums

Greywater treatment and reuse has been widely adopted in planned settlements across the globe especially in the US, Europe and the Middle East. In low income communities, onsite greywater treatment and reuse is not significantly reported.

In South Africa greywater reuse for non-potable reuse is widespread (Ilemobade *et al*, 2012). The practice however, has not been significantly adopted in informal settlements except for toilet flushing. Infact reuse of greywater generated in informal settlements has been contested. Carden *et al* (2007) argues that greywater produced in slums is highly concentrated and unsuitable for reuse. The authors suggest treatment of greywater before disposal to minimise negative impacts on public health and the environment. This generalisation has not been supported by field measurements and laboratory analysis.

In this study the residents at Zandspruit informal settlement expressed interest to invest time and labour to develop simple and low cost treatment systems at the household level. The partnership of the community and researchers will certainly yield positive results and advance reuse of greywater in urban slums. Onsite greywater treatment and reuse at Zandspruit is feasible recognising that the settlement is sewered and greywater with a high pollutant load can be safely disposed away. It is therefore imperative to characterise the different streams of greywater before establishing a treatment system. The characterisation of greywater at Zandspruit was not covered in this study.

5.3.4.2 Possibility of using a horizontal roof

The nature and stability of the housing units (shacks) at Zandspruit is not consistent. Visual inspection indicated that the majority of the shacks are rigid and the roof can support a simple treatment model. Most of the shacks are constructed using corrugated iron sheets and a few are of brick and mortar. The use of green roofs in slums has not been observed in this study. The use and studies of green roofs in South Africa is restricted to planned settlements. Nonetheless, a typical wood and iron sheet shack (Figure 21) built and mounted at the University of Johannesburg has been successfully used to run a simple greywater treatment model.

Figure 24: Tiny shack established at the University of Johannesburg.

At Zandspruit the height of some housing units and surface area of the roof renders the use of shacks impractical without modifications. The height of the units vary nonetheless a significant number of shacks are slightly taller (ca 1.85m) than an average South African man (ca 1.69m). Access to the roof is therefore limited. Besides, the shacks at the compound are closely packed and mostly accessible only on one side, the front end. Operation of the treatment system is henceforth compromised.

6. Conclusion

Urban slums are most affected by water scarcity. At Zandspruit settlement municipal water supply is rationed and unavailable for almost 18 hours daily. Water consumption per capita at the settlement is very low at 40 Lpcd compared to a national average of 233 Lpcd. Reuse of treated greywater represents a sustainable option to alleviate water shortage in the community.

Zandspruit informal settlement has the capacity to produce significant amount of greywater for reuse at the household. With a mean return factor of 0.62 a medium-sized family household will produce an average of 121 litres per day. The amount of greywater generated at Zandspruit depends more on the number of people in the household. In this study the maximum amount of greywater produced at a single household is 312 L/du.d. This was obtained from a household of eleven members.

The majority of the people living at Zandspruit accept reuse of treated greywater for daily household chores. Residents are aware of possible health implications and the impact of raw greywater on the environment and are willing to promote low cost onsite greywater treatment systems. The people are eager to reuse greywater even for potable purposes such as drinking and cooking if it is properly treated.

According to the literature reviewed and observations during fieldwork it is feasible to build a low cost treatment system to produce effluent of acceptable quality at Zandspruit. Most of the shacks are rigid and strong enough to support a simple treatment train and green roof.

The implementation of onsite greywater treatment systems at Zandspruit settlement will most likely unlock socioeconomic benefits to the community. Freshwater supply will also be enhanced. The burden of collecting water will be lessened particularly on women and children.

7. Recommendations

Greywater generation and characteristics is not uniform moreso in densely populated settlements. The foregoing study is a preliminary study to understand the potential for greywater in sewered urban slums in South Africa. The results obtained therefore are mostly estimates by the author and residents at Zandspruit. There is need therefore for further work as summarised below.

Onsite measurement of water use and greywater generation in sewered informal settlements. Literature used in this study has shown that most of the water use values adopted by authors are not supported by actual measurements in the community. Furthermore, these estimates of water use trends and greywater generation are mostly for studies of systems earmarked for planned settlements. Consumption trends and the potential for greywater generation in sewered urban slums have not been comprehensively documented in South Africa.

The quality of greywater varies significantly within communities. It is imperative to determine greywater characteristics at Zandspruit through laboratory tests and analysis. Greywater characterisation determines pollutant loads in wastewater and its suitability for reuse. Besides, characterisation is useful in selecting the appropriate treatment train.

8. References

Adel M, Shmueli L, Bas Y, Friedler E, 2012. Onsite greywater recycling and its potential future impact on desalination and wastewater reuse in Israel. In 4th international conference on drylands, deserts and desertification. Sede Boqer, Israel: Ben Gurion University.

