UNIVERSITY OF VENDA

SCHOOL OF ENVIRONMENTAL SCIENCES

ASSESSMENT OF THE USE OF CERAMIC WATER FILTERS MADE WITH SILVER NITRATE AS POINT-OF-USE WATER TREATMENT DEVICES IN DERTIG, NORTH WEST PROVINCE, SOUTH AFRICA.

NKOSINOBUBELO NDEBELE

18014884

A Master's dissertation submitted to the Department of Hydrology and Water Resources School of Environmental Sciences in partial fulfilment for the award of Master of Environmental Sciences Degree

Supervisor **Co-supervisors Prof J.O.**
Odiyo **1. Prof J.A. Smith**
2. Dr J.N. Edokpayi

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DECLARATION

I, Nkosinobubelo Ndebele, student number 18014884, hereby declare that this dissertation for the Master of Environmental Sciences degree at the University of Venda, submitted by myself, has not been previously submitted for a degree at this or any other institution. This is my work in design and execution, and all reference materials contained herein have been duly acknowledged.

Signature Date: 24/08/2020

I hereby certify that the above statement is correct.

We, the supervisors hereby attest that the above declaration is true.

Supervisor: Prof J.O. Odiyo Date: 24/08/2020

Date: 24/08/2020

Co-Supervisor: Prof J.A Smith

Co-Supervisor: Dr J.N Edokpayi Date: 24/08/2020

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DEDICATION

I dedicate this piece of work to my late parents Mr and Mrs P.C Ndebele who I’ll always love and strive to make proud.

ABSTRACT

Water borne diseases due to inadequate and unsafe drinking water is a global challenge that has led to a significant number of deaths and illnesses reported annually. These diseases are prevalent in less-developed countries, especially in rural areas where there is shortage of basic infrastructure and inadequate funds for piped water systems in individual households. Community members are forced to resort to collecting water from communal water points and later storing the water in containers for daily use. Recontamination of microbiologically safe drinking water during and after collection from the water source has been recognised as a problem; hence treating water at household level is one way to provide potable water for affected communities. The microbiological quality of household water may be improved by using point-of-use treatment technologies such as chemical disinfection, solar disinfection and ceramic water filters. Some of these technologies are expensive, less effective and difficult to implement in rural communities. This research thus focused on ceramic water filters and finding an appropriate method for silver application so as to produce filters that are effective in both the provision of clean drinking water and the release of silver levels that are safe for human consumption. An assessment of the efficiency of ceramic water filters made with silver nitrate as point-of -use water treatment device in Dertig Village, North West Province, South Africa was carried out. During production of filters made with silver nitrate, the filters undergo firing in an electric kiln and ionic silver is reduced to metallic nanopatches dispersed throughout the porous ceramic media. Both filters made with silver nitrate and conventional silver nanoparticles impregnated ceramic water filters were manufactured at the PureMadi Dertig Ceramic Filter Facility, South Africa. Resulting filters were evaluated and quantified for total coliform and *E. coli* removal as well as silver concentration in the effluent. Ceramic water filters made with silver nitrate had a high removal efficiency for total coliforms (94.7%) and *E. coli* (99.3%). A comparison of the performance of filters made with silver nitrate and silver nanoparticles in the provision of potable water was carried out and results showed that the different filters had similar levels of total coliform and *E. coli* removal, although the silver nitrate filters produced the highest average removal of 97.23% while silver nanoparticles filters produced the lowest average removal of 85.43%. Reasonable silver levels were obtained in effluent from all filters. Average effluent silver levels were 0.07±0.04mg/L, 0.6±1.10 mg/L and 0.8±1.0mg/L for 1 g, 2 g and silver nanoparticle filters, respectively (below the EPA and WHO standard of 100 mg/L). Because silver nitrate filters resulted in the lowest effluent silver concentrations, this could potentially increase the effective life span of the filter. A cost analysis of the process proved that it was cheaper to produce ceramic water filters using silver nitrate as the chemical can be purchased locally and also eliminates labour related costs. Thus, filters made using silver nitrate could potentially improve performance, reduce production costs, and increase safety of production for workers. The results obtained from this study will be applied to improve the ceramic filtration technology as point-of-use water treatment device in an effort to reduce health problems associated with microbial contamination of water stored at household level.

