An assessment of domestic greywater reuse: A case study of ga-thoka village in polokwane local municipality, south africa.

by

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DISSERTATION

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DECLARATION

I declare that the “An assessment of domestic greywater reuse: A case study of Ga-Thoka village in Polokwane Local Municipality, South Africa” (dissertation) hereby submitted to the University of Limpopo, for the degree of Master of Science in Geography (degree & field of research) has not previously been submitted by me for a degree at this or any other university; that it is my work in design and in execution, and that all material contained herein has been duly acknowledged.

Sekgobela, M.R. (Ms.)	14 December 2022
Surname, Initials (title)	**Date**

DEDICATION

I dedicate this dissertation first to Almighty God of Mount. Zion who has been there right from the beginning to this very point. Special dedication also to my ever supportive family for their support, courage and compassion towards me during the course of this dissertation. Furthermore, I want to dedicate this project to Ga-Thoka village households and Mothapo Community at large for their cooperation and knowledge.

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ABSTRACT

South Africa is a water scarce country, the 30th driest in the world. Certain parts of the country have been experiencing severe droughts since 2015. The study titled: An assessment of domestic greywater reuse: A case study of Ga-Thoka village in Polokwane Local Municipality, South Africa, aimed to assess domestic greywater reuse in Ga-Thoka village. Objectives of the study were to identify sources of freshwater and the nature of potable water supply, analyse the quality of greywater from selected households, establish the potential of greywater reuse by the households, and to determine the awareness and perceptions of the households on reuse of greywater. Data collection methods used to collect primary data included questionnaires, field observations and the key informant interview. Secondary data was also collected for the study. Greywater samples were collected from selected households in the village. The collected greywater samples (93) were taken to CDM water laboratories for the analysis of greywater quality. The analysis revealed the presence of metals such as copper and sulphates. The study found that 85% of the respondents said they always have freshwater available and it was discovered that 51% of the respondents get freshwater from their home taps. Ninety-two percent (92%) of the households generate greywater. Sixty-eight percent (68%) of the respondents do not have knowledge about greywater importance. The Pearson Chi Square test revealed association between factors investigated (socio-economic characteristics, water scarcity and awareness) and the willingness to reuse greywater by the respondents. It was concluded that Ga-Thoka village households reuse their greywater mostly for irrigation. The study recommends that the households should reuse their greywater on other different activities that do not strictly require freshwater.

KEYWORDS: Greywater, Greywater characteristics, Freshwater, On-site greywater reuse, Scarcity.

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Abbreviations:

CDM:	Capricorn District Municipality
CMA:	Catchment Management Agency
CU:	Constant Unit
GDP:	Gross Domestic Product
GHS:	General Household Survey
IWMI:	International Water Management Institute
NDP:	National Development Plan
NPC:	National Planning Commission
NWRIA:	National Water Resource Infrastructure Agency
NWRS:	National Water Resource Strategy
PLM:	Polokwane Local Municipality
QC:	Quality Control
SANS:	South African National Standards
SAWS:	South African Weather Services
SPSS:	Statistical Package for Social Sciences
Stats SA:	Statistics South Africa
TCTA:	Trans-Caledon Tunnel Authority
TREC:	Turfloop Research Ethics Committee
WHO:	World Health Organisation
WSA:	Water Services Authority

CHAPTER 1: INTRODUCTION

1.1. Background

Water is the most important substance on earth (LaFrance, 2018). All plants and animals need water to survive. Water carries nutrients to all cells in the human body and oxygen to the brain (Yeung and Wong, 2020). According to Molden (2007), water is the backbone of healthy communities and strong economies. Decency and economic security rely upon a protected, solid supply of water. Without water, there would be no life on earth (Guglielmi, 2017; Chan *et al*., 2018). Unfortunately, the world's fresh water sources are becoming scarce because of several factors, such as, population growth, improved living standards, changing consumption patterns, expansion of irrigated agriculture, climate change, pollution, and increased abstraction of groundwater resources (Giuliani *et al*., 2016; Toure *et al*., 2017). Accordingly, numerous communities are battling to access enough potable water to meet their needs (Johanson et al., 2000). Satisfying the needs for water in the 21st century requires an alternate thinking about water. People are employing various coping mechanisms such as rainwater harvesting, greywater reuse etc. to cope with water scarcity.

This chapter outlines the background, ways of coping with water scarcity such as domestic greywater reuse, problem statement, rationale, aim and objectives of the study, research questions, scientific contribution, ethical clearance, study area, limitations of the study, operational definitions and the outline of the dissertation.

1.1.1. Ways of coping with water scarcity

There are various ways of dealing with water scarcity such as water harvesting and greywater reuse. With the advances in technology, it is now easier for countries to harvest water and making water reusable.

<u>Water Harvesting</u>

There are different ways of harvesting waterthat people use as a way of water coping mechanism to supplement piped or municipal supplied water. Rainwater harvesting is one of the ways of water harvesting. It is the process of collection and storage of rain, rather than allowing it to runoff into the streams or other water bodies. Rainwater is collected from a roof-like surface and captured into a tank, cistern, deep pit, aquifer, or a reservoir with percolation (Ramachandran and Ravikumar, 2018). Dew harvesting is another way of harvesting water. It can be a supplementary source of freshwater in semi-arid and arid areas. Dew harvesting is the process of collecting moisture condensed on the surfaces of cool bodies using specially designed condenser panels, storing raw water and putting it through filtration process (Jalayer *et al.,* 2019).

Greywater Reuse

With the expanding demand for freshwater, greywater reuse may decrease the necessary freshwater needs, in substituting valuable drinking water applications which do not require drinking water quality, such as ,for industrial use, irrigation, latrine flushing and laundry washing. This will decrease freshwater utilisation, aside from wastewater generation (Al-Hamaiedeh and Bino, 2010). Through the reuse of greywater, water savings are expanded and expenses decreased (Madungwe and Sakuringwa, 2007).

1.1.2. Characteristics of Greywater

Composition of greywater presents the reflection of the lifestyle and the type and choice of chemicals used in the household for different purposes (laundry, cleaning and bathing). Greywater from different sources have different characteristics. Other factors such as the number of residents in a household, age distribution, living standard, residents' cultural habits and the quality of the water supply to the household may have an influence on the greywater generated from different households and from various sources within a household (Morel and Diener, 2006). Bathroom greywater (hand washing and bathing) generates about 50-60% of total greywater and is considered to be the least contaminated type of greywater while laundry generates around 25-35% of the total greywater and kitchen greywater contributes about 10% of the total greywater volume (Al-Jayyousie, 2003).

The quality of greywater depends on the source from which it is drawn as well as the use to which this water is put, but there are general characteristics that apply to greywater. The quality characteristics of greywater are physical, chemical and biological (Carden *et al.,* 2006).

1.1.3. Policies that govern water reuse

Reuse of greywater offers one means of relieving pressure on freshwater supplies. Safe management of greywater, which encourages reuse and recycling of the resources should be encouraged in a water scarce country, while at the same time focussing on ensuring the safety of reuse and recycling. The current policies under National Water Act (South Africa, 1998b) do not address the policy position on greywater. Management of greywater is encompassed in sanitation services provision (Ashok *et al*., 2018; Lambert and Lee, 2018).

1.2. Problem Statement

Water is a scarce yet catalytic resource towards economic development and it must therefore be conserved at all times. South Africa is a water scarce country particularly due to broader challenges caused by climate change and global warming. The level of freshwater in South Africa decreases daily as the water demand increases due to population and economic growth. In 2015, the total number of people in South Africa lacking access to an “improved” water supply was 3.64 million (Stats SA, 2011). The National Development Plan (NDP) aimed to achieve an increase in the percentage of households with access to a functional water service from 85% in 2013 to 90% by 2019 (Stats SA, 2011), which still leaves 10% of South Africans especially in rural areas without access to clean water.

Stats SA (2016) documented that Limpopo province has water services backlog of 20%, mainly in rural areas. In view of the above, it appears as if there is a problem in meeting daily water needs by different communities in South Africa, especially in rural areas. This shortage of water leads communities to use different coping mechanisms such as rainwater harvesting and reuse of greywater to supplement their daily basic water needs. These different ways of supplementing water needs could help to conserve the freshwater resources as well as lowering water bills. This trend of water shortage coping mechanisms has been reported extensively in different parts of the country (McBride, 2019) but less is documented on greywater reuse in rural areas of Polokwane Local Municipality (PLM). The study seeks to evaluate the greywater reuse in Ga-Thoka Village, a rural area in PLM, to meet the daily basic water needs.

1.3. Rationale

The total volume of freshwater on earth, far outweighs the human demands. Besides the 97% of earth water that can be found in the oceans, the remaining 3% is available for direct exploitation and only one-hundredth quantity of the 3% is estimated to be available for use by humans (Eakin and Sharman, 2010). United Nations' World Water Development Report (UNWWDR4, 2012) warns that as the demand for water increases across the globe, the availability of freshwater in many regions is likely to decrease because of the combination of population growth, climate change, socio-economic development, increasing economic activities and changing consumption patterns.

In South Africa, a lot of people are unable to access clean water despite the fact that the Constitution provides that everyone is entitled to have access to adequate clean water (Kamba *et al.*, 2016). The provision of basic water services delivery to all South African citizens is one of the biggest challenges of many municipalities (Netshipale, 2016). Capricorn District Municipality is among the identified district municipalities with water supply challenges (Municipalities.co.za, 2019). Municipalities are tasked with developing and maintaining infrastructure to ensure that water services are delivered, amongst other services. However, some municipalities are facing a serious backlog in the infrastructure maintenance and rehabilitation necessary for providing water and sanitation services, as a result of severe financial and capacity constraints (Municipalities.co.za, 2019). CDM water services has a backlog of 21.2% (CDM.org.za,2019). Polokwane Local Municipality, one of Capricorn District Municipalities, faces lack of skills as a major constraint with regard to water services provision (Mutyenyoka and Tsheola, 2017). Water projects in the municipality are mostly managed by people who do not have the “know how” concerning the delivery of water services and the training given to the water and ward committees is not sufficient which results in maintenance and fixing of water taps often taking a period of one-month delay (Municipalities.co.za, 2019).

According to Molden (2007), meeting the demand for water in the 21st century requires a different thinking about water. The currently available freshwater resources need supplements through various methods. By practising greywater reuse, rainwater and dew-water harvesting, the pressure on the freshwater resources will be eased. Reuse of greywater can help in substituting drinking water in other applications that do not need drinking water quality such as industrial, irrigation and toilet flushing. This will in turn, reduce freshwater consumption apart from wastewater generation especially in rural areas (Gross *et al.*, 2015). Hurliman and Mckay (2007) reported that the highest acceptability of greywater reuse is for non-potable uses. Greywater reuse can be applied as a supplement for freshwater especially in rural areas where there is shortage of potable water. The reuse of greywater will benefit the natural freshwater resources by easing the pressure and conserving them for the future generations. There is a possibility of harmful chemicals and pathogens being absorbed by vegetables through irrigation. To minimize the risk and harm that the reuse of greywater may cause, greywater should only be used to irrigate plants that are not consumed e.g., lawn, ornamental plants etc. alternatively if greywater is used to irrigate plants that are consumed by people, it should be treated before its reuse. Furthermore, greywater should not be allowed to flow into watercourses, swimming pools and dams, and children and pets should not be allowed to drink or play directly in or around greywater.

Human activities increase or mitigate pressure on the environment which means the link between humans and environment is direct since humans interact with the environment and the natural resources found in it. This study is grounded in the human-environment theory as it depicts the fact that humans extract natural resources from the environment for survival. Unfortunately, the increase in human activities in most cases tend to decrease the capacity of the natural environment to supply enough water and hence leading people to resort to other means of obtaining water (Anon, 2019).

1.3.1. Aim

The aim of the study was to assess domestic greywater reuse in Ga-Thoka village of Polokwane Local Municipality.

1.3.2. Objectives

The objectives of the study were to:

i. identify sources of freshwater and the nature of potable water supply in Ga-Thoka village,
ii. analyse the quality of greywater from selected households of Ga-Thoka village,
iii. establish the potential of greywater reuse by the Ga-Thoka village households, and
iv. determine the awareness and perceptions of the Ga-Thoka village households on reuse of greywater.

1.3.3. Research questions

This work directly or indirectly addressed the following questions:

i. How does greywater reuse lead to freshwater saving?
ii. What are the sources and uses of greywater?
iii. Does the community know or have enough knowledge about greywater and its importance?

1.4. Scientific Contribution

The results of this study will help strengthen awareness and add to the existing knowledge on greywater reuse in rural areas of Polokwane Local Municipality. The Department of Human Settlement and the Department of Water and Sanitation can use the results to intensify the on-site reuse of greywater. The Department of Environment, Forestry and Fisheries and the Department of Agriculture, Land Reform and Rural Development can find more ways of sustainable reuse of water that will help in conserving water resources.

1.5. Ethical Requirements

The University of Limpopo Turfloop Research Ethics Committee (TREC) provided ethical clearance since the study involved human participation. Local Authorities (Councillor, headman) granted consent to conduct research in their areas. That ensured respect for culture of the respondents in the area. It also ensured they participate in the study with ease knowing permission has been granted to the researcher. Prior, to conducting the research, the researcher explained clearly to each respondent the purpose of the study and sought their consent to participate. In doing so, the respondents were informed of their right during the study such as pulling out of the survey or not answering any questions should they feel uncomfortable. The nature of the study did not require collection of any personal information such as names and ID numbers or any information that could lead to the identification of the respondent. Furthermore , the collected information relevant to this study was not discussed with anyone else outside the research team. The respondents were assured that the provided information will be used solely for academic purposes. During the course of the study, the questionnaires were kept secure in a safe place that only the researcher had access to. After the conclusion of the study, the researcher ensured the questionnaires were shredded for confidentiality reasons.

1.6. Definition of Concepts

Dew harvesting is defined as the collection of tiny drops of water that form on cool surfaces at night, when atmospheric vapour condenses (Tavakoli and Kavehpour, 2015).

Freshwater refers to clean water from natural resources such as groundwater, glaciers, etc. or purified water that is suitable for human consumption (Siddha and Sahu, 2020).

Greywater is used water from showers, bathtubs, sinks, kitchen, dishwashers, laundry tubs, and washing machines except toilet water (Nolde, 1999).

Potable wateris explained as clean water that is suitable for human consumption (Cureau and Ghisi, 2019).

Reuse is the action or practice of using something again, whether for its original purpose or to fulfil a different function (Nolde, 1999).

Water scarcity refers to the lack of sufficient available water resources to meet the demands of water usage within a region (Pereira and Oliva-Teles, 2002).

Water security is defined as "the reliable availability of an acceptable quantity and quality of water for health, livelihoods and production, coupled with an acceptable level of water-related risks" (Grey and Sadoff, 2007).

Wastewater can be defined as any water that has been contaminated by human use or used water from any combination of domestic, industrial, commercial or agricultural activities, surface runoff or stormwater, and any sewer inflow or sewer infiltration (Gasperi *et al*., 2010).

Rainwater harvesting is defined as the collection and storage of rain, rather than allowing it to runoff (Vadas *et al.,* 2011).

1.7. Study Area

Ga-Thoka (also known as Paledi) is a village on the brink of major reinvention and transformation by some of its younger citizens (Kostecka, 2013). It is only 40 minutes from Polokwane, the capital city of Limpopo Province but unlike the better resourced capital it lacks basic infrastructure and resources (UNICEF South Africa, 2020). Basic needs such as water and health facilities are still inaccessible to many families of Ga-Thoka.

Ga-Thoka is located at latitude of 25° 52' 0"S and longitude of 31° 43' 0" E. It is one of the 23 villages of Ga-Mothapo community under the tribal authority of Kgoshigadi Moremadi Mothapo, in the Limpopo Province of South Africa. This village was selected because it has the largest population number compared to all other 22 villages in the community. It is a semi-rural village in Polokwane Local Municipality (Figure 1.1) with a population of 11 258 and 3 068 households (Stats SA, 2011). The village has two government schools, few pre-schools, local businesses, subsistence agricultural activities and a shopping mall. Polokwane Local Municipality has a dry climate with a summer rain season and a pronounced dry spell during winter. It has an average annual rainfall of 495 mm with December or (less often) January the wettest months and July the driest (SAWS, 2014).

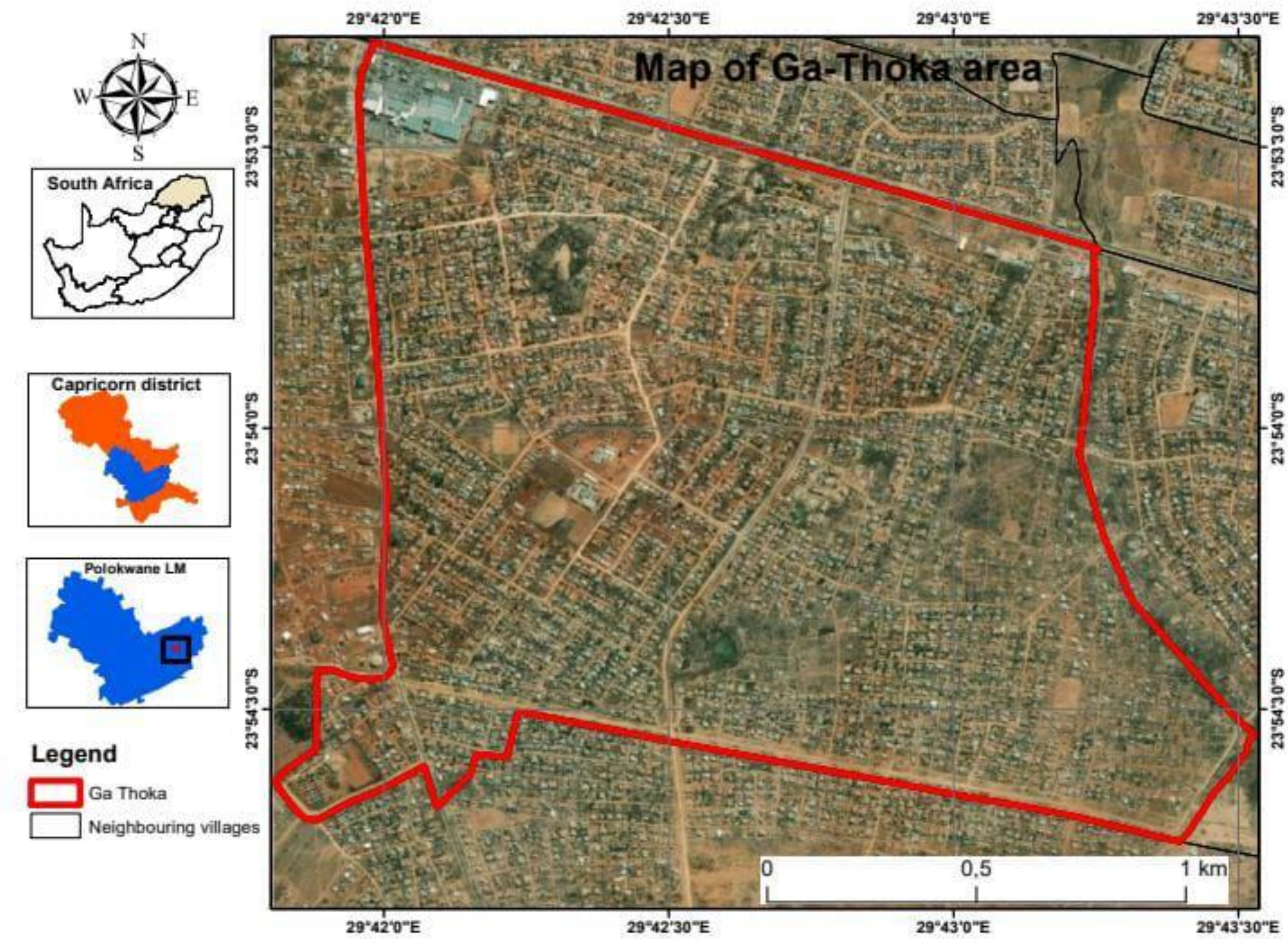

Figure 1.1: Map of the study area

According to the Census study conducted by Stats SA (2022), ninety-eight percent (98%) of Ga-Thoka village households get their water fromregional/local water scheme, 0.2% from borehole, 0.4% from rain water tank, 0.1% from dams, 0.2% from water tanker and 0.8% from other sources of water.

1.8. Limitation of the Study

The following challenges were encountered during the study

a) There are no enough published papers on the reuse of greywater at the local level for the collection of secondary data. Only the available articles were used to get secondary data, most were journals obtained through the internet.

b) The data collection process was costly. There was no budget allocation for necessities like transportation and so the researcher had to use personal funds. On particular occasions, the researcher had to access places on foot.

c) Data collection process was time consuming since it was through face-to-face interviews and observations. Hours planned for data collection per day had to be adjusted and extended so to cover the number of questionnaires scheduled for the day.

d) The Covid-19 pandemic (and associated regulations) delayed the data collection process which led to the study schedule disruption. The data collection period had to be re-scheduled (from March 2020 to August-December 2020) when the regulations were less strict (alert level 3-1) and more households could be approached per day.

e) Convincing the participants to share their greywater was never an easy task, especially when it comes to their bathroom greywater. Participants had to be convinced and begged to share their bathroom greywater which resulted in one not being so sure if the greywater given was really from the bathroom or any other greywater source (this may affect the quality of the bathroom greywater collected). In cases where the participants (household) could not be convinced to share their greywater, the neighbouring household was approached for greywater collection.

f) It was also difficult to determine the biological characteristics of greywater. The reagents for biological characteristics of water were too expensive and I could not afford to pay for the reagents because I have no funding or sponsor for my studies. Failure to determine the biological characteristics of water affected the results in a way that the objective of determining water characteristics was not fully achieved.

1.9. Organisation of the Study

The dissertation is organised as follows:

Chapter 1 (Introduction)outlines the background of the study, gives the statement of the problem and aims and objectives, study area, and highlights the limitation of the study.

Chapter 2 (Literature review) outlines water security, water scarcity, water availability and accessibility, National Development Plan 2030, coping mechanisms for water scarcity, case studies on greywater reuse, composition of greywater in relation to sources, perceptions on greywater reuse, and Laws, legislations and guidelines governing water.

Chapter 3 (Methodology) consists of the research design, sampling, data collection, and data analysis and presentation of results.

Chapter 4 (Results and discussion) focuses mainly on demographic characteristics of the households in the study area, freshwater sources and nature of water supply in the study area, quality of greywater from selected households, the potential of greywater reuse and perceptions of respondents on greywater reuse.

Chapter 5 (Summary, conclusions and recommendations) outlines summary of the study, conclusions of the study and recommendations forfuture studies.

CHAPTER 2: LITERATURE REVIEW

2.1. Introduction

Water is a ubiquitous natural resource, but statistics demonstrate that out of 326 million m^3 of water on the planet, only 0.5% of the freshwater is readily available for use (United States Bureau of Reclamation, 2017). Most of the available freshwater is limited to specific regions and dependent on annual climatic variations (Varghese and Behera, 2019). This has led to a huge demand of water in different parts of the world. The global water demand is expected to continue rising, accounting for an increase of over 20% to 30% above the current water use by the year 2050 due to the industrial and domestic sectors (UNESCO, 2019). Often these result into water security challenges in various regions of the globe.

This chapter reviews the literature on water security, water scarcity, water scarcity coping mechanisms, perceptions of greywater reuse, characteristics of greywater in relation to their sources, and South African legislation governing water and water reuse. From these reviews, a conceptual framework was developed to give an overview of what is expected in the results of this study.

2.2. Water Security

Water security has been defined as the reliable availability of an acceptable quantity and quality of water for health, livelihoods and production, coupled with an acceptable level of water-related risks (Grey and Sadoff, 2007). Water security can also be defined as the capacity of a population to safeguard sustainable access to adequate quantities of acceptable quality water for sustaining livelihoods, human well-being and socio-economic development, for ensuring protection against water-borne pollution and water related disasters, and for preserving ecosystems in a climate of peace and political stability (Merrey, 2015).

In order to achieve water security certain key aspects should be in place and fulfilled. These include infrastructural, institutional, political, biophysical, social and financial aspects.

2.2.1. Key Aspects of Water Security

Key aspects of water securityunder this review include infrastructural (built and ecological), institutional and political.

Infrastructural

Water infrastructure is a broad term for systems of water supply, treatment, storage, water resource management, flood prevention and hydropower (Pasha *et al*., 2020). The term also includes water-based transportation systems such as canals,underground pipes that bring the life-sustaining resource to users, as well as ecological infrastructure such as wetlands, that naturally improve the quality of water resources (Makropoulos and Butler, 2010). Water is often moved through pipes for longer distances. This is because dams are not always conveniently located. In these instances, pipes may start leaking due to age and this will lead to insufficient water reaching the desired destination. This situation calls for strategies to detect leakages or complete replacement of the leaking pipes (Hunaidi and Wang, 2006).

Many parts of the world have either reached or are fast approaching the point at which all financially viable freshwater resources are fully utilised (Gunawardena, 2000). Despite the good infrastructure, the occurrence of floods and droughts are part of the "normal" water cycle and water restrictions and flood management are a critical part of the water business. Furthermore, the poor and marginalised experience water scarcity most intensely, particularly in under-developed rural areas and areas such as the former homelands (Kamba *et al*., 2016).

Restoring and maintaining intact watersheds may not solve all the water demand challenges, but it does make a significant contribution to securing a sustainable supply of clean water. Watershed services can be seen as the upper end of the water value chain that includes watersheds, storage schemes, distribution, purification, reticulation and sanitation (treatment of return flows). Although dealing with the current water predicament will not be an easy task, with the necessary resolve to plan and implement the required interventions, a secure water future can be achieved (Macias, 2007; McCarthy, 2008; Richter, 2014).

The financing and ongoing operational management of all the activities is also involved. Initially, the focus of individual users is on the physical works required to take the water from the source and transport it to where it is needed, the focus then shifts to providing water security by storing enough water to sustain supply during dry periods as the quantity used increases (Lane and Flancher, 2015). Water based transportation infrastructure is composed of aqueducts. Aqueducts are designed systems such as canals, ditches, tunnels, pipes, water bridges and pipelines. Water transportation infrastructure is essential to supplywater for community, industrial, and agricultural use, storm water management and control of inland and coastal flooding(Volschenk, 2020).

Water storage infrastructure such as dams ensure that communities do not run out of water in times of drought. About half of South Africa's annual rainfall is stored in dams. Dams can also prevent flooding when there is an overabundance of water. South Africa presently has more than 4 395 registered dams, of which 2 528 are water supply related and with a well-developed infrastructure (Ternes, 2017).More than 500 of these dams are government owned, with a total capacity of 37 000 million cubic metres (m^3) – that is the same as about 15 million Olympic-sized swimming pools (Mettetal, 2019). To ensure water security, the water storage infrastructure can be increased by building new dams for the purpose of storing water during the rainy seasons for the dry seasons, and to utilize water from wet years in dry years. But, the building of more storage infrastructure can only be beneficial if there is likely to be sufficient rainfall to fill them (Ávila et al., 2016).

Water treatment infrastructure includes water and wastewater systems. The water intake to the treatment plant is from the dams and rivers. Raw water pass through coagulation and flocculation, sedimentation, filtration and disinfection processes to obtain potable water (Bratby, 2015). Wastewater treatment is a critical yet expensive procedure to the whole water supply process. The input is raw sewage, which is screened to remove large objects then passed on to primary settling tanks where sludge particles sink to the bottom. The overflow from the settling tanks gravitates into the balancing tanks then into an activated sludge reactor. The clear effluent goes through an anaerobic zone where it is deprived of oxygen and transferred to the secondary settling tanks where chlorine is added to the treated effluent to kill harmful human bacteria and viruses, after that it will remain in a maturation pond for 12 hours before being discharged into a natural river (Machido *et al*., 2015).

Ecological infrastructure can likewise help in guaranteeing water security. Ecological infrastructure refers to naturally functioning ecosystems that deliver valuable services to people, such as water and climate regulation, soil formation and disaster risk reduction (Vallecillo *et al*., 2019). It for instance incorporates healthy mountain catchments, rivers, wetlands, coastal dunes, as well as nodes and corridors of natural habitats, which together structure a network of interconnected structural elements in the landscape (Van Geert *et al*., 2010). Healthy environmental structures can help improve and guarantee water security. On the other hand, restoration of wetlands can help improve water quality through separating of pollutants and toxins while the improvement of range land management practices (such as grazing regime and fire management) can increase baseflow in dry season which is an affirmation of water supply (Aouissi *et al*., 2014; Pan and Guo, 2019; Sarker *etal*., 2020).

Natural environments are a final source of additional water. Legislations provide that water must be left in rivers to sustain an acceptable natural environment, prior to any allocation for economic purposes. The maintenance of “environmental flows” is important with a view to safeguarding environmental attractions, such as the country’s national parks and other sources of livelihoods. Environmental flows and the levels of their protection, are socially and administratively determined. In periods of shortage, water reserved for the environment might be taken illegally for economic or social uses unless there is strict management oversight at the local level, supported by national priorities (Hindmarsh, 2012).

In spite of the availability of water supply infrastructure, water shortage within a catchment may require water transfer schemes. Both within river basins and from other river basins water transfer, can be a possibility as local supplies become fully developed. In South Africa, the Vaal River which is supplemented with water brought from the Orange River via the Lesotho Highlands Water Scheme is the well-known example of this approach. Other basins have similar transfers occurring between them. Regions such as Gauteng, the Nelson Mandela Metropole in the Eastern Cape and other parts of the North West as well as Limpopo provinces rely on such transfers (Hellsten *et al*., 2002).

Institutional

Institutions are more than organizational structures. They are made of three interactive components, namely law, policy and administration, which create norms, rules and legal systems that affect the governance and management of natural resources (Hamzah, 2016). Institutional frameworks are influenced by the socio-economic, political and resources-related conditions in which they operate.

The management of water resources has been characterised by simplistic and short-sighted models. In such models a sectoral approach and fragmented administration have prevailed. The resulting institutional structures are inadequate for integrated water resources management (Mukheirbir, 2015). Institutions and decision-making in Nicaragua (Central America) have been quite centralized, with local governments having limited authority and resources to manage and decide over their natural resources, including water. For instance, fiscal policies have focused on increasing the income of the central government in order to face the external debt and the internal fiscal deficit (Figari and Florio, 2015). During the 60's, the central government authorised the opening of polluter industries without any environmental concern (Madigele and Mogomotsi, 2017). These industries were located in vulnerable areas such as along the lakeshore and close to Lake Asososca, which is the only cater lake in Managua sustainable for water supply (Dustin and Jacobson, 2015).

The South African National Water Act provided an institutional blueprint for the future management of water resources. It was, however, enabling legislation in that, for many innovations, no timeframe was set for their implementation. This was done deliberately in order to allow political heads and senior managers to determine their own priorities and implementation programmes. The first National Water Resource Strategy (NWRS) in 2004, was a step in this direction, establishing a comprehensive agenda for action. The agenda covered a range of management and institutional activities such as compulsory licensing, establishment of Catchment Management Agencies (CMAs), delegation of operational responsibility for physical infrastructure and transfer of the ownership of infrastructure to water management institutions, establishment of new water user associations (WUAs) and the expansion of existing monitoring networks and information systems, as well as establishment of new ones. In 2005, cabinet agreed that a National Water Resource Infrastructure Agency (NWRIA) should be established, merging the Trans-Caledon Tunnel Authority (TCTA) with the DWAF's branch for water resources infrastructure. In 2006, it was announced that a waste discharge charging system would be introduced (Karagiannidis *et al*., 2006).

Without institutional rebuilding water security will remain a pipe dream. In the past decades, there has been a loss of competence and continuity in the affairs of this precious resource. Water provides useful reflections of what is going on in the wider world, the National Planning Commission held a consultative meeting in the Union Buildings to discuss a document on the concept of "water security" and decided that the plan at national level need to provoke forward thinking, whilst ensuring that current demands and supplies are met. Urgent attention needs to be paid to the deconstruction and reconfiguration of models upon which incorrect analyses have been based (Schache, 2012). The National Planning Commission presented the water security plan for the country which recognised that there was a need to consider competing water requirements from all sectors, and also to look at water from neighbouring areas, rain precipitation and sea water desalination (Schache, 2012).

Political

Political water security refers to the state where politics are affected by the availability of water and water resources, a necessity for all life forms and human development. It can also be defined as the systematic study of conflict and cooperation between states over water resources that transcend international borders (Borrelli, 2012).

Access to water resources has far-reaching political and social implications, especially in areas where water is scarce. Natural water basins do not comply with man-made political borders, and as a result, the allocation of precious water resources becomes a point of negotiation in transnational treaties and agreements. Adding to the politicisation of water is the connection between water and energy production. Water is needed for all types of energy production, and energy is needed for the extraction and dissemination of clean water (Symonds and Breitbart, 2014).

Since water does not respect political borders, the conflicts can become international. One of the most high-profile disputes has been Ethiopia's damming of the Nile River for hydroelectric power, potentially threatening Egypt's ancient water source. In 2013, Egypt's then-president said he did not want war but he would not allow Egypt's water supply to be endangered by the dam (You Nakai, 2014). Egypt, Ethiopia and Sudan signed an agreement in 2015, allowing the construction of the dam provided that it did not cause significant harm to downstream countries.

