Extending the water life cycle in rural South African households: the role and potential of water reuse solutions

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by

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Picture on front page: Locked communal tap with collecting barrels in the background. Photo by Tshepiso Lehutjo.

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Preface

This study was conducted from the 13th of January 2019 to the 5th of June 2019.In a water scarce world it has become increasing important that the resilience of vulnerable societies be actively improved and invested in.

It is by the grace of God that I have been able to complete this Master's programme with the loving support of my friends and family.

To my parents, Enia and Daniel Lehutjo, thank you for the constant encouragement and unconditional support. My siblings, Reneilwe, Tumelo and Naledi Lehutjo, your belief in me is forever appreciated. My friends; Princess Malebye, Karabo Boshomane and Asive Mahlamvu, I can't thank you enough.

My newfound family and friends in Lund, I am blessed to have found you during my studies. To Selorm Kugbega and Khadija Saidi, your invaluable transfer of knowledge and guidance has contributed above and beyond the scope of this thesis.

I am grateful for the academic support and creative freedom afforded to me by my supervisor Åsa Davidsson. I would like to thank the Swedish Institute for the study scholarship, without which I would not have has this opportunity.

Lastly, to my beloved village in South Africa. Marulaneng, thank you for allowing me into your homes in the midst of frustration and desperation. It is through this and my future endeavors that your cries will be heard.

"For many have lived without love, but none without water"

Summary

Despite the issue of greywater management gaining more importance around the world, especially in developing countries, it still remains a challenge in non-sewered areas of South Africa. For a semi-arid country, reusing greywater on a household level has great potential as an alternative water source if done properly.

On a household level, the popular repurposing of greywater is for irrigation paired with simple technology. Although irrigation is a practical application, this study aims to extend the life cycle of water within the household by theoretically applying high-level technology to filter greywater within rural households of South Africa. Thus, greywater produced in the household can be repurposed for close human contact activities like bathing, laundry and dishwashing. This will extend the life cycle of water within the household, increasing the availability of potable water in a household.

To achieve the aim of the study, Marulaneng village in South Africa was selected as a case study. 17 household surveys were done to collect data on their greywater production and water supply sources. The results reveal that people in Marulaneng are affected by the water scarcity in the country and use multiple water resources as coping measures. Their water consumption is half of what should be available to them according to the free basic service of 6 kilo litres per household per month, granted to all households by the government of South Africa.

Two household technologies were found to apply theoretically and extend the life cycle of water within the household. The reuse of rinse water from dishwashing would increase the availability of potable water by 10% and reusing bath water would increase the availability of potable water by 28%.

Table of Contents

1 Introduction and Background

Whilst the road envisaged by 149 countries to meet the 17 United Nations Sustainable Development Goals by 2030 continues, an estimated 33 countries are expected to have extreme water stress by 2040 (Desjardins, 2015). As water pollution and climate change effects become more prominent, global populations grow and urbanization rates increase, reducing the stress on freshwater resources remains an ongoing and urgent challenge. In developing economies like South Africa, the availability of water supply acts as a major restriction on the socio-economic development of the country.

The reuse and recycling of domestic greywater, wastewater generated by sources that are separate from human waste, has been identified as having significant potential in decreasing the demand on freshwater resources. Although domestic greywater reuse is not explicitly mentioned, the targets of Sustainable Development Goal number 6 accentuate the importance of water reuse in ensuring water and sanitation for all[1]. Potential benefits of reusing greywater are not only for the sake of decreasing demand on freshwater resources but also play a role in environmental conservation by reducing pollution discharges and promoting ground water recharge.

As the benefits of reusing and recycling greywater in a water scarce world are obvious, management and use of greywater can pose significant health and environmental risks depending on the source of greywater, treatment process and intended use (Carden *et al.*, 2017).Owing to the fact that limited guidance in South Africa on how greywater systems should be designed, operated and maintained in the water supply system, greywater has mainly been utilized in restricted areas by individuals and companies during seasons of drought (Carden,*et al.*, 2007b).The gap in greywater use guidance has left the low-income, non-sewered areas[2] of South Africa dealing with a host of environmental and health problems. A stumbling block of what could be a reliable, productive and sustainable water use alternative for rural households.

In 2013, 11 million people in South Africa lacked access to improved sanitation (STATS SA, 2019). The most common method for households to manage greywater is to dispose of it onto the ground due to the lack of formal conveyance systems. Thus, leading to major concerns for both health and the environment. Stagnant water in high density urban settlements with poor drainage has resulted in mosquito infestation and caused children to fall ill.

With just 490 000m^3/d of greywater generation from non-sewered areas of South Africa, Carden *et al.*(2007a) suggests that potential benefits from greywater use in these areas would be at household level for irrigation and not as an alternative water resource country-wide. Using greywater for irrigation is a popular suggestion that has been credited for socio-economic growth by improving livelihoods through increased food production and alleviating high potable water costs in water scarce regions. The benefits of domestic greywater have been empha-

[1] Referring to target 6.3,6.4 and 6.A of United Nations Sustainable Development Goal 6

[2] Defined by (Carden, Armitage, Winter, *et al.*, 2007) as areas without on-site waterborne sanitation. Definition which rural areas of South Africa fall into

sized for mainly outdoor use. According to Carden *et al.* (2007a) due to the high levels of pollution indicated in the water quality, non-sewered areas should not be allowed to use greywater for edible food without management of risk factors.

For low-income areas, management of risks factors is done through low-level technology that can yield water quality fit for irrigation. However, with the advancement in innovation and understanding of greywater, urban households are afforded the options of beneficial reuse of greywater within the household through Clean technologies that filter greywater to acceptable quality fit for close human contact use[3]

Clean Technologies as defined by The Clean Technology Trade Alliance
(Rouse, 2019)

'A broad base of processes, practices and tools, in any industry that supports a sustainable business approach, including but not limited to pollution control, resource reduction and management, end of life strategy, waste reduction, energy efficiency carbon mitigation and profitability'

1.1 Aim

Even though guidelines rightfully claim that some technologies are not feasible for rural communities (because of the infrastructure and cost demand), this study investigates how much the life cycle of water within a household could be extended by. That is, if an acceptable level of water quality[4] could be guaranteed through the theoretical application of existing high-level technologies. This will be done by applying the filtration abilities of existing water reuse technologies which are designed for urban households' infrastructure to the community selected in this study.

Extending the life cycle of water in a household is achieved when there is an increase in the availability of potable water[5] through the application of greywater reuse within the household.

Households in rural South Africa are presented as a case study. Data will be collected through; the investigation of water consumption of greywater producing activities, observation of water scarcity coping measures and the research of existing technologies. Technical barriers in the application of high-level technologies in rural households will be discussed and considered when presenting modified options of technologies.

The intention is that such a study will add onto the various options of greywater management in non-sewered areas, drawing from proposed guidelines, and be of use to both the innovators of Clean technologies and the stakeholders that implement innovations in local communities.

[3] Defined in this study as activities that take place within the household like bathing, laundry and cleaning without posing health risks to the user.
[4] For close human contact use activities
[5] Defined in this study as water that is safe to drink and can be used for any household activity without risk to environmental and human health.

2 Contextual Background

The importance of domestic water reuse has become of great interest in many parts of the world with several projects being pioneered to contribute to the water and energy consumption reduction, environmental protection and economical savings. Some of the successful water reuse projects in the world are mentioned in the CSIRO Technical report of 2003 (Po *et al*.,2003). For example, the dual reticulation wastewater reuse scheme in the Rouse Hill, Australia providing water for toilet flushing, gardening and firefighting.

Greywater has piloted many interesting projects especially in urban areas. It should come as no surprise given that some definitions of grey water assume, if not explicitly, describes an urban setting. The main reason is possibly due to the technical advantage that urban homes have over rural/off-grid areas; that is, connection to sewer lines. Sewer line connections afford households the possibility to separate greywater from blackwater, convey it to treatment facilities and reuse.

In non-sewered areas of South Africa, greywater management is an ongoing challenge. Residents concerned with the environmental and health impacts of greywater have devised their own coping measures such as carrying all greywater to their nearest stormwater canal (Carden *et al.*, 2007a). This is despite the fact that management of water and the provision of water services are set out for the state in the National Water Act 36 of 1998[6] and the Water Services Act 108 of 1997[7]. The Water Services Act defines basic sanitation, that various administrative bodies are required to make provisions for, as *the prescribed minimum standard of services necessary for the safe, hygienic and adequate collection. removal, disposal or purification of human excreta. domestic waste-water and sewage from households, including informal households[8].* The principles of the National Water Act are sustainability and equity, one of the provisions being water reuse. However, water reuse is referred to the purpose of irrigation of land, where such wastewater has been generated by industrial activities or a waterwork[9]. The use of greywater in the domestic context is not addressed, leaving households that have not received basic sanitation without legislative guidance on greywater management.

An attempt to fill this gap has produced a string of guidelines for the beneficial use of greywater for irrigation(Carden, *et al.*, 2007b; Rodda, 2011; Newcomer *et al.*, 2017).Notably,(Carden, *et al.*, 2007b) considers the beneficial use of greywater as opposed to disposal the most sustainable management option but admits that in reality it is hardly achieved in non-sewered areas. Due to the health and environmental risks involved, Carden, *et al.*(2007b) has gone as far as to say that “the use of greywater for the irrigation of edible food should not be allowed in non-sewered areas unless the risk factors can be managed within acceptable limits.”