Adewumi J R, Olanrewaju O. O, Ilemobade A. A and van Zyl J E, 2010. Perceptions Towards Greywater Reuse and Proposed Model for Institutional and Commercial Settlements in South Africa. Conference Paper January 2010. https://www.researchgate.net/publication/292158625.Accessed February 15, 2019.

Albalawneh, A., Chang, T. K., Alshawabkeh, H., 2017. Greywater treatment by granular filtration system using volcanic tuff and gravel media. Water Science and Technology 75(10), pp. 2331-2341.

Alfiya Y, Friedler E, Westphal J, Olsson O, Dubowski Y, 2017. Photo-degradation of micropollutants using V-UV/UV-C processes; Triclosan as a model compound. Sci Total Environ 2017, 601 – 602:397–404.

Al-Gheethi A, Noman, Hashim bin mohd Kassim A & Saphira Radin Mohamed R M., 2015. Reduction of microbial risk associated with greywater by disinfection processes for irrigation. Journal of Water and Health. DOI: 10.2166/wh.2015.220.

Al-Hamaiedeh, H. & Bino, M., 2010. Effect of treated grey water reuse in irrigation on soil and plants. Desalination 256 (1–3), 115–119.

Al-Jayyousi, O. R., 2003. Greywater reuse: towards sustainable water management. Desalination 156 (1–3), 181–192.

Aonghusa, C. N., & Gray, N. F, 2002. Laundry detergents as a source of heavy metals in Irish domestic wastewater. Journal of Environmental Science and Health. Part A, Toxic/ Hazardous Substances & Environmental Engineering, 37, 1–6.

Awumbila M, 2017. Drivers of Migration and Urbanization in Africa: Key Trends and Issues. Centre for Migration Studies, University of Legon, Ghana Presented by Victor Gaigbe-Togbe, Population Division United Nations Expert Group Meeting on Sustainable Cities, Human Mobility and International Migration, New York, 7-8 September 2017.

Ayers R. S. & Westcot D. W. 1985 Water quality for agriculture, www.fao.org.

Bakare B F, Mtsweni S and Rathilal S, 2016. A pilot study into public attitudes and perceptions towards greywater reuse in a low cost housing development in Durban, South Africa. Journal of Water Reuse and Desalination 0.6.2.

Bakare B F, Mtsweni S and Rathilal S, 2019. Pilot study of a horizontal roughing filtration system treating greywater generated from a peri-urban community in Durban South Africa. Journal of Water Reuse and Desalination.

Barker F S, O'Toole J, Sinclair MI, Leder K, Malawaraarachchi M, Hamilton AJ, 2013. A probabilistic model of norovirus disease burden associated with greywater irrigation of home-produced lettuce in Melbourne, Australia. Water Res 2013, 47:1421 –1432.

Benami M, Busgang A, Gillor O, Gross A, 2016. Quantification and risks associated with bacterial aerosols near domestic greywater treatment systems. Sci Total Environ 2016, 562:344–352.

Beall J; Crankshaw O; and Parnell S, 2000. "Local government, poverty reduction and inequality in Johannesburg". Environment and Urbanization. 12.07 122. doi:10.1177/095624780001200108.

Benami M, Gillor O, Gross A, 2016. Potential microbial hazards from greywater reuse and associated matrices: a review. Water Res 2016, 106:183–195.

Bieker, S., Cornel, P., Wagner, M., 2010. Semi-centralised supply and treatment systems: integrated infrastructure solutions for fast growing urban areas. Water Sci. Technol. 61, 2905e2913.

Botha B E (2017) Estimating household groundwater abstraction by means of a probability model. Master's thesis, Stellenbosch University, South Africa. URL:http://scholar.sun.ac.za/handle/10019.1/100900. Accessed January 30, 2019.

Bowman R S, Micropor. Mesopor. Mater., 2003. 61(1–3) (2003) 43–56.

Boyjoo Y, Pareek V K, and Ang M, 2013. A review of greywater characteristics and treatment processes. Water Science & Technology 67.7 p1403-1424.

Brand D, 2018. Global Citizen. https://www.globalcitizen.org/en/content/south-africa-water-crises-johannesburg-cape-town-d/ Accessed 7 October 2018.

Carden K, Armitage N, Winter K, Sichone O, Rivett U and Kahonde J, 2007. The use and disposal of greywater in the non-sewered areas of South Africa: Part 1 – Quantifying the greywater generated and assessing its quality. Water SA Vol. 33 No. 4 July 2007. http://www.wrc.org.za. Accessed January 31, 2019.

Carden K, Fisher-Jeffes L, Young, C, Barnes J and Winter K, 2017. Development of resource guidelines for greywater use and management – Guidelines for greywater use and management in South Africa. WRC Research Project K5/2592, Final report, April 2017. Water Research Commission, Pretoria.

Carden K. Presentation at University of Cape Town 18 April 2016. Water Research Commission project K5/2592 Development of resource guidelines for greywater use and management.