Companies are accustomed to building water infrastructure into their business plans in developing countries. Environmental impact assessments and proactive community relations programs can bring potential problems to the surface before they start, helping companies manage water in environmentally and socially prudent manner. The geopolitical risks around water scarcity can be more difficult to manage, but in this area, companies should consider building water scarcity into their political risk management and forecasting frameworks, factoring it in when making investment and supply chain decisions (Iglesias *et al*., 2006; Zetland, 2019). If governments cannot find ways of sharing this limited resource, political violence risk may become even more of a factor for international businesses to consider (Bohn, 2010).

2.3. Water Scarcity

Scarcity in general refers to the shortage of resources in an economy (Grossman and Mendoza, 2003; Schmidt, 2018; Molden, 2019). It creates an economic problem of the allocation of scarce resources. There is a shortage of supply in comparison to the demand that creates a gap between the limited needs and unlimited wants in the economy (Bellemare, 2015; Headey, 2014).

Water scarcity is the lack of sufficient available water resources to meet the demands of water usage within a region (Kharraz *et al*., 2012; Varghese *et al*., 2013). Water scarcity can be defined as water stress, which is the difficulty of obtaining fresh water sources for use during a period of time and may result in further depletion and deterioration of available water resources (Binns *et al*., 2001; Kharraz *et al*., 2012). Water scarcity can mean scarcity in availability due to physical shortage, or scarcity in access due to the failure of institutions to ensure a consistent regular supply or due to a lack of adequate infrastructure (UN Water 2011). It affects every continent and was listed in 2019 by the World Economic Forum as one of the largest global risks in terms of potential impact over the next decade. It is estimated that by 2040, one in four of the world’s children under 18 years will be living in areas of extremely high-water stress (UNICEF, 2017). In India alone, the International Water Management Institute (IWMI) predicts that by 2025, one person in three will live in conditions of absolute water scarcity (IWMI, 2003). The challenge is that water scarcity will be exacerbated as rapidly growing urban areas place huge pressure on nearest water resources. Climate change and bio-energy demands are also expected to amplify the already existing complex relationship between world development and water demand (FAO, 2016). Water has to be treated as a scarce resource, with a far stronger focus on managing demand.

Water scarcity can either be quantitative, qualitative or both. It originates from inefficient use and poor management as well as from real physical limits. South Africa is the 30th driest country in the world and has less water per person than countries widely considered to be much drier, such as Namibia and Botswana (Grobler and Mearns, 2019). Water run-off is highly variable and unevenly spread in space and time. High variability of water flow is the norm, and the base flow varies from very low to zero (Brand and Noss, 2017; Bissig *et al.,* 2020).

2.3.1. Types of Water Scarcity

There are two types of water scarcity that a region can experience namely, physical and economic water scarcity.

Physical Scarcity

The physical water scarcity is the situation where there is not enough water to meet all demands (Kharraz *et al*., 2012), including the water needed for ecosystems to function effectively. It occurs in regions where surface and groundwater resources are inadequate to supply the region's water demands which means that physical access to water is limited in that region. Arid regions or dry parts of the world are mostly the victims of physical water scarcity. It also occurs where water seems abundant but resources are over-committed (Rijsberman, 2005), and the demand outstrips the land's ability to provide the needed water. However, there is an increasing number of regions in the world where physical scarcity is a man-made condition. An example of source of water leading to very serious physical water scarcity downstream is the Colorado River basin in the United States (Stockholm International Water Institute, 2006). South Africa is no exception, as it might be approaching physical water scarcity by 2025. The country's socioeconomic development has been directly hampered by the recent drought and it is expected to face a water deficit of 17% by 2030 based on the current usage trends. This shortage will be worsened by climate change (Ziervogel, 2018).

Physical water scarcity is caused by several factors which include climate change, drought, evapotranspiration, land use and land cover, rainfall, water extraction and overuse, earthquakes and invasive alien plants.

Climate Change

Climate change describes a change in the average conditions such as temperature and rainfall, in a region over a long period of time. Climate change can also be defined as the global phenomenon of climate transformation characterised by the changes in the usual climate of the planet (regarding temperature, precipitation, and wind) that are especially caused by human activities (Moellendorf, 2012; Iyappan, 2018).

Climate change has several effects on water resources as it causes polar ice to melt into the sea, which turns freshwater into sea water, although this has little direct effect on water supply. Higher temperatures cause more rain due to the increased evaporation, but the water does not stay where it is needed and is a cause of water shortage in certain areas.

Climate change is significantly transforming the water cycle. Higher temperatures are increasing evapotranspiration from vegetation, land, surface water and oceans. A warmer atmosphere is holding more water, and as air holds more water, more precipitation is leading to flooding. In addition, rain seasons have become shorter, creating more days when irrigation is needed and therefore increasing water demands. While not every element of a water crisis is related to climate change, some of them are, and others have been exacerbated by it. Therefore, one way to reduce future water impacts is to reduce climate change impacts (Hattermann *et al*., 2015).

Drought

Drought is the state of an area whereby it does not get enough rainfall to sustain the life that resides there. Some areas are in perpetual drought, whereas other areas may experience drought on occasions. Droughts are common all over the world, and there is little that can be done to prevent them from happening.

Drought happens when a period of low rainfall leads to a shortage of water. It starts when total rainfall is well below average for several months. The main impact of drought include water supply problems, shortages and deterioration of quality, intrusion of saline water in groundwater bodies (there is less water to dilute pollutant discharges) and drops in groundwater levels (Alameddine *et al*., 2016) and stream flow reduction and soil moisture depletion (Hughes *et al*., 2012). Drought can affect people's health and safety. The impacts of drought on society include but is not limited to anxiety or depression about economic losses, conflicts when there is no enough water, reduced incomes, fewer recreational activities, higher incidents of heat stroke, and even loss of human life (Ward, 2014).

Evapotranspiration

Evapotranspiration is the process by which water is transferred from the land to the atmosphere by evaporation from the soil and other surfaces and transpiration from plants. Evapotranspiration can also be defined as the sum of evaporation and plant transpiration from the Earth's land and ocean surface to the atmosphere (Blyth and Harding, 2011).

Evapotranspiration is the key part of the hydrological cycle as 75% of the annual precipitation returns to the atmosphere due to evaporation and transpiration (Twort *et al*., 2000). According to this source, a lot of water goes back to the atmosphere as a result of evapotranspiration which is a combination of the two processes, namely, evaporation and transpiration. Through these processes water is lost from any open water source, e.g. dams, reservoirs, rivers and the vegetation to the atmosphere (Twort *et al*., 2000).

In South Africa, evaporation ranges from less than 1 400 mm per year in the Drakensberg/Maluti areas to more than 2 800 mm per year in parts of the Kalahari. There is more or less an inverse relationship between average rainfall and average evaporation; the higher the rainfall, the lower the evaporation. Evapotranspiration is the main component and plays an important role in the hydrological cycle and it is essential to estimate evapotranspiration accurately for the evaluation of available water resources (Yin *et al*., 2016).

Land Use and Land Cover Change

Land use and land cover changes have a variety of impacts on water resources. Whilst reduction of vegetation cover may result in greater runoff, it reduces groundwater infiltration and the storage capacity of dams and lakes through siltation. The draining of large-scale wetlands or large-scale deforestation may change the micro-climate of a region (Binns *et al*., 2001).

Rainfall

Rainfall replenishes both surface and groundwater sources. Low rainfall leads to low water in aquifers and surface water e.g. in rivers, lakes, wetlands, etc. This pattern may lead to water shortages even for the households. It causes negative impacts such as famine, epidemics and land degradation (Bandyopadhyay *et al*., 2012). Sub-Saharan Africa for example, accounts for 80% of loss of life and 70% of economic losses caused by low rainfall. A balance must be maintained between the water supplied and the surface run-off to replace it (Fabris *et al*., 2008).

South African rainfall is unevenly distributed, with some of the north western regions receiving less than 200 mm per year while much of the eastern highveld receives 500 mm to 900 mm (SAWS, 2014). In Limpopo province, some areas receive less than 400 mm of rain while others get more than 800 mm per year (SAWS, 2014). South Africa is geologically characterised by hard rock with limited groundwater storage capacity. Groundwater is the only dependable source of water for many users but it is available in varying quantities depending upon the hydrogeological characteristics of the underlying secondary aquifers (Postel, 2000). A greater contribution to the nation's water supplies is from groundwater (as a source of freshwater) as surface water gets closer to the limits of its development and availability (DAFF, 2016/17). Surface water and groundwater play a central role in most of the national initiatives, such as agricultural development, energy security, tourism and recreation, mining, industry and municipal water supply (DWS, 2013/14).

Water Extraction and Overuse

When water is overused, the land is also usually depleted, which can change the climate in that area. It may be overused on people, animals, land, or any other activity that require water such as recreational activities. Water overuse is done without any care about the effects that it may have on the resources. The depletion of groundwater resources due to its over extraction also contributes to water scarcity as the aquifers will no longer be able to recharge and store more freshwater for future use. Apart from depletion of groundwater, aquifers are being polluted by chemical run off and salinity is increasing underground. Groundwater resources are also degraded by the mining activities which lead to groundwater pollution and water shortage (Stone, 1999). In some countries, specifically those ruled by autocrats, the use of water may be strictly controlled by those in power, causing a scarcity for those who may be located in those areas (Pereira and Oliva-Teles, 2002).

Earthquakes

Earthquakes and other natural disasters may cause water shortage in that, they may destroy a variety of infrastructures including those of water supply. The water service may be disrupted for days, weeks, months or even for longer periods depending on the seriousness of the damage (Uitto and Biswas, 2000). All these may result with insufficient safe/clean water for domestic use (FAO, 2006).

Invasive Alien Plants

Invasive alien plants are species that do not occur naturally in an area and are not indigenous. Various species of invasive alien plants have been brought into South Africa, either deliberately as commercial plants or as ornamental garden plants, or accidentally through seeds (Enright, 2000; Le Maitre *et al*., 2000). Invasive alien plants are the single biggest threat to water resources, indigenous plants and animal biodiversity in aquatic and terrestrial ecosystems (Baojiang and Lei, 2013). In the South African context, invasive alien plants have hydrological impacts. They use about 3.3 billion m^3 of water, deplete soil moisture, reduce groundwater recharge, reduce stream flow and dilution capacity, and impact water quality (Chase *et al*., 2016). Le Maitre *et al*. (2000) reported that invasive alien trees resulted in reductions of 350 mm of runoff per annum. In Cape Town for example, the impact of these plants resulted in the reduction on the yield of the Threewaterskloof Dam, a major reservoir for water supply (Enright and Spratt, 1999).

<u>Economic Scarcity</u>

Economic water scarcity is a type of water scarcity caused by a lack of investment in water infrastructure or insufficient human capacity to satisfy the demand of water in areas where the population does not have the means to utilise an adequate source of water (Rijsberman, 2006; Jiang, 2009; Daniell, 2012, Nechifor and Winning, 2018). The economic water scarcity is the most disturbing form of water scarcity because it is almost entirely a lack of compassion and good governance that allows the condition to persist. It exists when a population does not have the necessary monetary means to utilise an adequate source of water. Symptoms of economic water scarcity include a lack of infrastructure, with people often having to fetch water from rivers or lakes for domestic and agricultural uses (Binns *et al*., 2001). It is about unequal distribution of resources for many reasons, including political and ethnic conflict. Much of sub-Saharan Africa suffers under the effects of this type of water scarcity (Stockholm International Water Institute, 2006).

The main cause of economic water scarcity is the growing demand resulting from population increase and economic activities, which often lead to contamination. Lack of maintenance of ageing water infrastructure and the threat posed by invading alien plants also play an important role in economic water scarcity. Freshwater supplies can be polluted by a variety of sources, such as, industrial effluent; agro-chemical run-off fields; the causal disposal of human excreta and also poorly treated sewage from municipal works (Liu and Huang, 2009).

Large parts of Africa also suffer from economic water scarcity. Developing water infrastructure could help reduce economic water scarcity (Ziervogel, 2018). Overcoming this type of scarcity, however, can require not only new infrastructure but also socio-economic and socio-political interventions that address poverty and socio-inequality (Fedulova *et al*., 2020).

2.3.2. Key Aspects of Water Scarcity

Water scarcity is the lack of fresh water resources to meet the standard water demand. The key aspects of water scarcity include shortage of supply, flooding, pollution and allocation.

Shortage of Supply

Shortage of supply means the lack of sufficient water resources, including a lack of access to safe water supplies, to meet water needs within a region. Water scarcity can mean scarcity in availability due to physical shortage, or scarcity due to the failure of institutions to ensure a regular supply or due to a lack of adequate infrastructure (Flynn, 2014).

The most obvious water resource crisis, a shortage of supply, is easiest to manage. This is done through the construction and use of appropriate storage facilities, although lead times are often long and the facilities have to be in place before the shortage occurs. For all but the smallest systems, this requires a degree of specialised expertise and timeous management intervention, guided by good knowledge of local hydrology and patterns of water use. Even when infrastructure is available, the variability of rainfall and river flows should constantly guide the rates of abstraction (de Waal and Verster, 2012). Often, the greatest risk in this respect is that stored water will be used too rapidly, leaving inadequate reserves (Li and Takeuchi, 2016).

Flooding

Flooding is the covering or submerging of normally dry land with a large amount of water (Li and Takeuchi, 2016). Flooding occurs most commonly from heavy rainfall when natural watercourses do not have the capacity to carry excess water. In coastal areas, water inundation can be caused by a storm surge as a result of a tropical cyclone, a tsunami or a high tide coinciding with higher than normal river levels. River floodplains and coastal areas are the most susceptible to flooding, however, it is possible for flooding to occur in areas with unusually long periods of heavy rainfall (Lopez Diez *et al*., 2019).

Floods can carry with it harmful contaminants such as soil, animal waste, salt, pesticides, and oil which can potentially impact drinking water wells and water quality. Floods have a large social consequence for communities and individuals. The immediate impacts of flooding include loss of human life, damage to property, destruction of crops, loss of livestock, and deterioration of health conditions owing to waterborne diseases (Loop, 2014).

Flooding and other disasters can damage drinking water wells and lead to well contamination from livestock waste, human sewage, chemicals and other impurities (Moyer, 2013; Blackwell and Morrell, 2020). Where financial resources for flood control are available, vulnerable areas can usually be identified and floods managed, if not always prevented. Measures (floods management) include the construction of physical defences, catchment rehabilitation, as well as management activities, such as controlling settlements and other land use on flood plains. The cost of crises due to inadequately managed flooding has been documented and can be substantial. In countries with inadequate infrastructure investments, weak water management, and where water security is consequently limited, economic losses due to floods and droughts routinely reach the level of 10% of the annual GDP (Jefferson *et al .,* 2001).

South Africa experienced severe flooding in 2019 at the coastal city of Durban, caused by torrential rain brought on by a steep upper air trough, which deepened into low pressure in the city and its surrounding areas (Marshall, 2020). The Gauteng province of South Africa has been affected by floods also. Poorly planned infrastructure is making Gauteng vulnerable to floods, as was witnessed when storms destroyed buildings and left hundreds homeless (Gannon, 2019).

Pollution

Water pollution occurs when harmful substances (often chemicals or microorganisms) contaminate a stream, river, lake, ocean, aquifer, or other water bodies, degrading water quality and rendering it toxic to humans or the environment (Advances in Environment and Pollution Research, 2017; Shevchenko *et al*., 2018). Water is able to dissolve more substances than any other liquid on earth (universal solvent). Toxic substances from farms, towns, and factories readily dissolve into and mix with it, causing water pollution (Psillos, 2002; Advances in Environment and Pollution Research, 2017).

Water pollution is a more insidious problem, which can trigger a crisis. Water can become unusable for a variety of reasons that are often difficult to predict. For example, simple expansion of urban settlements and changes in agricultural practices can have serious effects (DWS, 2013/14). Once water is polluted, it may be difficult and expensive to remediate, particularly in the case of underground sources, which may be lost to use for long periods (Hecht, 2014).

Nutrient pollution, which includes nitrates and phosphates, is the leading type of contamination in the freshwater sources. While plants and animals need these nutrients to grow, they have become a major pollutant due to farm waste and fertilizer runoff. Municipal and industrial waste discharges contribute their fair share of toxins as well. There is also all the random junk that industry and individuals dump directly into waterways. Contaminants such as chemicals, nutrients, and heavy metals are carried from farms, factories, and cities by streams and rivers into the bays and estuaries then travel into the sea. Meanwhile, marine debris is blown by the wind or washed in via storm drains and sewers (Turrell, 2018).

Water pollution can result from many activities more especially human activities. Agricultural practices, if not well carried out may lead to eutrophication due to accumulated fertilizers. Mining activities also cause water pollution both directly and indirectly leading to water shortage. Directly, some mines spill their wastes into the water bodies which make the water highly toxic for human consumption while indirectly, the gases released during mine processes contribute to acid rain (Stone, 1999).

Allocations

Water allocation is the process of distributing water supplies to meet the various requirements of a community. Determining how to allocate water supplies requires the consideration of certain factors, including the source of the water and methods for obtaining it. Water allocation regimes consist of a combination of policies, laws and mechanisms to manage the risk of shortage and to help allocate resources among competing uses. Water allocation systems serve to equitably apportion water resources among users; protect existing water users from having their supplies diminished by new users; govern the sharing of limited water during droughts when supplies are inadequate to meet all needs and facilitate efficient water use (Grove, 2018).

Apart from inadequate pollution control or poor management of infrastructure that makes water use possible, a water-provoked crisis may also arise if allocations are not enforced. The resultant uncertainty could impair economic and social activity. A more insidious crisis may result if water is allocated solely for economic purposes, without regard for social considerations, or solely for social considerations, ignoring economic needs. Although this would leave many people poorer and hungrier than they otherwise would have been, it is unlikely that their plight would be identified as a water issue (Paavola and Adger, 2005).

Allocation of water shared with other countries such as rivers, is achieved through mechanisms such as national treaties and agreements. In the context of South Africa, four main rivers are shared with other countries, which together drain about 60% of the country's land area and contribute about 40% of its total surface runoff. Water resources from these rivers are allocated between nations by treaties and other agreements. For river basins encompassing portions of multiple states, water is allocated between them based on interstate compacts that are developed (Hall, 2008).

2.3.4. Effects of Water Scarcity

A lack of water can result in a number of problems such as lack of drinking water, hunger, lack of education and diseases among others.

The human body can barely endure or work well without water, and that can prompt more issues which can even bring about death. On the off chance that there is no water to irrigate crops, at that point people will go hungry and livestock will likewise die bringing about absence of meat for human consumption. Regarding education, people think that it is hard to get the education they deserve mainly on the grounds that they would either be too sick to even consider going to school or they will be focussing on getting water home. Absence of clean water gives exposure to waterborne diseases. Regardless of whether the water (unclean) would be utilised for drinking or bathing, the disease will get into the body. People are probably going to convey bacteria and infect others, additionally these diseases may cause loss of lives (Raina, 2020).

Water scarcity can have far-reaching consequences for a community, with a lack of clean water all but guaranteed to disrupt the day to day running of a household. This is particularly true in low-income communities where individuals often do not have the disposable income to buy bottled water which can have a devastating effect. Lack of water can cause a major obstacle to economic prosperity with many sectors relying on the precious resource in their operations (Robak and Bjornlund, 2018).

Water scarcity leads to food shortages while raising commodity prices thereby hindering trade with developing economies and in the long run causing civil unrest (Olakojo, 2017). Water scarcity has a direct impact on rain-fed and irrigated agricultural crops as well as livestock, and an indirect impact on food processing industries. In some regions, water scarcity could cost up to 6% of the Gross Domestic Product (GDP), spur migration and spark conflicts (Wouters, 2000). In South Africa, water shortage affects industrial productivity, reducing outputs and affecting economy through smaller GDP contributions. Tourism accounts for about 2.9% of South Africa’s GDP, and the Cape

Town water crisis has revealed just how water shortages can affect a destination's appeal for both tourists and investors (Rogerson, 2011).

Water scarcity makes it difficult for people to get the education that they need or that they deserve, mainly because children are either too sick to go to school, or they are working to help collect water for the home and the family (Pereira and Oliva-Teles, 2002). If one has no clean water access, there are more chances to get diseases because one would be forced to use or to consume unhealthy water. Whether one drinks the water or uses it for bathing, there is exposure to those diseases(Pereira and Oliva-Teles, 2002)

Without access to clean water, there is no way to keep food, dishes, or people clean. When people are not given access to proper sanitation, disease ends up becoming much more of an issue than it would have been otherwise. It also causes mental health issues, including depression and anxiety (Gross *et al.*, 2015). All in all, people who are dealing with water scarcity are often stuck in poverty as well. These people are not able to get the resources that they need in order to be able to survive, and instead they just barely struggle through these difficult times. Both water scarcity and the desire to increase the sustainability of domestic water resources have stimulated the search for efficient water use practices (Gross *et al.*, 2015).

Apart from an obvious lack of drinking water, hunger is one of the biggest effects of water scarcity. Water shortages directly contribute to lower crop yields and the death of livestock, which can quickly lead to food shortages. The most immediate impact of water scarcity is on people's health. Additionally, water scarcity causes many people to store water within the household, which increases the risk of household water contamination and incidents of malaria and dengue fever spread by mosquitoes (Asia and Lairamona, 2012).

2.4. Water Availability and Accessibility

According to Adewumi *et al*. (2012), the whole world has been having a challenge of water availability and accessibility. Purposes such as bathing, drinking and washing (clothes, dishes and cars) need water as a basic resource. The cultivation of a garden, field crops and livestock requires water as a basic need. Countries' industrial growth depends mainly on the accessibility and availability of water resources (Pinto *et al*., 2010).

2.4.1. Water Availability

Water availability, both as surface water and groundwater is the quantity of water that can be used for human purposes and other uses such as agriculture, industry and energy generation without significant harm to ecosystems (Conant *et al*., 2019). Water availability depends on climate. Low levels of rainfall and high temperatures lead to water deficits.Water surpluses are common where rainfall is high and temperatures are lower.Water availability is a broad topic, encompassing the biophysical supply of water, the demand for water, and access to water(Ahring and Steward, 2012).

The planet has only 3% of available freshwater where 2% of the freshwater is frozen in glaciers and polar ice caps and only 1% is usable water (Guo *et al*., 2013). Freshwater is available as surface water (lakes, rivers, reservoirs) and groundwater (found underground in rock or soil layers and accessed through wells or natural springs). As water is constantly moving on the Earth, factors such as climate, land use, local geology and water quality all affect the availability of freshwater resources in addition to the direct demands people place on them (Espinosa and Rivera, 2016).It is anticipated that climate change will impact water availability globally (Adenji-Olokola*et al*., 2013). The net effect of climate change for South Africa will be a reduction of water availability (DWAF, 2004).

South Africa's total surface water available is averaged about 49 200 million m^3 per year, of which about 4 800 million m^3 per year originates from Lesotho. A portion of this runoff, known as Ecological Reserve, needs to remain in the river in order to maintain the natural environment along the watercourse (Sebola, 2000). In 2014, a fifth of South African households with municipal piped water had interruptions that lasted for more than two days. This was three times higher in some regions of the country (Nieuwoudt and Armitage, 2004; Rawas *et al*., 2020). Few countries have water available continuously, but in many parts of the world a less than 24-hour supply is still considered sufficient (Rawas *et al*., 2020). Countries use a wide range of different measures to assess availability and these must catch up so that comparisons of service levels can be made across countries over time(Dutt, 2018)

2.4.2. Water Accessibiity

Accessibility is defined as the proportion of the population with reliable improved drinking water supply. Improved drinking water include piped water into dwelling or yard, public tap or standpipe, well, protected spring, and rainwater collection. Currently, South Africa has access to 77% (of the total use) of surface water, 9% of groundwater and 14% of recycled water. Nineteen percent (19%) of the rural population lacks access to a reliable water supply (Rahut *et al*., 2016).

Lack of access to water and sanitation is a matter of life and death. Contaminated water and improper sanitation help transmit diseases like diarrhea, cholera, dysentery and typhoid (Cumming and Cairncross, 2016; Chunga, *et al.,* 2017). Since 1990, 2.6 billion people have gained access to an improved drinking water source that is designed to protect against contamination. In 2015, 633 million people (one in 10) globally still drank water from unprotected sources (Gulland, 2015). Huge inequalities persist between and within countries; nearly half of the people drinking water from unprotected sources live in sub-Saharan Africa, eight in ten (8 in 10) live in rural areas, and there are huge gaps between the richest and the poorest (World Health Organization International, 2020; Water Supply and Sanitation- The Anthropocene Dashboard, 2020).

Poverty in Africa is often caused by a lack of access to clean, safe water and proper sanitation and the very same poverty can also cause inadequate water accessibility (Kasumov, 2012; Bisung and Elliott, 2016; Funders' Support for Water and Sanitation Efforts, 2020). In Africa, more than 38% of the population do not have access to a safe water supply, whereas 40% do not have access to adequate sanitation services (O'Hara *et al.,* 2007). Amongst the reasons why poverty has become an epidemic in Africa are political instability, ethnic conflicts, climate change and other man-made causes but the greatest cause of poverty is the lack of access to clean drinking water (MacDonald, 2005; Chatzigiannidou *et al.,* 2018). Nearly one billion people do not have access to clean and safe water, which is equivalent to 1 in every 8 people on the planet (O'Hara *et al*., 2007; Marris, 2016).

With unclean water sources which are often miles from villages, many of the able-bodied members of a community are forced to spend hours each day finding and transporting water to their homes (Khatri *et al*., 2017). In some regions, especially sub-Saharan Africa, many people spend more than 30 minutes on each trip to collect water. This burden still falls mainly on women and girls, who are responsible for this task in eight of ten households that do not have a piped water supply (Jorgensen, 1984; Rarassanti *et al.,* 2017).

According to WHO(2006), it is assumed that expanding access to water supply would result in time savings of 30 minutes per household per day, which is considered to be a conservative estimate. In most cases, the choice of water source is strongly influenced by a number of household characteristics as well as distance to sources. The World Health Organisation Joint Monitoring Program on water and sanitationstates that "Access to drinking water means that the source is less than 1 kilometer away from its place of use and that it is possible to reliably obtain at least 20 liters per member of a household per day"(O'Hara *et al*., 2007).

2.5. National Development Plan 2030

It is stated in the National Development Plan 2030 that, South Africa ranks 148th out of 180 countries in terms of water availability per capita. Furthermore, greater attention will be paid to water management and use since South Africa is already a water scarce country (Bourblanc, 2012). The National Development Plan aims to manage the water resources by reducing water demand. It is stated that reducing growth in water demand is just as increasing its supply. Current planning assumes it will be possible to achieve an average reduction in water demand of 15% below baseline levels in urban areas by

2030. Achieving demand reductions will require programmes to reduce water leakage in distribution networks and improvement of domestic and commercial water use efficiency. Demand-management projects with merit should be given priority and regarded as being on par with water-supply expansion projects in terms of importance.

According to the National Development Plan, there is extensive indirect reuse of water in inland areas, where municipal and industrial wastewater is reintroduced into rivers after treatment. Many municipalities lack the technical capacity to build and manage their wastewater treatment systems, and as a result, a regional approach to wastewater management may be required in certain areas. Projects to treat and reuse water should be included in water infrastructure investment, selected on their merits. Under the auspices of a national water-resource infrastructure agency or the Water Research Commission, research into water reuse and desalination and the skills to operate such technology should be developed. Sustainable Development Goal Number 6 aims to ensure access to water and sanitation for all while NDP aims to direct more attention to water management and use towards attaining the aim of Sustainable Development Goal Number 6 (de Lazaro Torres *et al*., 2020).

2.6. Coping Mechanisms for Water Scarcity

A coping mechanism is something a person does to deal with a difficult situation, it iscoping skills or strategy or adaptation that a person relies on to manage stress (Sapranaviciute *et al*., 2012).Adaptation to water scarcity means living in harmony with the environmental conditions specific to and dictated by limited available water resources (Pereira *et al*, 2009; Molden, 2019). It involves employing diverse measures or techniques to meet the water needs of the people. In many cases, adaptation activities to water scarcity are local, district, regional or national issues rather than international (Paavola and Adger, 2005). Communities possess different vulnerabilities and adaptive capabilities because they tend to be impacted differently, thereby exhibiting different adaptation needs. As a result, adaptation largely consists of uncoordinated action at household and organisation levels. It is therefore essential to reduce surface and groundwater use in all sectors of consumption, to supplement freshwater with alternative sources of water and to optimise water use efficiency through reuse options (Lee *et al*., 2010; Bennett, 2011; Niu *et al*., 2011). These alternative sources include rainwater harvesting, dew-water harvesting, desalination of seawater and greywater reuse.

2.6.1. Rainwater Harvesting

Rainwater harvesting is making optimum use of rainwater at the place where it falls so as to attain self-sufficiency in water supply without being dependent on remote water sources (RAHMAN, 2021). Rainwater harvesting has been in existence for many decades as a way of augmenting available water resources in the world. It is the intentional collection, storage and management of rainfall and other various forms of precipitation from different catchment surfaces. In the years of its existence, rainwater harvesting has positively impacted life, agriculture and economy (Singh *et al*., 2018).

Mashabela (2015) said that rainwater harvesting is the process of intercepting storm-water runoff and putting it to beneficial use. It is a way to cope with water scarcity and also it has been used successfully to help with water for industrial and domestic purposes, while being an essential element in the functioning of natural ecosystems. However, rainwater harvesting is rarely integrated into water management strategies, which usually focus exclusively on surface water and groundwater (WHO, 2006).

Harvesting of rainwater can be from roofs of private, public or commercial buildings (e.g. schools, greenhouses). Rooftop water harvesting is getting popular in both developed and developing countries to secure and improve water supply for domestic use such as sanitation or irrigation of gardens (Mekdaschi and Liniger, 2013). Due to small surface area and high runoff efficiency, rooftop can translate 80-90% of incident rainfall into runoff (Itsukushima *et al*., 2018). Rainwater is only available for a short period of time, either during rainfall or immediately afterward.

According to Mati (2007), various rainwater harvesting technologies have been in use for millennia and new ones are being developed all the time. These can be classified as Micro-catchment technologies. This is a system that involves the collection of runoffs from large areas which are at an appreciable distance from where it is being used. These technologies handle large runoff flows diverted from surfaces such as roads, hillsides, pastures and house roofs (the most and commonly used technology in South Africa) where the roof become the catchment, and the rainwater is collected from the roof of the house / building, stored in a tank then pumped to the household or used for irrigation of the garden. Hillside sheet / rill runoff utilization, rock catchments, sand and earth dams are examples.

Rainwater harvesting has mostly positive impacts such as simple treatments which use little to no chemicals and resources as compared to large-scale of potable water systems, it reduces the environmental impacts due to decreased demand of fossil fuels needed to handle and treat potable water at central water treatment plants as well as energy needed for water distribution. Rainwater harvesting generally has a minimal impact on the overall water balance, but larger operations may impact downstream surface water or groundwater resources where water is limited (Welderufael *et al*., 2013).

2.6.2. Dew-water Harvesting

Dew is a type of precipitation where water droplets form on the ground, or on objects near the ground in a process called condensation of moisture (Khatri *et al*., 2017). Dew forms during calm, clear nights when humidity condenses in low areas due to cooler night-time temperatures. Dew-water harvesting is sometimes called dew collection which is referred to simply as taking advantage of water vapour in the atmosphere to harvest clean and potable water through condensation, a passive process that allows water particles to return to the earth in a pure form (Khatri *et al*., 2017).

Dew harvesting can be a supplementary source of freshwater in semi-arid and arid areas but has so far not been widely applied (Daniell, 2012). Dew can bring substantial amount of water when other sources (groundwater, rain, fog) are lacking. The advantages of harvested dew-water are that the water quality can be good, unaffected by drought, and can possibly be a supplementary water source to rainwater harvesting.

Dew irrigation has low costs and it can possibly be done on a household level. On the other hand, the disadvantages of dew-water harvesting are that relatively small amounts of water can be harvested, there is also a huge variability in water collection which also varies according to the season and the variability leads to a need to supplement water from other sources (Li and Urban, 2016).

2.6.3. Desalination of Seawater

Desalination isthe removal of salts and minerals from a target substance. Desalination of seawateris the process whereby highly pressurised ocean water (salty) is pushed through tiny membrane filters and distilled into potable water (Al-Jayyousie, 2003). Desalination processes provide the extremely pure water forms necessary for chemical experiments and thermal exchange loops of nuclear reactors (Water Research, 2004) and it may be used for municipal, industrial or any commercial uses (Al-Jayyousie, 2003). Desalination processes prove to be a reliable source of fresh water and a solution for the world's water shortage problem (Science Daily, 2015). With advancement of technology, desalination processes are becoming cost effective compared to other methods of producing usable water to meet the growing demand (Al-Jayyousie, 2003). The water that is obtained after desalination should be remineralised to be fit for human consumption while the concentrated brine obtained in desalination process have to be disposed of in a proper and safe manner (Tissington, 2011).