It is this limitation that the present study is drawn from. Irrigation of edible food is considered as one of the examples of close human contact water reuse options outside of the household. Thus by “applying” rigorous technology in rural households for the application of greywater

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[6] The National Water Act 36 of 1998 makes provision for the sustainable use of water resources and aims to provide for the management of all water resources

[7] The Water Services Act 108 of 1997 pertains to the provision of water supply and sanitation services. It is concerned with the powers and duties of the various administrative bodies that are required to provide such services.

[8] Likely to be non-sewered areas

[9] Sec 37(1)(a)

reuse, risk factors are managed within acceptable limits and beneficial use of greywater is achieved.

The thesis comprises of both social and technical components. The social component provides insight of a water scarce rural community in South Africa; the household’s water resources, water consumption quantity and coping measures. The technical investigation helps explore what benefit existing technology could provide in terms of reducing freshwater consumption, and technical barriers of applying technology in rural households of South Africa.

Ultimately the greywater reuse norm in rural households is challenged by proposing the development or modifications of technologies to apply in non-sewered areas for beneficial and safe greywater reuse within the household.

3 Literature Review

3.1 Introduction

With the growing concerns of water scarcity, greywater is a recurring theme in literature as a coping measure. Extensive literature on the characteristics of greywater, quantity, treatment and perception exists. It is interesting to find that there is not a uniform definition of greywater (Table 3-1), contributing to the challenge of inconsistent water reuse guidelines.

Table 3-1 Greywater definition from various literature

Definition	*References*
Grey water is defined as the urban wastewater that includes water from baths, showers, hand basins, washing machines, dishwashers and kitchen sinks, but excludes streams from toilets	(Li *et al*., 2009a)
Greywater is defined as wastewater without any contributions from toilet water	(Oteng-Peprah *et al*.,2018)
Grey wastewater is defined as wastewater without any input from toilets, which means that it corresponds to wastewater produced in bathtubs, showers, hand basins, laundry machines and kitchen sinks, in households, office buildings, schools, etc.	(Eriksson *et al.*, 2002)
Greywater is the wastewater collected separately from sewage flow from clothes washers, bathtubs, showers and sinks, but does not include wastewater from kitchen sinks, dishwashers, or toilets.	(Al-jayyousi, 2003)
Greywater is defined as all wastewater from the non-toilet plumbing fixtures around the home. Kitchen greywater is not recommended.	(Christova-Boal *et al*.,1996)
Greywater includes domestic wastewater which is generated by sources that are separate from human waste such as bathing, laundry, and handwashing stations, i.e. unconnected from a toilet or urinal, and can result from around 80% of freshwater usage in certain residential.	(Jamrah *et al*., 2006)

Although a topic well explored, many of the suggested advanced treatment solutions are on a large scale, centralizing the reclaimed greywater. Literature on domestic greywater reuse is more challenging to find and perhaps more feasible in rural areas which have a nature of being decentralized. Water consumption in rural households is found in several literatures with various definitions of rural water supply. One of the challenges of collecting data in rural areas is the variability in water resources and supply. It is common to find greywater technology in rural areas as low-level technologies purposed for irrigation.

The quantity, quality and public perception studies have given a good overview to allow for minor projects to proceed. There are several suggestions on the suitability of greywater for different activities, often with recommendations to use treated water. However, studies don't go further to provide treatment options or technology on household levels.

To evaluate and synthesize findings keywords were used, greywater, household, rural. The rural areas of interest were particularly those in developing countries with insufficient water security. The household characteristics of interest were those lacking access to improved water supply or those with limited access to water supply. The rural areas referred to have either public access to water or intermittent water supply.

3.2 Domestic water consumption and uses in rural areas

When it comes to meeting the growing water demand; be it in developed or developing countries, rural or urban areas alike; the popular understanding is to shift from supply-side to demand side management[10]. Key to domestic demand-side water management strategies is studying water consumption on household level. To fully exploit the success of water demand strategies, it is worthwhile to identify the determinants that influence water consumption. This concept has been explored well in the urban areas giving rise to many applications based on the understanding between the interactions of determinants and water consumption. With the aid of model development, this knowledge has been advantageous in the planning, prediction and implementation of strategies in the urban water sector (Fielding *et al.*, 2013; Baki *et al*., 2018; Jeanne and Terlet, 2018).

Although the implementation of water demand management is accepted as a sustainable practice across the board, according to Basu *et al.* (2017) and Fan *et al.*(2013) water consumption and its determinants in the rural households has not been well researched compared to its urban counterpart. Fan *et al.*(2013), Keshavarzi *et al.*(2006) and Basu *et al.* (2017) have determined water consumption estimates as well as factors, behavior and determinants of water consumption respectively in their rural areas of interest. Fan *et al.*(2013) found that water supply pattern has a strong influence on water consumption in rural China upon access to improved water supply. Significant difference in water consumption is found between continuous water supply and the other two, intermittent water supply and public tap access. Intermittent water supply systems and public access, the most prevalent forms of water supply in developing areas (Vairavamoorthy *et al*., 2008), don't have a significant difference in water consumption patterns. Keshavarzi *et al.*(2006) uses household activities and water consumption relationship to determine the factors that affect water consumption in low, middle and high-water consumers in rural Iran. The activities are similar to those in Fan *et al.*(2013).

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[10] Supply-side water management works by increasing amount of available water. Demand-side water management works by decreasing water consumption in different sectors.

Literature reveals that although the behavior of household activities may differ, the determinants of water consumption are similar. Household activities affect only the water consumption quantity. In rural India where washing of utensils and laundry are done in open water sources, Basu *et al.* (2017) estimated an average 9.66 litres per capita per day . This is significantly less than the 121.7 litres per capita per day in rural Iran where there is access to piped water supply (Keshavarzi *et al*.,2006) and 56.2 litres per capita per day in the Wei River Basin of rural China (Fan et al.,2013). Regardless, Table 3-2 shows that the determinants of water consumption are the same.

Table 3-2 Correlation of household determinants with water consumption from various literature

	Correlation with water consumption		
Variable	Fan *et al.* (2013)	Basu *et al*. (2017)	Keshavarzi *et al.* (2006)
Household size	Significantly negatively correlated	Significantly negatively correlated	Significantly negatively correlated
Age of household head	Significantly negatively correlated.	Not researched	Significantly positive correlation.
Water source characteristic	Significantly correlated	Significant determinant	Not researched

Keshavarzi *et al.*(2006) claim that, because older individuals are less informed about water conservation, their domestic water consumption is higher. Because some water usages, kitchen uses, livestock needs, vegetable gardening and cleaning, are independent of family size, water consumption per capita is lower in larger families. This is verified by the results in Table 3-2.

The above literature (Table 3-2) presents similar results regarding household characteristics that influence water consumption. This suggests that water consumption in rural areas can be documented and aggregated similarly to data in urban areas despite local disparities. The challenge is the methodology of collecting data which currently proves to be cumbersome and time consuming activity.

3.3 Greywater

With water conservation being an ongoing and pressing matter around the world, greywater provides an alternative to existing water sources and reduces reliance on freshwater.

3.3.1 Characteristics of greywater

Various research on greywater has been done enabling papers such as (Li *et al*., 2009a) and (Oteng-Peprah *et al.*, 2018) to present the characteristics of greywater, quantity and quality, amongst other findings by means of a literature review. A large portion of the *Characteristics of greywater* chapter in this study has been obtained from these papers.

3.3.2 Quantity

Greywater accounts for up to 75% of wastewater generated in the household (Leal *et al.*, 2010) and accounts for 69% of domestic water consumption (Jamrah *et al.*, 2006). The amount of greywater generated varies depending on geographical location, population structure, customs and habits, lifestyle, climatic conditions, type of infrastructure and degree of water abundance. Discrepancies in greywater generation can be seen in Table 3-3.

Table 3-3 Greywater generation rates in different countries

Location	Generation (/Lc/day)	Reference
Africa and Middle East	14–161	Al-Hamaiedeh and Bino (2010); Halalsheh et al. (2008); Morel and Diener (2006)
Asia	72–225	Morel and Diener (2006)
Gauteng, South Africa	20	Adendorff and Stimie (2005)
Jordan	50	Faraqui and Al-Jayyousi (2002)
Mali	30	Alderlieste and Langeveld (2005)
Muscat, Oman	151	Jamrah et al. (2008)
Nepal	72	Shresta (1999)
Stockholm	65	Ottoson and Stenstrom (2003)
Tucson Arizona, USA	123	Casanova et al. (2001)
Vietnam	80–110	Busser et al. (2006)

Note: Source Oteng-Peprah et al.,2018. Reprinted with permission from Springer

3.3.3 Quality

The composition of greywater varies on an even smaller scale than quantity because it is a result of lifestyle and type and choice of chemicals used for laundry, cleaning and bathing. All which are personal preferences. A more general parameter that affects greywater quality is the type of water distribution network and the quality of water being supplied (Oteng-Peprah *et al*., 2018). Although variations in greywater exist, it is evident that its composition has a high biodegradability with a high BOD_5:COD ratio (Li *et al*., 2009b).