Chaillou, K., Gérente, C., Andrès, Y. & Wolbert, D., 2011. Bathroom greywater characterization and potential treatments for reuse. Water, Air, & Soil Pollution 215 (1), 31–42

Christova Boal, D., Eden, R.E., and McFarlane, S, 1996). 'An investigation into grey water reuse for urban residential properties', Desalination, pp. 391-397.

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

Clasen T, Cairncross S, Haller L, Bartram J, Walker D., 2007. Cost-effectiveness of water quality interventions for preventing diarrhoeal disease in developing countries, J. Water Health 5 (2007) 599–608.

Cochran, W.G. (1963) Sampling Techniques, Wiley, New York.

CSIR Building and Construction Technology, 2001. Guidelines for Human settlement planning and design (Red book, ISBN 0-7988-5498-7). Boutek Report No. BOU/E2001, CSIR, Pretoria

Dalahmeh, S.S., Pell, M., Hylander, L.D., Vinnerås, B., Jönsson, H., 2014. Effects of changing hydraulic and organic loading rates on pollutant reduction in bark, charcoal and sand filters treating greywater. Journal of Environmental Management 132, pp. 338-345.

Department of Water Affairs and Forestry (DWAF) (2003). Strategic Framework for Water Services. Government Printer, Pretoria, South Africa.

Department of Water and Sanitation South Africa, DWAF (2017). Benchmarking of Water Loss, Water Use Efficiency and Non-Revenue Water in South African Municipalities (2004/05 to 2015/16).

WP11084 (WP11047-PEP4): National WS Master Plan: Water Conceptual Design and Strategic Analysis Related to Feasibility/IRS/Non-Revenue and Other Related Study Categories.
Department of Human Settlements (DHS), 2009. Upgrading of Informal Settlement Programme, Part 3 of the National Housing Code (2009), p. 16.

Department of Housing (2002) Towards Sustainable Settlements Case Studies from South Africa Pretoria, STE Publishers for the Department of Housing.

Deshmukh, B. S., Pimpalkar, S. N., Rakhunde, R. M. & Joshi, V. A., 2013. Evaluation performance of natural strychnos potatorum over the synthetic coagulant alum, for the treatment of turbid water. Int. J. Innov. Res. Sci. Eng. Technol. 2 (11), 6183–6189.

Dixon A, Butler D, Fewkes A and Robinson M, 1999. Measurement and modelling of quality changes in stored untreated grey water. Urban Water. 1999; 1:293–306.

Dolnicar, S., and Schafer, A. I, 2006. Public perception of Desalinated versus recycled water in Australia. Faculty of Commerce Papers, University of Woolongong http://ro.uow.edu.au/commpapers/138. Accessed February 16, 2019.

Domènech L, March H, Vallès M, Sauri D, 2015. Learning processes during regime shifts: empirical evidence from the diffusion of greywater recycling in Spain. Environ Innov Soc Transitions 2015, 15:26–41.

Edwin, G. A., Gopalsamy, P. & Muthu, N. 2014. Characterization of domestic grey water from point source to determine the potential for urban residential reuse: a short review. Appl.Water Sci. 4 (1), 39–49.

Eriksson, E., Auffarth, K., Eilersen, A. M., Henze, M., & Ledin, A, 2003. Household chemicals and personal care products as sources for xenobiotic organic compounds in grey wastewater. Water SA, 29, 135–146.

Eriksson, E., Auffarth, K., Henze, M. and Ledin, A 2002. Characteristics of grey wastewater. Urban Water, Vol. 4(1), pp.85-104. DOI: 10.1016/s1462-0758(01)00064-4.

Eriksson, E., Srigirisetty, S., & Eilersen, A. M, 2010. Organic matter and heavy metals in grey-water sludge. Water SA, 36, 139–142.

Etchepare R, van der Hoek JP, 2015. Health risk assessment of organic micro-pollutants in greywater for potable reuse. Water Res 2015, 72:186–198.

European Environment Agency, 2012. European Bathing Water Quality in 2007. European Environment Agency, Copenhagen, Denmark.

Food and Agriculture Organization of the United Nations Rome, 1985. Water Quality for Agriculture. http://www.fao.org/docrep/003/T0234E/T0234E00.htm Accessed January 23, 2019.

Friedler, E., Kovalio, R., Galil, N. I., Mathew, K. & Ho, G., 2005. On-site greywater treatment and reuse in multi-storey buildings. Water Science and Technology 51 (10), 187–194.

Friedler, E., Lahav, E., Jizhaki, H. and Lahav, T, 2006. Study of urban population attitudes towards various wastewater reuse options: Israel as a case study. Journal of Environmental Management, 81, p360 – 370.

Garcia J.E., Gonzalez M.M. and Notario J.S., 1992. Appl. Clay Sci., 7(4) (1992) 323–333.

Gerba, C.P., & Smith, J.E., 2005. Sources of pathogenic microorganisms and their fate during land application of wastes. Journal of Environmental Quality, 34, pp. 42-48.