There are two major technologies that are mainly used for desalination, they are thermal desalination technology and membrane desalination technology. Both technologies include different processes, and apart from these there are alternative technologies like freezing and ion exchange which are not used. All these technologies require energy to operate. Conventional energy and renewable energy are used in these methods.

Though desalination costs seem to be progressively decreasing, they are still a bit higher than conventional drinking water processes. When checking the environmental aspects, each desalination plant has to take proper measures in case of water intake, pre-treatment of water as well as disposing concentrated water that is produced in the process because environmental aspects such as ocean pollutions as well as health concerns and energy use are equally important as commercial aspects (Bernard *et al*., 2003; Water Research, 2004). Desalination contributes to global warming and requires large amounts of energy. Emissions created by desalination plants contribute to climate change which is a leading factor of droughts and water shortages which are the processes it is intended to mitigate (Penn *et al.*,2012).

2.6.4. Greywater Reuse

Greywater is domestic wastewater that is collected from dwelling units, commercial building and institutions of the community (Penn *et al*., 2012). It may include processed waste of industry as well as ground infiltration and miscellaneous waste liquids. It is also defined as primarily spent water from building water supply which has been added to the waste effluent of bathrooms, kitchens and laundry (Newcomer *et al*., 2017). Greywater can also be defined as sullage, which is non-industrial wastewater generated from domestic processes such as washing dishes, laundry and bathing (Deshayes *et al*., 2015). Greywater is wastewater from showers/baths , washingbasins, washing machines and kitchen sinks (Varghese *et al.*, 2013). Allen and Cobb (2010), refers to greywater as simply wastewater generated from household uses like bathing, laundry and washing of dishes without input from toilets and also regards it as an immense resource that could find significant applications in regions of water scarcity. Greywater often includes discharges from laundry, dishwashers and sinks (Ilemobade *et al.,* 2012). One can collect it from some or all of these sources and use it around the home for purpose that do not require drinking water quality such as toilet flushing and gardening.

This subtopic covers the quantity of generated greywater, potential of greywater reuse, advantages and benefits of greywater reuse, disadvantages of greywater reuse and the greywater storage and its consequences.

<u>Quantity of Generated Greywater</u>

Greywater reuse has been considered as a reliable method of ensuring water security as compared to other methods of water capture such as rainwater harvesting which is dependent on hydrological conditions. Greywater accounts for up to 75% of the waste water volume produced by households, and there is a possibility of the percentage to rise to 90% if dry toilets are used (Laber and Haberl, 1999; Jefferson *et al*., 2001; Hernandez Leal *et al*., 2010).

The quantity of greywater generated can be controlled at the household level. The amount of greywater generated can be significantly reduced through behavioural changes, good maintenance of pipe and water taps, and the use of water-saving devices.

As indicated by Irshad *et al*. (2020), altogether lower amount of water utilisation and subsequently lower greywater generation has been accounted for in rural areas where facilities, for example, kitchen sinks, bathtubs, basins and washing machines are not available. In certain instances lower quantity of generated greywater is linked to households being served by one pipe inside the house and water should be physically conveyed to different spots for its utilisation, for example, kitchen (Sall and Takahashi, 2006). In such cases different uses of greywater has been accounted for. For example, rice washing water produced during food preparation is usually given as drinking water to animals, or utilised for irrigation (Sall and Takahashi, 2006).

The amount of greywater produced in a household can vary greatly ranging from as low as 15lper person per day for poor areas to several hundredslitersper person per day. In households with conventional flush toilets, greywater makes up about 65% of the total wastewater produced by that household (Tilley *et al*., 2014). The quantity of greywater depends greatly on the freshwater used in different households.

Potential of Greywater Reuse

Greywater reuse harbours a number of possibilities to meet different water use needs. In agriculture, treated greywater can be used to irrigate both food and non-food producing plants. The nutrients in the greywater (Nitrogen and Phosphorus) provide an excellent food source for these plants. For municipal uses, greywater can be used for firefighting, street cleaning, car washing, cooling and road construction operation. Non-potable domestic uses like toilet flushing, air conditioning, laundry, floor and concrete cleaning are among the possibilities where greywater can be used. Greywater can also be used for recreational purposes (ponds, lakes, streams and fountains) as well as to recharge surface water and groundwater (Azis *etal*., 2015).

Greywater has been reused for irrigation purposes for a long time everywhere in the world and explicitly in countries with fundamentally the same climatic conditions to South Africa, for example, Australia, Europe, Japan, Israel, Jordan and USA (Garber, 2006). Greywater systems acquire noteworthy reserve funds for drinking water by diminishing the measures of produced wastewaters, along these lines easing the tension on the environment (Nolde, 1999). Greywater reuse can be seen as far as economic execution as well as huge social and environmental advantages in contributing towards sustainable development and resource use (Nolde, 1995).

Possible uses of greywater are presented in the table below

Table 2.1: Uses of greywater (Eriksson *et al.*, 2002).

Users of Greywater	Purpose
• Individual household • School • Non/Government office • Hospital • Hotel • Airport • Railway station • Apartment/colony	• Toilet flushing • Floor cleaning • Irrigation of crops and flowers • Car washing • Construction

Advantages of Greywater Reuse

Advantages of greywater reuse refer to conditions or circumstances that put one in a favourable situation while benefits can be described as advantages or profits gained from reusing greywater. This section will cover advantages and benefits of greywater reuse on-site or nearby places where it is generated.

There is a need for careful planning for the future to ensure reliable water supplies are available for everyone whilst protecting the natural environment. When greywater is used for flushing, potentially a third of the freshwater used in the home could be saved. For other uses that do not require potable water quality, such as garden watering greywater could be reused. The greater the population that reuse greywater, the less freshwater will be needed, which will ease the pressure on water resources. Thirty-three percent (33%) of average water usage comes from showers, basins and baths. Reusing greywater not only reduces the consumption of freshwater, it also reduces the volume of water discharged into the sewage system. Consumers with water meters could therefore save money on both their water meter supply and wastewater bills (Jefferson *et al.*, 2001).

Greywater can possibly add to food security in poor communities by giving a source of both irrigation water and nutrients for crops (Domenech *et al*., 2014). Greywater might be utilised to water gardens during drought periods, food cropsand grazing field for animals (Anderson, 2007; Domenech *et al*., 2014; Radingoana*et al*., 2019).

Greywater can also be effectively utilised for flushing latrines, washing yards, vehicles, pavements and garages. This features the requirement for a participatory way to deal with the advancement of greywater reuse standards and principles, just as innovations, so that the water needs and worries of the consumers are addressed. Expanding greywater reuse can help give more versatility to dealing with the insecurity of potable water supply because of climate change (Garber, 2006). Water from hand basins, baths and showers can be harvested and recycled (Tiruneh, 2014).

The benefits of greywater reuse either on-site or nearby are that it has the potential to reduce the demand or new public water supply and thus reducing the energy and carbon footprint of water services (Allen and Cobb, 2010). Other benefits of greywater reuse are to shorten and close the water cycle, to prevent water shortage and to save money by reducing the water bills. The cycling of water occurs in a spatially limited area and the reuse of greywater takes place near the location where water was initially used. The reuse helps to reduce water shortage because precious and expensive water is saved. Greywater often contains valuable nutrients for plant growth and as a result there is no need to buy expensive mineral fertilisers (Reichman and Wightwick, 2013). Agricultural irrigation using greywater to support crop production is a well-established practice in arid and semi-arid regions (Lee *et al*., 2003). The use of greywater for agricultural irrigation purposes is occurring more frequently because of water scarcity and population growth (Bernard *et al,* 2003). A significant portion from existing greywater can meet the above demand (Lee *et al*., 2003).

The reuse of water is significant on the grounds that it limits water demand and decreases weight on treatment systems. Greywater reuse is especially significant with regards to availability of rainwater and over-extraction of groundwater for satisfying water needs during yearly cycles (Friedler, 2004). Reusing greywater at a domestic scale is commonly more energy and carbon concentrated than utilising freshwater, particularly when escalated treatment is utilised (Domenech *et al*., 2014). To spare energy, it is smarter to zero in on water productivity and explicitly on lessening the volume of hot water utilised. Utilising greywater instead of freshwater for garden water systems spares energy and water, however the water must not be stored for long. Greywater can give a more dependable and reliable supply of non-potable water than rainwater harvesting (Varghese and Behera, 2019).

The reuse of greywater can also help in reducing the amount of wastewater entering sewers or on-site treatment systems which will result in the benefits like reduced power consumption associated with aeration, the enabling of an existing activated sludge plant to treat double the flow and load and also to lower the embodied and operational carbon (Rudakova and Sakaeva, 2019).

Disadvantages of Greywater Reuse

Every action and activity have the good and the bad side of it. The downside to reuse water is that some systems can be very expensive. It may also require more maintenance than a regular sewer or septic system. Hair from the bath and shower can cause pipe and pump blockage if it is not filtered (Harrow *et al*.,2011; Maimon *et al*., 2017). Growth within the system is another source for microorganisms and some chemicals (Eriksson *et al.,* 2002), these have negative impact to people, soil and plants.

Apart from systems, pathogens from greywater may spread by direct contact (touching greywater or inhaling infectious water droplets) or indirectly by consumption of contaminated food (Santaeullllia-Llopis and Zheng, 2016). A pathogen is anything that can produce a disease and typically means an infectious agent or microorganism, such as a virus or bacteria that causes a disease in its host (Chalkias *et al.,* 2014). Solid particles and chemicals in greywater will alter the soil acidity and alkalinity balance, thus damaging the soil structure (Harrow *et al*.,2011; Maimon *et al*., 2017). Chemicals in bleaches and fabric softeners can have detrimental effects on soil and plants while soaps and detergents containing substantial amounts of sodium can negatively affect plants and soil (Pisarcik *et al*., 2019). There is a possibility of harmful chemicals and pathogens being absorbed by vegetables which will result in contamination of food (Harrow *et al*.,2011; Maimon *et al*., 2017).

There are a number of problems related to the reuse of untreated greywater. The risk of spreading diseases, due to the exposure of microorganisms in the water, will be a crucial point if the water is to be reused for toilet flushing or irrigation. Both inhalation (aerosols) and hand to mouth contact can be dangerous (Eriksson *et al.,* 2002). Another problem is the risk of sulphide production, which is produced when oxygen is depleted and gives bad odour (Han *et al*., 2018).

Even if the concentrations of solids in the greywater are expected to be lower than in combined wastewater, the combination of colloids and surfactants (from detergents) could cause stabilisation of the colloidal phase, due to sorption of the surfactants on the colloid surfaces. This prevention from agglomeration of the colloidal matter will reduce the efficiency of a pre-treatment step including settling of solid matter before infiltration. However, this stabilisation does not mean that the colloids will not induce clogging of the soil matrix (Eriksson *et al.,* 2002).

The effects of the infiltration of greywater on soil pH and buffering capacity is determined by the alkalinity, hardness and pH of the infiltrating water. However, the effect observed will also be influenced by the natural buffering capacity of the soil. The properties of the soil, regarding, for example, sorption capacity of pollutants, will change as a result of the infiltration (Eriksson *et al.,* 2002). Infiltration and irrigation may lead to elevated concentrations of detergents in the soil and some plants may suffer due to the alkaline water. When soil pH exceeds 8, some micronutrients deficiencies occur. Phosphorus disposed to clay-soils may make them become phosphate-saturated. There is a potential for leaching to groundwater or runoff to a water course. Excess phosphorous leaching to groundwater in sandy soil might be an even more significant problem (Christova-Boal *et al.,* 1996).

<u>Greywater Storage and Consequences</u>

This subsection covers storage containers and storage period and its consequences.

Storage Containers

Various types of containers such as tanks, drums and buckets can be used to store greywater temporarily. Greywater from the washing machine can be stored in the laundry drums. Wash water is pumped into a drum or temporary storage called a surge tank. At the bottom of the drum the water drains out into a hose pipe that is moved around the yard to irrigate. This is the cheapest and easiest greywater storage system to install, however, it requires constant moving of the hose pipe for it to be effective at irrigating (Gorgich *et al*., 2020).

Households can also use buckets as the temporary storage of their greywater while waiting for the greywater to cool down and allow the particles available in the greywater to settle so that when reusing their greywater they do not have a problem with the contained particles (Ashok *et al*., 2018). Mashabela (2015) reported that, in rural and informal settlements, greywater was stored in tanks and buckets.

According to Christova-Boal *etal.* (1996) the incorporation of collection and storage tanks is undesirable in any greywater design. Tanks containing greywater provide an ideal breeding ground for pathogenic microorganisms and mosquitoes and a source of odours. Tanks can be vented and child-proof and comply with local health and plumbing by-laws as well as all tanks being accessible for cleaning. Storage of greywater would require the addition of a disinfectant to avoid the biological degradation of fats, soaps, hairs etc.

Storage period and consequences

Like all wastewater, stored greywater will turn septic, giving rise to offensive odours and providing a suitable condition for microorganisms to grow and multiply unless treated (Filtration and Separation, 2009; Schoen *et al*., 2018). During the first 24 to 48 hours of greywater storage, thermotolerant coliforms were found to multiply (Water Science and Technology, 1998), which therefore means that it is best to use greywater immediately or to store it for a short period of time before use

A major factor affecting the characteristics of greywater between different recycling schemes is the residence time of the greywater in the collection network, which can range from minutes to days (Jefferson *et al.,* 2001). On the contrary, Eriksson *et al*. (2002) found that storage for 24 hours improved the quality of the greywater but storage for more than 48 hours could be a serious problem as the dissolved oxygen was depleted.

In a study conducted by Queensland University, (2002), thermotolerant coliforms multiplied by 10 to 100 times during the first 48 hours of greywater storage before gradually declining. Significant levels of pathogens were found in stored greywater after eight days. While it is unlikely for pathogens to grow in greywater, the low infective dose of some pathogenic microorganisms is still of concern.

The storage of greywater is very inconsistently discussed; and the references may even contradict each other. The common point of all opinions is that greywater storage is difficult and the danger of pathogen growth present. The number of thermotolerant coliforms increases strongly during the first days, which could imply that the number of pathogenic microorganisms increases, too.Another problem poses the depletion of oxygen during the degradation process which can lead to very bad smell (Hori *et al*., 2011).

A study conducted at Cranfield University in the UK revealed a rapid decline in organic strength with both real and synthetic greywater under quiescent and agitated conditions. However, although there is an increase in indicator species this does not imply an increase in pathogenic microorganisms (Patil and Yadav, 2018).

A model for foreseeing quality changes in stored greywater, in view of observed cycles of settlement of suspended solids, oxygen consuming microbial development, anaerobic arrival of dissolvable settled organic matter, and atmospheric re-aeration was tried by Finley and Lyew (2008).The study revealed that storage of greywater for 24 hours might improve water quality. Storage for beyond 48 hours could truly exhaust broke up oxygen levels and lead to what they call aesthetic issues, 24 hours including anaerobic cycles and related scents (Finley and Lyew, 2008). Finley and Lyew (2008) agreed with WHO (2006) that because of bacterial pollution of greywater, untreated greywater ought not be kept longer than one day. WHO (2006) further demonstrated that adding two tablespoons of chlorine bleach per gallon of water will extend storage time. Greywater ought to be utilised the day it is gathered because the high microscopic organisms count will cause questionable smell (WHO, 2006). In this manner storage of greywater before reuse is debilitated on the grounds that it can influence the number of microorganism of both raw and treated greywater(Schoen *et al*., 2018).

2.7. Case Studies of Greywater Reuse

The reuse of greywater as a water conservation method has been practised in different regions of the world from the old ages (Water Research, 2004). This section provides case studies on greywater reuse at the global, regional and national contexts.

(a) Global

In Sweden and other developed areas of the world, wastewater from cities is most often treated at a municipal treatment plant. All water is collected; stormwater from roofs, streets and other paved areas, blackwater from toilets, greywater from kitchen sinks, bathrooms and washing facilities and industrial wastewater and transported to the treatment plant. The treated wastewater is then released into a receiving water body with enough diluting capacity to take care of the harmful substances and organisms that have not been separated in the wastewater treatment plant (Maghsudi *et al*., 2018; Mohan and Balakrishnan, 2019).

In countries with limited water resources, greywater reuse has been practised for a long time. Greywater reuse in schools, hospitals and government institutions is proving to be an essential alternate water resource to fresh ground, surface or rainwater supplies (Godfrey *et al*., 2006). Studies from the Middle-East and India indicate that greywater systems have a water saving of between 3.4-33.4% per annum (Al-Jayyousie, 2003). Mcllwaine and Redwood (2010), conducted a study in India where one of the interesting findings of the study was that, about 93% of the respondents were not aware of the greywater concept and its potential importance to their community, including reuse of greywater for irrigation at their home gardens. The study suggested that there was a crucial need to implement appropriate educational programs for the community on the best practices on reuse of greywater in order to encourage and spread the implementation of reuse greywater concept around homes. Only 7% of the respondents knew about greywater and its significance to their community.

In Australia, direct greywater reuse for garden irrigation is currently illegal in all states, but greywater which has passed through a secondary treatment system may be reused for irrigation in certain states if disinfection is provided (e.g. chlorine tablets, UV or ozone). A study conducted at the University of Western Sydney, Australia, revealed that irrigation of silverbeet with 100% greywater had no significant effects on plant biomass and water use (Pinto *et al.,* 2010). Sondhia (2007) also reported that the community in Victoria, Australia reuses greywater for toilet flushing and watering their gardens as their coping mechanisms due to unavailability of water supply.

Regulations are set by conservative state health departments whose main concern is the perceived public health risk associated with greywater reuse. Encouragingly, direct greywater reuse for garden irrigation were examined by some Australian water authorities as an option for reducing freshwater demands in rural and urban areas. As a result of the examination by water authorities, areas like Melbourne see greywater reuse in gardens as a significant method to reducing domestic water demand (Marshall, 1996; Byrne *et al*., 2020).

A study conducted in Palestine, showed that greywater reuse in Palestine, has had multiple benefits of providing additional water supply, reducing wastewater disposal costs, and reducing pollution. Recognising the great potential for greywater reuse in Palestine, has installed 161 greywater treatment and reuse systems in the West Bank and Gaza Strip that serve a total of about 215 families and 27 schools (Rahil and Natsheh, 2012).

(b) Regional

During evaluation of theoretical potential and practical opportunity for using recycled greywater for domestic purposes in Ghana, Hyde (2013) found that treated greywater can be used for cleaning, flushing toilets where appropriate for washing cars and sometimes for watering gardens. The use of reclaimed water for irrigation of food crops is prohibited in some states, while others allow irrigation of food crops with reclaimed water only if the crop is to be processed and is not to be eaten raw. The use of reclaimed water for agricultural irrigation of non-food crops presents a reduced opportunity of human exposure to the water, resulting in less stringent treatment and water quality requirements than other forms of reuse.

The use of greywater in tower gardens in peri-urban areas Kampala, Uganda was reported by Kulabako, (2011). The study revealed that the effects of greywater application on the soil characteristics was not significant with respect to potassium, organic matter and nitrogen content, possibly due to plant uptake. Tomato and onion grown in the tower gardens survived with greywater irrigation (Wang and Zhu, 2011).

The use of greywater is possible in African cities such as Harare, where nearly two thirds of the population rely on agriculture for livelihoods (Madungwe and Sakuringwa, 2007). The problem of blue green algae in sewage ponds and water reservoirs is significantly reduced by household reuse of greywater (Madungwe and Sakuringwa, 2007).

In Ethiopia, most families are not connected with a sewerage system and collect their greywater (household wastewater that is not contaminated with fecal matter) in jerry cans or buckets to discard either on their own compound premises, or outside, to dodge "unattractive conditions" (Shewa *et al.,* 2010). In urban regions, greywater is regularly arranged through casual hand-dug sewerage connections or by emptying jerry cans on the streets, or into the municipal open storm water drains or streams and rivers flowing through the city. This water may then be utilised for beneficial purposes downstream (off-site).

(c) National

In South Africa, where there is a growing pressure on water resources, the challenge has always been to balance between the supply and demand for freshwater (Weinmann, 2007; Pott *et al.,* 2009). This has been triggered by low rainfalls and high evaporation rates faced in most parts of the country. Various efforts have been made, and some are still in progress, to identify new means of meeting the increasing water demands within South Africa (Vorster, 2005). Many research studies are being conducted to provide solutions on ways of reducing the growing pressure on the available freshwater resources by increasing the efficiency of water usage and to expand the usefulness of alternative sources of water which were previously considered unusable (Allen and Cobb, 2010). Among these alternative sources of water previously considered unusable is greywater.

Greywater reuse in South Africa is viewed with caution and not commonly practised. The most common greywater reuse sites in South Africa have been experimental domestic irrigation and non-domestic irrigation and this reuse has been driven by the heightened awareness of the nutritional benefits of applying suitably treated greywater to the irrigation of plants and the need to efficiently manage greywater disposal in especially non-sewered areas (Carden *et al*.,2007; Rhodda *et al*.,2010).

According to Ilemobade *et al*. (2009a and 2009b), greywater reuse for toilet flushing in South Africa has not been as popular as irrigation. The study recorded domestic respondents' preference for non-potable water reuse for toilet flushing similar to irrigation. Sites that have employed greywater reuse for toilet flushing included the creche within the Old Mutual building in Pinelands, City of Cape Town where greywater from hand basins was collected, sieved, disinfected and used to flush 30 toilets (Water Rhapsody Conservation Systems, 2011). A building in the City of Cape Town which houses 7 apartments uses a highly technical system to biologically purify , store and reuse greywater(from bath tubs, hand wash basins and showers) for toilet flushing (Kieslich, 2009).

In the study to investigate the use and disposal of greywater in non-sewered areas in South Africa, which included developing options for the management thereof, it was found that the reuse of greywater in non-sewered areas is not advised unless it is done under controlled conditions. Additional findings also showed that for settlements densities above 50 dwellings per hectare, reuse of greywater poses unacceptable risk to the occupants (Carden *et al*., 2007; Carden *et al*., 2010).

A student from the University of Cape Town also conducted a similar study on greywater reuse. Nkomo the project manager of AquaRenu and his friends, are working on a design that utilizes rainwater and greywater as primary sources of water for irrigation and toilet flushing for large properties such as schools and complexes. This design, coupled with their old greywater unit would reduce consumption by up to 80% per month. They are currently working with contractors in Mpumalanga and installing their greywater units in some of the local schools in the area (Gosling, 2018).

A study of greywater reuse was conducted in two villages of the Limpopo Province of South Africa in the Fetakgomo Local Municipality by the student of the University of Limpopo. The study found that in one of the villages, a high percentage of respondents reused their greywater after generation as compared to the other village. The percentages of the households who reused their greywater in both villages were over 50% due to the villages not having consistent flow of tap water, some communal taps being far and the households having to travel long distances to access water (Randingoana*et al*., 2019).

According to Mzini and Winter (2015), irrigation of soils with greywater did not change soil pH and sodium content, contrasted to soil irrigated with diluted greywater or potable water. Therefore, the greywater utilised in this investigation did not seem to cause an accumulation of salts and heavy metals in soil, in the short term.

2.8. Characteristics of Greywater in Relation to Sources

Greywater is a reflection of the household activities and its characteristics are strongly dependent on living standards, social and cultural habits, number of household members and the use of household chemicals (Uddin et al., 2016). These have influence on the quantity and quality of generated greywater in both place and time (Physics Today, 2012; Paciuszwicz *et al*., 2019).

Greywater makes up about 60%–70% of the domestic wastewater volume in most developed countries (Friedler, 2004). The generation of greywater is directly related to the consumption of water in a household and is dependent on a number of factors including the level of service provision, tolerance of residents to pollution and the communities' level of awareness of health and environmental risks (Carden *et al.,* 2006).

Greywater from different sources have different composition. Bathroom greywater (hand washing and bathing) contributes about 30%-40% of the greywater volume and is considered to be the least contaminated type of greywater.Cloth washing or laundry generates around 25%-35% of the total greywater and kitchen greywater contributes about 10% of the total greywater volume(Al-Jayyousie, 2003).

The quality of greywater in terms of physical, chemical and biological aspects vary from different sources within the household.Greywater contains pollutants that could have adverse effects on the environment and public health if the water is not treated before reuse. Successful implementation of any greywater treatment process depends largely on its characteristics in terms of the pollutant strength (Morel and Diener, 2006).

2.8.1.Physical Characteristics

The physical characteristics of water refers to the temperature, turbidity, colour, taste and odor of the water sample (Khiari, 2004). Physical characteristics of greywater are associated with the physical appearance of greywater. These characteristics include temperature, colour, turbidity and the suspended solid content. Food particles from the kitchen wastewater and solid particles, fibres and hair from laundry wastewater are sources of solid material in the greywater wastewater (Eriksson *et al.*, 2002).

Laundry greywater varies in quality from wash water to rinse water to second rinse water. It is high in suspended solids, lint and turbidity. Bathroom greywater is high in suspended solids, hair, and turbidity. Kitchen greywater is high in food particles, oils, fats and turbidity (Shoults and Ashbolt, 2017).

Kitchen greywater exhibit the highest turbidity (measured in Nephelometric Turbidity Units; NTU) compared to laundry and bathroom greywater (Bakare *et al.,* 2017). This could be a result of the amount of soap used in the kitchen and the fact that greywater from the kitchen source was highly contaminated with food particles which contribute to high suspended solid materials. In the study conducted by Bakare *et al*. (2017), the average measured turbidities for different sources (kitchen, laundry and bathroom) were found to be 252 NTU, 170 NTU and 120 NTU respectively.

2.8.2.Chemical Characteristics

The chemical characteristics of water refers to the pH, electrical conductivity and dissolved oxygen of the water sample (Lu *et al*., 2016). Greywater with most of its sources originating from the laundry will generally exhibit high pH due to the presence of alkaline materials used in detergents. The major chemical constituents found in greywater which is generated as a result of cleaning or washing activities are surfactant (Ziemba *et al*., 2018).

Bathroom and kitchen greywater generally have lower pH values while greywater that originates from the laundry is alkaline and generally has pH values that range between 8-10. The higher pH value observed in greywater from laundry show the importance of the use of chemical products (Eriksson *et al.*, 2002). Laundry greywater contains chemicals such as sodium, phosphate, boron, surfactants, ammonia and nitrogen from soap powders and soiled clothes. Kitchen greywater contains chemical pollutants such as detergents and cleaning agents which are alkaline in nature and contain various chemicals (Gruber,2018).

Bakare *et al*. (2017) reported that greywater from the kitchen has the lowest pH value which may be due to the fact that greywater generated from the kitchen was mostly contaminated with food particles and oil, and degradation of the greywater will occur more rapidly in an anoxic condition compared to the greywater generated from other sources. It was further reported in the study that the higher pH values of greywater collected from the laundry and from bathrooms may be as a result of the alkalinity of the type of detergent and soap used for these activities.

Common chemical contaminants in bathroom greywater include soap, shampoo, hair dye, tooth paste and cleaning products. Greywater sources with high nutrient concentrations are mostly made up of a high fraction of kitchen and laundry sources (Boyjoo *et al.,* 2013).

2.8.3.Biological Characteristics

The biological characteristics of water refers to the presence of living organisms such as pathogenic viruses, bacteria, protozoa, helminths (Eriksson *et al*., 2002), E.coli, fecal coliforms, algae and phytoplankton (Reckhow, 2015; Barinova and Mamanazarova, 2021). Laundry greywater is high in biochemical oxygen demand (BOD) . BOD is the amount of dissolved oxygen needed by aerobic biological organisms to break down organic material present in a given water sample at certain temperatures over a specific time period (Lehto and Allen,2016; Kumar,2020). It may have fecal contamination with the associated pathogens such as bacteria and parasites such as helminthes. Bathroom greywater has some fecal contamination (associated with bacteria and viruses) through body washing and has lower levels of thermotolerant coliforms (Milaidi *et al.,* 2019).

According to Li (2009), greywater generated from household kitchens and those from the laundry are higher in organics compared to bathroom and mixed greywater. Kitchen greywater is contaminated with food particles, oils, fats and other wastes. It readily promotes and supports the growth of micro-organisms and it has variable thermotolerant coliform loads. Microbial pathogens are often considered the most significant health concern associated with greywater reuse.

The study conducted by Bakare *et al.* (2017) found that the priority pollutants in greywater from different sources within households which are usually the organic components present in the greywater BOD is the parameter used to measure the organic pollutants in water. It was found in the study that the BOD ranged between 320 to 812 mg/l for greywater from the kitchen, the highest amongst sources was greywater from laundry with 300 to 600 mg/l and 85 to 253 mg/l for greywater from the bathroom.

Pathogenic viruses, bacteria, protozoa and helminths (Skinner *et al*., 2014) escape from the bodies of infected persons in their excreta and may be passed onto others via exposure of wastewater. These microorganisms may be introduced into greywater by hand-washing after using the toilet or changing nappies, baths, washing babies and small children, and from uncooked food products in the kitchen. If the greywater is reused for irrigation, parasitic protozoa and helminths will not be a problem in relation to groundwater contamination due to their large size, which results in their removal by filtration as the water percolates under gravity (Eriksson *et al.,* 2002). Bacteria and virus contamination of groundwater may, on the other hand, be a serious problem.

2.9. Perceptions on Greywater

Perception which is a social phenomenon can be seen as the difference between an absolute truth based on facts and virtual truth shaped by popular opinion (Xie, 2017). Public perception has been recognised as an integral factor in determining the success of the project in the implementation of any project (Taana and Raju, 2020).

Strategies such as interviews, questionnaires, focus group discussions, informal discussions and other social surveys has been used to assess public perceptions on the reuse of greywater in different parts of the world. The concept of greywater reuse acquired clear support as an environmentally sustainable method of protecting freshwater resources and pollution prevention. The highest acceptability of greywater reuse schemes is for non-potable uses (Marks, 2004; Hurliman and McKay, 2007).

The study conducted by Bruvold and Smith (1998) in the United States indicated that there is poor acceptance of water reuse for non-potable uses that involved low human contact such as swimming and drinking. In developing countries, level of public greywater reuse acceptance is generally relatively high, and it is certainly much safer than the current common practice of using raw mixed domestic wastewater for urban agriculture. Public acceptance for certain reuse options such as toilet flushing and garden watering isusually high while reuse options such as laundry and bath/shower has a lower acceptance. The acceptability of greywater reuse is heavily influenced by what it is used for. For example, use in golf courses, parks and industry is relatively well accepted, but reuse in people's houses is less popular. Furthermore, acceptability is lower for water uses where contact is minimal, like in toilet flushing (Jeffery, 2002).

Researchers at the Zuckerberg Institute for Water Research at Ben-Gurion University of the Negev,reported that in Israel greywater is safe for irrigation and does not pose a risk for gastrointestinal illness or water-related diseases (Science Daily, 2015). A positive attitude to the use of greywater for toilet flushing is supported by the findings of a number of studies (March *et al*., 2004; Ilemobade *et al*., 2013; Olanrewaju and Ilemobade, 2015; Ezzeddin and HongBin, 2019). Other uses that require more direct contact, such as watering the garden are generally less accepted. Studies into people's perceptions of communal recycling schemes have found that users prefer to reuse their own greywater rather than someone else's (Jeffery, 2002). Research suggests that where communal systems are installed, people prefer larger area where they may know many of the people involved (Po *et al*., 2003). In South Africa, there is still a need to investigate the reuse of greywater and also create awareness towards the importance and underlying opportunities related to the reuse of large volumes of greywater generated in many low-cost housing developments spread across the country. In a study that was conducted in the two villages of Fetakgomo Local Municipality (Ga-Nkwana and Ga-Seroka) in Limpopo Province, households reused their greywater with caution as they did not know the effects it might have on their produce (Radingoana *et al.,* 2019). Households indicated that they do not irrigate any plants with greywater from bathtubs due to the detergents suspected could kill plants, they instead used rinsing water from dishwashing and laundry (Stevens *et al*., 2011; Mohamed *etal*., 2018). Though the greywater was used to irrigate mature fruit plants as it killed small plants, it also worked to their advantage as a pesticide and repelled some of the insects that used to eat their plants (Hammadi and Ahmed,2015; Radingoana *et al*., 2019).

Ilemobade *et al.* (2012) revealed that respondents at the University of Cape Town, Wits University and University of Johannesburg liked to reuse greywater for latrine flushing contrasted with irrigation. In contrast with irrigation, most respondents at all institutions favoured latrine flushing however they were worried of becoming ill from greywater reuse for latrine flushing. Moreover, Ilemobade *et al.* (2012) revealed that latrine flushing was favoured than irrigation. This was because of the view of potentially lesser contact with greywater whenever utilised for latrine flushing than if utilised for irrigation.

2.10. Laws, Legislations and Guidelines Governing Water in South Africa

Law is a rule of conduct or action prescribed or formally recognized as binding or enforced by a controlling authority as a command or provision enacted by a legislature (Sridhar, 2012; Gorobets, 2020). This subtopic covers the constitution of South Africa, National Water Act, National Water Resources Strategy 2, National Strategy for reuse, National Sanitation Policy, Water Services Act, Water reuse by-laws and Greywater reuse rules.