Greywater from the bathroom is deficient in nitrogen and laundry greywater is deficient in phosphorus and nitrogen (Li *et al.*, 2009a) when compared to the suggested BOD:N:P ratio of 100:20:1 for aerobic treatment of sewage wastewater of (Tchobanoglous *et al.*, 2003). In some cases, laundry greywater is low in phosphorus because of the use of phosphorus free detergents. Along with higher levels of organic substances, kitchen greywater has sufficient nitrogen and phosphorus to have a BOD:N:P ratio close to that suggested by(Tchobanoglous *et al*., 2003). The nature of greywater gives it various characteristics, physically, chemically and biologically as presented in Table 3-4. .This is a simplified representation when considering that (Oteng-Peprah et al., 2018) has presented these characteristics for low and high income countries respectively.

Table 3-4 The characteristics of greywater by different categories

	Bathroom	Laundry	Kitchen	Mixed
pH (−)	6.4–8.1	7.1–10	5.9–7.4	6.3–8.1,
TSS (mg/l)	7–505	68 – 465	134–1300	25–183
Turbidity (NTU)	44–375	50 – 444	298.0	29–375
COD (mg/l)	100–633	231 – 2950	26–2050	100–700
BOD (mg/l)	50–300	48 – 472	536–1460	47–466
TN (mg/l)	3.6–19.4	1.1 – 40.3	11.4–74	1.7–34.3
TP (mg/l)	0.11– >48.8	ND – >171	2.9– >74	0.11–22.8
Total coliforms (CFU/100 ml)	$10–2.4\times10^7$	$200.5–7\times10^5$	$>2.4\times10^8$	$56–8.03\times10^7$
Faecal coliforms (CFU/ 100 ml)	$0–3.4\times10^5$	$50–1.4\times10^3$	–	$0.1–1.5\times10^8$

Note: Source Li et al.,2009 Reprinted with permission from Elsevier

The characteristics and treatment of greywater have been researched, however there is insufficient guidelines for greywater reuse or the evaluation of treatment technologies (Li *et al.*, 2009a). Further research into this gap should be prioritized considering the findings of recent studies where appreciable amounts of toxic heavy metals (Aonghusa and Gray, 2002; Eriksson *et al.*, 2002), health and beauty products, aerosols, pharmaceuticals, pigments (Eriksson *et al.*, 2002) have been discovered in greywater.

3.3.4 Reuse guidelines

Greywater can be used for any purpose, provided that appropriate treatment has been used to meet the desired water quality. According to Nolde (2000), four criteria that greywater reuse should adhere to is economic feasibility, hygienic safety, aesthetics and environmental tolerance. Jeppesen, (1996) believes that with adequate water reuse guidelines substantial water savings could be made even though there exists valid health and environmental concerns. Li *et al*. (2009a) claims that there has been no enforcement of uniform international water reuse guidelines to control quality and reclaimed wastewater- a hindrance, says Lazarova *et al*,(1999), to the appropriate reuse of greywater

What exists is variations of guidelines from state to state depending on the need, application and social factors. The water quality specifications rely on the intended application, consequently defining the complexity of treatment system required and depends on the resources available in the state. A significant variation in guidelines is the identifiable values and limited parameters. The 2006 World Health Organization guideline, for greywater reuse for restricted and non-restricted agricultural irrigation, only outlines the microbiological requirements, leaving out the physical and chemical requirements (Li *et al*., 2009b).A consensus across literature is that a comprehensive water reuse guideline shall at least include requirements for pH, BOD_5, fecal coliform, total coliform, TSS and turbidity. Occasionally limits on parameters such as nitrogen, phosphorus, ammonia and chlorine residual have been included (Li *et al*., 2009b).

Evidently the gap in water reuse guidelines has been identified, resulting in several guidelines being proposed by various studies like Jeppesen (1996); Li *et al*.(2009b); Rodda (2011) and Carden *et al*.(2017).Although well intended, the inception of these guidelines reveal the main challenge, lack of uniformity. The studies all have different boundary conditions which dictate the outcome of the guideline.

Guideline by Rodda (2011) is intended for small-scale agriculture and gardens in South Africa. The focus of the guideline is to minimize risk by applying the guidelines only to irrigated land and maximizing the benefit of supporting plant growth by using greywater. The application of these guidelines can be used even in non-sewered areas, unlike Jeppesen (1996) who researched for the development of minimum requirements for the design and installation of greywater systems in sewered areas in Australia.

Li *et al*.(2009b) proposed greywater reuse guidelines based on several studies (Table 3-5). Using this table and the evaluation of treatment systems, the study concludes by providing greywater recycling schemes for unrestricted non-potable urban reuses (Figure 3-1). Unrestricted non-potable water reuses require higher water quality than restricted water reuses. Thus, the guideline in Table 3-5 is based on how stringent the post-treatment water quality is. (Li *et al*., 2009b) proposes treatment options to reach goal quality, unlike Rodda (2011) and Jeppesen, (1996) who discuss the mitigations on how reclaimed water can be used with limited risks and health concerns. Another challenge is enforcing these guidelines; for as it stands, they are all merely suggestions to local authority and decision makers.

Table 3-5 The standards for non-potable greywater reuses and applications

Categories		Treatments goals	Applications
Recreational impoundments, lakes	Unrestricted reuses	BOD_5: ≤10 mg/l TN: ≤1.0 mg/l TP: ≤0.05 mg/l Turbidity: ≤2 NTU pH: 6–9 Faecal coliform: ≤10/ml Total coliforms ≤100/ml	Ornamental fountains; recreational impoundments, lakes and ponds for swimming
	Restricted reuses	BOD_5: ≤30 mg/l TN: ≤1.0 mg/l TP: ≤0.05 mg/l TSS: ≤30 mg/l pH: 6–9 Faecal coliforms ≤10/ml Total coliforms ≤100/ ml	Lakes and ponds for recreational without body contact
Urban reuses and agricultural irrigation	Unrestricted reuses	BOD_5: ≤10 mg/l Turbidity: ≤2 NTU pH: 6–9 Faecal coliform: ≤10 / ml Total coliforms ≤100/ ml Residual chlorine: ≤1 mg/l	Toilet flushing; laundry; air conditioning, process water; landscape irrigation; fire protection; construction; surface irrigation of food crops and vegetables (consumed uncooked) and street washing
	Restricted reuses	BOD_5: ≤30 mg/l Deterge t (anionic): ≤1 mg/l TSS: ≤30 mg/l pH: 6–9 Faecal coliforms ≤10/ml Total coliforms ≤100/ml Residual chlorine: ≤1 mg/l	Landscape irrigation, where public access is infrequent and controlled; subsurface irrigation of non-food crops and food crops and vegetables (consumed after processing)

Note: Source Li et al.,2009 Reproduced with permission from Elsevier

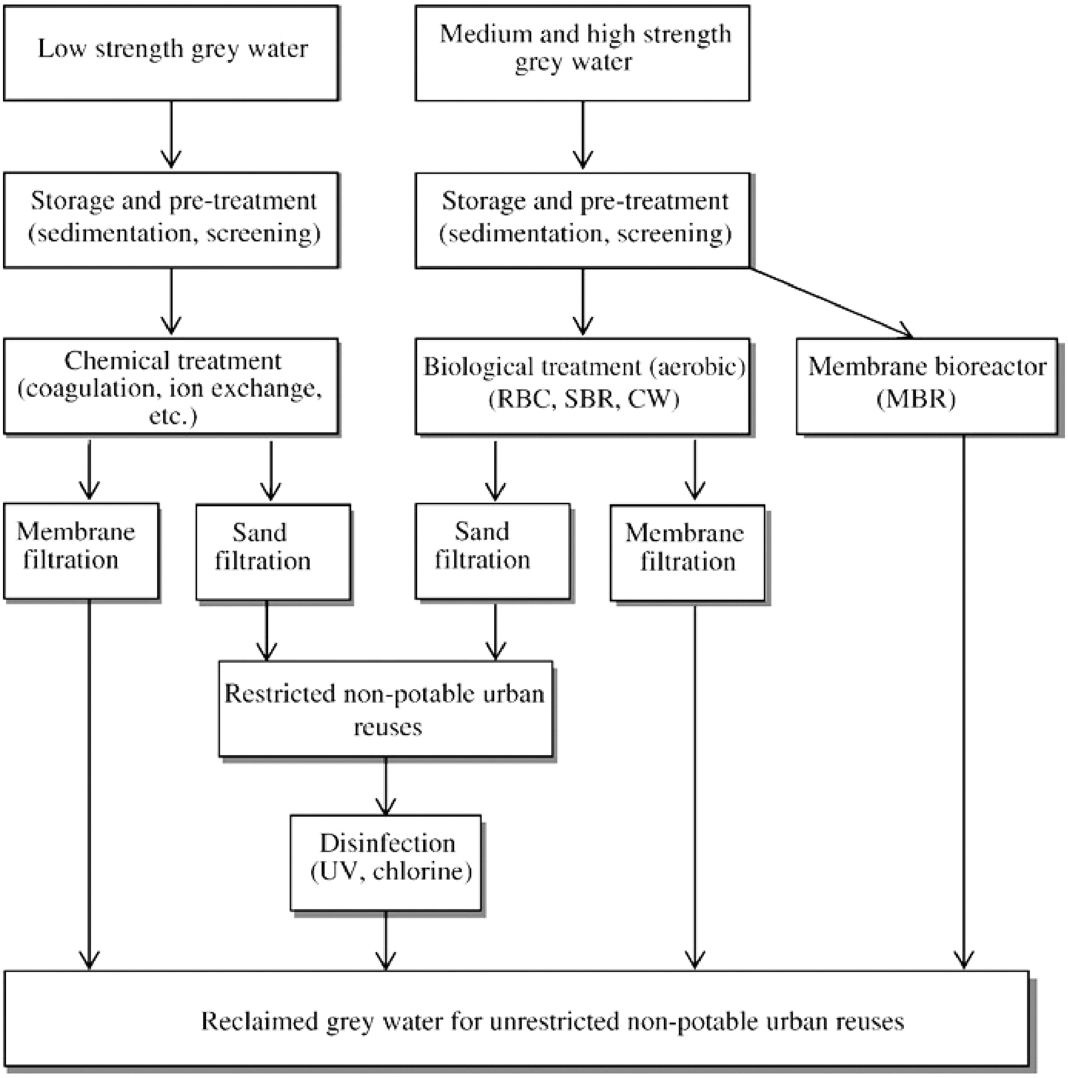

Figure 3-1 The grey water recycling schemes for non-potable urban reuses

Note: Source Li et al.,2009 Reprinted with permission from Elsevier

The logic adapted in 22 Western US states is that the safest method of greywater reuse is to prevent human contact (Jeppesen, 1996). This concept limits the potential benefits of greywater reuse. Otterpohl *et al*.(2003) believe that it is important to inform and train the users regarding innovative water technology – or at least about its basic philosophies. According to Otterpohl *et al*. (2003) many of these innovative concepts demand only a minor change of the user's behavior. For example, separating wastewater streamflow in the households and using less harmful soaps and detergents.