Ghaitidak M B and Yadav K D, 2013. Characteristics and treatment of greywater—a review. Environ Sci Pollut Res (2013) 20:2795–2809 DOI 10.1007/s11356-013-1533-0. Springer-Verlag Berlin Heidelberg.

Gomez-Couso, H., Fontan-Sainz, M., Sichel, C., Fernandez-Ibanez, P. & Ares-Mazas, E., 2009. Efficacy of the solar water disinfection method in turbid waters experimentally contaminated with Cryptosporidium parvum oocysts under real field conditions. Trop. Med. Int. Health 14 (6), 620–627.

Govender T, Barnes J M and Pieperch, 2011. Contribution of Water Pollution from Inadequate Sanitation and Housing Quality to Diarrheal Disease in Low-Cost Housing Settlements of Cape Town, South Africa. Am. J. Public Health 101 (7) e4–e9. https://doi.org/10.2105/AJPH.2010.300107.

Government Gazette, 8 September 2017. Department of Water and Sanitation. National Norms and Standards for Domestic Water and Sanitation Services Version 3- Final.

GRAHAM N (2003) A Review of Infrastructure Services for the Upgrading of South African Informal Settlements. M.Sc. Thesis, Department of Civil Engineering, University of Cape Town, Cape Town, South Africa.

Hamid, A. S. H., Lananan, F., Din, W. N. S. & Su, S. L., 2014. Harvesting microalgae, Chlorella sp. by bio-flocculation of Moringa oleifera seed derivatives from aquaculture wastewater phytoremediation. Int. Biodeterior. Biodegrad 95, 270–275.

Harju V, 2010. Assembling and testing of laboratory scale greywater treatment system. Degree Thesis, Tampere University of Applied Science, Finland.

Hartley T W, 2006. Public perception and participation in water reuse. Desalination 187 (2006) 115–126.

Hernandez Leal L., Temmink H., Zeeman, G. and Buisman C, 2010. Comparison of three systems for biological greywater treatment. Water, 2, 155–169.

Hurlimann A and McKay J, 2007. Urban Australia using recycled water for domestic non – potable use – An evaluation of the attributes price, saltiness, colour and odour using conjoint analysis. Journal of Environmental Management, 83, p93 – 104.

IDRC, International Development Research Centre, 2010. http://www.idrc.ca/en/ev-1-201-1-DO_TOPIC.html. Accessed February 9, 2019.

Ilemobade A. A, Olanrewaju O. O and Griffioen M L, 2012. Greywater Reuse for Toilet Flushing in High-Density Urban Buildings in South Africa: A Pilot Study. WRC Report No. 1821/1/11.

Ilemobade, A. A., Olanrewaju O. O. & Griffioen M. L., 2012. Greywater reuse for toilet flushing in high-density urban buildings in South Africa: a pilot study. WRC Report No. 1821/1/11. Water Research Commission, Pretoria.
Impophomo, 2016. https://www.impophomo.org.za/about-us/ Accessed January 24, 2019.

Jefferson, B., Palmer, A., Jeffrey, P., Stuetz, R. & Judd, 2004. Grey water characterisation and its impact on the selection and operation of technologies for urban reuse. Water Sci. Technol. 50 (2), 157–164.

Jeffrey, P. & Jefferson, B., 2002. Public receptivity regarding in-house water recycling: Results from UK survey. Paper presented at the Environmental Convention and Exhibition, Melbourne, Australia.

Jeppeson, B. and Solley, D, 1994. Domestic Greywater Reuse: Overseas Practice and its Applicability to Australia". Research Report No 73. Urban Research Association of Australia, Brisbane City Council.

Källerfelt C and Nordberg A, 2004. Evaluation of Local Greywater Treatment in South Africa – Greywater Characteristics, Water Use and User Acceptance. M.Sc. Diploma Thesis, Department of Analytical and Marine Chemistry, Chalmers University of Technology, Göteberg, Sweden.

Kantanonleon, N., Zampetakis, L. and Manios, T, 2007. Public perceptive towards wastewater reuse in a medium size, seaside, Mediterranean city: A pilot survey Resources, Conservation and Recycling, 50, p282 – 292 (2007).

Katukiza A Y, Ronteltap M, Niwagaba C B, Kansiime F and Lens P N L, 2015. Grey water characterisation and pollutant loads in an urban slum. Int. J. Environ. Sci. Technol. (2015) 12:423–436 DOI 10.1007/s13762-013-0451-5.

Kehoe S C, Joyce T M, Ibrahim P, Gillespie J B, Shahar R A, McGuigan K G., 2001. Effect of agitation, turbidity, aluminium foil reflectors and container volume on the inactivation efficiency of batch-process solar disinfectors, Water Res. 35 (2001) 1061–1065.