2.10.1. The Constitution of South Africa (106 of 1996)

The Constitution of the Republic of South Africa (106 of 1996), is the supreme law of the Republic of South Africa. It provides the legal foundation for the existence of the republic; it sets out the rights and duties of its citizens and defines the structure of the Government. Chapter 2 (Bill of Rights), section 24 of the Constitution states that everyone has a right to an environment that is not harmful to their health and well-being; and to have the environment protected for the benefit of present and future generations, through reasonable legislative and other measures that prevent pollution and ecological degradation; promote conservation; and secure ecologically sustainable development and use of natural resources while promoting justifiable economic and social development. Chapter 2 section 27 of the Constitution of South Africa provides that everyone has the right to have access to sufficient food and water.

South Africa has a policy of free fundamental administrations including water, electricity and solid waste collection. The overseer of water resources in South Africa is the Department of Water and Sanitation (DWS) which means to guarantee the availability and supply of water on a public level and an equitable and efficient provision of water administrations at local level (Purbo *et al.,* 2019).

2.10.2. National Water Act (36 of 1998)

The National Water Act (NWA) of 1998 is a major piece of legislation addressing the management, use, conservation, development, control, protection etc. of water esources. The Act makes no specific reference to greywater, but refers to 'disposal of wastewater or water containing waste'. The national government through the Minister for Water and Sanitation is responsible for the equitable allocation and use of the scarce and unevenly distributed water resources to the nation. The aim of water resources management is to ensure the sustainable use of water through the protection of the quality of water resources for the benefit of all water users in the country. It does not clearly provide for water reuse.

Greywater reuse is referenced in the National Water Act of 1998, under "the use of water containing waste for irrigation purposes", a "controlled activity" requiring a wastewater irrigator to obtain a licence. Greywater is also categorised as domestic wastewater under the General Authorisation (GA) regulatory requirements of the DWS (Government Gazette, 2013).

2.10.3. National Water Resources Strategy (2013)

The major focus of the National Water Resource Strategy 2013 (NWRS2) is equitable and sustainable access and use of water by all South Africans while sustaining the water resource. Equity and redistribution will be achieved through the authorisation process and other mechanisms and programmes, such as water allocation reform, financial support to emerging farmers and support to urban and rural local economic development initiatives (Nepfumbada and Muller, 2012).

The NWRS2 promotes the development of a clear regulatory framework for water resources and coordinating regulatory standards and processes with other government departments and regulatory institutions. Compliance monitoring and enforcement is one of the priorities identified by the strategy and legal, financial and forensic capacity will be developed to ensure effective prosecution for the ultimate protection of South African water resources against any illegal action by institutions or persons in contravention of the required quality and quantity standards. The NWRS2 emphasises that the achievement of the vision and objective will require support by strong institutions, competent and capacitated personnel with the requisite financial resources to implement interventions. A National Water Infrastructure Investment Framework for the Strategy, contained in the financial chapter, outlines the financial capital required to effectively implement all key programmes. This is done within the context that government, development institutions, the private sector and other funders will join hands to provide the necessary funding to support water resource management in the country (Ghaitidak and Yadav, 2015).

The NWRS2 states that due to the increase in water shortages, improved purification technology and costs of treatment that are decreasing, the reuse of water has become more acceptable and feasible. The strategy highlights that up to 14% of water reused, is through wastewater return flows to rivers from which it is abstracted downstream for indirect reuse. In coastal cities where wastewater ordinarily drains into the sea, there could be a significant increase in the reuse of the return flows. It further outlines that the direct reuse of treated wastewater can pose a risk to public health and safety, therefore giving direction that advanced treatment technologies, sufficient operating capacity and proper monitoring of all processes and quality of potable water produced should be put in place and as an essential, together with the proper and careful management to water quality management and control. The NWRS2 states that the South African water industry will need to grow capacity to confidently implement some of the more advanced water reuse technologies. The NWRS2 therefore recognizes water reuse as a key component of the basket of water resource development and use options (Ghaitidak and Yadav, 2015).

2.10.4. National Strategy for Water Reuse(2013)

The Department of Water and Sanitation (DWS) developed a National Strategy for Water Reuse, which provides a considered approach to the implementation of water reuse projects. Water reuse projects typically involve a range of activities that are subject to regulatory authorisation and control. These controls exist in a range of legislation that includes, but is not limited to the National Water Act, 1998 (Act 36 of 1998), the Mineral and Petroleum Resources Development Act, 2002 (Act 28 of 2002), the National Environmental Management Act, 1998 (Act 107 of 1998), the National Environmental Management: Waste Act, 2008 (Act 59 of 2008), the Water Services Act, 1997 (Act 108 of 1997), the National Environmental Management: Integrated Coastal Management Act, 2008 (Act 24 of 2008), and municipal by-laws. The above mentioned Acts govern the water reuse projects through controls and authorization (Rojas-Valencia *et al*., 2011).

The fact that these controls exist in so many different Acts, and that regulatory approaches may differ between the Acts, makes it difficult to implement water reuse projects confidently, speedily, and cost-effectively. This makes water reuse projects less favourable compared to other alternatives, even where it is practical and cost-effective to reuse wastewater (Hellegers and Leflaive, 2015).

The DWS addressed this issue by developing clear and practical guidelines for typical water reuse projects on what regulatory approvals were needed, the status of reclaimed water in terms of right to use and how these could be obtained with regard to cost and time effectively. The DWS worked with other national departments to align legislation, reduce the regulatory burden wherever practical, and unblock regulatory obstacles to water reuse, act as the lead regulatory authority to assist in working with other departments in getting approval for justifiable water reuse projects. It is the obligation of DWS to work with municipalities to ensure that municipal by-laws support the appropriate reuse of water, ensuring the water quality standards implemented are appropriate in a context where water reuse is a strategic imperative, use the water licensing process as a key tool to promote water use efficiency, implement the waste discharge system and the DWS will also review water related laws and regulations to assess the need for revision driven by water reuse. Legislation may then be revised to accommodate the need to facilitate, streamline, encourage, and control water reuse projects (Membrane Technology, 2006; May, 2009).

Water quality standards for discharges into the water resource, and water quality standards and regulations for different types of water use (for example, minimum standards for potable water use, irrigation use for food and non-food crops) play a large role in influencing water reuse decisions. It is important that these standards are not so onerous that they make treatment for reuse prohibitively expensive and not so lax that they compromise public safety and the environment (Vandertulip, 2010).

2.10.5. National Sanitation Policy(2016)

Regulations (governing sanitation) indicate that a sanitation services institution is only obliged to accept the quantity and quality of effluent or any other substance into a sewage system that the treatment plant linked to that system is capable of purifying or treating to ensure that any discharge to a water resource complies with any standard prescribed under the National Water Act (South Africa, 1998b) and the minimum requirements governing wastewater disposal. The Department of Environmental Affairs (DEA) has taken the view that the disposal of effluent into coastal waters can be considered a viable option provided that it is conducted in an environmentally sustainable manner and does not adversely affect other beneficial uses of the marine environment. The requirements of the coastal aquatic ecosystem, as well as the requirements of the beneficial uses of coastal water resource, will ultimately inform how a particular discharge is managed (Pongkijvorasin *et al*., 2010).

Tissington (2011) reported that sanitation in particular, had the absence of regulation at all levels of government. At a national level, a number of incentive-based regulatory systems are utilised in the sanitation services sector. These systems are an effective mechanism for encouraging Water Services Authorities (WSAs) to ensure performance of their sanitation services functions and Constitutional responsibilities.

Reuse of greywater offers one means of relieving pressure on freshwater supplies. Safe management of greywater, which encourages reuse and recycling of the resource should be encouraged in a water scarce country, while at the same time focussing on ensuring the safety of reuse and recycling. The current policies do not address the policy position on greywater. Management of greywater is encompassed in sanitation services provision (Ashok *et al*., 2018; Lambert and Lee, 2018).

2.10.6. Water Services Act (108 of 1997)

The Water Services Act deals mainly with water services or potable (drinkable) water and sanitation services supplied by municipalities to households and other municipal water users. It contains rules about how municipalities should provide water and sanitation services (Wegelin and Jacobs, 2013).

The Act states that all water services institutions must take reasonable steps to achieve every citizen's basic right to water supply and basic sanitation. This Act provides a framework for the provision of water supply and sanitation services to households in South Africa but it does not provide for greywater reuse. It sets the standards for the local and provincial agencies and establishes the norms and standards for tariffs. It sets out the rights and duties of the state and of water services providers in monitoring water services and promote effective water resource management while on the other hand the South African Water Quality Guidelines governs the quality of water intended for irrigation, domestic, livestock watering, aquaculture, aquatic ecosystem, industrial and recreational uses (Molle *et al*., 2012).

2.10.7. Water Reuse By-Laws in South Africa

The by-laws are locally established by municipalities and their scope is regulated by the central government of the nation (Mashabela, 2015). Examples of by-laws on wastewater reuse in South Africa are; the City of Cape Town Treated Effluent by-law (2010), the Durban Metro Water Supply by-laws (2008) and the Moses Kotane Local Municipality Water and Sanitation by-laws (2008).

The City of Cape Town remains the only municipality in South Africa with a by-law specifically addressing treated effluent. The by-law aims to control and regulate treated effluent in the city of Cape Town, and to provide for matters therewith. The Durban Metro Water Supply by-laws (2008) state that no person shall use or permit the use of water obtained from a source other than the potable water supply system, except prior to the consent of the Authorised Officer and in accordance with such conditions as it may impose for domestic, commercial and industrial purposes as well as filling of swimming pools. The by-law employs the term non-potable which caters for diversity of non-conventional water resources including greywater (Mashabela, 2015). On the other hand, the Moses Kotane Local Municipality Water and Sanitation by-laws (2008) Section 78(1), understands greywater to be wastewater excluding water derived from any kitchen,clothes washing machines, or from toilet discharges.

Limpopo Province, specifically the Capricorn District Municipality, does not have by-laws on wastewater or greywater reuse. The Capricorn District Municipal by-laws only state in Chapter 6 (Water) under Section 37 (Use of water from source other than the municipal supply) that no person may use, or permit to be used; any water obtained from a source other than the municipal water supply for domestic consumption, unless the water concerned has been approved for that purpose and complies with standards of potable water. It states again in Section 41 (Containment of wastewater) that any dam or channel used for the containment of wastewater must have a free board of at least 0.5 meters above the highest level of precipitation which could be expected within a period of 24 hours with an average frequency of recurrence of one in 100 years. In simple terms, the Capricorn District Municipality by-laws do not in any way govern or rule the reuse of any water including greywater except if the water is potable (Pecson *et al*., 2018; Shultz, 2019).

South African arrangement of protected and adequate drinking water relies upon the freshwater resources' availability (Van Ginkel *et al.,* 2001). National legislation does not deny the reuse of greywater and, as of now, there are no conventional standards or rules for the reuse of greywater for irrigation in South Africa but, the coordinated water resources management gives an expansive framework to governments to adjust water use designs with the requirements and demands of various users including the environment. The disposal of wastewater is dependent upon guidelines and by-laws of important local boards and as it is right now, there are no known guideline or by-laws prohibiting the reuse of greywater in the Rand Water supply area, In any case, utilization must not repudiate the National Health Act 61 of 2003 (the most significant Act passed by Parliament to offer impact to one side of everybody to access medical care services) and permit greywater to make a disturbance, which is characterised as fly/mosquito breeding, offensive smells, the surface ponding of water as well as the entry of contaminated water onto a neighbouring property.

2.10.8. Greywater Reuse Rules

Population growth, pollution and climate change put water systems under a huge pressure. The reuse of greywater for domestic uses will help and or benefit homeowners and water utilities alike. Greywater is, however, different from freshwater and as such requires different guidelines for it to be reused (Maimon *et al*., 2010; Lambert and Lee, 2018).

Greywater can be reused if the natural cleaning products or environmentally safe products are used where possible, and there is a supplementation of irrigation once a month with clean municipal water or rainwater, all the greywater originates from one’s own residence and is not allowed to leave the boundary on which it is generated. Furthermore, the application of the greywater should not be in such a way that it is allowed to form ponds on the surfaces after watering, irrigation systems that spray a fine mist should never be used and the greywater system must has an overflow or diversion directed into the sewage collection system. Lastly, the greywater system collection tank should be covered to restrict access and to eliminate a habitat for mosquitoes or other vectors (Qomariyah, 2016; Ashok *et al*., 2018).

Greywater reuse is restricted where greywater was stored for longer than 24 hours before it is reused. It is not advisable to use water from the kitchen and laundry especially if it has been used to wash nappies or other clothing soiled by faeces and/or urine. Children and pets are not allowed to drink or play directly in or around greywater. The flow of greywater into watercourses, swimming pools or dams is not safe and can therefore be avoided. The spraying or mist with greywater, may introduce pathogens into the air, which could be inhaled leading to health problems and it is not advisable to use greywater if anyone on the premises is suffering from an infectious disease and also, fruits and vegetables irrigated with greywater can cause health problems if they are going to be eaten raw (Ensink *et al*., 2007; Sheik, 2016).

Under the National Norms and Standards for sanitation benefits, the Constitution expresses that for greywater management, greywater from baths, showers and hand bowls can be effectively utilised for garden irrigation, flushing latrines or washing vehicles, pavements and driveways with an objective that the sanitation services shall advocate and actualise viable and sustainable wastewater, greywater and nutrient reuse practices to forestall contamination of the environment and to ensure public wellbeing and water resources (Nel and Jacobs, 2019).

2.11. Conceptual Framework

A conceptual framework is an analytical tool with several variations and contexts. It can be applied in different categories of work where an overall picture is needed. It is used to make conceptual distinctions and organize ideas (Varpio *et al.,* 2019), that are related to the intended study. Ryan *et al*. (2009), reported that the relationship between socio-economic characteristics (such as gender, age, household size, education or income) and the likelihood of households reusing greywater as an alternative water supply is unclear. Awareness (perceptions or access to information) has a huge influence on the reuse of greywater. Water scarcity (which may be due to water availability, water accessibility or depletion/overuse of freshwater resources) can also be the determinant of willingness to reuse the greywater.

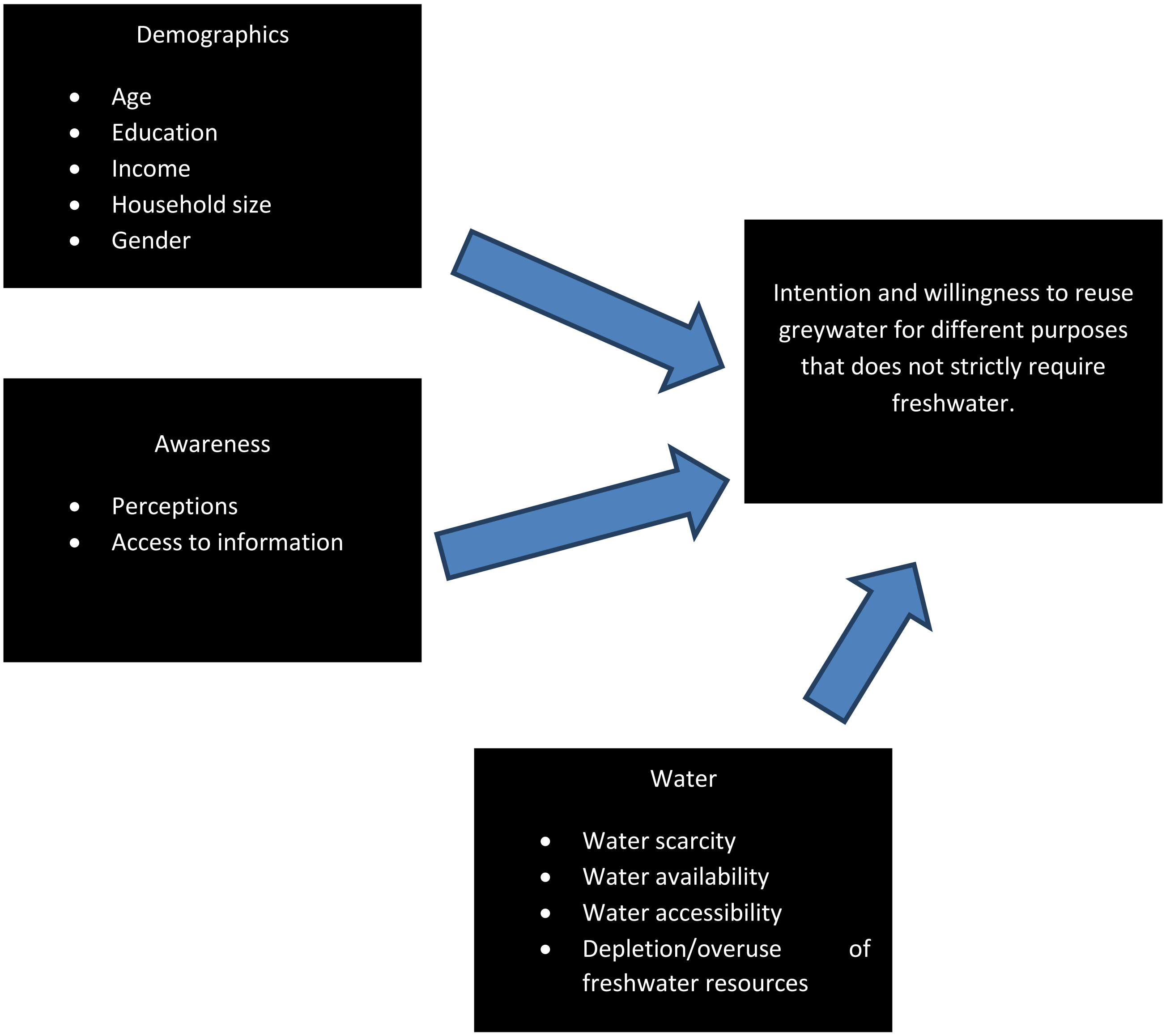

Figure 2.1: Conceptual framework for greywater reuse

2.12. Summary of the chapter

This chapter outlined the water security, water scarcity, water availability and accessibility, National Development Plan 2030, coping mechanisms for water scarcity, case studies of greywater reuse, characteristics of greywater in relation to sources, perceptions on greywater, the laws, legislation and guidelines governing water in South Africa and conceptual framework of the study.

CHAPTER 3: METHODOLOGY

3.1. Introduction

Methodology is a technique of collecting data systematically (Creswell, 2003). Research methodology is the specific procedures or techniques used to identify, select, process, and analyse information about a topic (McMillan, 2012). Data collection methods on the assessment of greywater reuse in Ga-Thoka Village are discussed in detail in this chapter. Research design, qualitative and quantitative research methodologies which were used in data collection for this study, the sampling procedures, methods of data collection and data analysis as well as the presentation of the results are outlined in detail.

3.2. Research Design

The research design is intended to provide an appropriate framework for a study. A very significant decision in research design process is the choice to be made regarding research approach since it determines how relevant information for a study will be obtained; however, the research design process involves many interrelated decisions (Aaker *et al*., 2000).

In order to achieve the objectives of this study, a mixed research approach was used because different methods complement each other and overcome the weakness of a single design.

Qualitative research deals with words and meanings while quantitative research deals with numbers and statistics (Jervis and Drake, 2014; Liao *et al.,* 2014). Qualitative methods allow one to test a hypothesis by systematically collecting and analyzing data, while qualitative methods allow one to explore ideas and experiences in depth (Barrett, 2004; Jervis and Drake, 2014).Qualitative methods were used to understand views and perceptions of participants on greywater reuse. Quantitative methods were used to quantify attitudes, opinions, behaviours, and other defined variables on greywater reuse.

3.3. Sampling

Sampling is the selection of a subset of individuals from a statistical population to gather characteristics of the subgroup to estimate characteristics of the whole population (Lauce and Hattori, 2016).

3.3.1. Sampling Frame

A sampling frame is a list of all things used to characterise a researcher's population of intrigue/focus/interest. Sampling frame characterises a lot of components from which a researcher can choose a sample of the objective population (Lewis-Beck *et al*., 2004). The sampling frame for the study was all 3 068 households of Ga-Thoka village (Stats. SA, 2011).

3.3.2. Sample Size

Sample size refers to the quantity of things selected from the absolute population to constitute a sample (Lewis-Beck *et al*., 2004). The sample size is a significant element of any experimental study where the objective is to make derivations about population. Sample size estimates the quantity of individual samples estimated or perceptions utilised in a survey or test (Orekici Temel *et al.*, 2016). Muralidharan (2014) characterises sample size as the quantity of observations in a sample.

The sample size for the study was 10% of the complete number of households in Ga-Thoka village since it creates a sensible sample size as long as it does not surpass 1000 and a survey that involves 5-10% of the target population is fairly representative of the whole population (Gans *et al*., 2018).

The sample size for the study was calculated using the formula:

$$\text{Sample size (n)} = \frac{N \times 10}{100} \quad (1)$$

Where; n= households sample size

N= total number of households

$$\text{Sample size (n)} = \frac{3068 \times 10}{100}$$

Therefore, the sample size for this study was 307 households.

3.3.3. Sampling Method

A sampling method is a procedure for selecting sample members from a population (Omair, 2014; Pérez Salamero González et al., 2016). This study used a systematic random sampling which is the type of probability sampling method whereby sample members are selected from a larger population according to a random starting point and a fixed periodic interval (Lewis-Beck *et al.*, 2004). Systematic random sampling was used to select the respondents because households are arranged in a grid plan pattern.

The periodic interval was calculated using the formula:

$$\mathrm{k^{th}} = \frac{N}{n} \quad (2)$$

Where; k^{th} = the interval

N= the population size, and

n = the sample size

$$\mathrm{k^{th}} = \frac{3068}{307}$$

Therefore, the k^{th} value was 10 households. The first household was randomly selected and thereafter every 10^{th} household was chosen.

3.4. Data Collection

Data collection is characterised as the way of gathering and estimating information on factors of enthusiasm, in a set up deliberate style that empowers one to answer inquiries, expressed research questions, test speculations, and assess results (Berger, 2019). Rajeswari and Arunesh (2016) define data collection as the methodology of gathering, measuring and analysing exact bits of knowledge for research utilising standard approved procedures. The most critical objective of data collection is ensuring that information-rich and reliable data is collected for statistical analysis so that data-driven decisions can be made for research. Secondary and primary data was collected for this study.

3.4.1. Secondary Data

Secondary data implies second-hand information which is gathered and recorded by any individual other than the user for a reason, not relating to the current research issue (Spear *et al*., 2016; Bornmann, 2018). It is the promptly accessible type of information gathered from different sources such as censuses, government publications, records of the organisation, reports, books, journal articles, and internet. The data in this study was collected from these sources.

3.4.2. Primary Data

Primary data is one that originated for the first time by the researcher through direct endeavours and experience, explicitly to address the research problem. It is called direct or raw data and was never published (Spear *et al*., 2016). Primary data collection is very costly, it is under direct control and management of the researcher (Reis *et al*., 2013).

Primary data for this study was collected through questionnaires, field observations, key informant interviews and greywater characteristics determination.

Questionnaires

A total number of 307 questionnaires consisting of both close-ended and open-ended questions were distributed and self-administered to participants in Ga-Thoka village, in order to identify the sources of freshwater and the nature of potable water supply in Ga-Thoka village (objective i), assess the awareness and perceptions on greywater reuse of Ga-Thoka village households (objective iv) and greywater reuse by Ga-Thoka village (objective iii). The data was collected for a period of 26 days from 02 November 2020 to 07 December 2020. Twelve(12) questionnaires were administered per day from 08:00 to 16:00 and on the 26th day, the remaining 7 questionnaires were administered. Only households members who were 18 years old and above were allowed to participate in the study, they were selected by asking their age before starting with the actual questionnaire.

A pilot survey was conducted at Ga-Thoka village on the 1st and the 2nd of October 2019 to verify the validity and reliability of the questionnaire. Ten questionnaires were used to test the research instrument. These questionnaires were not included in data analysis.

Field Observation

In order to get a deeper insight of how people in the village generate (sources) and reuse greywater, observations were undertaken and pictures were captured (objective i and iii).

Key Informat Interviews

Two key informant interviews were conducted in order to fulfil objective i. Key informants (water services manager in PLM and ward councillor of Ga-Thoka village) were interviewed on the role of water distribution (how many times do they supply water to the residents, in which way, etc.) within the municipality.

Greywater Characteristics Determination

Greywater samples were collected from a tenth ($\frac{1}{10}$) of the 307 sampled households (31 households) during the month of August and September in 2020. A total of 93 samples were collected from different sources of household greywater (laundry, kitchen sink, bathtubs). Greywater samples were collected in separate sterilised 1 litre bottles. The samples were stored in a cooler box with ice blocks and immediately sent to the Capricorn Water Laboratory for testing of physical (colour, electroconductivity and turbidity) and chemical (pH, ions and anions) characteristics (objective ii). Capricorn Water Laboratory is an accredited facility.

Physical Properties

Colour

Colour may be expressed as apparent or true colour. The apparent colour includes that from dissolved materials and suspended matter. By filtering and centrifuging out the suspended materials, the true colour can be determined (Ghosh and Norton, 2017).

- Equipments used to measure colour were HACH DR6000 spectrophotometer and 5 cm Sample cell

- Analytical procedure

Colour determination was done according to HACH COMPANY (2008, 2012).

The HACH D6000 spectrophotometer was first calibrated before actual determination of colour. The calibration procedure used to set up the method on the instrument was done according to HACH COMPANY (2008, 2012). The instrument was switched on, DR 6000 was selected, followed by selection of color, programme options, edit and calibration. Edit was selected again to edit calibration to read all correct standards (0, 5, 10, 15, 20, 50 and 100 CU standards). The instrument was left for 30 minutes to warm up, afterwhich the sample cell was rinsed with deionised water. The blank was wiped with soft cloth and inserted into the cell holder, the lid was closed and then Zero was pressed. The display showed 0 units, the sample cell was rinsed with deionised water and then with sample Quality Control (QC). Sample QC was added in to the sample cell, wiped with soft cloth and it was inserted into the cell holder, the lid was closed and then read was pressed. The results were read in Constant Units (CU).

After instrument calibration, the sample cell was rinsed with deionised water and then with sample. The greywater sample was loaded into the sample cell and it was inserted into the cell holder, the lid was closed and the instrumental read greywater colour as CU. The procedure of loading the sample cell and reading the colour was repeated for all greywater samples.

Electroconductivity

Electroconductivity can be defined as how much voltage is required to get an amount of electric current flow (Crotty and Jackson, 2017).Electroconductivity is the measure of the ability of a substance to allow the flow of an electric current. Pure water is a poor conductor. Generally, tap water, pond water, and well water, etc., contain a lot of impurities, most of which are usually dissolved salts. The presence of even a small amount of impurities makes water a good conductor.

•Equipments used to determine electroconductivity were; HACH sension5 conductivity meter, Conductivity electrode and 100ml Beakers.

•Analytical procedure

Calibration of HACH sension5 conductivity meter was done according to HACH COMPANY (2008, 2012). The instrument was switched on, COND key on the keypad was pressed. The Instrument displayed the conductivity value for the sample being measured.The electrode was rinsed with deionised water and then blotted dry with soft cloth where after the sample was added to a clean glass beaker such that when inserted the electrode sensing portion is completely covered.The electrode was placed into the verification sample and the slot on the end of the electrode was totally immersed. The sample was stirred during measurement. READkey on the meter was pushed. As the electrode stabilised in the sample, the display showed stabilizingand a progress bar. The display then showed the lock icon and the temperature compensated result was displayed and automatically stored in the data log.The conductivity was recorded at 25°C when the readings have stabilised.

After calibration, the electrode was rinsed with deionised water and the sample was added to a clean glass beaker such that when inserted the electrode sensing portion was completely covered and the measuring steps used for calibration were repeated for every sample.When the measurements were finished, the sensor area was rinsed and blotted dry.

Turbidity

Turbidity is a measure of the degree to which the water loses its transparency due to the presence of suspended particles (Prest *et al*., 2021). Turbidity describes the amount of light scattered or blocked by suspended particles in a water sample-particularly sediment. Clear water has low turbidity level while cloudy or murky water has a higher turbidity level. Turbidity is caused by particles of soil, organic matter, algae, metals, or similar matter suspended in the water column. These particles scatter light and make the water appear cloudy or murky (Beni *et al*., 2021).

- Equipments used to measure turbidity were; HACH TURBIDIMETER Model 2100N and 20 ml glass sample cell.

- Analytical procedure

Calibration procedure was done according to HACH COMPANY (2008, 2012).The turbidity meter was switched onand it was warmed for at least 10 minutes before being used.CAL was pressed, then the S0 light turned on. The NTU value of the turbidity standard used in the last calibration was shown on the display.The vial was cleaned with a soft, lint-free cloth to remove water spots and fingerprints then asmall bead of silicone oil was applied from the top to the bottom of the vial using the oiling clothto apply the oil equally to the surface ofthe vial to compensate for the little scratches that were on the vial and to eliminate any optical variances on the vial. The excess oil was removed using soft, lint-free cloth. The sample cell was inverted approximately 5 times over a period of about 5 seconds to put the sample standard back to suspension.The vial was put in the sample cell holder with the triangle on the vial aligned with the reference mark on the sample cell holder andthe cover was then closed.ENTER was pressed then the instrument displayed count down, and then measured the standard. The next expected standard (e.g., 20.00) was shown and the S1 light turned on.The vial was removed from the sample cell holder, CAL was pressed to go back to measurement mode.

After calibration, the sample cell was rinsed with water once and with a sample once.A sample cell was filled with QC to the line (about 15ml).The sample cell was handled with care the top and the cell was capped.Turbidity QC was measured immediately to prevent temperature changes and particle flocculation and sedimentation from changing sample characteristics.The turbidity in NTU showed on the display. The turbidity was measured in a minute. The procedure was repeated for all the samples.

Chemical Properties

pH

pH is a measure of the relative amount of free hydrogen and hydroxyl ions in the water. The range goes from 0 to 14, with 7 being neutral. A pH of less than 7 indicate acidity, whereas a pH of greater than 7 indicates a base. Water that has more free hydrogen ions is acidic, whereas water that has more free hydroxyl ions is basic. Since pH can be affected by chemicals in the water, pH is an important indicator of water that is changing chemically(Ca, 2018).

•Apparatus used to measure the pH were; pH meter (Hach Sension + pH3 meter with, magnetic stirrer), Teflon coated stirring bar, pH electrode and Beakers.

• Analytical procedure

The pH electrode calibration was done according to HACH COMPANY (2008, 2012) using standard solutions (pH verification buffers) at pH 4.00, 7.00 and 10.00. The instrument was switched on, then the electrode was inserted in a verification pH buffer sample, pH was pressedto start sample measurements. During the measurement, the parameter flashed and the timer shown the stabilisation.The reading as well as the temperature was recorded after the meter has been stabilised. After stabilization, the probe was rinsed with deionized water and dapped dry using a soft paper towel.

After the instrument calibration, the process was repeated for all other samples.When the measurementswere finished and recorded, the probe was rinsed with deionised water and put into a storage solution 3M KCl.

Ions

Ions are charged atoms or molecules because the number of electrons are not equal to the number of protons in the atom or molecule (McConnon, 2020).An ion is an atom or molecule that has lost or gained one or more electron. Losing or gaining an electron results in the atom or molecule having an electrical charge. Since electrons have a negative charge, an atom or molecule that has lost electron(s) has a positive charge. Ions with a positive charge are called “cations.” An atom or molecule that has gained electron(s) has a negative charge and is called an “anion” (Ca, 2018).

All the procedures for the determination of Ions was done according to HACH COMPANY (2008, 2012).

• Apparatus used were Inductively Coupled Plasma (ICP), Pipets, Balance and Volumetric glassware.

- Analytical procedure

Argon Gas Purging

The Argon gas was opened to purge for at least two hours and the gas pressure was ensured to be at 6 bar.The ICP instrumentwas switched on to warm up for at least two hours then the Qtegra program was opened,LabBooks was selected and the set of samples were given a name. The radio button “create a new LabBook from and existing template” was clicked and a template was selected.The template from the dropdown list under “Template name” was selected. “Create LabBook” was clicked and a template opened on a new tab then the template was edited to include the samples to be tested.The sequence of samples on the template were ensured to correspond with the sequence of samples on the auto-sampler.

After the purging and warming up was completed, the ICP was ready for ignition.The calibration standards was inserted into the standards racks then the deionised water was inserted. The water level in the chiller was ensured to be above the minimum level and sufficient water in the water reservoir bottle and emptying of the wastewater container were ensured.

After the completion of purging and warming up, the ventilation switch was put on followed by the auto sampler and the chiller.The peristaltic tubes were ensured to be clipped onto the peristaltic pump and all interlocks were ensured to be green.“Dashboard” was selected under home page and to ignite the plasma, “Get ready button”was clicked.The ICP performed a spectrometer optimisation and performance checks run. When the spectrometer optimisation and performance checks run was completed as signified by “success”, the ICP was ready to analyse samples.