Key words: ceramic water filter, point-of-use (POU) water treatment technologies, silver nitrate, silver nanoparticles, water borne

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LIST OF ABBREVIATIONS AND ACCRONYMS

Ag_3N	Silver Nitride
AgCl	Silver Chloride
$AgNO_3$	Silver Nitrate
AgONC	Silver Fulminate
CBA	Cost Benefit Analysis
CFU	Colony Forming Unit
CIWEM	Chartered Institute of Water and Environmental Management
CMWG	Ceramic Manufacturing Working Group
DALY	Disability Adjusted Life Year
E. coli	*Escherichia coli*
EPA	Environmental Protection Agency
FIB	Faecal Indicator Bacteria
EDL	Electrodeless Discharge Lamp
EMB Agar	Eosin Methylene Blue Agar
FFA	Family Foundation of the Americas
GFAA	Graphite Furnace Atomic Absorption spectrophotometry

HCL	Hollow Cathode Lamp
HIV	Human Immuno Virus
OECD	Organisation for Economic Co-operation and Development
SANS	South Africa National Standards
UNICEF	United Nations Children's Emergency Fund
UV	Ultra Violet
WHO	World Health Organization

CHAPTER 1: INTRODUCTION

1.1 BACKGROUND

Access to clean, safe, and adequate amount of water is a fundamental human need and therefore a basic human right. Drinking water is a medium for microbes such as viruses, bacteria and protozoa to be transported and ingestion of such pathogens in water leads to the greatest water-related health risk and is a major cause of water borne diseases (Pruss-Ustun *et al*., 2008; WHO, 2011). Globally, over 800 000 people are estimated to die each year from diarrhoea and other water borne diseases as a result of contaminated drinking-water, the lack of proper sanitation, and poor hygiene (WHO, 2018).

Peterson *et al*. (2008) asserts that third world countries report the highest number of deaths related to waterborne diseases, more especially in rural areas. It is increasingly difficult for local governmental bodies to set up centralised water treatment plants and provide potable water via a piped distribution system due to inadequate funds and the lack of basic infrastructure in rural areas (Bates, 2012).

As under-developed countries continue to encounter water quality challenges, it is imperative to focus on the provision of safe drinking water rather than focusing on the provision of high-quality large volumes of water for all uses. Due to the low economic status in underdeveloped countries, options of low-tech water treatment should possess at least the following characteristics:

- A technology that is produced using locally available materials and labour
- A technology that is cost effective and easy to manufacture
- A technology that is easy to operate and socially acceptable so that users are willing to maintain it. This will enable it to last for its maximum possible lifetime (Contruvo and Sobsey, 2006).

Thus, more practical options for third world countries could include using proven point-of-use (POU) water treatment methods.

In rural South Africa, POU water treatment technologies are being widely promoted by the government and other organisations as an appropriate intervention for reducing the burden of water borne diseases. Ceramic water filters are examples of POU water treatment technologies that are being used by rural communities in South Africa. Currently, silver nanoparticles are introduced to these ceramic water filters to act as a disinfectant towards disease-causing pathogens.

With the advancement of material development, silver nanoparticles can be easily applied on solid materials for the inactivation of microorganisms in contaminated water (Nair and Pradeep, 2007). Studies have proven that silver nanoparticles possess excellent antibacterial characteristics (Matsumara *et al.*, 2003; Sondi and Salopek-Sondi, 2004). Silver nanoparticles have therefore been widely used to aid drinking water purification due to their broad spectrum of bactericidal activities (Stoimenov *et al.*, 2002; Cho *et al.*, 2005; Jain and Pradeep, 2005).

Regardless of the success that has been recorded in attempts aimed at the provision of potable water through the use of silver impregnated ceramic water filters, research is still ongoing to improve on previous concepts and discover more cost-effective methods that could be applicable particularly in marginalised areas with low economic status.

1.2 PROBLEM STATEMENT

Every continent around the world is affected by water scarcity. According to the United Nations (2017), about 65% of the world's population currently resides in areas that experience the challenge of water scarcity for at least one month in a year. A lack of water directly contributes to unsanitary living conditions which increases the transmission of many diarrhoeal diseases and poses a great burden on global public health. The World Health Organization (2013) reported that diarrhoeal diseases alone amount to an estimated 4.1% of the total Disability Adjusted Life Year (DALY) global burden of disease and also lead to the death of about 2 million people annually.