3.3.5 Perceptions

Key to the success of greywater use is public acceptance, not only the water quality and what it will be used for but the technology accompanying it.

Oteng-Peprah *et al.* (2018) says that the rejection of greywater use programs by their intended beneficiaries have caused the failure of many technically sound and environmentally friendly programs because they were not accepted. Greywater use has greater public support in areas which are water stressed or have unreliable water supply (Alhumoud and Madzikanda, 2010). This should come as no surprise as the core value of greywater use is based on reducing over-reliance on freshwater sources.

Public perception on greywater use is a social phenomenon which require various strategies to assess. Oteng-Peprah *et al*. (2018) mentions a few strategies namely, surveys, interviews, focus group discussions, informal discussions and social surveys. Through the study of Adewumi (2016), the level of education and that of one's awareness pays a role in the success of greywater use. In the case of Jamrah *et al.*(2006), 89.1% of their survey respondents said that they had never heard of greywater and only 3.6 % were aware of greywater. While religious and cultural practices also influence reuse programs, Dolnicar and Schafer (2006) identified language of the names given to recycled water as a hindrance to reuse programs.

The closer recycled water gets to human contact, the less it is accepted according Dolnicar and Saunders (2005). Oteng-Peprah *et al*. (2018) identifies several studies which state that the highest acceptability of greywater use projects is for non-potable uses. This is supported by the detailed study of Jamrah *et al.*(2006) who distributed a questionnaire of 250 questions randomly in the city of Amman for four months. The results can be seen in Figure 3-2. Similarly, the results of the survey revealed that greywater reuse is favorable towards non-potable uses.

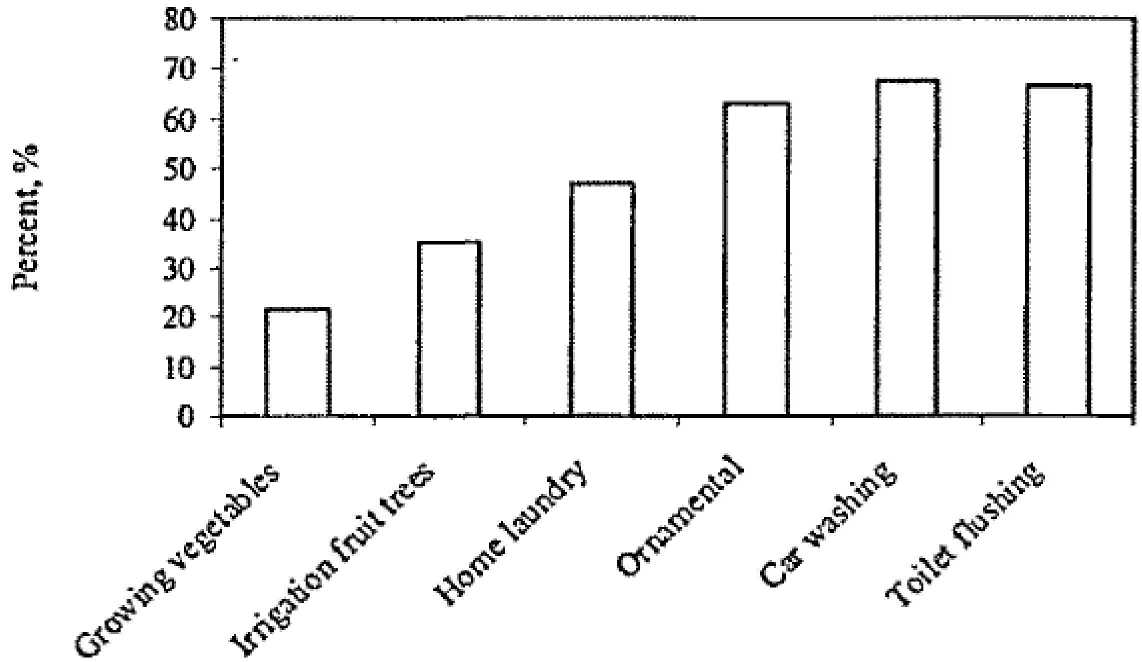

Figure 3-2 Percent of people accepting reuse of greywater projects for various household activities

Note: Source Jamrah et al.,2006. Reprinted with permission from Taylor&Francis

The significant opposition to greywater reuse schemes, particularly potable use, highlights the lack of trust that the public has towards the implementing authority even in the cases of advanced treatment technology (Friedler *et al.*, 2006; Russell, *et al.*, 2008; Omerod and Scott, 2013) . Jeffery (2001)identified that people are more willing to use their own “recycled water” than from an unknown source. Other oppositions are health concerns, impact to the environment, cost and seeing no value in greywater (Jeppesen1996; Jamrah *et al.*, 2006). According to Jeppesen (1996) although there is high public acceptance in Australia there is a need to correct the perception that greywater is innocuous. Ultimately (Oteng-Peprah et al., 2018) conclude that both technical and non-technical expertise are required to achieve effective greywater treatment and reuse. Water scarcity adaption strategies for households

When faced with water insecurity, rural households devise their own coping strategies independent of traditional leadership (Water Research Commission, 2016). Pasakhala *et al*.(2013) investigated household coping measures and the factors that influence them. Eight measures were discovered, the most prominent being the use of multiple water supplies (Figure 3-3)[11].

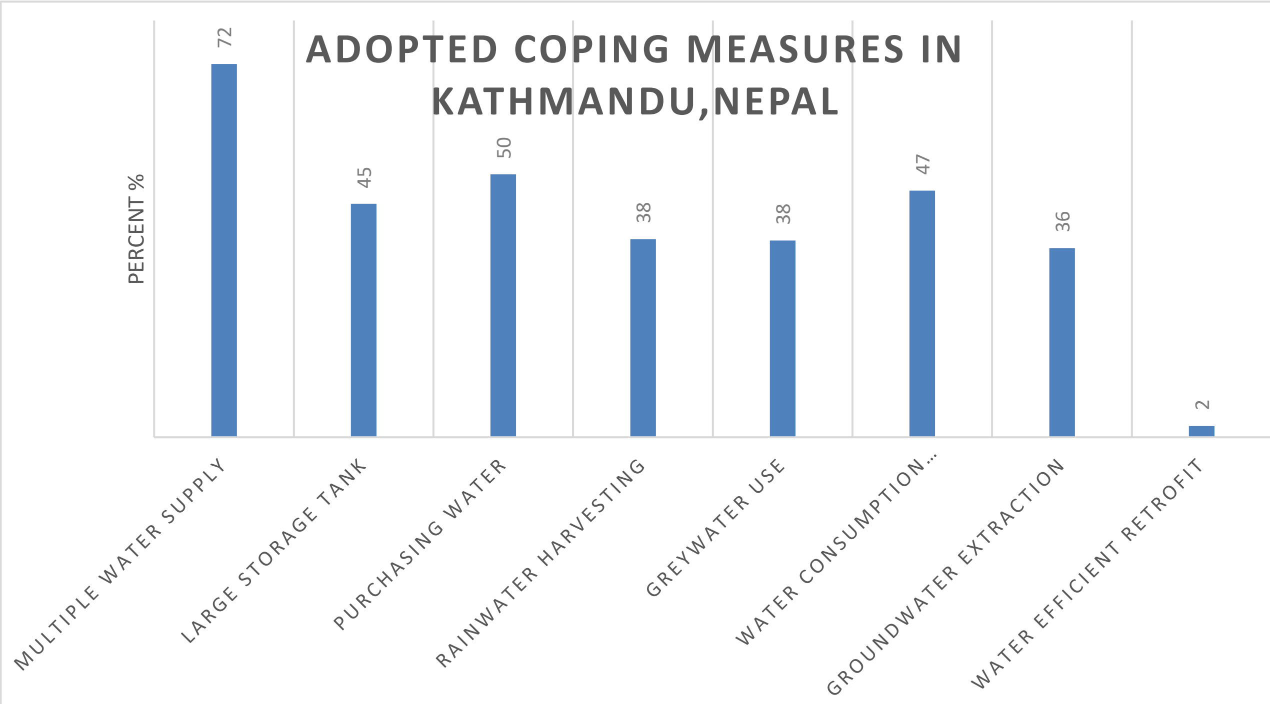

Figure 3-3 Adopted coping measures based on a case study by Pasakhala et al. (2013)

Compiled by author

[11] Multiple water supply: Households use different water resources to meet their domestic water consumption demand
Water efficient retrofit: using devices in the homes to lower water consumption such as low-flush toilets and efficient showerheads

Kanda *et al*. (2017) found, in rural Zimbabwe, that in cases of limited freshwater supplies households respond by exploiting readily available water resources despite the quality or the distance to travel. Households also tend to store large quantities of water and prioritize its use. By studying how adaption strategies influence water usage and quality, Kanda *et al*. (2017) observed households storing large quantities of water, limiting the number of trips required to collect water. The prioritized water uses were cooking, drinking and washing of dishes. Washing of clothes was done at the water source.