For samples to be analysed, all tubes on the auto sampler wereopenedand the tab with the samples to be analysed was selected then the “Play icon” was selected.A small window appeared where comments were optionally included and “OK” was selected.Another play icon was selected at the bottom left and the calibration of ICP begun then followed by sample analysis.

Upon completion of analysis, the ICP was shut down. “Get ready” button was selected under dashboard then “Shut down” was selected and the plasma was switched off. The ventilation switch was switched off followed by switching off the auto sampler then the chiller. The peristaltic tubes were unclipped from the peristaltic pump and the ICP was switched off then the argon gas was closed.

Samples whose results were more than 10% outside calibration range were diluted to allow the results to fall within the calibration range and a rerun of the sample was performed. Only results of the diluted samples were reported on the rerun results.

Anions

Anions are negative ions that are formed when a nonmetal atom gains one or more electrons (Nieto, 2000).

• Apparatus used for the determination of Anions were Ion chromatograph (IC), pipets and Balance meter.

• Analytical procedure

Calibration procedure for the determination of Anions was done according to HACH COMPANY (2008, 2012). The IC instrument was switched on and standard 1-7 was placed on the auto sampler. “Single determination” was clicked under workplace and the sample table was loaded to include standard 1 to standard 7 then “Start” was clicked. The calibration was accepted when the relative standard deviation was ≤3% and correlation coefficient being ≥0.999.

Calibration was followed by reprocessing where to database and all the standards (std1-7) were selected then “Reprocessing”was clicked either at the top tool bar of right click and the reprocessed window opened.Under the reprocess table, the standard at the middle was selected and standard 4 was moved to the top of the list of standards. The retention time for each element was updated and “components” was selected under the “evaluation” parameter.“Fluoride” was clicked under components then the fluoride peak (highlight in blue) was clicked under the chromatogram and “Update retention time” was clicked.Reprocessing was selected “from standards of reprocessing table” then “OK” clicked.Under chromatogram, calibration curve was clicked and checked that for each element R<3% and correlation coefficient ≥0.999.It was ensured that the last standard was highlighted.At the bottom left corner, method was clickedfollowed by save and“yes”when the last standard was highlighted followed by“OK” at the bottom right.

After the reprocessing, the Anion measurement procedure began.The eluent and regenerant tubing were ensured to be sufficiently immersed in the eluent or regenerant respectively. The MagIC Net was opened and purged only after filing new eluent or regenerant.In manual control window, High Pressure Pump (HPP) was clicked on and the purge valve was opened and flow of the high pressure pump was changed to 2.0mL/min in the manual control window.Start was clicked in the manual control window. After the syringe was filled with eluent,“Stop” was clicked to stop the HPP and changed flow back to working rate of 1.0mL/min then closed the window. The purge valve finger tight was closed tight and the syringe was removed.Under workplace, the equilibration window was clicked and the hardware started. For conditioning, the system was continuously rinsed with eluent for at least 30minutes while the pump pressure was ensured to be 12-15MPa and conductivity was 30 - 40uS/cm then the determination series was clicked. The sample table was clicked and “New” was selected.The yellow raw was right clickedso that the“Edit line” can be selected.In the Edit line window, the three dots “…”were clicked next to the method and under method group “main group” was selected then method CDM_Anions_Auto_Eco appeared and open was clicked. The edit line window appeared and started loading sample information onto the sample table.After every 10 samples was a QC and after every last sample was also a QC and a duplicate for the first sample. Dilution factor was 1 if there were no dilution otherwise determined the dilution factor then “Apply” was clicked and closed. Under the determination series window, the option “Stop hardware when sample table is finished” was selected then “Start” was clicked to commence the analysis.

Samples whose results were highlighted in red were diluted to allow the results to fall within the calibration range and a rerun of the sample was performed. Only results of the diluted samples were reported on the rerun results.

3.5. Data Analysis and Presentation of Results

Data analysis and presentation forms a necessary aspect of every single academic study (Van Tuyl and Whitmire, 2018). The filled questionnaires (collected data) were numbered 1-307 before they could be analysed to ensure that one questionnaire does not get analysed more than once. This is meant to increase the validity and reliability of the data. Responses for close-ended questions data was entered and analysed using Statistical Package for the Social Sciences (SPSS) version 26 software. Responses for open-ended questions data was analysed thematically.

Field observation data (objective i: identify sources of freshwater and objective iii: establish the potential of greywater reuse) was presented by means of pictures while written notes were analysed thematically and presented by means of paragraphs (narrative). These methods help in adding visual aspect to data which makes it much easier and quick to understand. The quality of greywater (objective ii) was analysed in the laboratory and the data was analysed through descriptive statistics and presented in the form of tables containing numerical values. The potential of greywater reuse (objective iii) was analysed through descriptive statistics and Chi square test while the awareness and perceptions on greywater reuse (objective iv) were analysed thematically, through narrative analyses and Chi square test. The results were presented in the form of graphs, tables, figures and charts.

3.5.1. Narrative analysis

Narrative analysis is a useful method for uncovering the underlying ideologies embedded in stories and the larger culture that creates the narratives (Saint Arnault and

Sinko, 2021). The responses from the questionnaires were analysed such that they can be narrated in the study as first and third person. Much of the analysis were narrated as third person, few as first person using quotes and where possible literature was also used. The respondents gave consent to be asked questions on the questionnaires.

3.5.2. Descriptive analysis

Descriptive analysis is the type of analysis that helps describe, show or summarize data points in a constructive way such that patterns might emerge that fulfil every condition of the data (Nassaji, 2015). The main purpose of descriptive statistics is to provide a summary of the samples and the measures done on a particular study. The numerical data collected (Laboratory data analysis results: objective ii) were analysed quantitatively using statistical tools (descriptive analysis).

3.5.3. Pearson Chi-Square test analysis

Pearson Chi-Square test is used to verify the possible relationship between two categorical variables, where a two-way table is created, and the observed counts are compared to the expected counts of the cells. According to Moore *et al.* (2012), Pearson Chi-Square statistics is a measure of how much the observed cell counts in a two-way table diverge from the expected cell counts. For objectives i, iii and iv, the following Chi square test formula was used:

$$x^2 = \sum \frac{(Oi - Ei)^2}{Ei} \qquad (3)$$

Where $\boldsymbol{x^2}$ is the Pearson Chi-Square value, ∑ is the sum of the observed and expected frequency, ***O*** is the observed frequency, and ***E*** is the expected frequency. This test was used to verify the relationships that were established from the cross tabulations. The test was conducted at the significance level of 0.05 (5 %). When computing the Pearson Chi-Square test, the variables used include age, education status, employment status, gender,sources of freshwater, potential of greywater reuse, awareness and perception on greywater reuse.

3.5.4. Thematic analysis

Thematic analysis is a method of analysing qualitative data which is usually applied to a set of texts, such as interview transcripts where the researcher closely examines the data to identify common themes (topics, ideas and patterns) of meaning that come up repeatedly (Lochmiller, 2021). The responses on the perceptions and awareness were thematically analysed to identify patterns in meaning across the data.

In short, data analysis can be summarised in table 3.1 below.

Table 3.1: Objectives and proposed methods of analysis.

Objectives	Data analysis
Objective i: Sources of water and the nature of supply	Narrative analysis and Pearson Chi-Square Test
Objective ii: Quality of greywater	Laboratory and descriptive analysis
Objective iii: Potential of greywater reuse	Descriptive statistics and Pearson Chi Square test
Objective iv: Awareness and perceptions	Thematic, narrative analysis and Pearson Chi Square test

3.6. Summary of the chapter

This chapter outlined the research design, sampling, data collection and data analysis and presentation of results.

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Introduction

Proper reuse of water is of great importance in environmental management, livelihoods, and health (Kay, 2021). Beyond the direct benefit of freshwater reservation through water reuse, the health and sustainable reuse of water is likely to make water management more resilient and beneficial to communities and their citizens (Edalat and Hoek, 2020).

The chapter showcases the results and discussion of the study. The results are structured to respond to the objectives of the study which are:

- Identifying sources of freshwater and potable water supply
- Analysing quality of greywater from households
- Establishing the potential of greywater reuse by Ga-Thoka village households
- Investigating the awareness and perceptions on the reuse of greywater

To preface the showcase of the results, socio-economic characteristics of those who participated is presented, these include gender, age group, education level, employment status, household size, marital status and household income. Pearson Chi Square test was performed to check if these characteristics influence greywater reuse in Ga-Thoka village respondents.

4.2 Socio-economic characteristics

A group of participants were identified and interviewed (or assisted to fill in the questionnaire). The results show socio-economic characteristics of all those who participated in the study.

4.2.1. Gender

Gender refers to the characteristics of women, men, girls, and boys that are socially constructed (Mayo *et al.,* 2020). This includes norms, behaviours and roles associated with being a woman, man, girl, or boy, as well as relationships with each other. As a social construct, gender varies from society to society and can change over time. Some define gender as a word that is used to talk about how people express masculine (traits most people think of as male) or feminine (traits most people think of as female) traits. It is commonly used for a person's sex (male or female) but this word only means someone's biology (body parts). The data collected reveals that Ga-Thoka village is comprised of more females than males (Figure 4.1). Fifty-four percent (54%) of the respondents who participated in the study were females while males made up 46%.

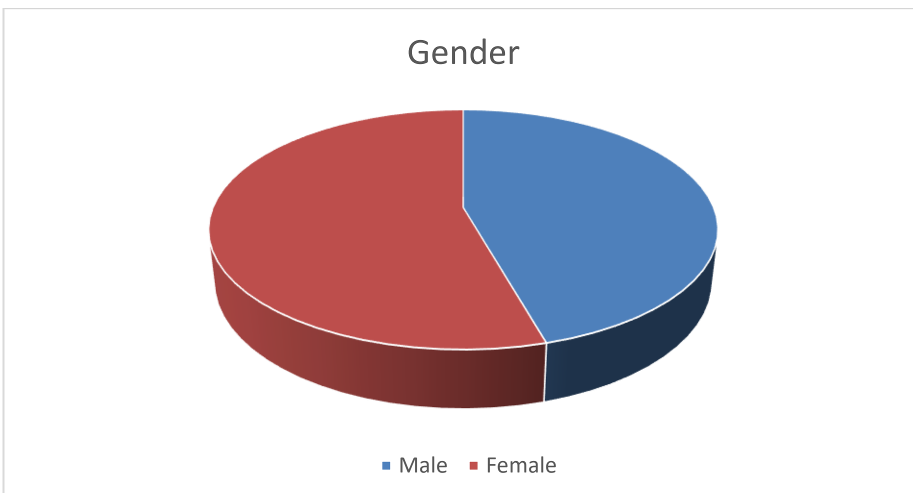

Figure 4.1: Gender

In most studies, females tend to participate in answering questionnaires more than males. In a comparative study conducted in semi-urban and rural areas of the Polokwane Local Municipality, Ramasenya (2021) had more females willing to participate in his study than males. In a study conducted at the Thulamela Local Municipality of the Vhembe District, Netshipise (2021) had more female respondents participating in the study than the male respondents. Amfo-Otu *et al*. (2012) had the same results when conducting their study in Ghana.

Pearson Chi Square test was performed to elucidate if gender influences greywater reuse. According to Pearson Chi Square test, there is association between gender and the willingness to reuse greywater, $X^2 = 332.583$, $p< 0.001$ (Table 4.1). This means that the willingness of a person to reuse greywater is influenced by the person's gender.

Table 4.1: Pearson Chi Square test for gender and willingness to reuse greywater

	Value	df	Significance (*p*)
Pearson Chi-Square	332.583[a]	6	<0.001
Likelihood Ratio	160.467	6	<0.001
N of Valid Cases	307		

a. 8 cells (66.7%) have expected count less than 5. The minimum expected count is 0.00.
0.05 significance level.

4.2.2. Age

Age refers to the length of time that a person has lived, or a thing has existed (Perissinotto, 2015). Every population has different age groups that make it function in a normal way. Figure 4.2 below shows different age percentages of people who participated in the study.

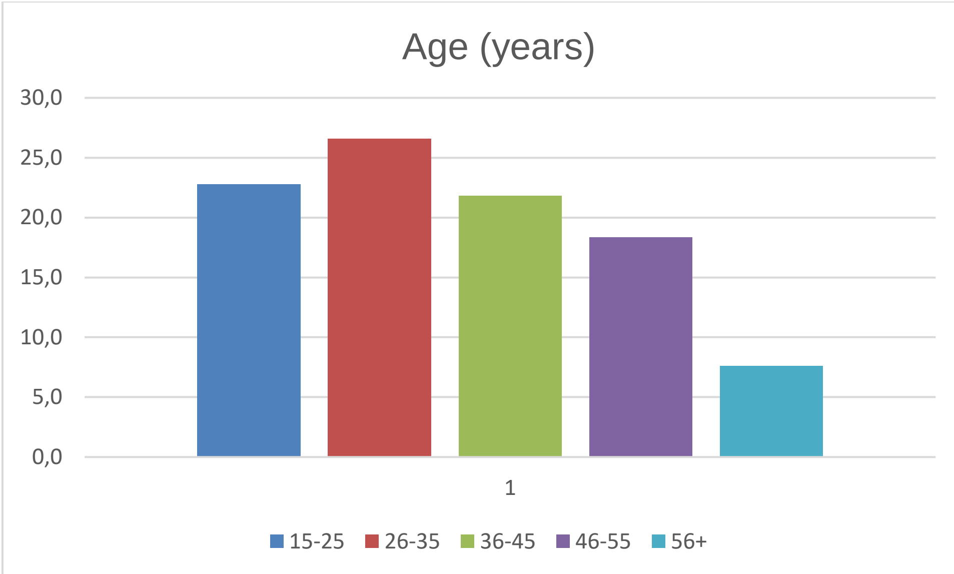

Figure 4.2: Age

The highest percentage (27%) of the respondents were aged between 26-35 years whereas those aged between 15-25 years contributed 24%. Respondents aged between 36-45 years made up 23% of the respondents while those aged between 46-55 years contributed 18% and lastly respondents aged 56 years and above made only 8%. It was found through the study that Ga-Thoka village has a higher percentage of people younger than 36 years. This might be because the data was collected during level 3 covid-19 restrictions and almost all the learners and students were home, and it might also be because Ga-Thoka village is well developing with a shopping mall which therefore attracts the working class to come closer or live in the area. In contrast, Netshipise (2021) found that the Thulamela Local Municipality households had the least percentage of respondents falling within the working class (20- 29 years) with the highest respondents' percentage of the old people (50-59). However, in his study, Ramasenya (2021) had results where the working-class age (21-30 years in his case) dominated in the semi-urban area. According to Boateng *et al.* (2016), the dominating age group in the semi-urban areas were below 40 years in their Ghana study.

Pearson Chi Square test was performed to elucidate if age influence greywater reuse. According to Pearson Chi Square test, there is association between age and the willingness to reuse greywater, X^2 = 372.786, p< 0.001 (Table 4.2). This means the study found association between the respondents' ages and their willingness to reuse greywater.

Table 4.2: Pearson Chi Square test for Age and willingness to reuse greywater

	Value	df	Significance (p)
Pearson Chi-Square	372.786[a]	10	<0.001
Likelihood Ratio	161.997	10	<0.001
N of Valid Cases	307		

a. 15 cells (83.3%) have expected count less than 5. The minimum expected count is 0.00.
0.05 significance level.

4.2.3. Marital status

Civil status, or marital status, are the distinct options that describe a person's relationship with a significant other (Denson and Szelenyi, 2020). Married, single, divorced and widowed are examples of civil status. Marital status can also be defined as the civil status of everyone in relation to the marriage laws or customs of the country. Figure 4.3 presents the marital status of the participants in the study.

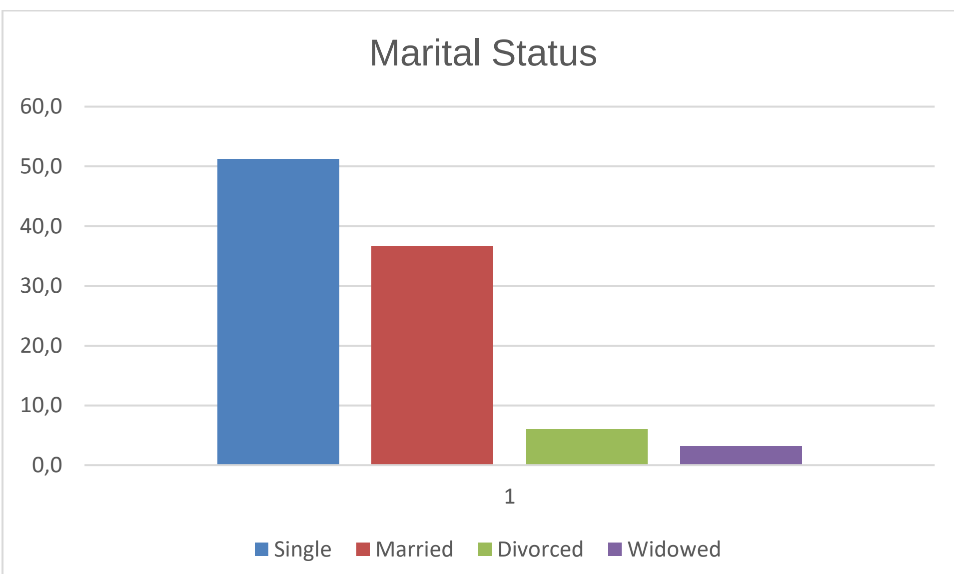

Figure 4.3: Marital status

It was found in the study that a higher number of respondents (53%) of the Ga-Thoka households are single. Married respondents contributed the second highest percentage of 38% of the data while the divorced made up 6% with the widowed at 3%.Similar results were witnessed in other studies over time. Netshipise (2021) discovered in their study that Thulamela Local Municipality had most single people (52%) followed by the married respondents. In his comparative study, Ramasenya (2021) discovered that majority of the respondents were single in both rural and semi-urban areas which might highlight that the residential area does not have any influence on the marital status of people while age does.

Pearson Chi Square test was performed to establish if marital status influence greywater reuse. According to Pearson Chi Square test, there is association between marital status and the willingness to reuse greywater, X^2 = 338.327, p< 0.001 (Table 4.3). The study revealed relationship between the marital status of the respondents and their willingness to reuse greywater in their households.

Table 4.3: Pearson Chi Square test for Marital status and willingness to reuse greywater

	Value	df	Significance (p)
Pearson Chi-Square	338.327[a]	8	<0.001
Likelihood Ratio	160.754	8	<0.001
N of Valid Cases	307		

a. 11 cells (73.3%) have expected count less than 5. The minimum expected count is 0.00.
0.05 significance level.

4.2.4. Educational level

Educational level refers to how long any person stays in the education system and what level of educational qualifications they hold (Benton, 2014). Due to different financial backgrounds and the opportunity to study, households within the same population will never have all the same educational qualifications. As such, participants had to fill in their educational achievement and the results are presented by figure 4.4.

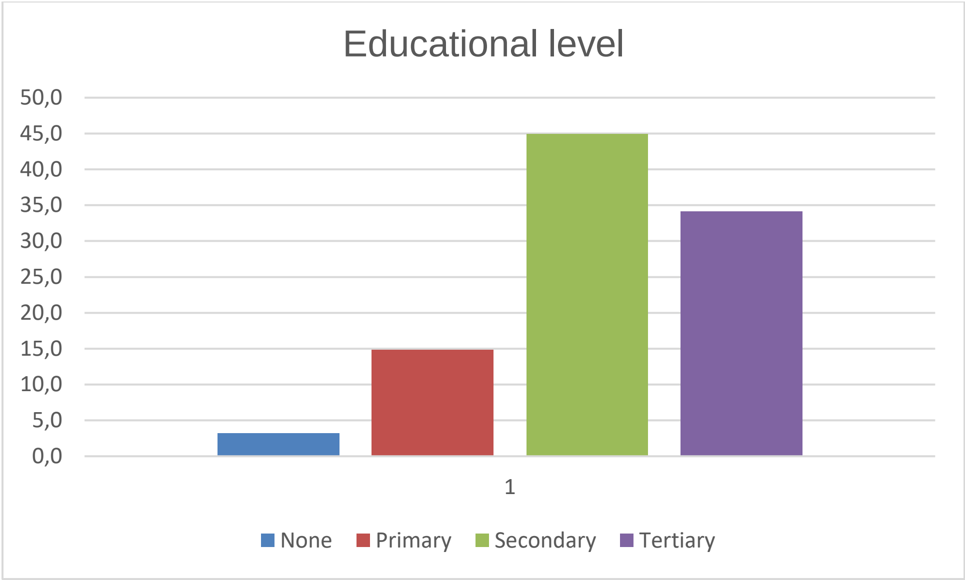

Figure 4.4: Educational level

Respondents had educational experience because of the constitution of South Africa that grants all pupils the right to an educational experience (Kranz *et al.,* 2005). Respondents who had no education at all contributed 4% of the total, respondents with primary level education made only 16% and respondents with tertiary level made 34%. Secondary level contributed 46% of the respondents. A study conducted in Kenya by Lydia (2017) found similar results where most of the respondents had secondary education compared to any other educational level. Same results were witnessed in the study conducted by Netshipise (2021) where a high level of respondents had secondary education with those with no education contributing the least percentage. In contrast, the study conducted in one of the semi-urban areas of the Polokwane Local Municipality by Ramasenya (2021), found that a higher percentage of respondents had tertiary education as their highest level of education.

Pearson Chi Square test was performed to find out if education level influence greywater reuse. According to Pearson Chi Square test, there is association between educational level and the willingness to reuse greywater, X^2 = 332.583, p< 0.001 (Table 4.4). The study found that the level of education one has,had an influence on their willingness to reuse greywater at Ga-Thoka village households.

Table 4.4: Pearson Chi Square test for Educational level and willingness to reuse greywater

	Value	df	Significance (*p*)
Pearson Chi-Square	332.583[a]	6	<0.001
Likelihood Ratio	160.467	6	<0.001
N of Valid Cases	307		
a. 8 cells (66.7%) have expected count less than 5. The minimum expected count is 0.00. 0.05 significance level.			

4.2.5. Employment status

Employment status is the status of a worker in a company on the basis of the contract of work or duration of work done (Pichault and McKeown, 2019). The rate of unemployment at Ga-Thoka village seems to be high. Most participants (39%) in this study were unemployed. The employed participants made 38% while those who are self-employed made a contribution of 23% of the total participants.

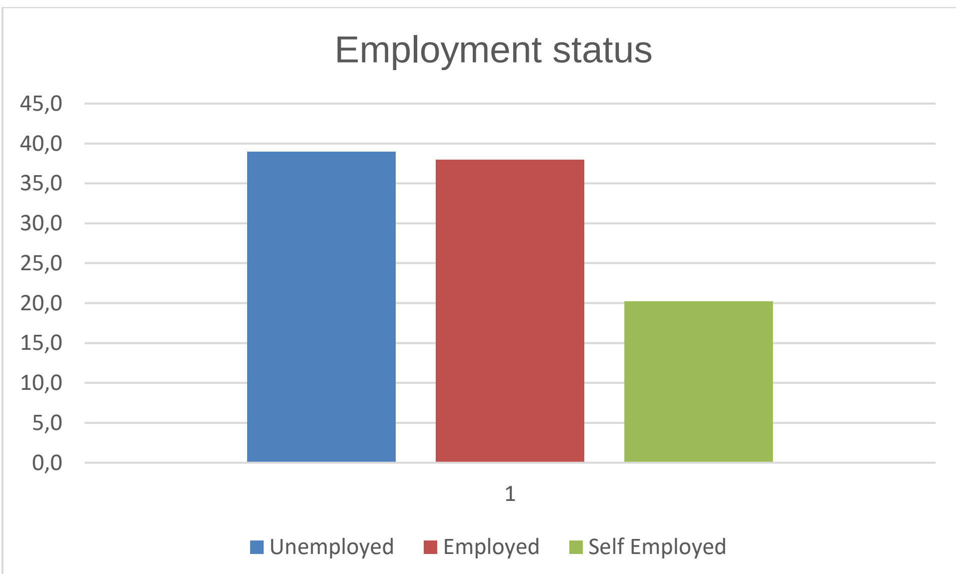

Figure 4.5: Employment status

The high percentage of unemployment in this study might be because a higher percentage of participants only had secondary education, they could still be studying which means they are not yet at the stage of being employed. This is in contrast to PLM (2016), as Visagie (2018), Netshipise (2021) and Ramasenya (2021) reported. According to PLM (2016), the employment rate in Polokwane Local Municipality is higher than the unemployment rate. The quarterly labour force survey released by Statistics South Africa, shows that the country's unemployment rate remained unchanged at 26.7% over the first quarter of 2018 compared to the fourth quarter of 2017 (Visagie, 2018). Thulamela Local Municipality has the high employment rate compared to the unemployment rate in the municipality (Netshipise, 2021). Ramasenya (2021) also reported that the rate of unemployment is lower than the employment rate in both his areas of study.

Pearson Chi Square test was performed to ascertain if employment status influence greywater reuse. According to Pearson Chi Square test, there is association between employment status and the willingness to reuse greywater, X^2 = 313.822, $p< 0.001$ (Table 4.5). It was found in the study that, Ga-Thoka village households' willingness to reuse greywater is influenced by their employment statuses.

Table 4.5: Pearson Chi Square test for Employment status and willingness to reuse greywater

	Value	df	Significance (*p*)
Pearson Chi-Square	313.822[a]	4	<0.001
Likelihood Ratio	159.148	4	<0.001
N of Valid Cases	307		

a. 5 cells (55.6%) have expected count less than 5. The minimum expected count is 0.02.
0.05 significance level.

4.2.6. Household size

Household size simply refers to the number of people in a household. Saygi (2019) defines household size as essentially the number of persons for whom is financially responsible. Every household has their own size. Majority of the respondents (35%) in

Ga-Thoka village has the household size between 5 to 6 members, followed by those who have 7 to 8 members at 25%. Respondents with less than 2 members only made 7%, and households with members between 3 and 4 was 24% while those with greater than 8 members made 9% (Figure 4.6).

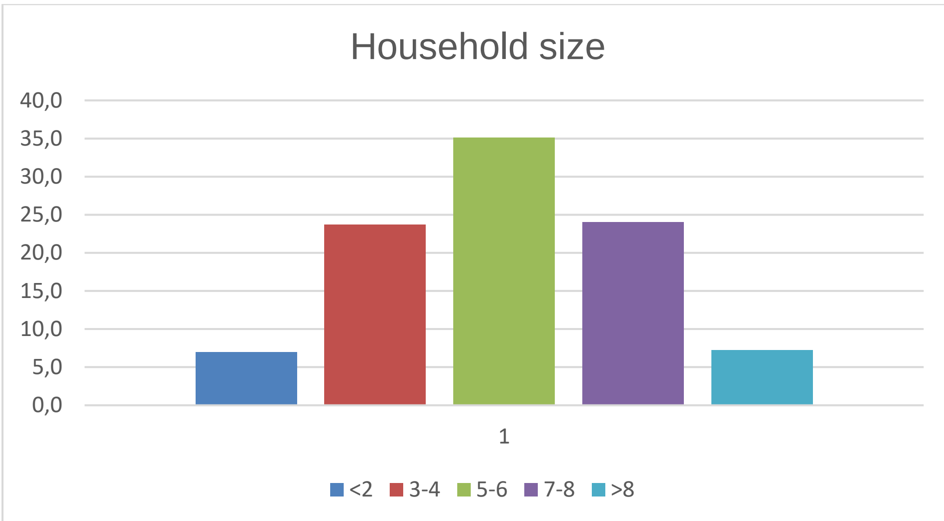

Figure 4.6: Household size

South African average household size has decreased from 4.38 in 1993 to 3.21 in 2014 (Schartz *et al.,* 2015). Reduction in household sizes is fuelled by rapid household formation, much of which is intertwined with shifts in location (Schartz *et al.,* 2015).Different studies find different results in terms of household sizes, that might also depend on the area the study is being conducted. In his study, Ramasenya (2021) found the household size of 2-4 people in high percentage which is in contrary with what was found in this study where the household size of 5-6 was discovered to be the highest.

Pearson Chi Square test was performed to ascertain if household size influence greywater reuse. According to Pearson Chi Square test, there is association between household size and the willingness to reuse greywater, X^2 = 319.183, p< 0.001 (Table

4.6). The study found a relationship between the number of people living in a household (household size) and their willingness to reuse greywater.

Table 4.6: Pearson Chi Square test for Household size and willingness to reuse greywater

	Value	df	Significance (*p*)
Pearson Chi-Square	319.183[a]	8	<0.001
Likelihood Ratio	159.612	8	<0.001
N of Valid Cases	307		

a. 11 cells (73.3%) have expected count less than 5. The minimum expected count is 0.00.
0.05 significance level.

4.2.7. Household income

Household income is a measure of the combined incomes of all people sharing a particular household or place of residence (Dikanovic, 2018). It includes every form of income, e.g., salaries and wages, retirement income, near cash government transfers like food stamps, and investment gains. At Ga-Thoka village, respondents having an income over R2000 contributed 20% (Figure 4.7). It could be assumed that their common source of income might be social grants which in some cases is less than R2000 depending on how many recipients does the household have.

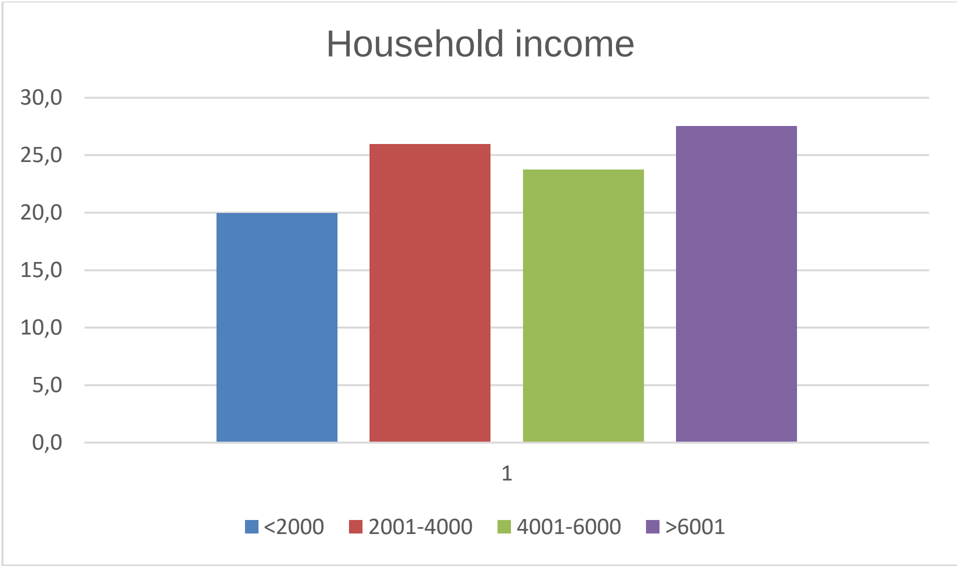

Figure 4.7: Household income

Twenty-six percent (26%) of the respondents had an income between R2001-R4000 followed by respondents who had income over R4000 but less than R6000 at 25%. Lastly, respondents who had household income greater than R6001 made 29% of the participants. The results of this study are closely similar to other studies where the majority of the household income are above the minimum income of South Africa (R 3 500). In his study, Ramasenya (2021) discovered that most households had a total income of about R7501 and above. In contrast to the above-mentioned results, 48.6% (highest in the study) of households having a household income of less than R3000 per month were discovered by Netshipise (2021).

Pearson Chi Square test was performed to find out if household income influence greywater reuse. According to Pearson Chi Square test, there is association between household income and the willingness to reuse greywater, $X^2 = 332.583$, $p< 0.001$ (Table 4.7). This means that the household income influence the persons'/ households' willingness to reuse greywater.

Table 4.7: Pearson Chi Square test for Household income and willingness to reuse greywater

	Value	df	Significance (*p*)
Pearson Chi-Square	332.583[a]	6	<0.001
Likelihood Ratio	160.467	6	<0.001
N of Valid Cases	307		

a. 8 cells (66.7%) have expected count less than 5. The minimum expected count is 0.01.
0.05 significance level.

4.3 Identify sources of freshwater and the nature of potable water supply in Ga-Thokavillage.

This section covers sources of freshwater, distance from the water source, quantity of freshwater used per day in a household, availability of freshwater in the village and if the water is sufficient (water sufficiency).

4.3.1 Sources of Freshwater

Freshwater is obtained from rainwater, surface water and groundwater. The main sources of water are rain and snow which form part of the hydrological cycle (Wulf *et al*., 2016). However, for this study, sources of freshwater refer to the available man-made (reservoirs, boreholes, taps, etc.) or natural infrastructures (rivers) that the household gets their freshwater from. The community has various sources of water that are at different capacity and availability. Figure 4.8 below shows different sources of water available at Ga-Thoka village.