In numerous developing countries, water scarcity has prompted community members to collect water from communal sources which are either unimproved (for example, unprotected wells, unprotected springs, and rivers) or improved (for example, protected wells, boreholes and public standpipes) (WHO/UNICEF, 2000). These communal water sources are usually located far from the households, especially in rural areas. Families therefore have to travel long distances to fetch water and this may subsequently affect water quality. Rufener *et al*. (2010) asserts that after water collection, microbiological water quality will be strongly affected by both quality status at the source and handling practices of water during collection, transportation, and storage in the home. The absence of piped potable water supplies affects such communities. In some circumstances, even when a piped system is available in households, the major challenge is that water is not always available due to water rationing and water storage is a therefore a prerequisite (Edokpayi *et al*., 2018).

There are also instances whereby water at the source is not contaminated but due to occurrences happening during and after collection, the microbiological quality of water is compromised (Gundry *et al*., 2004). A study by Harris *et al*. (2013) explains the causal mechanisms of microbiological contamination of drinking water after collection from a communal water source. The study recorded the presence of faecal indicator bacteria immediately after filling of the water storage container at source and after extraction of water from the storage container in the household. Faecal indicator bacteria were also recorded with various water extraction containers such as cups. Additionally, *E. coli* strains were detected in stored drinking water but not in the source from which it was collected, highlighting the potential health risks of post-supply contamination. The results of the study confirm that storage containers and extraction utensils introduce microbial contamination to stored drinking water (Harris *et al*., 2013).

Water shortages in South Africa's North West district have forced the communities to resort to unsafe water sources. Communities in rural North West, such as Dertig, suffer from water rationing and only get running water during weekends. Only 5% of the Dertig households have piped water inside their dwellings. 95% of the inhabitants get water from community shared water points (Statistics South Africa, 2018). The community members then have to store large amounts of water in buckets so that the water is sufficient for use throughout the week. However, large families with about eight to twelve people, draw water from open wells and boreholes as the stored water cannot sustain them for the whole week. The quality of water in storage buckets may deteriorate due to recontamination, where proper hygiene is not practiced. Also, water drawn from open wells may not be wholly safe to drink as it might be contaminated by microbial organisms from both naturally occurring sources and human activities. Hence, the shortage of water in the Dertig area puts community members at risk of acquiring water borne diseases.

The government and other organisations are making efforts to counter incidences of water borne diseases that might arise due to water shortage in the North West Province.

PureMadi, an example of such an organisation, promotes the use of POU water treatment technologies by making and distributing ceramic water filters in the Dertig area, North West Province (PureMadi, 2018a). Currently, PureMadi applies silver nanoparticles to their ceramic water filters and despite the antibacterial nature of silver nanoparticles; they can become airborne easily due to their size and mass. Inhalation of silver nanoparticles by workers making the ceramic water filters puts them at risk of occupational respiratory exposure. Examples of health problems associated with the inhalation of silver nanoparticles include irritation of the cardiovascular and respiratory systems; asthma complications and chronic bronchitis (Quadros and Linsey, 2010).

Even though a number of studies have been conducted on the effect of conventional silver nanoparticles impregnated ceramic water filters in the removal of pathogenic microorganisms from drinking water, little is known on the effect of substituting silver nanoparticles with silver nitrate in the production of ceramic water filters, for the same purpose of providing clean potable water at household level.

1.3 MOTIVATION FOR THE STUDY

Simple water treatment schemes such as ceramic filtration and bio sand filtration are continuously under review so as to improve their efficiency in providing safe drinking water in areas of scarcity. Hence, the findings of the study might contribute to the body of knowledge on sustainable approaches aimed at preventing and reducing incidences of water borne illnesses.

The study will directly benefit PureMadi and other organisations promoting the ceramic filtration technology on whether using silver nitrate on the ceramic water filters is a more efficient and economically viable option compared to other methods that have been previously used in terms of improving the health of communities and ensuring environmental sustainability.

Since the study aims at establishing whether the use of silver nitrate impregnated ceramic filters is a feasible adaptation for providing safe drinking water to inhabitants in marginalised areas, the research will contribute to the appreciation of ceramic filtration by public health authorities such as the Department of Health and Local Municipalities. As such, the study will benefit the public as they will be educated about the importance of using such low cost water purification technologies in reducing incidences of water borne diseases.

1.4 OBJECTIVES

1.4.1 Main objective

To assess the efficiency of the use of ceramic water filters made with silver nitrate as point-of-use water treatment device.