Khalaphallah R, 2012. Greywater treatment for reuse by slow sand filtration: study of pathogenic microorganisms and phage survival. Chemical and Process Engineering. Ecole des Mines de Nantes, 2012.

Kourik R, 1991. Grey water use in the landscape: How to help your landscape prosper with recycled water. Santa Rosa, CA, USA: Metamorphic Press.1991.

Larsen, T.A., Maurer, M., 2011. Source separation and decentralization. In: Wilderer, Peter (Ed.), Treatise on Water Science. Elsevier, Oxford, pp. 203e229.

Lazarova V, Hills S, Birks R 2003. Using recycled water for non-potable, urban uses: a review with particular reference to toilet flushing. Water Sci Technol Water supply 2003;3 (4):69–77.

Li F, Wichmann K and Otterpohl R, 2009. Review of the technological approaches for grey water treatment and reuses. Science of the Total Environment 407 (2009) 3439–3449.

Lin, C. J., Lo, S. L., Kuo, C. Y. & Wu, C. H., 2005. Pilot-scale electrocoagulation with bipolar aluminium electrodes for onsite domestic greywater reuse. Journal of Environmental Engineering 131, 491.

Ludwig A, 1997. Grey water Central. Oasis Design Press, Santa Barbara, California. http://oasisdesign.net/greywater/index.htm Accessed January 29, 2019.

Maimon A and Gross A, 2017. Greywater: Limitations and perspective. Current Opinion in Environmental Science & Health 2018, 2:1–6. https://doi.org/10.1016/j.coesh.2017.11.005. Accessed February 09, 2019.

Maimon A, Friedler E and Gross A, 2014. Parameters affecting greywater quality and its safety for reuse. Science of the Total Environment 487 (2014). (20-25).

Mandal, D., Labhasetwar, P., Dhone, S., Dubey, A. S., Shinde, G. & Wate, S., 2011. Water conservation due to greywater treatment and reuse in urban setting with specific context to developing countries. Resources, Conservation and Recycling 55 (3), 356–361.

Mani S K, Kanjur R, Bright Singh I S, Reed R H., 2006. Comparative effectiveness of solar disinfection using small-scale batch reactors with reflective, absorptive and transmissive rear surfaces, Water Res. 40 (2006) 721–727.

March, J. G., Gual, M. & Orozco, F., 2004. Experiences on greywater re-use for toilet flushing in a hotel (Mallorca Island, Spain). Desalination 164 (3), 241–247.

Marks, J. S., Martin, B., and Zadorozny, M., 2006. Acceptance of water recycling in Australia: national baseline data. Water Journal of the Australian Water Association 33 (2), p151– 157.

Marks, M, 2004. Advancing community acceptance of reclaimed water. Water Journal of the Australian Water Association, 31 (5), p46-51 (2004).

Mashabela K, 2015. Onsite greywater reuse as a water conservation method: A case study of Lepelle-Nkumpi local municipality, Limpopo province of South Africa. DISSERTATION Submitted in partial fulfilment of the requirements for the degree of Master of Science in Geography and Environmental Science in the FACULTY OF SCIENCE AND AGRICULTURE (School of Agricultural and Environmental Sciences) at the UNIVERSITY OF LIMPOPO.

Mbiza H., 2018. Verbal communication.

McGuigan K G, Conroy R G, Mosler H G, du Preez M, Ubomba-Jaswa E, Fernandez-Ibanez P., 2012. Solar water disinfection (SODIS): A review from bench-top to roof-top. Journal of Hazardous Materials 235–236 (2012) 29–46.

Memon FA, Fidar AM, Ward S, Butler D, Alsharif K, 2015. Energy and carbon implications of water saving micro-components and grey water reuse systems. In Alternative water supply systems. Edited by Memon FA, Ward S, IWA Publishing London; 2015: 265–285.

Mofokeng N M, 2008. The Greywater Situation in Informal Settlements of the Ekurhuleni Metropolitan Municipality - Eastern Region (Gauteng, South Africa). Mini-Dissertation Submitted In Partial Fulfilment Of The Requirements For The Degree Master Of Environmental Management At The Potchefstroom Campus Of The North-West University.

Mohamed, R.M.S.R., Chan, C.M., Senin, H., Kassim, A.H.M., 2014. Feasibility of the direct filtration over peat filter media for bathroom greywater treatment. Journal of Materials and Environmental Science 5(6), pp. 2021-2029.

Moyo J, 2016. International Press Syndicate. https://archive.indepthnews.net/index.php/the-world/africa/758-water-crisis-a-challenge-in-south-africa-s-squatter-camps. Accessed 7 October 2018.

Mukheibir P, Boyle T, Moy C and White S, 2014. Estimating the reliable residential water substitution from household rainwater tanks. Water Practice Technol. 9 (3) 377–385. https://doi. org/10.2166/wpt.2014.040. Accessed January 30, 2019.