In rural areas, the most common greywater technology applications are for irrigation of non-edible plants. This is the case, not only because irrigation works well with low-level technologies but also because of the greywater perception principle, the further greywater is from human contact, the more acceptable it is. Some of the characteristics of greywater generation that have been researched are related to the type of settlement and the fixtures (Oteng-Peprah *et al*.,2018). Therefore, it should come as no surprise that greywater technologies or any technology in rural areas need to be well adapted to the area. In South Africa low-technology subsurface irrigation systems, mulch tower for treatment and tower gardens are some of the greywater technologies proposed by Rodda (2011) (See Appendix A)

4 Methodology

This chapter describes the study area and details the data collection method which best complimented the aim of the thesis. In this study, to analyze the greywater production, recording of the water consumption of greywater producing activities was done. This was made possible through adopting a case study research design approach. The study quantifies water consumption in the household for three main activities. While some definitions of greywater do not include dishwashing water, it was included in this present study as to not limit the possible outcomes of the study.

4.1 Overview of South Africa

Located on the southernmost tip of the African continent, the Republic of South Africa, after roughly 50 years of apartheid, historically became a democratic state in 1994. Although driven by racial segregation, the structure of apartheid has had severe impact on the development of South Africa until present day. After apartheid, amongst the many challenges of the new government was to supply basic services to the majority of the population that the apartheid government had neglected. In Africa, South Africa boasts as the largest country in the continent and the 25^{th} largest in the world marked by several ecosystems, varied topography, natural beauty and cultural diversity. Northern neighboring countries are Namibia, Botswana and Zimbabwe, to the east Swaziland and to the northeast Mozambique. The Southern Africa coastline stretches along the South Atlantic and Indian Ocean. The population of approximately 57 million people is spread across nine administrative provinces.

Generally, South Africa has a temperate climate influenced by oceans that surround it to the east, south and west (Lowe *et al.*, 2019). South Africa is characterized as a semi-arid water stress country with an average annual precipitation of 450mm. The total surface water available in South Africa is 49200 million m^3 per year, 10% of which originates from Lesotho (Department of Water Affairs & Forestry, 2004). The main source of water in South Africa is surface water, groundwater is extensively utilized in the rural and arid areas. The rural water sector demands a little over 4% of the country's total water requirements (Department of Water Affairs & Forestry, 2004). In total there are six major water use sectors, the renewable internal freshwater resource per capita is 821 m^3 (The World Bank, no date). The challenges facing water availability in South Africa are spatial distribution and seasonality of rainfall, low stream flows in rivers and the need for large scale water transfers across catchments because of the remote location of urban and industrial developments.

4.1.1 The Marulaneng village

Marulaneng village is an arid locality in the northernmost province of South Africa, Limpopo. Limpopo is considered to be a developing economy, exporting primary produce and importing manufactured products and services. Northern Sotho people (Bapedi) are the predominant ethnic group in the province which distinguishes ethnicity by culture, language and race. Marulaneng village is governed by the Mogalakwena municipality, characterized as a category B local municipality[12](STATS SA, no date). Limpopo is one of the poorest regions of South Africa.

The Marulaneng village is selected as a case study primarily because it is a non-sewered area having a widespread and ongoing water scarcity crisis, making it ideal to explore the benefits of water reuse. The nature of the crisis is not unique to Marulaneng village; however, it renders the opportunity for a convenient sampling procedure. The sampling takes place in two sub-communities of Marulaneng, namely Masakaneng and Phomolong, with a count of approximately 800 and 350 houses respectively (Majabadibodu,2019).

The primary water sources for households has naturally evolved with the changing socio-economic, political and environmental climate. The water source has progressed from river collection to rainwater harvesting and communal taps sourced from groundwater. Prior to 1994, during the apartheid era, the village was isolated from the development plans of the country. It is only in the democratic period that government has implemented projects to provide services, this is one of the reasons why service delivery is delayed and has not reached its peak in this village. In 2011 only 20.2% of the Limpopo population had water inside their dwelling(STATS SA, no date)

The municipal service delivery has a high reliance on groundwater. The municipality extracts groundwater and stores, without treatment, in various reservoirs equating to 120 cubic meters of storage. The water works are manually operated by local representative who intermittently supplies water to the community. The government has undertaken a project to import water from a neighboring watershed, but it is yet to be implemented in Marulaneng. Water is provided to the community as a free basic service, currently a rate of 6 kl per month per household. However, poor water supply infrastructure and low rainfall, this rate is not accessible in Marulaneng.

4.2 Data collection

To have a comprehensive overview and reflection about the state of rural water supply services in South Africa Data collection method comprised of a literature study, series of face to face interviews with various stakeholders from the custodians of water (National government) to the user (households) Figure 4-1.

[12] Category B municipality is a local municipality.

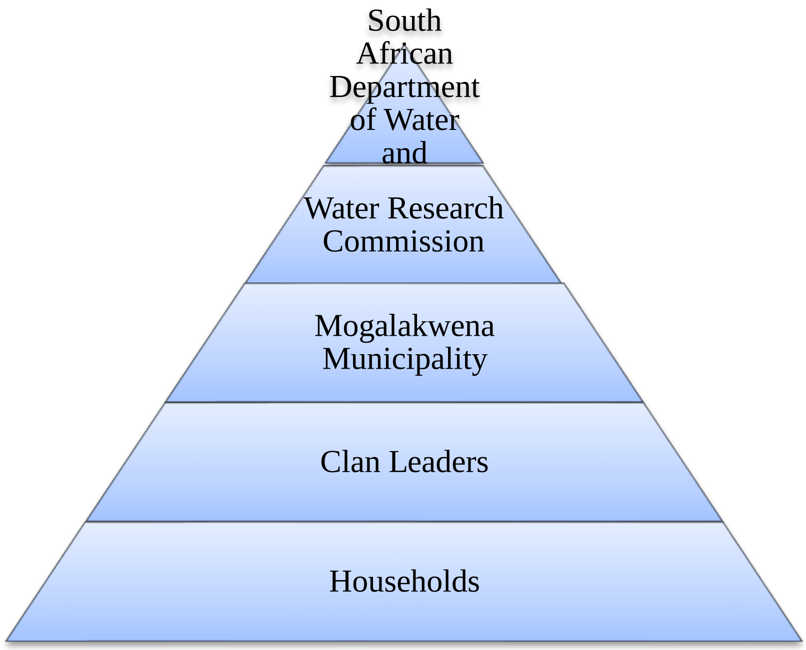

Figure 4-1 Stakeholder hierarchy structured according to stakeholder engagement during this study from top to bottom. This hierarchy represents only those in the data collection. This is not an exhaustive representation of the South African water sector stakeholders.

The interviews took place during a period of three weeks. Permission was granted to record some of the interviews. There was a general willingness to engage with no major objections.

- A discussion with the Department of Water and Sanitation, custodians of water resources, official on policy and legislation that shapes the structure of the water sector.

- Informal interviews with the Water Research Commission; which the government relies on for decision making and policy advise. This interview provides insight on what direction research is taking regarding greywater in rural South Africa. What the considerations and concerns are when implementing technology.

- Informal interview with Marulaneng village local municipal representative for an overview of the study area and the water supply procedure in the area.

- Informal interview with one clan leader as a reflection on how water resources have evolved in the village, the current reality of the village and their household water use activities.

- Household face to face interviews in 17 homes (54 occupants). These are the users of water and dependents of the government with regards to service delivery. Acquire knowledge on the relationship between water consumption and rural household activities.

4.2.1 Methods of data collection

A literature review was done to investigate water consumption and water use activities to in rural households. This was achieved through the use of Google Scholar, Research Gate and the Lund University library search, literature on water consumption in rural households, greywater in households and greywater technologies in rural areas was found.

An online investigation of water reuse technologies was conducted to find technologies that will be used to quantify the potential for water reuse and explore technical challenges.

The interviews were brief and aimed only to map out water consumption related to the three household activities, namely, laundry, dish washing and bathing. These activities were selected based on the definition of greywater. Because piped bathroom structures are rare, pit latrines are most common form of sanitation, hand wash basins were not included. The questions are presented in Table 4-1

Table 4-1 Questions in the household interview survey

1. *How many are you in the household*	Count children and adults separate
2. *Where do you get your water to use at home from?*	Communal tap Communal borehole Personal borehole Buy from small scale providers (residents with personal boreholes) Buy from large scale providers (water trucks) Rainwater
3. *How much water do you use for the following?* *(water measured in terms of sgupo[13])*	Bathing Laundry dishwashing
4. *What water source do you use for your harvest?*	
5. *What do you do with your used water (greywater)?*	

[13] Barrels. Popular water collecting container found in various colours. Refer to Figure 4-2

The household interviews allowed for a case specific analysis of the water consumption in the households Studies with similar objectives, finding water consumption in rural households, have used the 'drop and collect'[14] method as a means of collecting data. This method was abandoned in the present study because the Marulaneng households are dominated by elderly and children whom have low levels of literacy. A disadvantage confirmed by Brown (1987)who says that the "drop and collect" method favours the literate and cannot guarantee whether the correct individual completes the survey. Therefore, household visits were done during the day and the questions were answered by whomever was available at the time. The households selected were under the guidance of the local contact.