1.4.2 Specific Objectives

1. To evaluate and compare the microbiological quality (total coliform and *E. coli* count) of water from ceramic filters made with silver nitrate and silver nanoparticles.

2. To determine how different concentrations of silver nitrate affect the quality of filtrate.

3. To investigate the economic benefit of replacing silver nanoparticles with silver nitrate in the ceramic filter technology

1.5 RESEARCH QUESTIONS

1. What is the microbiological quality and how does the quality (total coliform and *E. coli* count) of water from ceramic filters made with silver nitrate differ from that of ceramic filters made with silver nanoparticles?

2. How do different concentrations of silver nitrate affect the quality of filtrate?

3. What is the economic benefit of replacing silver nanoparticles with silver nitrate in the ceramic filter technology?

1.6 STUDY AREA

Dertig (means 'thirty' in Afrikaans. It is said that people who originally stayed in this area contributed thirty pounds each to buy pieces of land), is situated in the Bojanala District, North West Province, South Africa (Figure 1.1). Dertig is governed by the Moretele Municipality and its geographical coordinates are 25° 16' 45" South, 28° 13' 21" East (za.geoview.info). This area of study is conducive as it is where the PureMadi Dertig Ceramic Filter Facility is located (PureMadi, 2018a).

1.6.1 Population

Dertig has a total population of 2996 and 786 number of households (S.A Stats, 2018).

1.6.2 Weather conditions

The prevailing climate in Dertig is known as a local steppe climate. The area is semiarid and has a dry and grassy plain. There is little rainfall throughout the year whereby precipitation averages 459 mm per year. The highest rainfall is recorded during summer, in the month of January (88 mm) and the lowest rainfall is recorded in the month of June where there is no rainfall at all (saexplorer.co.za). The average annual temperature in the whole Moretele area is 19.7°C (climate-data.org). In summer, the average daily temperatures are 29.7°C whilst in winter the average daily temperatures are 20.6°C. The coldest month in that area is July where temperatures go as low as 2.9°C at night (saexplorer.co.za).

1.6.3 Distribution of water sources

The main water source in the Dertig area is a piped water system from Magalies Water. Due to water rationing, residents in the Dertig area suffer from 3-7 day water interruptions. Water rationing has therefore forced families to store enough water for usage during times when there is no running water from the taps. Secondary water sources in the Dertig area include groundwater, rain water and water from tanker trucks.