Municipalities of South Africa, 2019. City of Johannesburg Metropolitan Municipality. https://municipalities.co.za/map/2/city-of-johannesburg-metropolitan-municipality. Accessed on February 28, 2019.

Mzwakhe E, 2019. Zandspruit Baptist Church. Verbal communication.

Nel N, Jacobs H E, Loubser C and Du Plessis K, 2017. Supplementary household water sources to augment potable municipal supply in South Africa. http://dx.doi.org/10.4314/wsa.v43i4.03 ISSN 1816-7950 (Online) = Water SA Vol. 43 No. 4 October 2017. Accessed January 30, 2019.

Nikashina V.A. and Myaosedov B.F., 1999. Environmental applications of modified natural zeolites, P. Misaelides, ed., Natural Microporous Materials in Environmental Technology, Kluwer Academic Publisher, The Netherlands, 1999, pp. 335–343.

Nolde E. Greywater reuse systems for toilet flushing in multi-storey buildings — over ten years' experience in Berlin. Urban Water 1999;1(1999):275–84.

O'Toole J, Sinclair M, Malawaraarachchi M, Hamilton A, Barker SF, Leder K, 2012. Microbial quality assessment of household greywater. Water Res 2012, 46:4301 –4313.

Opher T, Friedler E, 2016. Comparative LCA of decentralized wastewater treatment alternatives for non-potable urban reuse. J Environ Manage 2016, 182:464–476.

Oteng-Peprah M, Acheampong M A and deVries N K, 2018. Greywater Characteristics, Treatment Systems, Reuse Strategies and User Perception—a Review. Water Air Soil Pollut (2018) 229: 255. https://doi.org/10.1007/s11270-018-3909-8. Accessed January 29, 2019.

Oteng-Peprah M, Acheampong M A and deVries N K, 2018. Greywater characterization and generation rates in a peri urban municipality of a developing country. Journal of Environmental Management 206 (2018) 498e506. https://doi.org/10.1016/j.jenvman.2017.10.068.

Oviedo-Ocaña ER, Dominguez I, Ward S, Rivera-Sanchez ML, Zaraza-Peña JM, 2017. Financial feasibility of end-user designed rainwater harvesting and greywater reuse systems for high water use households. Environ Sci Pollut Res 2017:1 –17.

Pansonato, N., Afonso, M. V., Salles, C. A., Boncz, M. A. & Paulo, P. L., 2011. Solar disinfection for the post-treatment of greywater by means of a continuous flow reactor. Water Sci. Technol. 64 (5), 1178–1185.

Penn R, Schütze M, Alex J, Friedler E, 2017. Impacts of onsite greywater reuse on wastewater systems. Water Sci Technol 2017, 75:1862–1872

Pidou M, Avery L, Stephenson T, Jeffery P, Parsons SA, Liu S, Memon FA, Jefferson B, 2008. Chemical solutions for greywater recycling. Chemosphere 71:147–155.

Pidou, M., 2006. Hybrid membrane processes for water reuse. PhD thesis, Cranfield University.

Po, M., Kaercher, J. D., & Nancarrow, B. E., 2003. Literature review of factors influencing public perceptions of water reuse. Report to Australian Urban Water Conservation and Reuse Research Program.

Rattan, R.K., Datta, S.P., Chhonkar, P.K., Suribabu, K., 2005. Long-term impact of irrigation with sewage effluents on heavy metal content in soils, crops and groundwater—a case study, Agriculture, Ecosystems and Environment, 109, pp. 310–322.

Roesner, L., Qian, Y., Criswell, M., Stromberger, M., Klein, S., 2006. Long-Term Effects of Landscape Irrigation Using Household Gray water– Literature Review and Synthesis, Resource Document. Water Environment Research Foundation. http://www.cleaning101.com/files/SDA_WERF_ Graywater_2006. pdf. Accessed February 10, 2019.

Rose, J B.; Sun, G S.; Gerba, C P. and Sinclair, N.A, 1991. Microbial Quality and Persistence of Enteric Pathogens in Greywater from Various Household Sources. Water Research,1991, 25(1): 37-42.

Shafiuzzaman Md, Haider H, AlSaleem S.S, Ghumman A R and Sadiq R, 2018. Development of Consumer Perception Index for assessing greywater reuse potential in arid environments. Water SA Vol. 44 No. 4. http://dx.doi.org/10.4314/wsa.v44i4.25

Siang Oh K, Cheng Leong J, Eong Poh P, Nan Chong M, 2018. A review of greywater recycling related issues: Challenges and future prospects in Malaysia. Journal of Cleaner Production 171 (2018) 17 e29. https://doi.org/10.1016/j.jclepro.2017.09.267.

Sostar-Turk, S., Petrinic, I. & Simonic, M., 2005. Laundry wastewater treatment using coagulation and membrane filtration. Resources, Conservation and Recycling 44 (2), 185–196.

South Africa. 2003. National Health Act No. 61 of 2003.Government Printers, Pretoria

Statistics South Africa (StatsSA), 2016. Community Survey Statistical release P0301 107pp.