The standard water collecting container referred to as "sgupo"(Figure 4-2), which all households are familiar with and use to collect water, was used to give estimates of how much water is consumed for bathing, dishwashing and laundry. Therefore, question two was rephrased as; "how many sgupos do you use for (insert activity)?"

Figure 4-2 "Sgupo" Container used as standard measuring tool when conducting the survey

[14] Surveys are presented to households and left there for a certain period of time for the user to fill out. After that, the surveys are picked up by the researchers.

4.3 Data Analysis

Estimation of how greywater can be used to extend the life cycle of water in a household is done by developing a *Life cycle extension coefficient*, β. This coefficient, β, is a ratio of greywater savings to the total household water consumption. Greywater savings is calculated as the difference in greywater produced in a scenario where greywater in reused and another where greywater is not reused. β increases the availability of potable water in the household.

$$\beta = \frac{(GW_{NR} - GW_R)}{Total\ household\ water\ consumption} \tag{4.3.1}$$

Where:

GW_{NR} greywater produced in scenario without greywater reuse

GW_R greywater produced in a scenario with greywater reuse

With no indication of greywater reuse within Marulaneng households, the data collected is entirely greywater produced without reuse.

4.3.1 Estimate total water consumption in households

The present study collected data on only the water consumption which produces greywater in Marulaneng households. Carden *et al.(*2007a) estimates that greywater in non-sewered areas accounts for 75% of the total water consumed in households. Therefore the total household water consumption and potable water can be estimated as follows:

$$Total\ household\ water\ consumption = \frac{Greywater\ produced}{0.75} \qquad 4.3.2$$

$$Potable\ water = Total\ household\ water\ consumption * 0.25 \qquad 4.3.3$$

4.3.2 Extension of the lifecycle of water using technologies

Existing greywater reuse technologies were researched to match the greywater producing activities presented in the Marulaneng village. The capabilities of these technologies are used to support the extension of the water life cycle in the household's calculation.

Two technologies were found, water recirculation shower from Orbital Systems and water recycling dishwashing machine from KitchenAid. Thus the reuse of bath water and dishwashing water is selected. These technologies can filter used water to an acceptable quality which allows for close human contact reuse activities, therefore extending the life cycle of water in the household. It is the filtration ability of these technologies that is used to calculate the potential of greywater reuse, not the application of the whole product.

4.3.3 Estimate the greywater reuse potential from bath water

$$GW_{NR} = B + L + D_w \quad (4.3.4)$$

$$GW_R = B(1 - R_b) + Dw + L \quad (4.3.5)$$

Where:

B is greywater produced from bathing in Marulaneng

D_w is greywater produced from dishwashing in Marulaneng

L is greywater produced from laundry in Marulaneng

R_b is ratio of reuse for bathing greywater

A filtration efficiency of 70% is assumed 70%. Therefore;

$$R_b = 0.7$$

4.3.4 Estimate the dishwashing greywater reuse potential

$$GW_{NR} = B + L + D_w \quad (4.3.6)$$

$$GW_R = B + L + D_w(1 - R_{dw}) \quad (4.3.7)$$

Where

R_{dw} is the ratio of reuse of dishwashing greywater

The technology identified to propose this scenario filters rinse water from dishwashing. Based on the assumption that half of the dishwashing greywater generated is from rinsing water;

$R_{dw} = 0.5$

Assumptions

- Owing to the limitations of space and time, the water recirculation shower of Orbital Systems only filters water that can be filtered in real-time to the acceptable quality. That means some water that needs more rigorous filtration is flushed away. An interview with Orbital Systems could not confirm the average amount of water filtered per shower, this present study assumes 70% filtration efficiency.
- Due to measurement difficulties and inter-household variations in total household water consumption, data was collected only on greywater producing activities, namely, bathing, laundry and dishwashing. Thus, the data on grey water collected serves as an important metric for estimating total household water consumption and freshwater availability.

5 Results and Discussion

This chapter presents the results of the fieldwork with support from literature. 17 households, with 54 occupants in total, were interviewed. The socioeconomic description of an area is a common theme found in literature regarding human interaction with water. Sources of water supply, coping measures and water consumption results are used to gather data to understand communities and set the preamble for future work. A theme not so common is calculation of greywater potential for rural households, the present study was guided by Pasakhala *et al.*, (2014) in this regard. However, unlike Pasakhala *et al.*(2014) the greywater potential in the present study is substantiated by the possible application of existing technologies in rural households. The chapter concludes with a discussion on the barriers of applying these technologies in rural low-income households.

5.1 Socioeconomic description of households

Literature related to water consumption patterns in rural areas tends to describe households according to their monthly income, age of household head, family size, education level and size of land holding (Fan *et al.*, 2013; Pasakhala *et al.*, 2014; Basu *et al.*, 2017),. In this present study, the family size was the sole description acquired during the survey. The average household size was 3 persons, ranging from 1 person to 8 person households.

5.2 Sources of water supply and coping measures

With increasing water supply shortages, multiple sources of water are common in households as a coping mechanism. Table 5-1 presents the water supply sources used by the interviewed households. Regardless of its intermittent supply, the communal tap, at 83.3%, is a major water supply source in the community. This is indicative of the high reliance that the households of Marulaneng have on government water supply for their basic needs.

Table 5-1 Description of water supply sources

Sources	*Description*	*Respondents (%)*[a]
Personal Boreholes	Well on private land whose use is controlled by landowner	11
Communal tap	Water tap for shared community use	83
Communal boreholes	Borehole for shred community use	11
Small scale buying	15-25 litres of water supplied by some households with personal boreholes	33
Large scale buying	Commercial supplier who supplies in bulk	27

[a] *Sum>100% because respondents use more than 1 water source*

All respondents, including households with personal boreholes had multiple water supply sources Table 5-2.This suggests that water shortages have an impact on all households, even those with economic leverage. The major coping measure for water supply is the collection of rainwater, its popularity may be because it is an inexpensive alternative requiring little effort. The average size of land for agriculture per household, mostly maize plantation is 1.1 ha in Limpopo (De Cock et al., 2019). Therefore, it comes as no surprise that households prefer to rely on rain to water their harvest given that the demand of fresh water to grow this size of maize is an amount not readily available under the challenges of water shortage.

Table 5-2. Coping measures adopted by households

Coping measure	*Description*	*Respondents (%)*
Multiple water supply	Use more than one water supply source	100
Purchasing of water	Purchase water from either small scale or large-scale supplier	56
Rainwater collection	Collect and use rainwater as water supply	94
Reliance on rainwater for agriculture	Do not use domestic water supply in their agricul-ture/gardening	89

5.3 Quantity of water consumption for greywater producing domestic activities

Water consumption of activities that result in greywater was estimated during the interviews. (full data can be found in appendix B) This water will be referred to as greywater produced. Unit of measurement in this section is litres per capita per day, allowing the results of the present study to be compared to existing literature on this theme.

Greywater produced per capita was calculated using the following equation:

$$\text{Greywater produced} = (\sum \text{B} + \sum \text{DW} + \sum \text{L})/n \tag{5.1}$$

where *greywater produced* is the total greywater produced (litres/cap/day); *B, DW, L* stands for bath, dishwashing water and laundry water per household per day respectively and *n* is the total number of people,54, in the 17 households. Morel and Diener (2006) claim that amongst other things water installations and the degree of water abundance determines the volume of grey-water produced in households. In low income countries with water shortage they found that greywater varies between 20 litres per capita per day to 30 litres per capita per day. A result that is comparable in this present study where 23 litres per capita per day of greywater was estimated using *Equation 5.1,* of which 53.9% is from bathing *Table 5-3*. Bathing takes place usually once a day, dishwashing at least twice a day and laundry washing is performed once a week. Marulaneng is a village where dwellers wash their clothes by hand (only one household used a washing machine), bath in medium sized containers and wash dishes in small containers.

Table 5-3 Average amount of greywater produced from various activities

Activity	*l/cap/d*	*Minimum (l/c/d)*	*Maximum (l/c/d)*
Bathing	12.4	10	25
Laundry	3.9	2	7
Dishwashing	6.74	2.5	15
Total	23		

The results in Marulaneng are significantly lower than the water consumption results in Dhani Mohabbatpur, India *Table 5-4*. However, a comparison of the greywater producing activities in the present study and water consumption pattern in Kathmandu, Nepal and Bangladesh present similar estimates. Variations in domestic water consumption can be attributed to different calculation procedures and data collection methods.