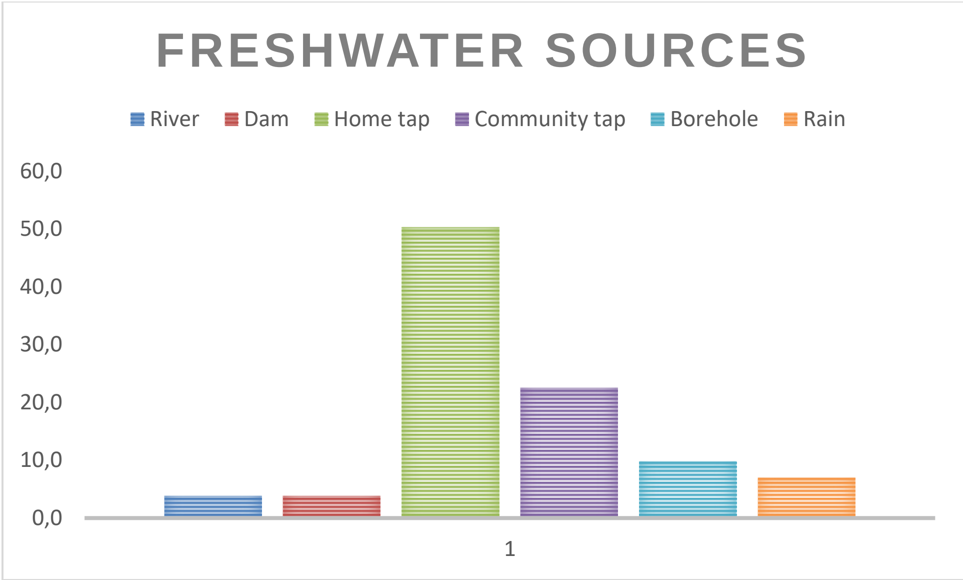

Figure 4.8: Freshwater sources

Most Ga-Thoka households rely on tap-water. The study revealed that 51% of the respondents get freshwater from their home taps. Households relying on rain as their source of freshwater made up 8%. Four percent (4%) of the respondents depended on rivers as their source of freshwater and the respondents who depended on dams as their freshwater source also contributed 4%. Twenty-three percent (23%) of the respondents depend on few available community taps as their source of freshwater. The few community taps do not have running water daily. Only 10% of the respondents own boreholes in their homes and these are their freshwater sources.

Ga-Thoka village has community taps around where households get their water for daily use. The presence of these taps depend on how old the section is, the new stands do not have community taps. In the old sections of Ga-Thoka village, households indicated that there are about 5 taps for the community which they can consider to be closer to them even though most of the taps have no water and some are broken.

Due to lack of water infrastructure in rural settlements, 74% of all rural people are entirely dependent upon groundwater (local wells and pump) (Singh Cheema, 2018). In comparison to the above statement, the results of this study show that Ga-Thoka Village households depend largely on surface water that is being delivered to them through taps and municipal trucks at times. Some respondents said that they know of five (5) community taps around them while others did not know if there are any community taps around their village.

Figure 4.9: Some of water infrastructures situated at Ga-Thoka village.

Pearson Chi Square test was performed to find out if freshwater sources influence greywater reuse. According to Pearson Chi Square test, there is association between freshwater sources and the willingness to reuse greywater, X^2 = 614.000, $p < 0.001$ (Table 4.8). This means that the availability and type of water sources in Ga-Thoka village influence the households' willingness to reuse greywater.

Table 4.8: Pearson Chi Square test for Freshwater sources and willingness to reuse greywater

	Value	df	Significance (*p*)
Pearson Chi-Square	614.000[a]	10	<0.001
Likelihood Ratio	166.496	10	<0.001
N of Valid Cases	307		

a. 14 cells (77.8%) have expected count less than 5. The minimum expected count is 0.00.
0.05 significance level.

4.3.2. Distance from the water source

The distance from the water source is defined as the distance one travels to get water. RSA (1997) indicates that according to the RDP standard of South Africa it is 200 m or less. The distance to the water source is a robust independent predictor of disease risk in the household. A 15-minute decrease in one-way walking time to the water source is associated with a 41% average relative reduction in diarrhoea prevalence (Wang *et al*., 2019). Figure 4.10 below shows the distance to the water source.

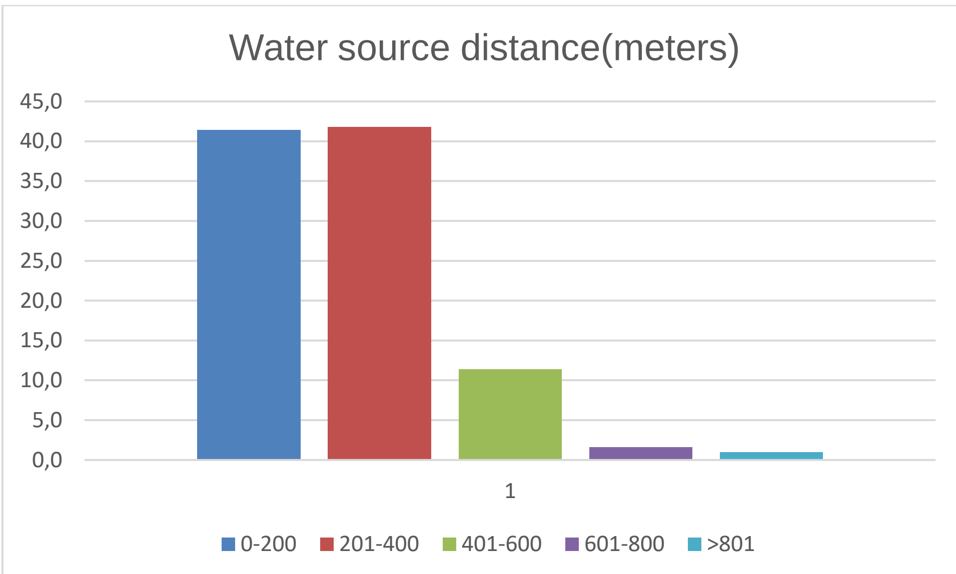

Figure 4.10: Water source distance

Respondents having the water sources closer to their homes at 0-200 meters made up to 42% while the ones who had them at more than 200 meters but less than 400 meters (201- 400m) contributed 42%. Twelve percent (12%) of the respondents had their water sources at 401-600 meters away from their homes while 3% had their sources at 601-800 meters and only 1% had their water sources at a distance greater than 801 meters. In a study conducted in Malawi, it was found that households rely on multiple water sources during rainy seasons compared to the dry season. When the main water source is broken or not functional, households use additional water sources that are more likely to be distant as a supplementary source (Cassivi *et al*., 2021) The results of this study shows that majority of the respondents (42%) fetch water from a source located at a distance between 201 and 400m from their households. This is due to the non-functional infrastructure and/or the lack of water infrastructure in their households.

Pearson Chi Square test was performed to find out if distance from water sources influence greywater reuse. According to Pearson Chi Square test, there is association between the distance from water sources and the willingness to reuse greywater, X^2 = 313.822, $p < 0.001$ (Table 4.9). The study found that Ga-Thoka village households' willingness to reuse greywater is influenced by the distance they travel to their water sources.

Table 4.9: Pearson Chi Square test for Water source distance and willingness to reuse greywater

	Value	df	Significance (*p*)
Pearson Chi-Square	313.822[a]	6	<0.001
Likelihood Ratio	159.148	6	<0.001
N of Valid Cases	307		
a. 9 cells (75.0%) have expected count less than 5. The minimum expected count is 0.01. 0.05 significance level.			

4.3.3. Quantity of freshwater used per day in a household

When determining the quantity and reuse of greywater, the amount of freshwater use per day is also an important factor. Figure 4.11 presents the amount/quantity of freshwater per liters used per household at Ga-Thoka village.

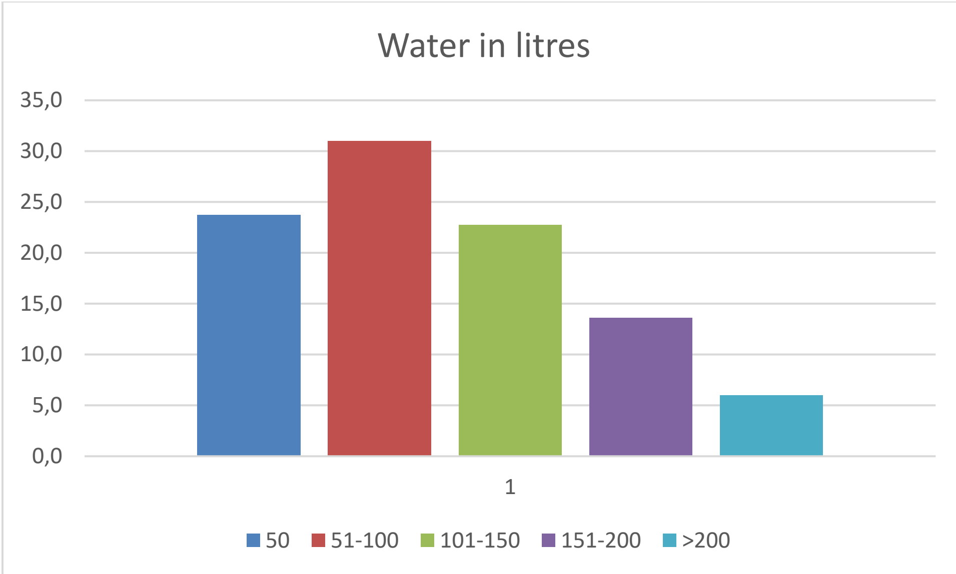

Figure 4.11: Quantity of used water per day(freshwater)

Thirty-two percent (32%) of the respondents said they use between 51 to 100 liters of freshwater per day in their households. The study found that 24% of the respondents used 50 liters or less of freshwater per day while at other households the amount between 101 liters to 150 liters were used by 24% of the respondents. The households which used between 151 liters and 200 liters of freshwater daily were at 14% while those who used more than 200 liters per day contributed only 6% of the respondents. According to the World Health Organisation (WHO) (2020), the basic need for water includes water used for personal hygiene but defining a minimum has limited significance as the volume of water used by households depends on accessibility. Ohno *et al*., (2018)reported that average household water consumption in Spain was 137 liters per person per day in 2012, and that far exceeds the minimum required per person according to WHO (between 50 and 100 litres per day). In contrast with the results of this study, a higher percentage of respondents were found to be using 51-100 liters of water per household per day which is way too less compared to the amount of water used per person per day in Spain.

When respondents were asked about the quantity of water they use in their household, they were also asked about their household products that they use daily with water. On the question of which types of soaps, shampoos and detergents does the respondent use in their household, it was found that they use almost the same products. Household products used by respondents are washing powders, detergents, bath salts and toothpastes.

Pearson Chi Square test was performed to find out if the quantity of water used per day influence greywater reuse. According to Pearson Chi Square test, there is association between the quantity of water used per day and the willingness to reuse greywater, X^2 = 319.183, p< 0.001 (Table 4.10). The study revealed that the amount of water used per day in a household have influence on their willingness to reuse greywater.

Table 4.10: Pearson Chi Square test for Quantity of water used per day and willingness to reuse greywater

	Value	df	Significance (p)
Pearson Chi-Square	319.183[a]	6	<0.001
Likelihood Ratio	159.612	6	<0.001
N of Valid Cases	307		

a. 8 cells (66.7%) have expected count less than 5. The minimum expected count is 0.01.
0.05 significance level.

4.3.4. Availability of freshwater

As South Africa is a water scarce country, it is unlikely to find a place where freshwater is always available in all cases (Bwapwa, 2017). Some parts of the country get enough water during the rainy seasons since their water sources depend mainly on rainfall.

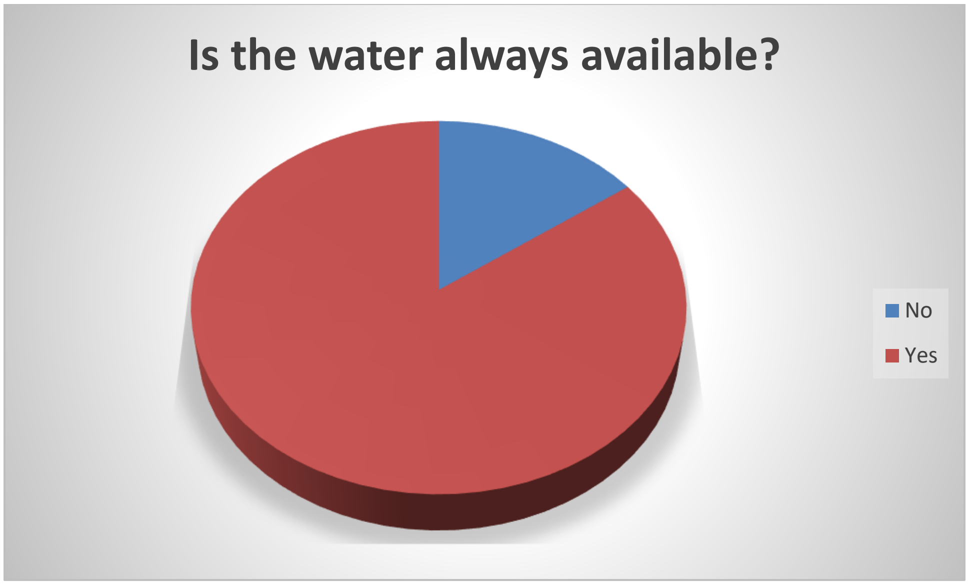

Figure 4.12: Water availability

Eighty-five percent (85%) of the respondents in Ga-Thoka village said that they always have freshwater available for their personal and household uses. That can mainly be because they have more than one freshwater source for their households. It was found that only 15% of the respondents said that water is not always available for their use. There is a high chance that households that depend solely on rain as their source of freshwater might only have water available for them during the rainy seasons. Households also gave reasons that the water is not always available because they only get water from the taps once in a week while some indicated that they have gone for months without their taps running water, they only depended on municipal trucks which only come once in a week and sometimes once in two weeks.

Households responded that their main uses of water are bathing, cooking, drinking, irrigating their ornamental plants and food crops, washing their cars, and feeding their livestock (drinking). Africa (2022), reported that the General Household Survey (GHS) released by Statistics South Africafound that households' access to drinking water (89%) was most common in 2018. However, it is important to note that household number keep increasing annually. The results of this study found that 85% percent of the households have water available for their daily household use which is slightly different from the percentage released by Stats SA.

Pearson Chi Square test was performed to find out if water availability has any influence on greywater reuse. According to Pearson Chi Square test, there is association between water availability and the willingness to reuse greywater, X^2 = 372.786, p< 0.001 (Table 4.11). The availability of water has an influence the households' willingness to reuse greywater.

Table 4.11: Pearson Chi Square test for Water availability and willingness to reuse greywater

	Value	df	Significance (*p*)
Pearson Chi-Square	372.786[a]	4	<0.001
Likelihood Ratio	161.997	4	<0.001
N of Valid Cases	307		

a. 6 cells (66.7%) have expected count less than 5. The minimum expected count is 0.01.
0.05 significance level.

4.3.5. Water sufficiency

Water sufficiency simply means enough water to meet a need or purpose (Park and Lee, 2019). At some point, water sufficiency might depend on water availability such that water cannot be sufficient if it is not available.

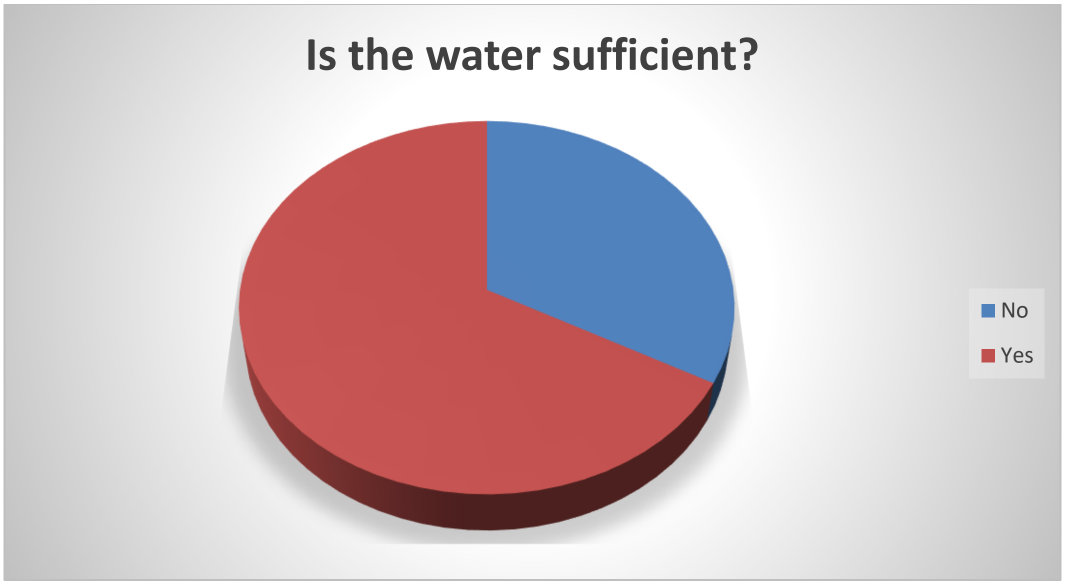

Figure 4.13: Water sufficiency

Sixty-seven percent (67%) of the respondents said that the freshwater they have in their households issufficient for their daily needs, whereas 33% of the respondents said the water is not sufficient for them to meet their daily needs (Figure 4.13). The sufficiency of water may be affected by different factors for each household. For instance, the respondents indicated that they must go a long way to fetch their water, and they end up not having enough for the day due to tiredness or other disadvantages coming with the distance having to be travelled to get water daily, they also responded that they do not have sufficient water because they do not have running water daily in their village. According to Booysen *et al*. (2019), a project that was implemented to ensure water sustainability in Western Cape resulted in poorer schools having a water efficiency of around 50%, while affluent schools had a water efficiency of closer to 80%. This study found that 67% of the respondents find their water being sufficient for their daily needs. However, the reasons or measures taken to ensure the sufficiency are unknown since they indicated that their taps do not have running water daily.

Respondents who said they do not have sufficient water highlighted that the biggest challenge for them to access sufficient water is lack of water infrastructure in their village and the available infrastructure is either old and covering only a few households or not functioning at all.

Pearson Chi Square test was performed to find out if water sufficiency influence greywater reuse. According to Pearson Chi Square test, there is association between water sufficiency and the willingness to reuse greywater, $X^2 = 345.984$, $p < 0.001$ (Table 4.12). The study revealed that water sufficiency has an influence on the willingness of Ga-Thoka village households to reuse their greywater.

Table 4.12: Pearson Chi Square test for Water sufficiency and willingness to reuse greywater

	Value	df	Significance (*p*)
Pearson Chi-Square	345.984[a]	4	<0.001
Likelihood Ratio	161.089	4	<0.001
N of Valid Cases	307		
a. 5 cells (55.6%) have expected count less than 5. The minimum expected count is 0.02. 0.05 significance level.			

4.4. Analyse the quality of greywater from selected households of Ga-Thoka village.

Ninety-three (93) greywater samples were collected from selected households of Ga-Thoka village for the purpose of greywater quality determination. The collected greywater samples were a combination of thirty-one (31) samples per source (kitchen, bathroom and laundry) respectively. Samples were delivered to the laboratory in a group of 30 with the last bunch having 33 water samples.

Figure 4.14: The water samples in the lab (right) and some of the analysis process (left).

Water quality describes the condition of the water in terms of chemical, physical, and biological characteristics, usually with respect to its suitability for a particular purpose such as drinking or swimming (Mahmud *et al*., 2020). The characteristics of greywater samples collected from Ga-Thoka village households were determined and compared to the South African National Standard of Drinking water limits (SANS 241) because the Capricorn District Municipality Laboratory uses the SANS 241 as their limit standards. The samples were tested for physical, aesthetic and chemical characteristics (inorganic and metals). Average values per source for each parameter are presented on Table 4.13. Several pollutants have been identified in greywater samples such as organic carbon, total and volatile solids, nutrients, surfactants, heavy metals and emerging contaminants (Eriksson *et al*., 2002, Hernandez Leal *et al*., 2010; Eriksson and Donner, 2009).

Physical and Aesthetic characteristics

The physical and aesthetic characteristics determined are pH, electrical conductivity (mS/cm), total dissolved solids (mg/L), turbidity (NTU), colour (mg/L) and total hardness (mg/L).

pH is a measure of how acidic/basic water is. The range goes from 0-14, with 7 being neutral. pHs of less than 7 indicate acidity, whereas a pH of greater than 7 indicates a base. It is a measure of the relative amount of free hydrogen and hydroxyl ions in the water. Water that has more free hydrogen ions is acidic, whereas water that has more free hydroxyl ions is basic (Hikmat, 2003).

The study found that greywater from the laundry had the highest pH average of 8.05 which clearly indicates that laundry greywater is basic. Jefferson *et al.*(2004)reported that the alkalinity of soaps and detergents affects the pH of the greywater thus it tends to range around 7-8. The bathroom greywater pH average was found to be 7.17 which is almost neutral while the kitchen greywater was found to be slightly acidic with the pH level of 6.50. In the study conducted by Bakare *et al*. (2017), similar findings were discovered where laundry greywater had the highest pH value (9.58) and kitchen greywater had the pH value of 6.25, however the bathroom greywater pH was at the value of 9.24 (Table 4.13). In this study, the overall average pH value from the three sources was found to be 7.24 which falls within the range 6.5-8.4 (USEPA, 2004) which is said to be an appropriate value that will enhance easy treatment or will not have adverse impacts on soil or plants when used for irrigation. Similarly, Bakare *et al*. (2017) found the value falling within the 6.5-8.4 range.

Electrical conductivity results from this study show that kitchen greywater has a reading of 248.59 mS/cm, while laundry greywater had 294.56 mS/cm and bathroom greywater had the highest electrical conductivity of 342.89 mS/cm (Table 4.13). On the contrary, ABU Ghunmi *etal*., (2008) reported a higher electrical conductivity of 4540 mS/cm in laundry greywater in Jordan. According to Nieć and Spychała (2014), the high conductivity value is not a problem unless the greywater is intended to be reused for irrigation because a high conductivity value could have an adverse effect on the plants and may lead to a long-term impact of salt loading in the soil. The study conducted by Bakare *et al*. (2017), found that bathroom greywater had a lower conductivity compared to the kitchen and the laundry. Regardless of greywater source, previous studies reported that the ranges recorded for electrical conductivity in greywater is between 14 and 3000 mS/cm (Prathapar *et al*., 2005;March and Gual, 2009). Results from this study are within the reported limits by Prathapar*et al*. (2005) and March and Gual (2009). The authors opined that water scarce areas are mostly associated with high electrical conductivity due to dissolved materials. Poor or old plumbing materials also contribute to the increase in electrical conductivity due to leaching into greywater sources.

In this study, the bathroom greywater was found to have the average of 2228.77 mg/L total dissolved solids, followed by the kitchen greywater with total dissolved solids average of 2185.50 mg/L. Laundry greywater had the total dissolved solids of 1925.78 mg/L in average (Table 4.13). Abinaya and Loganath (2015) reported low values of total dissolved solids (712 mg/L to 990 mg/L) in greywater collected in Chennai, India compared to the values from this study.

The study conducted by Md Shamsuddin (2019) reported the mean percentage of reduction in TDS as 54% and the high percentage of reduction in TDS and its presence within the permissible limits suggests that the greywater is suitable for reuse after treatment. Smith and Bani-Melhem (2012) reported relatively steady dissolved TDS concentrations with minimum reading of 166 mg/L and maximum of 327 mg/L over their study area.

The greywater characteristics in terms of turbidity indicate that the laundry greywater had a turbidity average of 246.96 NTU while the kitchen greywater had the average turbidity of 213.24 NTU and the bathroom greywater measured average turbidity of 16.58 NTU (Table 4.13). However, contrary to this study, Bakare *et al*. (2017), reported that the laundry greywater was found to have the highest turbidity value. Similarly, the study conducted by Boros *et al*. (2014), discovered that samples from bathing water were less polluted with low turbidity average value of 75 NTU. Boros *et al*. (2014) found turbidity measurements ranging from 6 to 1026 NTU, with 223 NTU mean value, which suggests that greywater can be clear like drinking water or so muddy like wastewater. According to the study conducted by Bakare *et al*. (2017), kitchen greywater had the highest turbidity as a result of the amount of soap used in the kitchen and the fact that kitchen greywater gets contaminated with food particles which contribute to high suspended solid materials. Oteng-Peprah *et al*. (2018) argued that greywater originating from kitchen and laundry is expected to become more turbid because of the presence of suspended matter.

Colour is organic material that has dissolved into solution (Saito, 2021). The most common cause of water colour is the presence of minerals. Red and brown colours are due to iron; black to manganese or organic matter; yellow to dissolved organic matter such as tannins (Cao *et al*., 2017). Greywater from the kitchen measured the average of

1008.48 mg/L in colour, followed by the laundry greywater with the average of 889.89 mg/L and the bathroom greywater had the average of 0.18 mg/L (Table 4.13).

Table 4.13: Greywater characteristics from different sources (average values)

Sources			
Parameters	Kitchen	Bathroom	Laundry
Physical and aesthetic			
pH	6.50	7.17	8.05
Electrical Conductivity (mS/cm)	248.59	342.89	294.56
Total dissolved solids (mg/L)	2185.50	2228.77	1925.78
Turbidity (NTU)	213.24	16.58	246,96
Colour (mg/L)	1008.48	0.18	889.89
Total Hardness (mg/L)	0.00	1.07	27.26
Inorganic characteristics			
Fluoride as F (mg/L)	0.08	0.14	0.11
Chloride as Cl (mg/L)	34.79	194.30	64.55
Bromide as Br (mg/L)	0.17	0.50	0.08
Nitrate as NO3_N (mg/L)	0.16	0.19	0.19
Sulphate as SO4 (mg/L)	90.68	101.15	90.49
Metals			
Potassium as K (mg/L)	1.02	1.55	2.39
Calcium as Ca (mg/L)	1.01	2.91	3.16
Magnesium as Mg (mg/L)	0.00	0.10	0.09
Sodium as Na (mg/L)	17.98	29.43	70.53
Zinc as Zn (mg/L)	0.28	0.53	0.99
Lead as Pb (mg/L)	0.02	0.01	0.04
Manganese as Mn (mg/L)	0.05	0.04	0.09
Vanadium as V (mg/L)	0.00	0.00	0.00
Aluminium as Al (mg/L)	0.69	1.23	3.13
Chromium as Cr (mg/L)	0.00	0.00	0.01
Copper as Cu (mg/L)	0.08	0.05	0.10
Iron as Fe (mg/L)	0.59	0.68	1.62

<u>Inorganic characteristics</u>

Inorganic characteristics covered are Fluoride as F (mg/L), Chloride as Cl (mg/L), Bromide as Br (mg/L), Nitrate as NO_3_N (mg/L) and Sulphate as SO_4 (mg/L). According to Li (2009), greywater generated from household kitchens and those from the laundry are higher in organics and physical pollutants compared to bathroom and mixed greywater.

Al-Jayyousi (2003), indicated that literature mostly reports on several metals in relation to agricultural aspects and none was found directly on the greywater characteristics. The studies previously published, test greywater characteristics on the soil and the effects they have on the agricultural crops and vegetation.Gordeev *et al*., (2019) investigated the presence of several metals (Cu, Fe, Pb, Zn) in household and personal care products and found that Fe and Zn were present in most products and traces of Pb were also in many products. In their study of treatment and effective utilization of greywater, Samayamanthula *et al*. (2019) found the nutrients ammonium, nitrate, potassium and phosphate to be slightly higher, and found Sodium ion to be lower.

Results from this study in terms of Fluoride indicates that bathroom greywater have the highest amount of F (0.14 mg/L) compared to the other greywater sources. Laundry greywater followed with 0.11 mg/L and kitchen greywater having the least F reading (0.08 mg/L) (Table 4.13). Alsulaili *et al*., (2017) reported to have observed Flouride in all their greywater samples which ranged from sub-optimal to close to higher level. Higher concentration of Fluoride might be attributed to higher fluoride content in toothpaste, soaps, etc. (Levine, 2020).

In this study, bathroom greywater was found to contain more Cl (194.30 mg/L) when compared to the other greywater sources. Laundry greywater was the second with Cl amount of 64.55 mg/L and kitchen greywater was the least with 34.79 mg/L (Table 4.13). Potivichayanon*et al*. (2021) observed the untreated greywater chlorides of the various water samples to have exceeded the permissible limit of 150 mg/L while the treated greywater was below the limits and concluded that the reuse of greywater is indicated by the fact that the treated samples' chloride content was within the permissible limits.

The study found that kitchen greywater had more Bromide (Br) (0.17 mg/L) than the other greywater sources, followed by the Br present in laundry greywater which was 0.08 mg/L and the bathroom greywater had 0.50 mg/L (Table 4.13). López*et al*.(2009)

reported the discovery of Brominated flame retardants in greywater which is a constituent of Bromide. The constituent of Bromide is just the properties of Br which indicates the presence of Br maybe in smaller amounts.

Greywater characteristics results from selected households of Ga-Thoka village in terms of Nitrate (NO_3_N) indicate that kitchen greywater had 0.16 mg/L NO_3_N which was lower than both the bathroom greywater and laundry greywater, each had 0.19 mg/L NO_3_N respectively (Table 4.13). Boyjoo *et al*. (2013) reported that kitchen wastes are the primary source of nitrogen in greywater and range between 4 and 74 mg/L. The high waste particles contained in kitchen greywater will result in the high nitrogen. In their study of treatment and effective utilization of greywater, Samayamanthula *et al*. (2019) found the nutrients ammonium, nitrate, potassium and phosphate to be slightly higher, and found Sodium ion to be lower.

Greywater characteristics from this study indicated that highest amount of Sulphates (SO_4) was detected in bathroom greywater which read 101.15 mg/L. Laundry greywater had 90.49 mg/L SO_4 while kitchen greywater had 90.68 mg/L (Table 4.13). Sulphates found in greywater are caused primarily by the washing detergents (Boyjoo *et al*., 2013).

<u>Metals</u>

Twelve (12) metals were determined in greywater samples collected from kitchen, laundry and bathroom of selected households in Ga-Thoka village. The metals are Potassium as K (mg/L), Calcium as Cl (mg/L), Magnesium as Mg (mg/L), Sodium as Na (mg/L), Zinc as Zn (mg/L), Lead as Pb (mg/L), Manganese as Mn (mg/L), Vanadium as V (mg/L), Aluminium as Al (mg/L), Chromium as Cr (mg/L), Copper as Cu (mg/L) and Iron as Fe (mg/L) (Table 4.13). Kitchen greywater had the lowest K reading of 1.02 mg/L followed by the bathroom greywater with 1.55 mg/L K and laundry greywater had the highest with 2.39 mg/L. Kitchen greywater contained the lowest Ca (1.01 mg/L) whereas bathroom greywater had 2.91 mg/L and laundry greywater had the highest amount of Ca compared to other greywater sources at 3.16 mg/L. Magnesium was not detected in the kitchen greywater while the laundry greywater had Mg of 0.09 mg/L, the bathroom greywater had0.10 mg/L Mg. A high amount of Na was detected in the laundry greywater which read 70.53 mg/L and bathroom greywater followed with Na at 29.43 mg/L while kitchen greywater had 17.98 mg/LNa. The amount of Zn in the laundry greywater was detected to be 0.99 mg/L while in the bathroom greywater it was 0.53 mg/L and in the kitchen greywater it was detected to be 0.28 mg/L. The amount of Pb detected in all the greywater from the three different sources were less than 0.1 mg/L. Bathroom greywater had the Pb reading of 0.01 mg/L, while kitchen greywater had 0.02 mg/L and laundry greywater had 0.04 mg/L Pb. Compared to other sources, laundry greywater had a highest Mn reading of 0.09 mg/L while kitchen greywater had 0.05 mg/L and bathroom greywater the lowest concentration (0.04 mg/L). In all the three greywater sources, the average of V detected was 0.00 mg/L (rounded to 2 decimals). V detected in the kitchen greywater, bathroom greywater and laundry greywater were 0.00 mg/L respectively. Kitchen greywater had the lowest Al detection of 0.69 mg/L followed by the bathroom greywater with 1.23 mg/L and laundry greywater had the highest detected concentration of Al (3.13 mg/L). Laundry greywater had Cr detection of 0.01 mg/L while both kitchen greywater and bathroom greywater had Cr detection of 0.00 mg/L (rounded to 2 decimals) respectively. The Cu that was detected in the laundry greywater was 0.10 mg/L while kitchen greywater had 0.08 mg/L and bathroom greywater had 0.05 mg/L. Kitchen greywater was found to have less Fe (0.59 mg/L) followed by the bathroom greywater with 0.68 mg/L and laundry greywater having highest Fe (1.62 mg/L) (Table 4.13).

Various studies have found toxic heavy metals such as Lead, Nickel-cadmium, Copper, Mercury and Chromium (Sturman and Loginovskaya, 2020; Balali-Mood *etal*., 2021) in appreciable concentrations in greywater. The presence of these contaminants in greywater is an indication of the gradual increase in the level of complexity in the composition of greywater.