Statistics South Africa (StatsSA), 2018. Statistical release P0302 Mid-year population estimates.

Stephenson D, Kisembo C and Owusu-Asante Y, 2006. Drainage in Rural and Peri-Urban Townships. WRC Report No. 1440 (in preparation, not yet published – permission obtained from author to cite). Water Research Commission, Pretoria, South Africa.

Turner RDR, Warne MSJ, Dawes LA, Vardy S, Will GD, 2016. Irrigated greywater in an urban sub-division as a potential source of metals to soil, groundwater and surface water. J Environ Manage 2016, 183:806–817.

Toze, S. 2005. Reuse of effluent water – benefits and risks. Agric. Water Manage. 80, 147–159.

U. S. EPA, 2015. Evaluation and Expansion of Solar Disinfection Method for Reclaimed Residential Greywater. Austin Community College, United State Environmental Protection Agency, Washington DC, USA.

U.S. Environmental Protection Agency (EPA) 2004 Guidelines for Water Reuse, EPA/625/R-04/108, September 2004.

Ubomba-Jaswa E, Navntoft C, Polo-Lopez M I, Fernandez-Ibanez P, McGuigan K G., 2009. Solar disinfection of drinking water (SODIS): an investigation of the effect of UV-A dose on inactivation efficiency, Photochem. Photobiol. Sci. 8 (2009) 587–595.

United Nations. Statement by Secretary General Koffi Annan. June 2003. Accessed 7 October 2018. http://www.un.org/News/Press/docs/2003/sgsm8707.doc.htm

United Nations: World water development report, 2017.

Van der Ryn, Sim, and Stuart Cowan. 1995. Ecological design. Washington, DC: Island Press.

Water Environment Research Foundation (WERF), 2006. http://www.cleaning101.com/files/SDA_WERF_ Graywater_2006.pdf. Accessed February 10, 2019.

WHO, 2002. Environmental Health Regional Office for the Eastern Mediterranean (EMRO). Regional Centre for Environmental Health Activities CEHA. Amman, Jordan.

Widiastuti, N., Wu, H., Ang, H. M. & Zhang, D., 2011. Removal of ammonium from greywater using natural zeolite. Desalination 277 (1–3), 15–23.

Widiastuti, N., Wu, H., Ang, M. & Zhang, D., 2008. The potential application of natural zeolite for greywater treatment. Desalination 218 (1–3), 271–280.

Wielshafran, A., Ronen, Z., Weisbrod, N., Adar, E., Gross, A., 2006. Potential changes in soil properties following irrigation with surfactant-rich grey water, Ecological Engineering, 26, pp. 348-354.

World Economic Forum (WEF), Global Risks, 2014. Ninth Edition. http://www3.weforum.org/docs/WEF_GlobalRisks_Report_2014.pdf. Accessed February 9, 2019.

World Health Organization "Key Facts from 2015 JMP Report" http://www.who.int/water_sanitation_health/publications/JMP-2015-keyfacts-en-rev.pdf?ua=1. Accessed on 7 October 2018.

Wurochekke A. A, Mohamed R. M. S, Al-Gheethi A. A., Atiku H, Amir H. M. and Matias-Peralta H. M., 2016. Household greywater treatment methods using natural materials and their hybrid system. Journal of Water and Health 14.6 p914-928.

Yaka A, Das D K & Woyessa Y E, 2006. Recycling perspectives of grey water: Reflections from literature. Central University of Technology.

9. Appendices

9.1 Appendix 1: Popular science summary

Nearly 15 million South Africans live in shacks. Indeed, the urban landscape in Johannesburg is marred by informal settlements. People living in slums have no access to sufficient clean water and improved sanitation. Besides, South Africa is a country with an alarming water scarcity problem. Municipal water supply is erratic and severely rationed. Consequently, water-related diseases are common with over 80% directly linked to poor water and sanitation conditions.

At Zandspruit informal settlement municipal water supply is unavailable for almost 18 hours per day. Mean daily water consumption per capita is quite low at 40 Lpcd compared to a national average of 233 Lpcd. Daily water consumption varies from 40 – 400 Litres per dwelling. With a mean return factor of 0.62 a medium-sized family will produce an average of 121 litres per day. Zandspruit informal settlement has the capacity to produce significant amount of greywater for reuse at the household.

The majority of the people living at Zandspruit (83%) accept reuse of treated greywater for non-potable purposes. A further 69% expressed willingness to reuse treated greywater for drinking and cooking if it is properly treated. Residents are aware of possible health implications and the impact of raw greywater on the environment and are willing to adopt low cost onsite greywater treatment systems.

The implementation of onsite greywater treatment systems at Zandspruit settlement will most likely unlock socioeconomic benefits in the community. Freshwater supply will also be enhanced. The burden of collecting water will be lessened particularly on women and children.