Table 5-4 Household domestic water consumption pattern of greywater producing activities in rural [a]Nepal, [b]Bangladesh and [c]India

Activity	*Kathmandu,Nepal[15] l/c/d*	*Rural Bangladesh, l/c/d*	*Dhani Mohabbatpur, India l/c/d*
Bathing	4.9	12	19
Laundry	5.8	8	22
Dishwashing	7.1	5	13
Total	17.8	25	54

Source: [a] (Pasakhala *et al.*, 2014). [b] (Ahmed and Smith, 1987). [c] (Singh and Turkiya, 2013)

[15] Middle income group of study

(Gleick, 1996) stipulates 15 and 20 litres per capita per day as a minimum domestic water consumption requirement for bathing and washing clothes. According to these requirements, households in Marulaneng have been coping with water shortage by reducing their water consumption for washing of clothes.

A greater uncertainty is expected in the estimate for bathing water as the interview was administered to one household member who had to give total volumetric estimates for all the household activities, which could be different to what the rest of the house members rightfully use. However, there is a degree of reliability as it was women who were available to answer the survey and it is women who oversee the washing of dishes, household laundry and bathing of children. In one case it was a man, who lives by himself.

The trend of household size influence on water consumption, observed in Keshavarzi *et al.*(2006) Fan *et al.*(2013) and Basu *et al.*(2017), is also observed in this present study (*Figure 5-1*). That is, water consumption is negatively correlated with the household size (occupants). Therefore, an increase in domestic water consumption can be better explained by a growth of households as opposed to population growth (Keshavarzi *et al.*, 2006)

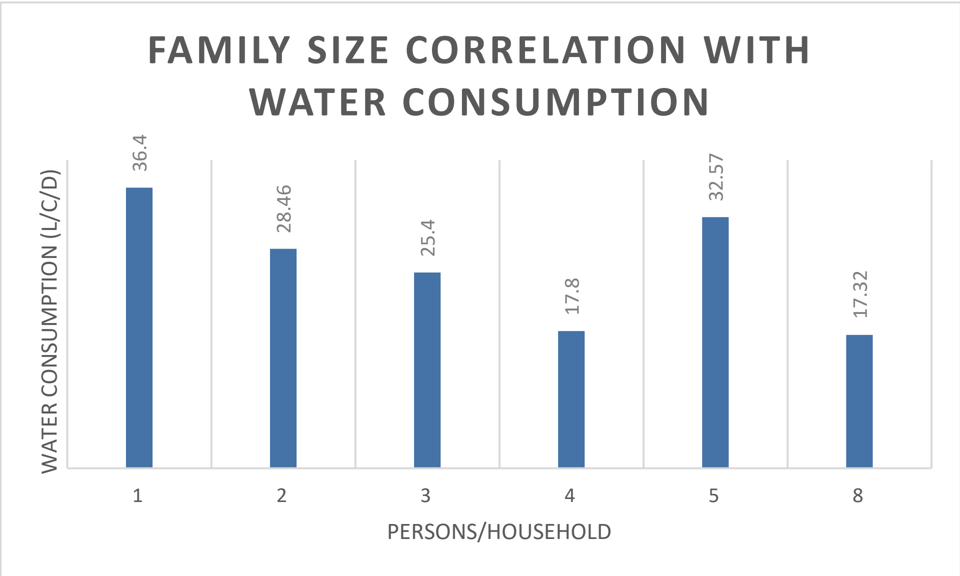

Figure 5-1 Water consumption with increasing family size

5.4 Greywater potential

Every household produces greywater thus greywater use as a coping measure has a potential in every household by increasing the availability of freshwater. This section will use litres per household per day as the unit of measurement to fulfil the definition of β, life cycle of water extended in the household.

5.4.1 Potable water availability in Marulaneng

The average greywater production is 73 litres per household per day based on *Equation 5.2*.

$$Greywater\ produced = Capita_h * GW_c \tag{5.2}$$

Where:

$Capita_h = 3.17$ is the average number of persons per household.

$GW_c = 23\ litres$ is the average greywater produced per capita.

Equations 4.3.2 and 4.3.3 estimate the total household water consumption and available water in Marulaneng. The potable water available is 24 litres per household per day. This yields 3 kilo litres of water consumption per household per month as seen in Table 5-5 .This is half of the intended free basic water service of 6 kilo litres per month per household.

Table 5-5 Water consumption balance

	Marulaneng	*Free basic service intended*
Greywater (litres per household per day)	72	150
Potable (litres per household per day)	24	50
Total water consumption (litres per household per day	97	200
Total water consumption (kilo litres per household per month)	~3	6

5.4.2 Reuse of bathing water

Bathing in Marulaneng is commonly practised in medium-sized containers where heated water and cold water is manually poured in and mixed. Similar bathing practises are known around the world in rural households as “bucket-bath” method. 39 litres per household per day of bath greywater is generated from bathing

According to categorisation of Carden et al. (2017) water from the shower is Class Ia, the “light-est” form of greywater, and water from basins and baths is a class below, Class Ib. The lighter the greywater, the lower the organic content and the better it is for greywater reuse. The need to use less water in households has initiated interesting solutions within the shower industry, probably owing to its major role in domestic water consumption. Normally water goes down the drain during a shower, resulting in significant water and heat consumption.

Amongst some of the solutions to increase water-use efficiency is the water recirculation shower, Orbital Systems, of Sweden. While the user is in the shower, water is filtered, heated and reintroduce back into the shower. Orbital Systems claims that the filtration is rigorous enough to produce drinking water quality. The parameters which are measured are electric conductivity and turbidity. For the calculation of β, this present study assumes 70% filtration efficiency.

The nature of a shower presents a better greywater quality than water contained in a bath like environment, an off-grid shower with the filtration abilities of the Orbital Systems recirculation shower is proposed. The shower will not have a constant feed of water but a tank with limited capacity. The tank will be filled manually with hot and cold water mixed and raised overhead. Thereafter, showering continues as normal. In the floor of the shower lies a filtration and water storage component with water quality sensor to ensure secure reuse.

With this technology in mind, not for recirculation but water recycling, the hypothetical adaptation of Orbital Systems filtration technology in rural households is done. Using *Equation 4.3.4* and *Equation 4.3.5*, the total greywater production calculated is 73 litres per household per day and 45 litres per household per day for the scenario without greywater reuse and the greywater reuse potential scenario respectively (Table 5-6). According to *Equation 4.3.1*, with 70% of the bathing greywater filtered, β is 0.28. The potable water availability is increased to 51 litres per household per day.

Table 5-6 Calculation of greywater reuse potential

				Filtered amount for
	Greywater Produced l/h.d		Greywater produced l/h.d	Bath l/h.d
Bath	39	*Bath*	12	27.5
Laundry	12	*Laundry*	12	
Dishwashing	21	*Dishwashing*	21	
Total	72	*Total*	45	

The filtered water, if used for another bath activity as the Orbital Systems allows for, would require an additional 11 litres to fulfil the whole bathing activity. Illustrated in Figure 5-2 is a non-reuse scenario and Figure 5-3 illustrates a scenario of reusing bath greywater for bathing.

Figure 5-2 Water consumption without reuse implementation scenario.

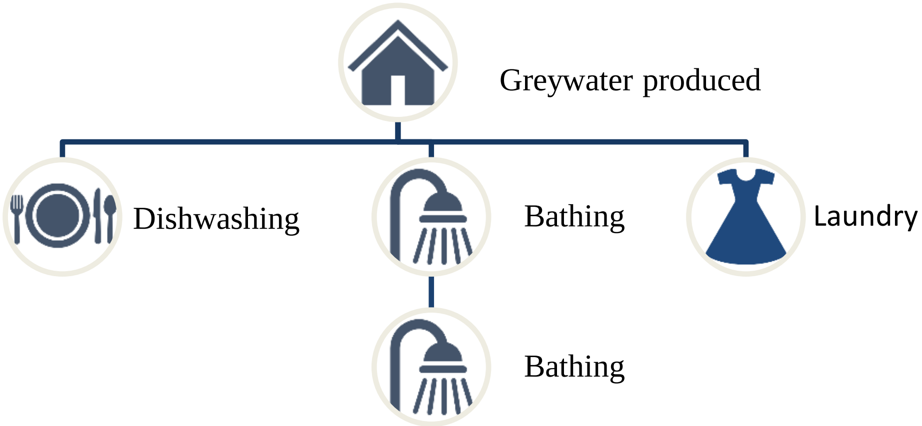

Figure 5-3 Water consumption with reuse implementation scenario.

In the case of bath greywater being filtered to an acceptable quality to ensure safe reuse for another bath, one could argue that another reuse activity could be laundry instead. Reusing bath greywater for laundry would meet the total demand for laundry of 12 litres per household per day.

5.4.3 Reuse of dishwashing water

Households in Marulaneng use round containers or buckets to wash dishes and crockery. There is one for the main wash and another for rinsing. Typically, 21 litres per household per day of greywater is produced from dishwashing, half of which (11 litres per household per day) is assumed to be rinse water.

During the main wash in standard dishwashers, water collects in the dishwasher sink at the bottom and is continuously recycled (used to wash) until dirty. A filter catches most of the large waste while smaller waste particles remain suspended in the water (Baguley and McDonald, 2015). To conserve water, a dishwasher from KitchenAid, filters water from the final rinse cycle. The clean water is then collected and stored for the next wash (Keith, 2014). The technology is based on the assumption that dishes are relatively clean by the final rinse stage. The capacity of the tank where the water is stored is 3.3 litres. A complete normal wash consumes approximately 6.2 litres, half of which is recycled water.

For the reuse of rinse water from dishwashing in the case of Marulaneng, a filtration bucket is proposed. The filter would be found at the entry of the bucket, where rinse water is poured in. After passing through the filter the water is stored in the bucket, which has a water quality sensor to ensure secure reuse.