Erdogan and Aydin (2015) investigated the presence of As, B, Cd, Cu, Fe, Pb, Ni, Sn and Zn in a range of household and personal care products and found tha Fe and Zn were present in the majority of products, B was present in a large range of products (laundry, kitchen and bathroom) and traces of Pb and Ni were also in many products. Similarly, Varian (2001) and Eaton and Franson (2005) collected greywater samples and analysed using a Varian ICP-OES with simultaneous detection analysis for Al, As, B, Be, Bi, Cd, Co, Cr, Cu, Fe, Mn, Mo, Ni, Pb, Sb, Se, Sr, Ti, V, and Zn. Results for Al, B, Fe and Mn were combined between the two analytical methods (ICP-OES and ICP-MS). Sodium as a constituent can be from cooking and preservation activities in the kitchen and can be found in appreciable levels (Boyjoo *et al*., 2013). A significant quantity of Sodium into greywater is mostly contributed by sodium-based soaps (Hagvall *et al*., 2014).

4.5. Establish the potential of greywater reuse by the Ga-Thoka village households

Greywater can be explained as untreated wastewater which comes from baths and showers (body washing) and handwash basins. Laundry water from washing machines or hand washing is also regarded as greywater but it only qualifies as greywater for reuse if environmentally friendly detergents have been used. Water reuse (also known as water recycling or water reclamation) reclaims water from a variety of sources then treats and reuses it for agriculture and irrigation, potable water supplies, groundwater replenishment, industrial processes, and environmental restoration (Arena *et al.,* 2020). It was observed that, some households have gardens that they irrigate using greywater and some irrigate using freshwater from the taps while some use both greywater and freshwater to irrigate their gardens (Figure 4.15).

Figure 4.15: Garden (spinach) irrigated strictly with freshwater only (left) and garden (purple-leaves sweet potatoes) irrigated with both greywater and freshwater (right).

4.5.1. Knowledge of greywater

Knowledge is a familiarity, awareness, or understanding of someone or something, such as facts, skills, or objects. Knowledge can be acquired in many ways and from many sources, such as perception, reason, memory, testimony, scientific inquiry, education, and practice (Shinskey and Munakata, 2010). The respondents were asked if they knew what greywater was in order to get understanding of how they might respond to some of the questions regarding greywater. Figure 4.16 shows the responses of the households.

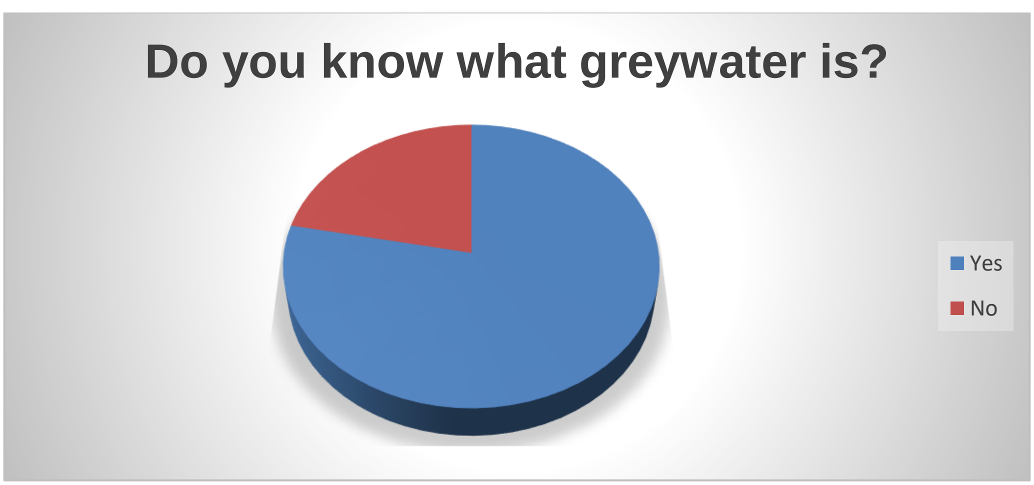

Figure 4.16: Greywater knowledge

Seventy-eight percent (78%) of the respondents said that they know what greywater is and it was only 22% of the respondents who said they did not know what greywater is. Similarly, the study conducted by Mashabela (2015) discovered that most respondents knew what greywater is. In contrast to this study and what Mashabela (2015) found, a study conducted by Al-Mashaqbeh *et al*. (2012) in Jordan discovered that 93% of the respondents were not aware of the greywater concept and its potential importance to their community, including reuse of greywater for irrigation in their home gardens.

Pearson Chi Square test was performed to find out if the knowledge of greywater influence greywater reuse. According to Pearson Chi Square test, there is association between greywater knowledge and the willingness to reuse greywater, $X^2 = 372.786$, $p< 0.001$ (Table 4.14). The knowledge people had about greywater and its reuse was found to have effect on the reuse/ willingness to reuse greywater in their households.

Table 4.14: Pearson Chi Square test for Greywater knowledge and willingness to reuse greywater

	Value	df	Significance (*p*)
Pearson Chi-Square	372.786[a]	4	<0.001
Likelihood Ratio	161.997	4	<0.001
N of Valid Cases	307		

a. 6 cells (66.7%) have expected count less than 5. The minimum expected count is 0.01.
0.05 significance level.

4.5.2. Greywater generation by the respondents

The participants were asked if they generate greywater or not and it was found that most of the households generate greywater and only a few said they do not generate it (Figure 4.17). Ninety-two percent (92%) of households generate greywater, whereas only 8% does not generate.

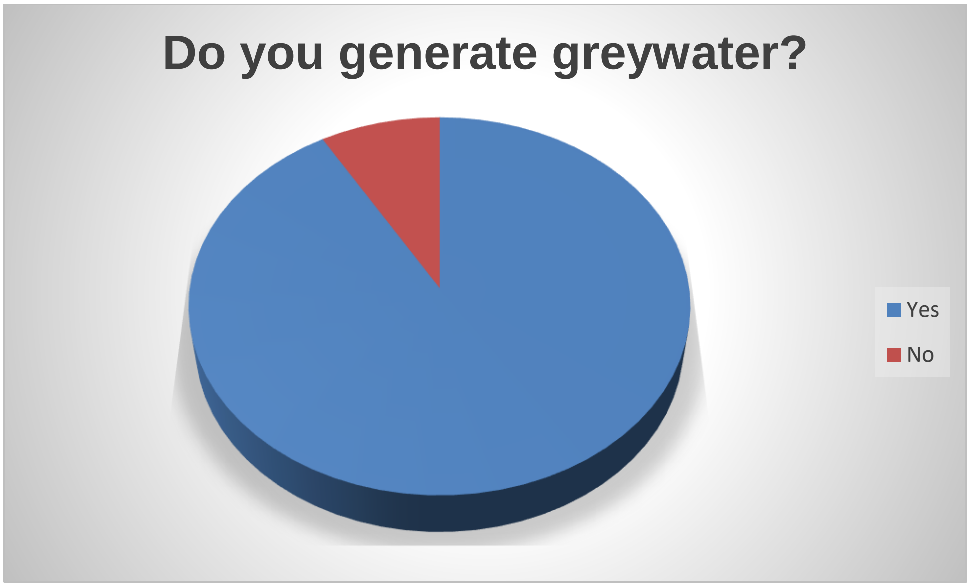

Figure 4.17: Greywater generation

Previous studies reported that greywater production in a household is directly influenced by water consumption which is dependent on a number of factors including the existing water supply service and infrastructure, the number of household members, the age distribution, the lifestyle characteristics, the typical water usage patterns, etc. (Morel and Diener, 2006; Carden *et al*., 2007; Maiga *et al*., 2014).

Pearson Chi Square test was performed to find out if greywater generation influence willingness to reuse greywater. According to Pearson Chi Square test, there is association between greywater generation and the willingness to reuse greywater, X^2 = 307.000, $p < 0.001$ (Table 4.15). It was found that the households' level of greywater generation have an influence on their willingness to reuse their generated greywater in their households.

Table 4.15: Pearson Chi Square test for Greywater generation and willingness to reuse greywater

	Value	df	Significance (*p*)
Pearson Chi-Square	307.000[a]	2	<0.001
Likelihood Ratio	158.360	2	<0.001
N of Valid Cases	307		
a. 3 cells (50.0%) have expected count less than 5. The minimum expected count is 0.07. 0.05 significance level.			

4.5.3. Sources of greywater

A source is a place from which something originates or can be obtained from (Dyevre, 2010). There are several sources of greywater that a single household could have such as laundry, bathing, washing of dishes, just to name a few. All the sources that were included in the questionnaire were for every household but not everyone took them as their sources. The data below, shows that laundry is the greywater source for many households followed by the dishwashing and bathing/showering being the least with the combined sources excluded (Figure 4.18).

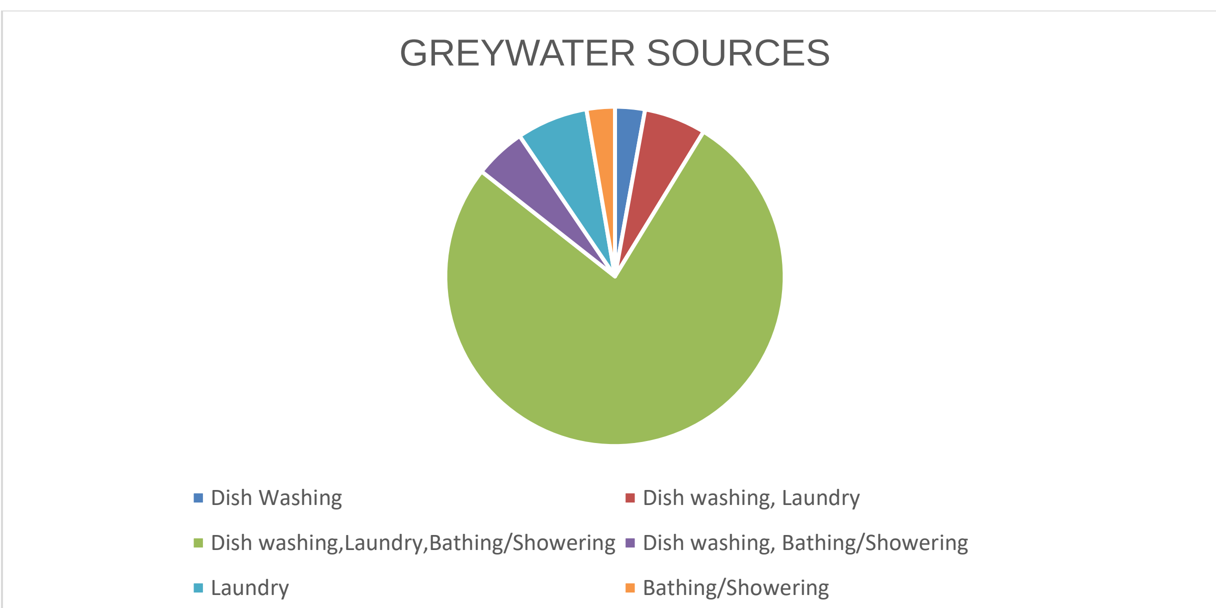

Figure 4.18: Greywater sources

Figure 4.18 reveals that, laundry is the most selected source of generating greywater at 7%. The dishwashing followed with 3% while bathing had 3%. Some respondents choose several sources as their household source of greywater. Respondents whose sources were dishwashing, laundry and bathing/showering made a percentage of 77% followed by dishwashing and laundry at 6% while dishwashing and bathing/showering made only 4% of the total sources. This study revealed that Ga-Thoka village households' sources of greywater are kitchen, bathroom and laundry. This is in harmony with Mashabela (2015), Rodda *et al*. (2010) and Queensl (2003) who reported in their studies that the respondents' sources of greywater are kitchens, bathtubs, laundry and showers.

According to Pearson Chi Square test, there is association between greywater sources and the willingness to reuse greywater, $X^2 = 307.000$, $p < 0.001$ (Table 4.16). Where greywater came from (source) had an influence on the households' willingness to reuse their greywater.

Table 4.16: Pearson Chi Square test for Greywater sources and willingness to reuse greywater

	Value	df	Significance (*p*)
Pearson Chi-Square	307.000[a]	2	<0.001
Likelihood Ratio	158.360	2	<0.001
N of Valid Cases	307		
a. 3 cells (50.0%) have expected count less than 5. The minimum expected count is 0.07. 0.05 significance level.			

4.5.4. Greywater drainage systems

Drainage system is the system or process by which water or other liquids are drained from a place (Černohous *et al.,* 2014). Drainage systems are in place to remove the excess water in development. This could be floodwater, and different kinds of run off. Drainage systems are also in place to remove wastewater effectively, and they are referred to as sewer system. Figure 4.19 below shows different ways that Ga-Thoka households use to drain their greywater.

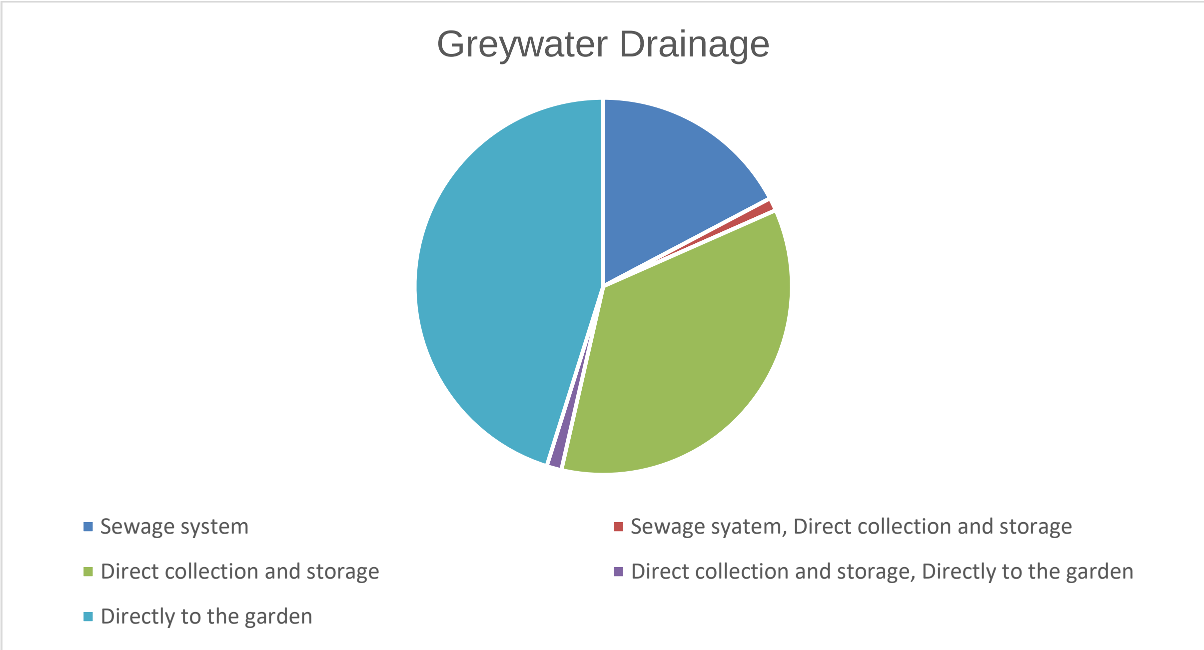

Figure 4.19: Greywater drainage

At Ga-Thoka village, 44% of the respondents collected their greywater directly to their gardens after they generated it using different containers or pipes. The respondents that collect their greywater and store it for some time before use or disposal were found to be 36% while 17% of the respondents had sewage systems as their greywater drainage systems. However, some of the households had more than one way of drainage for their greywater. Households who directly collected their water to the garden and sometimes collected and stored their greywater before use made a percentage of 2% and those who had sewage systems and collected and stored their greywater made only 1% of the respondents. Mashabela (2015) reported that respondents in one of her study areas said that they reuse their greywater for irrigation while in the other study area respondents said that their greywater is drained to the sewage system except for greywater from laundry.

Pearson Chi Square test was performed to find out if greywater drainage system influence greywater reuse. According to Pearson Chi Square test, there is association between greywater drainage and the willingness to reuse greywater, $X^2 = 317.121$, $p< 0.001$ (Table 4.17). Ga-Thoka village households' drainage system had an effect on their willingness to reuse their greywater.

Table 4.17: Pearson Chi Square test for Greywater drainage and willingness to reuse greywater

	Value	df	Significance (*p*)
Pearson Chi-Square	317.121[a]	6	<0.001
Likelihood Ratio	159.445	6	<0.001
N of Valid Cases	307		

a. 8 cells (66.7%) have expected count less than 5. The minimum expected count is 0.00.
0.05 significance level.

4.5.5. Greywater storage containers

Water storage containers are various vessels that are used to store water. They vary in different shapes and sizes. These range from buckets, drums, tanks, dam, etc. (Kumar, 2020). In Ga-Thoka village, the containers that are used to store greywater includes buckets, drums, tanks, cemented pit or any other container the household might be using. Water containers are used to collect, transport, treat, store, and consume water. Figure 4.20 presents the types of containers that Ga-Thoka village households use at their homes to store their greywater.

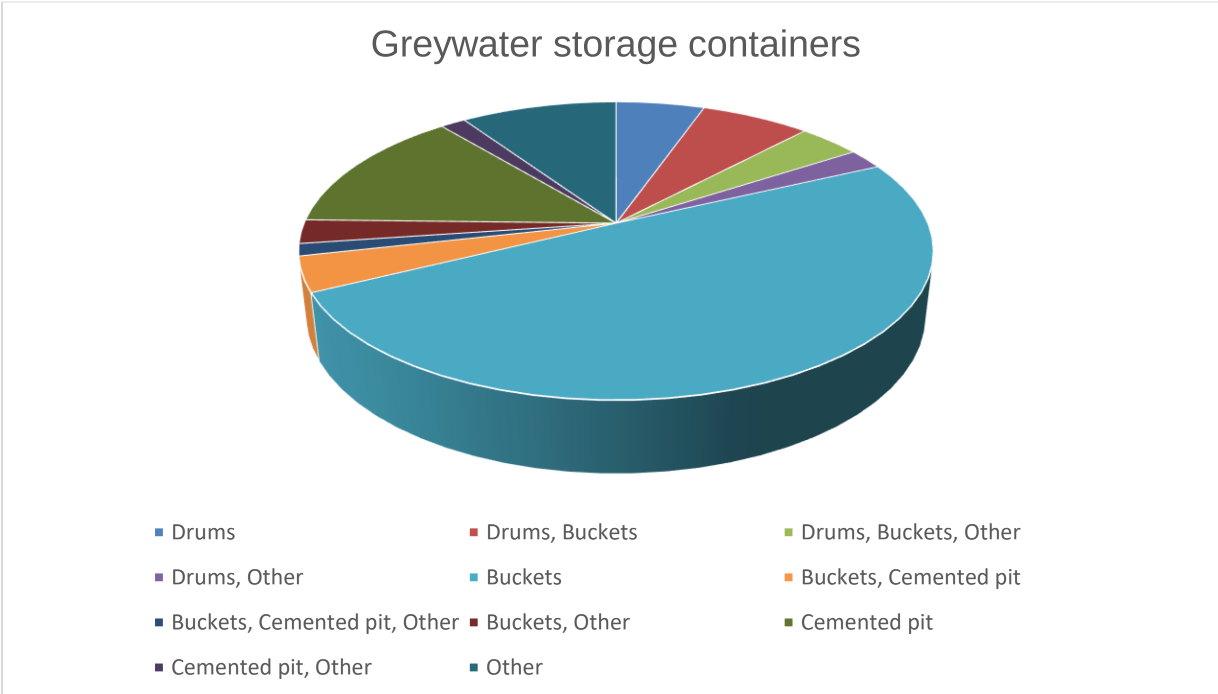

Figure 4.20: Greywater storage containers

Most of the households (50%) use buckets to store their greywater, either for direct storage or for transporting to the garden or anywhere where they will be reusing their greywater for the purpose given. Fourteen percent (14%) had cemented pits as their storage containers where they store their greywater prior to use, 5% of the respondents used drums as their greywater containers. There were households which had more than one container to store or collect their greywater. The households who had buckets and cemented pits as their containers made up 4% of the participants, those with drums, buckets and other containers (not mentioned in the questionnaire) also made 4% contribution to the study participants and participants who had drums and buckets as their containers made up 6%. Participants using drums and other containers; buckets and other containers; cemented pit and other containers; buckets, cemented pit and other containers made 2%, 3% ,1% and 1% respectively. Households who used other containers that were not mentioned in the questionnaire such as tanks, made up a contribution of 10%. It was reported by Mashabela (2015) that Mashite village households (one of their study areas) used large containers (drums) and tanks as storage containers for their water which is like the study conducted by Radingoana *et al*. (2019).

Pearson Chi Square test was performed to find out if greywater storage containers influence greywater reuse. According to Pearson Chi Square test, there is association between greywater storage containers and the willingness to reuse greywater, X^2 = 399.587, $p < 0.001$ (Table 4.18). The study found that the containers households use to store or transport their greywater after generation, had relationship with their willingness to reuse greywater.

Table 4.18: Pearson Chi Square test for Greywater storage containers and willingness to reuse greywater

	Value	df	Significance (*p*)
Pearson Chi-Square	399.587[a]	4	<0.001
Likelihood Ratio	162.677	4	<0.001
N of Valid Cases	307		

a. 6 cells (66.7%) have expected count less than 5. The minimum expected count is 0.01.
0.05 significance level.

4.5.6. The quantity of greywater generated

It is not always easy for everyone to keep the record of the water they use daily but some do measure the liters they use per day. Most of the respondents (43%) generate between 51-100 liters of greywater per day while 26% of the respondents generate less than 50 liters per day.

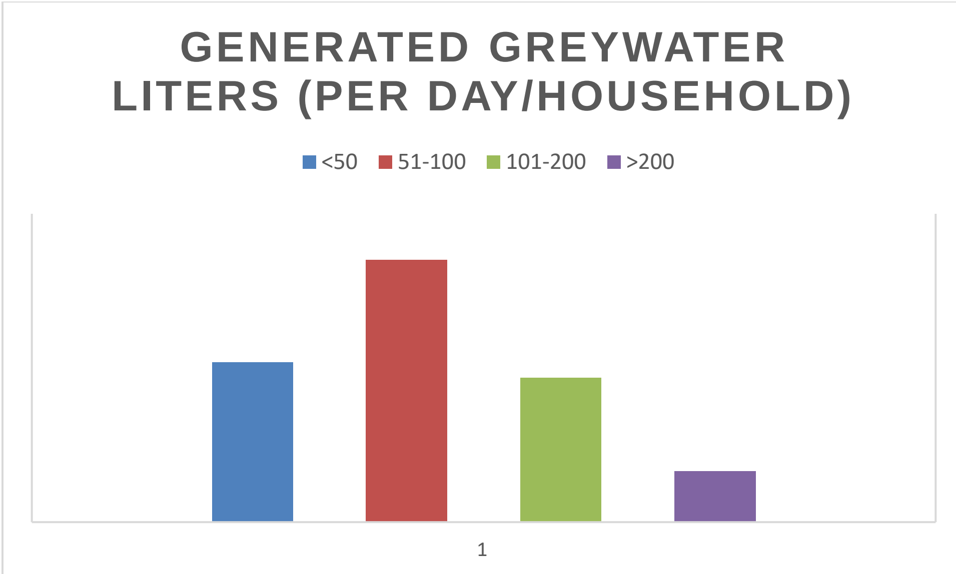

Figure 4.21: Quantity of generated greywater

Respondents who generated 101-200 liters per day made a percentage of 23%, followed by respondents generating greater than 200 liters per day at the lowest percentage of 8% (Figure 4.21). The generated quantity of greywater can vary greatly between different households within one community and depends on different factors (Al-Mashaqbeh *et al*., 2012). In general, the volume of greywater accounts between 50% and 80% of the domestic household water uses (Burnat and Eshtaya, 2010; Redwood, 2008; Eriksson *et al*., 2002). Faruqui and Al-Jayyousi (2002) reported that the domestic generated greywater volume in Jordan is estimated at about 50 liters per capita per day. Andreadakis *et al*. (2015) reported that in Greek households per capital per day greywater generation was 98.1 liters. Oteng-Peprah *et al*. (2018) indicated that the amount of greywater produced in a household can vary greatly ranging from as low as 15 L per person per day for poor areas to several hundred per person per day. The authors further opined that factors that account for such huge disparities are mostly linked to geographical location, lifestyle, climatic conditions, and type of infrastructure, culture and habits.

Pearson Chi Square test was performed to find out if the quantity of generated greywater influence greywater reuse. According to Pearson Chi Square test, there is association between the quantity of greywater generated and the willingness to reuse greywater, $X^2 = 312.482$, $p< 0.001$ (Table 4.19). This means that there was influence between the amount of greywater generated and the households' willingness to reuse greywater.

Table 4.19: Pearson Chi Square test for Quantity of generated greywater and willingness to reuse greywater

	Value	df	Significance (*p*)
Pearson Chi-Square	312.482[a]	4	<0.001
Likelihood Ratio	159.014	4	<0.001
N of Valid Cases	307		

a. 5 cells (55.6%) have expected count less than 5. The minimum expected count is 0.02.
0.05 significance level.

4.5.7. Experience of greywater reuse

Experience is practical contact with and observation of facts or events (Eprikyan, 2017). Greywater reuse is very beneficial if one wants to save freshwater and to lower the freshwater bills. However, not everyone or every household reuse their greywater or have reused their greywater before. Figure 4.22 shows the percentages of Ga-Thoka households who have reused greywater before and those who have never reused their greywater.

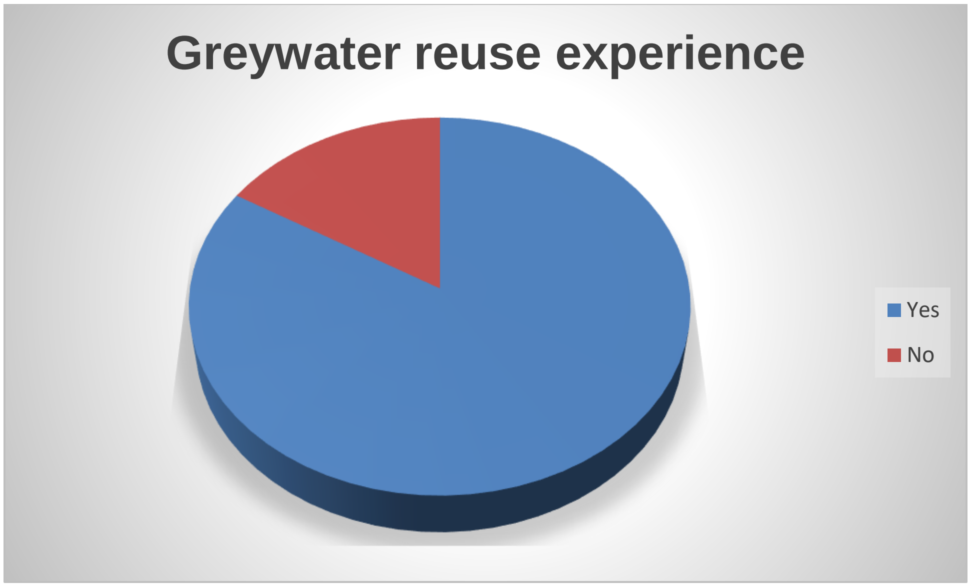

Figure 4.22: Greywater reuse experience

The study revealed that 84% of the respondents had experience in greywater reuse. This may have happened at different cases for different purposes according to individual preference of greywater reuse. It was only 16% of the respondents who said they have never reused greywater for any purpose. Previous studies reported that respondents had experience in reusing greywater for irrigating their home gardens, ornamental plants, fruit trees, lawns and flushing toilets (Mashabela, 2015; Radingoana *et al*., 2019).

Respondents gave reasons for their answer to whether they have ever reused greywater in their household or not. Most households reused greywater before only because they grew up finding their families reusing greywater, some reuse it because they really know that it helps them save their freshwater. Those who have never reused their greywater before indicated that it was because they believe greywater is dirty and can get them sick. Pearson Chi Square test was performed to find out if the experience on greywater reuse influence greywater reuse. According to Pearson Chi Square test, there is association between greywater reuse experience and the willingness to reuse greywater, X^2 = 614.000, $p < 0.001$ (Table 4.20). The households' experience on the reuse of greywaterhad influence or relationship with their willingness to reuse greywater.

Table 4.20: Pearson Chi Square test for Greywater reuse experience and willingness to reuse greywater

	Value	df	Significance (*p*)
Pearson Chi-Square	614.000[a]	4	<0.001
Likelihood Ratio	166.496	4	<0.001
N of Valid Cases	307		

a. 6 cells (66.7%) have expected count less than 5. The minimum expected count is 0.00.
0.05 significance level.

4.5.8. Greywater reuse purposes

Different people use greywater differently while some do not use it at all. Figure 4.23 reveals that, a higher percentage (52%) of Ga-Thoka village households reuse their greywater for irrigation among other uses. Some of the households use their greywater for more than one purpose such as irrigating and flushing toilets, irrigation and washing cars, and flushing toilets and washing their cars while there are others who reuse their greywater by irrigating, washing cars and flushing toilets in their households.

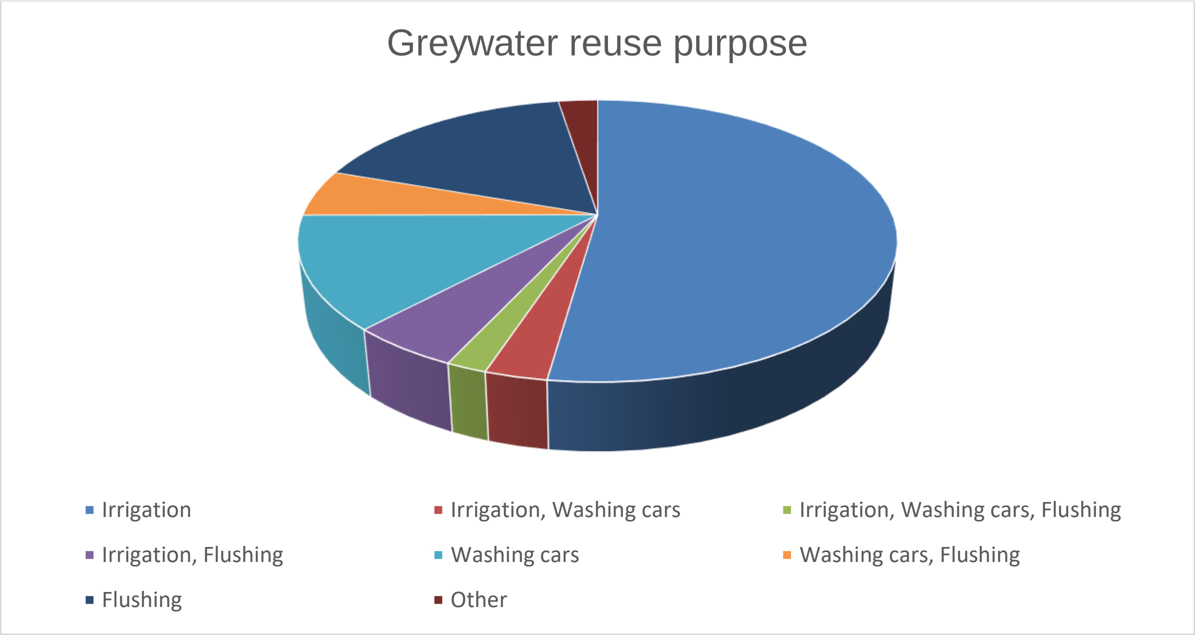

Figure 4.23: Greywater reuse purpose

Respondents who use their greywater for flushing toilets made up 17% and it was found that those who use their greywater to wash only their cars were making a 13% contribution. Some respondents perform several duties with their greywater. There were respondents who use their greywater for irrigation, washing their cars and flushing their toilets and they only made up 2% while respondents who use greywater for irrigation and flushing toilets made 5%. The respondents who used their greywater for washing cars and flushing toilets contributed 5% while those who used their greywater for irrigation and car washing made 3%. As there could be many uses of greywater, it was found that 3% of the participants use their greywater for other uses other than the mentioned ones. The results of this study are in line with Mashabela (2015) who found that most of the respondents in the study she conducted, used greywater for irrigation and other respondents used their greywater for toilet flushing, however while some respondents did not reuse their greywater.

Within the 52% of the respondents who reused their greywater for irrigation, they irrigated their lawns, ornamental plants, food crops (sweet potatoes, spinach, carrots, beetroots, cabbage), fruit plants and others just irrigated plants they grew for shade purposes. Pearson Chi Square test was performed to find out if greywater reuse purpose influence greywater reuse. According to Pearson Chi Square test, there is association between greywater reuse purpose and the willingness to reuse greywater, $X^2 = 307.000$, $p < 0.001$ (Table 4.21). The purpose greywater reuse serve in Ga-Thoka village households was found to have an influence on the willingness to reuse greywater.

Table 4.21: Pearson Chi Square test for Greywater reuse purpose and willingness to reuse greywater

	Value	df	Significance (*p*)
Pearson Chi-Square	307.000[a]	8	<0.001
Likelihood Ratio	153.187	8	<0.001
N of Valid Cases	307		

a. 12 cells (80.0%) have expected count less than 5. The minimum expected count is 0.00.
0.05 significance level.