The aim of the present study was to ascertain household daily water consumption and quantify the amount of greywater generated at Zandspruit slums with a view to suggest greywater reuse as a sustainable option for freshwater supply. The second objective was to assess perceptions and user acceptability towards treated greywater reuse in urban slums. Overly, the study endeavour to elucidate the potential benefits of greywater reuse in informal settlements.

The author used a systematic literature review and administered a survey questionnaire at Zandspruit to fulfil these objectives. The survey was conducted between the 1st of February and the 29th of March 2019 covering 294 households.

The promotion of onsite greywater treatment and reuse will certainly improve water availability to some of the poorest people in South Africa. It is therefore imperative for future studies to ascertain greywater characteristics in informal settlements through laboratory analysis so as to formulate the appropriate treatment train.

9.2 Appendix 2: Survey Questionnaire

Division of Water Resources Engineering, Lund University, Sweden.

in partnership with

Department of Civil Engineering Science, University of Johannesburg, South Africa.

My name is **Tendai H Madzaramba.** I am a registered student at Lund University in Sweden. I **WOULD LIKE TO INVITE YOU TO PARTICIPATE** in a research study on Greywater treatment and reuse in low income communities. THE PURPOSE OF THIS STUDY is to assess perceptions and acceptability towards treated greywater reuse in the community. The exercise is voluntary and all information will be treated with utmost confidentiality. Thank you very much for your assistance.

Date of survey………………………………………………………
Respondent…………………………………………………………
Gender…………………….Age………………………………………
Stand number……………………………………………………..

Part 1: Household Profile Data

Member	*Sex*	*Age*	*Marital status*	*Educational level*	*Occupation*

Part 2: Water source and use

What is your major source of household water supply?	*a) Piped water into dwelling* *(b) Piped water to yard/plot* *(c) Public tap or standpipe* *(d) Private borehole* *(e) Public borehole* *(f) Well* *(g) Tanker truck* *(h) Surface water* *(i) Other*		
Point of water supply (Distance from home)		*Comment:*	
How long do you take to fetch water for daily household chores?		*Comment:*	
How much drinking water (in litres/buckets) does your household consume each day?		*Comment:*	
Would you like to use more water?	*Yes.* *No.*	*If yes, what prevents you from doing so?*	
How often do you experience water scarcity in your community?	*(a) Daily* *(b) Monthly* *(c) Seasonally* *(d) Other*		
What is the likely cause of scarcity in your community?			
For personal hygiene, which of the followings do household members use?	*Shower* *Bathtub* *Others*	*Comment:*	
In a typical week, what is the frequency does the household do the following per day?	*Household cleaning,*	*Once, twice, thrice*	*Qty/day =*
	Washing dishes,	*Once, twice, thrice*	*Qty/day =*
	Bathing,	*Once, twice, thrice*	*Qty/day =*
	Laundry,	*Once, twice, thrice*	*Qty/day =*

Part 3: Water availability and regulations.

Rules for collecting water	*On-demand*	*Imposed*	*Comment:*
Is water supply restricted?	*Restricted*	*Not-restricted*	*Comment:*
Is domestic water adequate?	*Yes*	*No*	*Comment:*
Is domestic water reliable?	*Yes*	*No*	*Comment:*
Is water quality good?	*Yes*	*No*	*Comment:*
Have you/your family member affected by diarrheal diseases	*Yes*	*No*	*Comment:*
Are there alternative sources of water you are using for domestic purposes.	*Yes* *Streams* *Wetlands* *Vendors* *Rainwater* *Wells*	*No*	*Comment:*
Do you receive government support for water supply or treatment in your community?	*Yes*	*No*	*Comment:*
Do you pay a water tariff to obtain water from the source facilities?	*Yes*	*No*	

Part 4: Sanitation and wastewater disposal

Do you have access to sanitation facilities? *Yes* *No*	*If Yes:* *(a) Pour flush toilet* *(b) Piped sewer system* *(c) Septic tank* *(d) Pit latrine* *(e) Bucket* *(f) Commune sanitation* *No facilities, bush or field (open defecation)*	*Commune, how many households?*
Are there hand washing facilities near the toilet?	*Yes* *No*	*Comment:*
What do you do with your greywater?	*Disposal* *Gardening* *Cleaning* *Other*	*How do you dispose greywater?*
Are you worried/affected by wastewater disposed by your neighbours? *Yes* *No*	*If Yes, Why?* *Health risk* *Odour* *Environmental pollution* *Other*	*Any improvements?*
What do you think should be done to greywater generated in the household?	*Treated and reused?* *Disposed away from the household?* *Other*	*If treated are you willing to reuse it?*

Part 5: Perceptions towards treated greywater reuse

Are you comfortable using treated greywater for:

Intended purpose	*Yes*	*No*
Drinking		
Cooking		
Personal hygiene		
Toilet flushing		
Watering the garden		
Washing basins		
Laundry		