The calculation for potential in Marulaneng for the reuse of dishwashing water is based on the hypothetical adaptation of KitchenAid filtration technology in rural households. Using *Equation 4.3.7* and *Equation 4.3.7,* the total greywater production calculated is 73 litres per household per day and 62 litres per household per day for the scenario without greywater reuse and the greywater reuse potential scenario respectively (Table 5-7). According to *Equation 4.3.1*, with 50% of the dishwashing greywater filtered, β is 0.10. The potable water availability is increased to 34 litres per household per day.

Table 5-7 Calculation of greywater reuse potential

	Greywater produced (l/h.d)
Bath	39
Laundry	12
Dishwashing	21
Total	72

	Greywater produced (l/h.d)	*Filtered amount for* Dishwashing (l/h.d)
Bath	39	
Laundry	12	
Dishwashing	11	11
Total	62	

The filtered water, if used for another dishwash activity as the KitchenAid dishwasher allows for, would require an additional 11 litres to fulfil the whole dishwashing activity. *Figure 5-5* illustrates a non-reuse scenario and *Figure 5-4* illustrates a scenario of reusing dishwashing greywater for dishwashing.

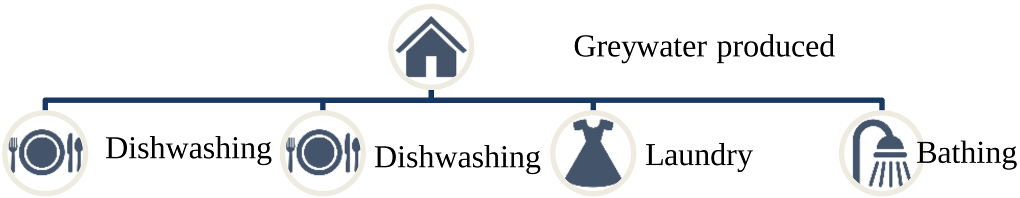

Figure 5-5 Water consumption without reuse implementation scenario.

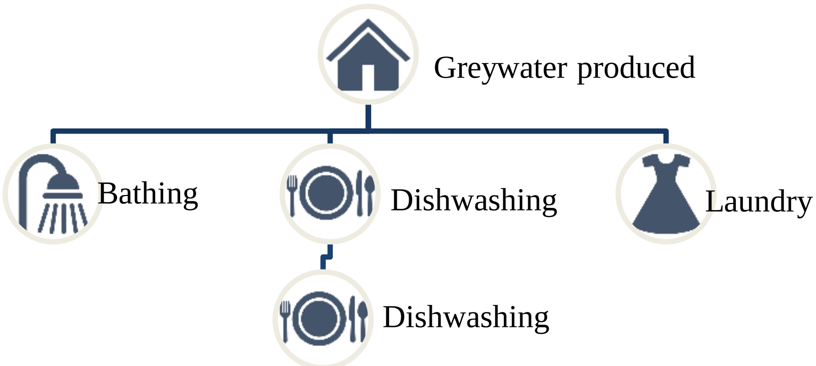

Figure 5-4 Water consumption with reuse implementation scenario.

5.4.4 Barriers for advanced greywater technologies in rural households

For rural communities, access to technology is often initiated through the intervention of a third party. Over time an understanding within the water sector has developed on how to select appropriate technology. Factors to consider are local financial and geographical conditions, operation and maintenance and technical capabilities of the society (WaterAid, no date). Therefore, although the benefits of advanced technology are evident, local conditions restrict implementation.

Both dishwashers and the water recirculation shower rely on constant pressurized water supply, infrastructure that the current households in Marulaneng don't have. In the case of the Orbital Systems shower, the objective is to have a water conservative shower that can still be functionally comparable to the modern-day shower. This means that there is no compromise on what users perceive as having a "good shower", which is often determined by heat and pressure of the water.

An interview with the product development official at Orbital systems revealed that from a technical perspective it should be possible but there are barriers in implementing water recirculation in off-grid households. The shower requires water supply, pressure, heating and power supply to work. A minimum flow of 9 to 10 litres per minute is required. It is a highly electromechanical product with a vital software component that can detect containments in real time, in line without delay. The shower is self-cleaning but like all products, the results of the product rely on the consumer using the product as intended. The infrastructure demand of such a product are highly technical and cannot be expected in low income households.

6 Conclusion

In this study, an investigation on the potential reuse of greywater in Marulaneng, South African is done. The greywater production was found to be 73 litres per household per day and potable water availability of 24 litres per household per day. The water consumption in households is 50% less than what it should be had there been access to the prescribed 6 kilo litres per household per month. Generally, an increase in household size correlated with a decrease in per capita water consumption. As it stands greywater reuse is not a common coping measure unlike seeking multiple water supply sources.

Technologies filtering greywater to acceptable water quality for close human contact exist and were used to support theoretical application of household level technology for greywater reuse in Marulaneng. By reusing bath water and dishwashing rinse water, the lifecycle of water is increased by 28% and 10% respectively in the households of Marulaneng. With filtered greywater available, dishwashing greywater can be reused to wash dishes and bathing greywater can be used to bath or do laundry. Currently technical barriers do exist; however, it is possible to modify existing technologies to suit rural areas and overcome the conditions and limitations. With the modification of high-level technology, greywater would not only be limited to irrigation but can also be beneficial within the household as a means of alleviating water scarcity challenges. The lack of policy and legislation hinders the use of greywater, not only in rural areas but in urban areas as well.

Although the Government of South Africa has well intendedly committed to provide basic water supply, interventions are required to address greywater management in non-sewered areas. In light of the environmental and health concerns compounded by water scarcity challenges, it is short-sighted to invest in improved water services without addressing greywater management.

7 Future work

With the lack of service delivery planning for greywater management in South Africa, the risks that greywater pose to health and the environment and potential benefits in alleviating water scarcity. Because greywater reuse without treatment is not recommended, this study finds that it is important to develop suitable and effective technologies to allow for secure water reuse particularly in non-sewered water scarce areas, especially in areas where greywater irrigation may not be suitable. This study recommends the modification of existing technologies for feasible implementation in rural households.

Although it wasn't investigated in this study, public perception plays a major role and should be a major consideration when developing technology. To overcome health risks, water quality sensor and a time keeping component should be essentials in the technologies.

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8.1 Interviews

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9 Appendix

9.1 Appendix A Low technology applications in South Africa

Pictures from Rodda,2011.

Picture 1 Low technology subsurface irrigation

Picture 2 Tower garden

Picture 3 Mulch tower

9.2 Appendix B Results from households in Marulaneng, South Africa

	1	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***	***11***	***12***	***14***	***15***	***16***	***17***
cap/house-hold	3	2	4	2	2	3	4	8	4	2	4	4	5	1	3	2
Bathing (l/d)	30	20	40	32	40	70	40	90	40	20	40	40	100	20	18	18
Laundry (l/week)	90	60	60	80	60	120	80	200	40	40	40	200	160	30	60	100
dish washing (l/d)	32	30	30	28	10	20	20	20	18	18	18	10	40	10	20	20

9.3 Appendix C Popular Science Summary

There is no doubt that access to clean and safe water is a necessity for all and has in the modern world become an indicator of sustaining the environment, peace and humanity. In South Africa, a semi-arid country with a reputation of water scarcity, it is a constitutional right to have free basic water supply of 6 kilo litres per household per month. The management of greywater, wastewater generated by sources that are separate from human waste, has unfortunately not been as well established in legislation as water supply.

The reuse and recycling of domestic greywater has been identified as having significant potential in decreasing the demand on freshwater resources. Although domestic greywater reuse is not explicitly mentioned, the targets of Sustainable Development Goal number 6 accentuate the importance of water reuse in ensuring water and sanitation for all. However, in South African non-sewered areas, greywater management remains an ongoing and pressing challenge. Without alternative options, households commonly dispose of greywater on the ground. A shame, considering the beneficial potential that greywater reuse has in socio-economic growth and alleviating high potable water costs in water scarce regions

Marulaneng village in South Africa suffers from inadequate water supply infrastructure and water scarcity. By determining the average amount of greywater produced in the households, the present study was able to estimate what the increase in availability of potable water would be if household greywater technologies were adapted in rural areas. The average amount of greywater produced per household per day was 71 litres. Interestingly, in the case where greywater production is assumed to be 75% of the total water consumption in households, Marulaneng households only use only 3 kilo litres of water per month. This falls 50% short of their basic human right. This should be an alarming result to government and decision makers considering that the residents of Marulaneng already use multiple water supply sources to cope with water scarcity. Greywater could serve as an alternative resource for some household activities.

Through literature research, one can see that the challenge is not whether or not greywater reuse is beneficial but rather what the appropriate use is without environment or health risks. The present study thus believes that because existing guidelines prohibits greywater reuse in non-sewered areas unless risks have been adequately addressed, it is important to develop household level greywater treatment technologies. Simple technologies are advocated for low-income, rural areas which are mostly developed for beneficial irrigation use. However, this study has found that potable water availability can be increased by 10% when reusing greywater from rinse during dishwashing to wash dishes and 28% when reusing greywater from bathing for bathing and laundry. This requires a higher level of technology than the low-level technology provided presently.

These higher levels of technology can be found in urban households decreasing their water and energy consumption significantly. It is no secret that urban households use significantly more water than their rural counterparts, how much more then is such technology necessary in rural areas?