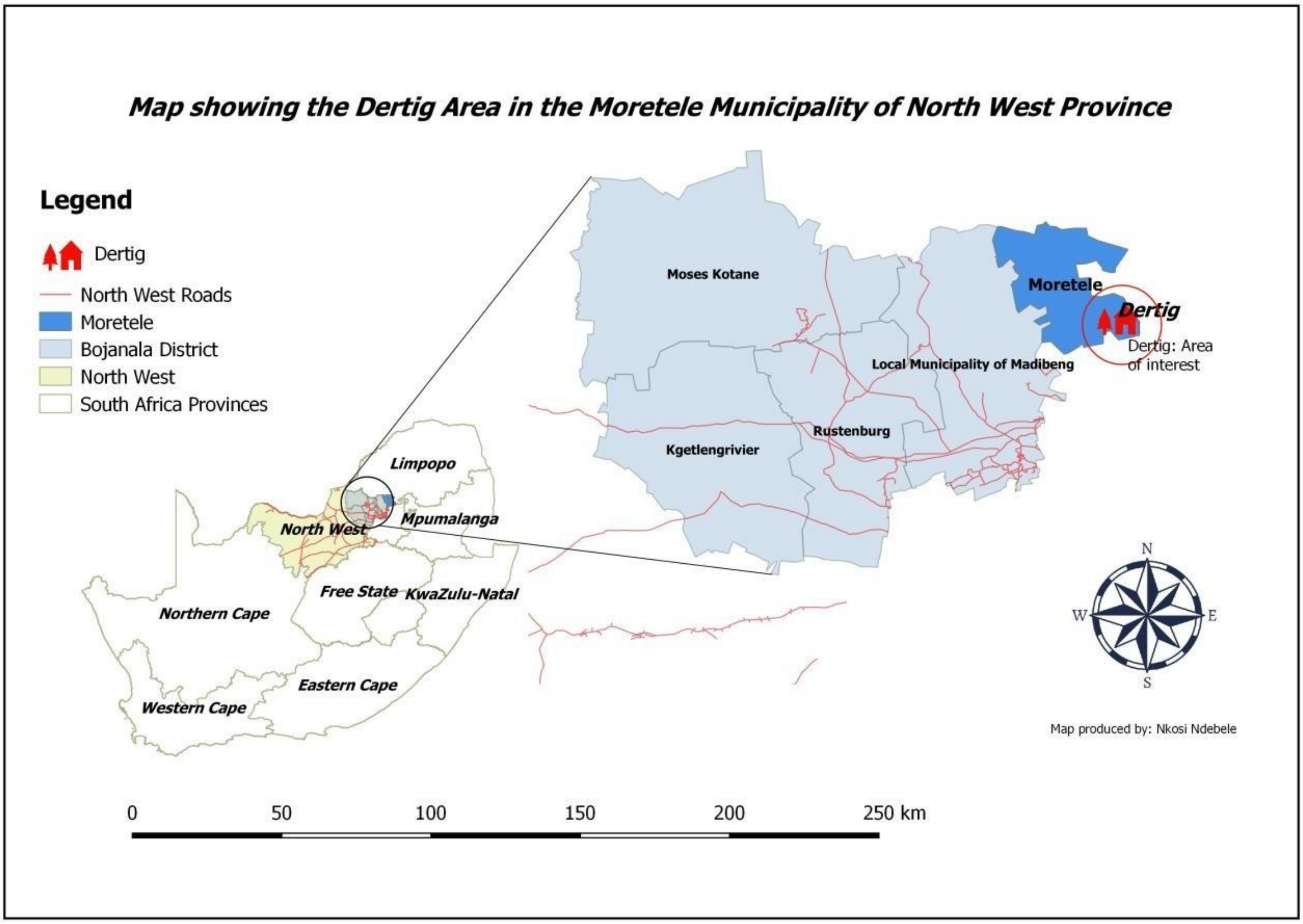

Figure 1.1: Map showing the study area

CHAPTER 2: LITERATURE REVIEW

2.1 INTRODUCTION

Poor drinking water quality is gradually becoming a leading problem in underdeveloped countries. In Africa, lack of clean and safe water increases the risk of diarrhoeal diseases and results in 115 deaths every hour (WHO, 2018). Drinking water sources are under increasing threat from contamination, which holds widespread consequences not only for public health but also for socio-economic development of various developing countries. An article by Amir (2016) states that health departments in third world countries invest over $7 million annually specifically for the healthcare of water borne diseases. Moreover, health problems associated with water borne diseases lead to the loss off huge amounts of money due to the countries' citizens failing to attend work and school.

The problems associated with the occurrence of water borne diseases in the developing world can be reduced through the installation of protected water sources such as boreholes and standpipes, which could possibly provide drinking water of better microbiological quality. Such communal water sources are usually located far away from the home and will require families to travel some distance to collect the water. Water quality at the source is usually higher than the quality of water in storage vessels due to possible contamination during collection, transportation, subsequent storage in water vessels and handling of the water (Too *et al*., 2016). In worst case scenarios, water stored in vessels for hours or even days increases the possibility of faecal contamination of water that previously was of good drinking water quality (Valerie, 2010; Subbaraman *et al*., 2013). A study by Wright *et al*. (2004) found that water contamination is greater at POU than at the source, and microbiological water quality deteriorates significantly from source to POU.

Despite the economic status in under-developed countries, the ultimate goal is to have treated piped water in every household as this will eliminate challenges associated with the collection of water at communal water sources. Having treated piped water is however expensive to implement and can take years to be a possibility in all third world country households (Jeffreys, 2012).

POU water treatment technologies are therefore a viable solution to the provision of clean drinking water in such communities with low economic status. There are a wide variety of household water treatment technologies depending on the location and resources; and these have been in existence for many years.

2.2 POINT-OF-USE WATER TREATMENT TECHNOLOGIES IN DEVELOPING COUNTRIES

POU water treatment technologies are methods or physical devices that are used for the purification of drinking water at household level. Because these technologies are mostly used in developing countries, ideally, they should be cheap to purchase and/or implement; be easy to use; require low maintenance and be made from locally available material (Bitton, 2014).

POU water treatment technologies take many different forms and these enable communities to disinfect their drinking water to eliminate disease-causing microbiological pathogens. There are some devices that could possibly remove the chemical and radiological aspects of drinking water, however the POU water treatment technologies are mainly used for the elimination of microbial pathogens.