4.6. Determine the awareness and perceptions of the Ga-Thoka village households on reuse of greywater.

The increase in socio-economic developments of South African communities has led to an overall increase in water demand for various purposes. The potential of greywater to supplement freshwater resources, provide reliable water services in remote or environmentally sensitive locations among others and has increased the global courage to reuse greywater. The potential beneficial use of greywater is irrigation which can conserve freshwater resources and improve quality of life.

Researchers at the Zuckerberg Institute for Water Research at Ben-Gurion University of the Negev have determined that, greywater is safe for irrigation and does not pose a risk for gastrointestinal illness or water-related diseases (Science Daily, 2015). When households were asked if they could eat food crops grown from greywater, 27% of them did not answer the question while 17% said; "*Ke mang a ka jang dijo tsa meetse a go* *hlapa ruri? Gape e jo ba go ja ditshila moo*". Meaning they could not eat such food crops because they believe that greywater is dirty making the food crops unhealthy. Fifty-six percent (56%) of the households said they could eat food crops grown from greywater because they do not see any difference between those grown from greywater and those grown from freshwater as long as they are cooked before they are eaten. With their direct words they said, "*Ga ke bone bothata felo ka go ja dijo tsa go tsheletswa ka meetse a ditshila, ka gobane re ja dienywa le merogo eseng meetse ao. Le tsona tsela re di rekang a rena bohlatse bja gore go somisitswe meetse a go hlweka eupsa re gare re a phela"*.

Ga-Thoka village respondents replied that they can really reuse their greywater if they are given enough and relevant information on the reuse of greywater. The households that reuse their greywater, really reuse it with passion maybe because they know the benefits and advantages of greywater reuse and some have just adopted it as a norm from their elders.

4.6.1. Importance of greywater

Households were asked if they knew the importance of greywater in their lives in general, and the figure below presents the results.

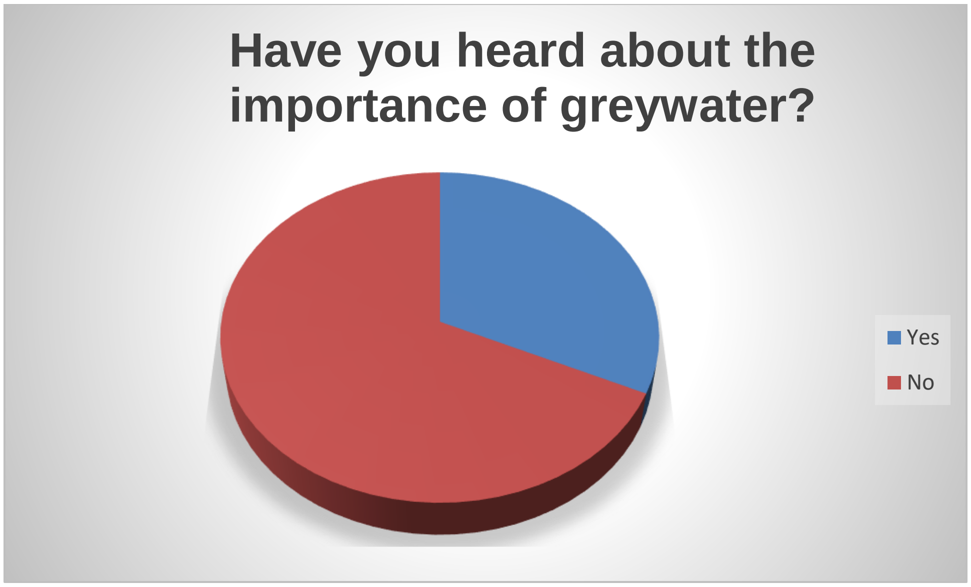

Figure 4.24: Knowledge of greywater importance

It was only 32% of the households who said they know about the importance of greywater and the other 68% of the respondents said they do not know the importance of greywater (Figure 4.24). Greywater plays important roles in agriculture and the environment. The use of greywater in agriculture fits in well with the concepts of Ecological Sanitation to prevent pollution and it can also act as a fertilizer and therefore be beneficial to the garden through sulphates and nitrates from soap and other residue (Rodda *et al*., 2010). In the economical sector, it was reported that families that adapted to greywater reuse were able to reduce food expenditures by consuming their garden produce in Jordan (Al-Jayyousi, 2004). This was supported by Mashabela (2015) who reported that community members were able to sell their vegetables, fruits and trees grown from greywater to other people in order to generate an income.

Pearson Chi Square test was performed to find out if knowledge of greywater influences its reuse. According to Pearson Chi Square test, there is association between the knowledge of greywater importance and the willingness to reuse greywater, X^2 = 313.822, $p < 0.001$ (Table 4.22). Knowledge (knowing/ not knowing) of the importance of greywater by Ga-Thoka village households had influence on their willingness to reuse greywater.

Table 4.22: Pearson Chi Square test for Knowledge of greywater importance and willingness to reuse greywater

	Value	df	Significance (*p*)
Pearson Chi-Square	313.822[a]	4	<0.001
Likelihood Ratio	159.148	4	<0.001
N of Valid Cases	307		

a. 5 cells (55.6%) have expected count less than 5. The minimum expected count is 0.02.
0.05 significance level.

4.6.2. Greywater information

Information is knowledge communicated or received or learned concerning a particular fact or circumstance (Rapple, 2008). For the community to be aware of their surroundings, information should be published to them in the media they can access. As not everyone knew what greywater was or its importance, households were further asked if they get enough information about greywater. Figure 4.25 presents their responses to the question.

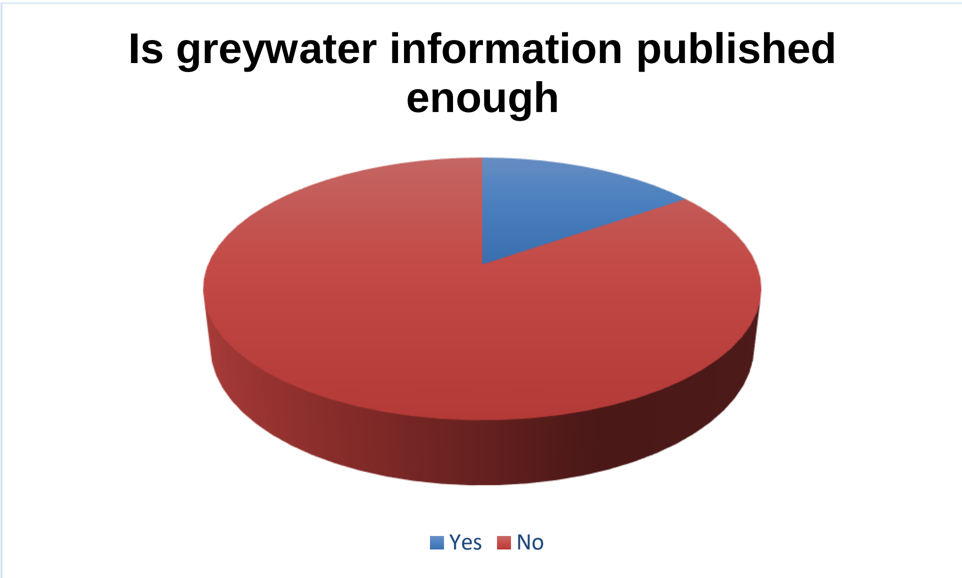

Figure 4.25: Greywater information

It was only 15% of the respondents that said the information about greywater is published enough and 85% said that the greywater information is not published enough for their reach. The 15% of the respondents that has enough information about greywater might be those in schools and who get taught about it at schools.

Respondents highlighted books and internet as the sources of information on the importance of greywater. However, they suggested that for them to really reach the information on the importance of greywater, the information should be published on radios, televisions, newspapers and pamphlets. Greywater information and its use for irrigation and other purposes have been reported in relatively high-income, developed countries such as USA, UK, Australia, Germany and Sweden (Roesner *et al*., 2006), and in less developed, low-to-middle income countries such as Costa Rica, Jordan, Malaysia, Mali, Nepal, Palestine and Sri Lanka (Morel and Diener, 2006).

Pearson Chi Square test was performed to find out if greywater information influence greywater reuse. According to Pearson Chi Square test, there is association between greywater information and the willingness to reuse greywater, X^2 = 307.000, $p < 0.001$ (Table 4.23). Lack of information on greywater had influence on the willingness to reuse greywater by Ga-Thoka village households.

Table 4.23: Pearson Chi Square test for Greywater information and willingness to reuse greywater

	Value	df	Significance (*p*)
Pearson Chi-Square	307.000[a]	2	<0.001
Likelihood Ratio	158.360	2	<0.001
N of Valid Cases	307		

a. 3 cells (50.0%) have expected count less than 5. The minimum expected count is 0.07.
0.05 significance level.

4.6.3. Provincial Department of Human Settlement, Water and Sanitation'svisitation to Ga-Thoka village

The provincial department of Human Settlement, Water and Sanitation has never visited Ga-Thoka village to give them information, awareness or to educate them about greywater, its importance and uses. The participants were asked if the department has ever visited their area. All the respondents said that the department has never visited their village.

4.6.4. Legal reuse of greywater

Almost everything is governed by the law in South Africa. Respondents were asked if the reuse of greywater is legal or not. Figure 4.26 below shows the response to the question.

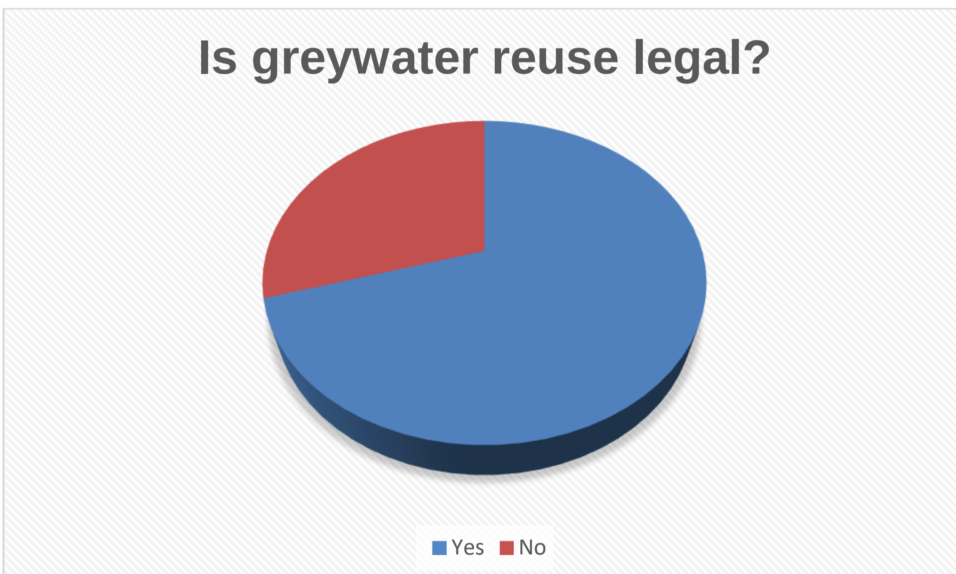

Figure 4.26: Greywater legal use

Seventy percent (70%) of the respondents said that the reuse of greywater is legal while the other 30% said that the reuse of greywater is illegal. According to Rodda *etal*. (2011), the existing legislation in South Africa does not specifically exclude use of greywater for irrigation, but there are inconsistencies which arise from the absence of a clear definition of greywater. Carden *et al*. (2007) reported that some local authorities, e.g., Cape Town Local Municipality has introduced policies and by-laws which provide guidance relevant to the management and use of greywater for irrigation, either explicitly or implicitly, however, the status of such guidance remains in doubt if the legislative status of greywater use is not clarified.

Pearson Chi Square test was performed to find out if the legal use of greywater influence greywater reuse. According to Pearson Chi Square test, there is association between greywater reuse being legal or not and the willingness to reuse greywater, X^2 = 245.096, p< 0.001 (Table 4.24). Greywater reuse being legal or not legal influence the Ga-Thoka village households' willingness to reuse greywater.

Table 4.24: Pearson Chi Square test for Greywater legal use and willingness to reuse greywater

	Value	df	Significance (p)
Pearson Chi-Square	245.096[a]	2	<0.001
Likelihood Ratio	110.974	2	<0.001
N of Valid Cases	307		

a. 3 cells (50.0%) have expected count less than 5. The minimum expected count is 0.06.
0.05 significance level.

4.6.5. Intentions of reusing greywater

Intention is a determination or plan to do a specific thing (Blackstone, 2012). Any perception people have on a particular practice, determines their reaction towards that practice. Respondents were asked if they would reuse greywater in their households and responses are presented on figure 4.27.

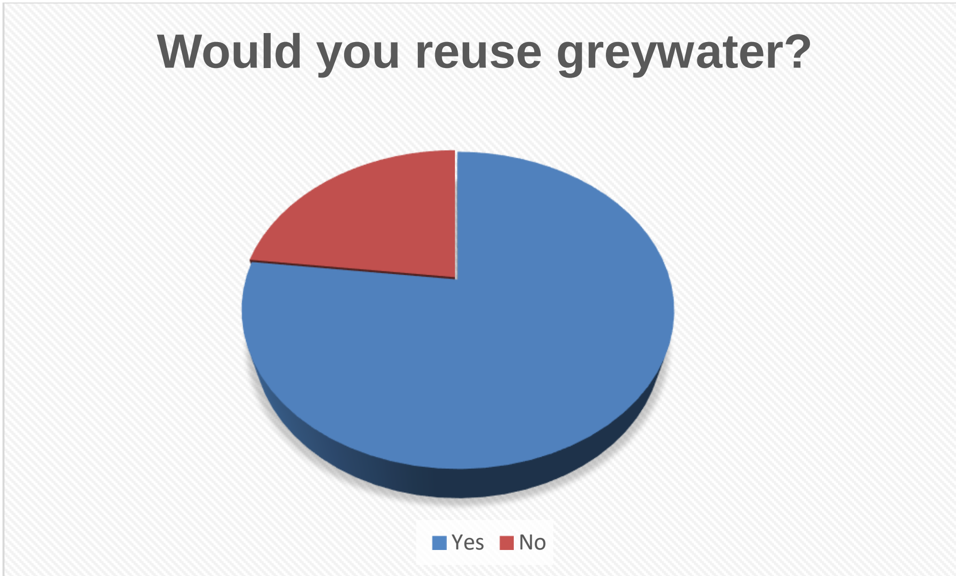

Figure 4.27: Greywater reuse intentions

On the question of whether respondents would reuse greywater in their households, twenty-three percent (23%) of the respondents said that they would not reuse greywater in their household and seventy-seven percent (77%) of the households said that they would reuse greywater in their households.

The 23% of the respondents who said they would not reuse greywater in their households said it is because greywater is dirty and would as such put their health at risk. Respondents who said they would reuse greywater in their households (77%) said because it would help them save freshwater for other uses that only requires potable water and it would also help to conserve freshwater resources for future use.

Public attitudes towards water reuse are highly influenced by perceived health risk, religious prohibition, political issues, and the degree of human contact with recycled water (Bakare *et al*., 2017). The investigated factors in this study had influence in the households' intention to reuse greywater, it was found that Ga-Thoka village households do and are willing to reuse their greywater (77%). Their intention is also influenced by lack of proper sanitation facilities (sewage systems) where households have nowhere to take their greywater to but just to reuse it in order to reduce/ avoid wastewater filling up their streets and exposing them to some waterborne diseases.

Several studies have been conducted to assess public perception towards greywater reuse in different parts of the world using different strategies. These strategies include interviews, questionnaires, focus group discussions, informal discussions and other equally good social surveys. Most of these surveys identified clear support for the concept of greywater reuse as an environmentally sustainable method of protecting freshwater resources and pollution prevention. It has been reported by several studies that the highest acceptability of greywater reuse schemes are for non-potable uses (Marks, 2004; Dolnicar, 2006; Friedler and Hadari, 2006; Hurliman and McKay, 2007).

4.6.6. Preference to consume greywater irrigated food crops

Everyone has their own preference when it comes to certain things. Not everything that can be considered as normal or harmless by the society will be regarded as such by everyone. The same applies to the consumption of food crops irrigated using greywater. Figure 4.28 shows how households perceive the consumption of greywater irrigated food crops.

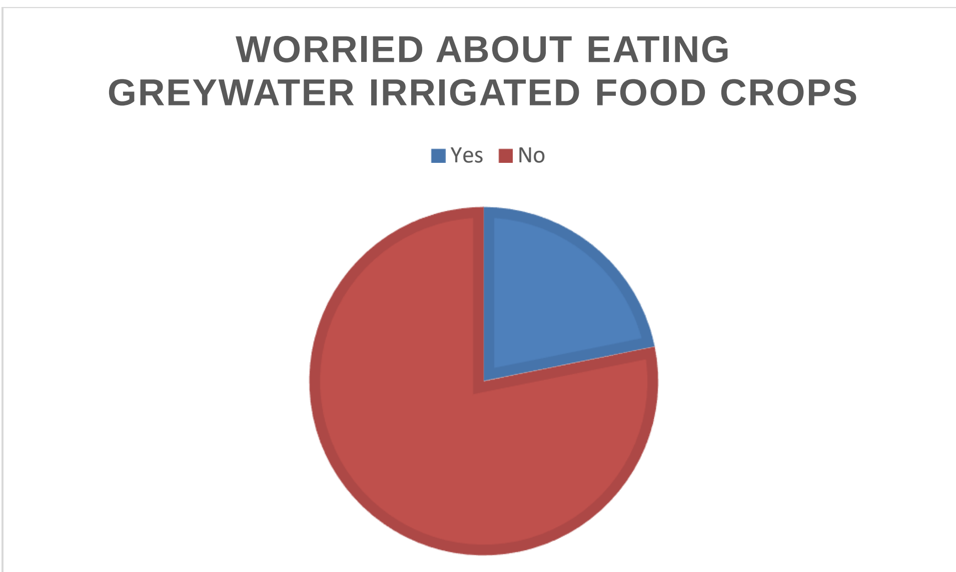

Figure 4.28: Consumption of greywater irrigated food crops

Twenty-two percent (22%) of the households were worried that their families might get sick from eating the food crops grown and irrigated using greywater. Seventy-eight percent (78%) of the respondents said that they are not worried that their families might get sick from eating/consuming food crops irrigated with greywater. They believed that if the food crops are cooked before consumption, then any pathogen that would cause harm or sickness would be dead and will have no effect on them and their families.

Respondents were asked about environmental impacts from reusing greywater. It was only 3% of the respondents who said they have observed the negative environmental impacts caused by the reuse of greywater. They mentioned that they have observed soil appearance change where greywater has been reused several times in a week especially if the greywater is from bathing. Some mentioned that bad smell occurs if one kept greywater for long (days) before reusing it, then the time one decides to reuse it, they are confronted by the bad odour of the greywater. None of the respondents ever had their neighbours complaining about the above mentioned negative environmental impacts of greywater reuse. According to Finley *et al*. (2009), the reuse of untreated greywater does hold risks to crops, soil and human consumers, which include the potential accumulation of pathogens, metals and organic chemicals in the soil and/or in plants. The effects of greywater irrigation on several conventional crops such as tomato, carrot, lettuce, red pepper, green pepper and swiss chard were investigated in previous studies (Finley *etal*., 2009; Rodda *et al*., 2011; Misra *et al*., 2011).

Pearson Chi Square test was performed to ascertain if the preference to eat greywater irrigated food crops influence greywater reuse. According to Pearson Chi Square test, there is association between preference to eat greywater irrigated food crops by the households and the willingness to reuse greywater, $X^2 = 356.705$, $p< 0.001$ (Table 4.25).

Table 4.25: Pearson Chi Square test for Consumption of greywater irrigated food crops and willingness to reuse greywater

	Value	df	Significance (*p*)
Pearson Chi-Square	356.705[a]	4	<0.001
Likelihsood Ratio	161.492	4	<0.001
N of Valid Cases	307		

a. 6 cells (66.7%) have expected count less than 5. The minimum expected count is 0.02.
0.05 significance level.

4.7. Summary of the chapter

This chapter outlined the introduction of the chapter, demographics, water reuse, quality of greywater, awareness and perceptions on reuse of greywater.

CHAPTER 5: SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

The previous chapter presented the results and discussion of the study's findings to meet the aim of the study which was to evaluate the potential of greywater reuse in Ga-Thoka village. Every study deserves to have a conclusion based on the factors studied and analysed. This chapter outlines the summary of the study, conclusions, and the recommendations.

5.2 Summary

This section provides a summary of the crucial findings of the study based on the objectives. The objectives were to identify sources of freshwater and nature of potable water supply, analyse quality of greywater from household, establish the potential of greywater reuse by Ga-Thoka village households and to investigate the awareness and perceptions on the reuse of greywater by Ga-Thoka village households.

5.2.1 Identifying sources of freshwater and nature of potable water supply.

The highest percentage of the households had their freshwater/potable water from taps while the least percentage relied on rivers and dams as their sources of freshwater. Most households travelled less than 400m to fetch their water. Households who used about 100 liters of water per day made a higher percentage than the other given quantities. Water is not always available in the village. A smaller percentage of the households said that the available water is not sufficient for their daily use.

5.2.2 Analysing the quality of greywater from households.

Ninety-three (93) greywater samples were collected from the households and taken to Capricorn Water Laboratories for water characteristics analysis. The samples were analysed for physical and aesthetic characteristics, anions, and cations. The greywater was found to have some inorganic characteristics and metals. In terms of physical and aesthetic characteristics, greywater from the kitchen had high colour reading than the other two sources (bathroom and laundry). Laundry greywater had high turbidity and pH. Greywater from the bathroom dominated with electrical conductivity and total dissolved solids. Greywater from the bathroom had highest concentrations of inorganic characteristics (fluoride, chloride, bromide and sulphate) compared to that from the kitchen and laundry. However, bathroom and laundry greywater had the same amount of nitrates which were higher than the kitchen greywater. Greywater from the laundry had highest concentration of metals such as potassium, calcium, sodium, zinc, lead, manganese aluminium, chromium, copper and iron than kitchen and bathroom sources. Bathroom greywater had the highest concentration of magnesium than the other two sources (kitchen and laundry)

5.2.3 Establishing the potential of greywater reuse.

A higher percentage of Ga-Thoka village households had knowledge of what greywater is. A higher percentage of respondents generate greywater. Laundry was found to be the greater source of greywater in households. The households directed their greywater to the garden for irrigation. Most of Ga-Thoka village households used buckets as storage containers for their greywater. The amount of greywater generated by the households corresponds with the quantity of greywater they used per day. A higher percentage of households generated about 100 liters of greywater per day. The respondents had experience in reusing greywater in their households and they reuse their greywater for irrigation.

5.2.4 Investigating the awareness and perceptions on the reuse of greywater.

Most of the respondents had no knowledge about the importance of greywater and they also highlighted that the information about greywater is not published enough for their reach. The provincial department of Human Settlement, Water and Sanitation has never visited Ga-Thoka village for the purpose of educating residents about greywater use and its importance. The respondents do not know if the reuse of greywater is legal or not. However, they have intentions of reusing their greywater. Majority of the respondents have intentions of reusing greywater, they are not prepared to eat food crops for as long as they are cooked.

Conclusions

- There are different sources of freshwater at Ga-Thoka village such as taps, boreholes, reservoirs, etc.
- There is a higher generation of greywater at Ga-Thoka village.
- All the three sources of greywater at Ga-Thoka village (kitchen, bathroom, laundry) had concentrations of inorganic characteristics and metals (in different concentrations).
- Ga-Thoka village households mostly reused their greywater for irrigation.
- Households reused their greywater as “raw” as it was without any means of cleaning it.
- Soil change (change in colour and texture) caused by bathroom greywater was observed.
- It was concluded that the demographics, awareness and water resources of Ga-Thoka village households influenced their intention and willingness to reuse greywater for different purposes (conceptual framework) and it is recommended to the households that they use more of greywater than freshwater on the activities that do not strictly require freshwater.

Recommendations

- The households should reuse their greywater not only for irrigation but also for washing, toilet flushing and yard cleaning (washing walls and pavements).

- It is recommended that households from Ga-Thoka village should reuse their greywater for irrigation of food crops that they will cook before eating.
- The households should practice greywater cleaning mechanisms such as sand filtering to avoid soil effects caused by greywater irrigation.
- It is recommended by the study that the Department of Human Settlement, Water and Sanitation use the results in this study to intensify the on-site reuse of greywater.
- The study recommends to the Department of Agriculture, Land Reform and Rural Development to find more ways of sustainable reuse of greywater to help in conserving water resources.
- It is recommended for future studies/researchers to evaluate the relationship/ effect of culture and religion on the willingness to reuse greywater by respondents.
- The study recommends that future studies focus on the implementation/availability of greywater treatment technologies in rural and urban areas.

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APPENDICES

Faculty of Science and Agriculture

10/12/2019

NAME OF STUDENT:	Sekgobela MR
STUDENT NUMBER:	201813208
DEPARTMENT:	Geography and Environmental Studies
SCHOOL:	Agricultural and Environmental Sciences
QUALIFICATION:	MSCA01

Dear Ms Sekgobela

FACULTY APPROVAL OF PROPOSAL (PROPOSAL NO. 172 OF 2019)

I have pleasure in informing you that your **masters** proposal served at the Faculty Higher Degrees Committee meeting on **24 October 2019** and your title was approved as follows:

"**An assessment of Domestic greywater reuse: A case study of Ga-Thoka Village in Polokwane Local Municipality, South Africa**"

Note the following: The study

Ethical Clearance	Tick One
Requires no ethical clearance Proceed with the study	
Requires ethical clearance (Human) (TREC) (apply online) Proceed with the study only after receipt of ethical clearance certificate	√
Requires ethical clearance (Animal) (AREC) Proceed with the study only after receipt of ethical clearance certificate	

Yours faithfully

Prof P Masoko
Secretariat: Faculty Higher Degrees Committee

CC: Dr MHN Mollel
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TURFLOOP RESEARCH ETHICS COMMITTEE

ETHICS CLEARANCE CERTIFICATE

MEETING: **24 April 2020**

PROJECT NUMBER: **TREC/76/2020: PG**

PROJECT:

Title:	An Assessment of Domestic Greywater Reuse: A Case Study of Ga-Thoka Village in Polokwane Local Municipality, South Africa
Researcher:	MR Sekgobela
Supervisor:	Dr MHN Mollel
Co-Supervisor/s:	Mrs JM Letsoalo
School:	Agricultural and Environmental Sciences
Degree:	Master of Science in Geography

PROF P MASOKO
CHAIRPERSON: TURFLOOP RESEARCH ETHICS COMMITTEE
The Turfloop Research Ethics Committee (TREC) is registered with the National Health Research Ethics Council, Registration Number: **REC-0310111-031**

Note:

i) **This Ethics Clearance Certificate will be valid for one (1) year, as from the abovementioned date. Application for annual renewal (or annual review) need to be received by TREC one month before lapse of this period.**

ii) **Should any departure be contemplated from the research procedure as approved, the researcher(s) must re-submit the protocol to the committee, together with the Application for Amendment form.**

iii) **PLEASE QUOTE THE PROTOCOL NUMBER IN ALL ENQUIRIES.**

Finding solutions for Africa

Bakgaga ba Mothapo Traditional Council

P.O Box 22

Tholongwe

0734

HEADMAN RAMOGALE

REQUEST FOR PERMISSION TO CONDUCT A RESEARCH STUDY

Mothapo Tribal Authority

I am writing to request a permission to conduct a research study at your area. I am currently enrolled in the Department of Geography and Environmental Studies at the University of Limpopo (UL) for a Master's degree under the supervision of Prof. M.N.H Mollel and co-supervision of Dr. J.M Letsoalo. The study is entitled: An assessment of domestic greywater reuse: A case study of Ga-Thoka village in Polokwane Local Municipality, South Africa. I therefore need to collect data from Ga-Mothapo, Ga-Thoka. Interested residents who volunteer to participate will be given consent forms to be signed and returned to the researcher. They will be reassured that they can withdraw their permission at any time during this project without any penalty. There are no foreseeable risks in participating in this study.

The participants will not be disadvantaged in anyway. The results of the survey will be used for the dissertation project and the participants will remain confidential and anonymous. Should the study be published, only the pooled results will be documented. Your approval is required for me to continue with the study.

Yours Sincerely,

Sekgobela M.R

0766586341

201813208@ul.ac.za

BAKGAGA BA GA MOTHAI

Supported by:

Prof. M.N.H Mollel

Tel.: 015268

Email: huruma.mollel@ul.ac.za

Dr. J.M. Letsoalo

Tel,.: 0152682324

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APPROVED BY: MASOBE RAMOGALE ....(Name in print)

....

....................(Signature) 2020-07-16

Questionnaire

AN ASSESSMENT OF DOMESTIC GREYWATER REUSE: A CASE STUDY OF GA-THOKA VILLAGE IN POLOKWANE LOCAL MUNICIPALITY, SOUTH AFRICA.

My name is Sekgobela M. R., a Masters student at the University of Limpopo Turfloop Campus. I am conducting my research on: **An assessment of domestic greywater reuse at Ga-Thoka village in Polokwane Local Municipality, South Africa**, as part of the requirements to complete my studies. You have been selected in a systematic random sampling to be part of the representative sample of the Ga-Thoka village households. Participation is voluntary and participants can withdraw at any time. I guarantee that your responses will be completely and strictly confidential and no information will be disclosed.

Section A: Demographic characteristics

1. Gender

a. Male	b. Female

2. Age (years)

a. 15-25	b. 26-35	c. 36-45	d. 46-55	e. 56+

3. Marital Status

a. Single	b. Married	c. Divorced	d. Widowed

4. Educational level

a. None	b. Primary	c. Secondary	d. Tertiary

5. Employment status

a. Unemployed	b. Employed	c. Self employed

6. Household size (people)

a. <2	b. 3-4	c. 5-6	d. 7-8	e. >8

7. Household income (in Rands)

a. < 2 000	b. 2 001-4 000	c. 4 001-6 000	d. > 6 001

Section B: Greywater reuse

8. Where do you collect water from?

River	Dam	Home tap	Community tap	Borehole	Rain	Other(s)-specify

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9. How many community taps do you have in your area?

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10. How far is the water source from your home (in meters)?

a. 0-200	b. 201-400	c. 401-600	d. 601-800	e. >801

11. How much water do you use per day in your household (in liters)?

a. 50	b. 51-100	c. 101-150	d. 151-200	e. >200

12. What types of soaps, shampoos, detergents, etc. do you use in your household?

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13. Is the water always available?

a. Yes	b. No

14. Give reasons for your answer above.

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15. What are the main uses of your water?

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16. Is the water sufficient for your needs?

a. Yes	b. No

17. If no, what are the challenges of accessing sufficient water?

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18. Do you know what greywater is?

a. Yes	b. No

19. Do you generate greywater?

a. Yes	b. No

20. What are the sources of greywater in your household?

a. Dish washing	b. Laundry	c. Bathing/showering

21. Where is the greywater from the sources (above) drained to?

a. Sewage	b. Cesspool	c. Direct	d. Directly to the

system		collection and storage	garden

22. If direct storage, what type of container do you use?

a. Drums	b. Buckets	c. Cemented pit	d. Other(s)- specify

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23. How much greywater do you generate daily (in liters) in your household?

a. <50	b. 51-100	c. 101-200	d. >200

24. Have you ever reused greywater in your household?

a. Yes	b. No

25. Give reasons for your answer above.

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26. What do you reuse your greywater for?

a. Irrigation	b. Washing cars	c. Flushing	d. Other(s)- specify

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27. If you reuse greywater for irrigation, what do you irrigate?

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Section C: Awareness and Perceptions

28. Have you heard about the importance of greywater?

a. Yes	b. No

29. Do you think greywater reuse information is published enough?

a. Yes	b. No

30. What are the sources of information on the importance of greywater?

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31. Has the Department of Human Settlement, Water and Sanitation ever visited your area to teach you about greywater reuse as a water shortage coping mechanism?

a. Yes	b. No

32. Is it legal to reuse greywater?

a. Yes	b. No

33. Would you reuse greywater in your household?

a. Yes	b. No

34. Give reasons for the answer above.

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35. Are you worried that your family members might get sick from irrigating crops with greywater compared to irrigating with clean water?

a. Yes	b. No

36. Have you observed the following negative environmental impacts caused by the reuse of greywater?

a. Bad smell	b. Soil and vegetation appearance change	c. Other(s)- specify

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37. Have your neighbours complained about any of the above problems?

a. Yes	b. No

38. How much importance do you place on water conservation in your household?

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39. Have you always been sensitive to water conservation in your household?

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40. What do you think must be done to promote greywater reuse as a coping method to meet basic water needs in your area?

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THANK YOU!!!

Consent form

Consent form

Title of research project: An assessment of domestic greywater reuse: A case study of Ga-Thoka village in Polokwane Local Municipality, South Africa.

The study has been described to me in a language that I understand. My questions about the study have been answered. I understand what my participation will involve and I agree to participate of my own choice and free will. I understand that my identity will not be disclosed to anyone. I understand that I may withdraw from the study at any time without giving a reason and without fear of negative consequences or loss of benefits.

Participant's name………………………………

Participant's signature…………………………..

Date………………………………………………..