POU water treatment technologies have the potential to fill the service gap in developing countries where piped water systems are difficult to implement and are currently not a possibility. These POU water treatment devices have the potential to result in enormous positive health impacts and lead to the reduction and elimination of water borne disease incidences that result from the consumption of contaminated drinking water. Besides water quality being compromised through the collection of water at communal water sources, piped water supply systems may also be microbiologically contaminated due to post-collection and post-treatment contamination during distribution. POU water treatment technologies can also be adopted in such instances. Tourists can also make use of such devices when travelling to areas with uncertain drinking water quality (Sobsey *et al*. 2008).

2.2.1 Types of point-of-use water treatment technologies in developing countries

- **Chemical disinfection**

Chemical disinfection is the most common type of POU water treatment method because it is effective, cheaper to purchase and easy to produce (Classen, 2005). Examples of chemical disinfection include chlorine gas and chlorine solution (hypochlorite); ozone gas; potassium permanganate; and metallic ions. Free chlorine is however the most popular form of chemical disinfection that is preferred in developing countries because of its affordable price and easy availability. Free chlorine is the widely used form of chemical disinfection which has been proven to remove 99.99% of enteric bacteria and viruses. Quick *et al*. (2002) has documented the impact of using chemical disinfection in reducing diarrhoeal diseases. Chlorine also provides a residual effect and due to this characteristic, recontamination of chlorine treated water is prohibited (Sobsey, 2008). A disadvantage of using chlorine is that microorganisms such as Cryptosporidium parvum oocysts are resistant to the chemical even at high doses (CDC, 2017). Another disadvantage of using chlorine is that most often, people do not like the taste and smell of the chemical. Like most POU water treatment technologies, chemical disinfection will be more effective in reducing microbial contamination of water when accompanied by extensive behaviour change in order to stimulate adoption and continued utilisation by households (Classen 2005).

- **Membrane filters**

Membrane filters are made of a single layer of porous material which allows water to pass through at the same time removing physical contaminants of water and microorganisms by size exclusion (Organization for Economic Co-operation and Development and World Health Organization, 2003). Examples of membrane filters include ceramic filters, cloth filter, and paper filters. Membrane filters can be modified to increase performance, for example the painting of silver nanoparticles on ceramic water filters. They can also be modified to remove specific pollutants such as arsenic (Hoslett *et al*., 2018). A study was carried out by Francis *et al*. (2016) with an objective to assess the effectiveness of membrane filters in improving drinking water in India. The results proved that membrane filters are effective in the removal of total coliform, fecal coliform and *E. coli* in contaminated water therefore can be used in providing safe drinking water for communities affected by the lack of access to clean drinking water. Membrane filters can also be a good option in areas that do not have a continuous supply of piped water. A disadvantage of membrane filters such as ceramic filters is that they are fragile, hence it is important that end users are advised on how to handle the filters with great care so that they last longer and continually provide potable water for households.

• Granular media filters

Granular media filters typically use sand and anthracite coal for water treatment. Sand filters are the most common type of granular media filters used for household water treatment in developing countries (Laurent, 2005). Sand filters are affordable, easy to operate and are better used for pre-treatment in the removal of turbidity and the retention of solid materials, microorganisms and heavy metals (Hoslett *et al.*, 2018). Because this method of filtration cannot remove minute microorganisms such as enteric viruses, the removal of smaller microorganisms can be enhanced by the modification of the filters. Torkelson (2015) added quaternary ammonium silane, zero valent iron, and biochar to granular media filters in order to determine whether there was an improvement in the removal of bacteria and viruses from drinking water and stormwater. Results proved that modified granular filters were more effective in the removal of bacteria and viruses than plain sand either through electrostatic attraction, hydrophobic interactions, or both. A disadvantage of granular media filters is that they require expertise in construction and this can somehow be expensive for low income earning communities (Sobsey, 2002)

• Solar disinfection

Solar disinfection is a low cost method of treating contaminated water that uses thermal and ultra violet radiation. This method has proved to be effective in inactivating water borne disease-causing microorganism (Dessie *et al.*, 2014). The SODIS system has been widely adopted as it is the most practical and economic method of treating water especially in the developing world (SODIS, 2018). The SODIS system entails placing plastic bottles on a roof top so that the contaminated water is exposed to direct sunlight. The contaminated water is usually exposed to the sun for about 6-48 hours, depending on the weather conditions. A study carried out by Bitew *et al*. (2018) to assess the effectiveness of SODIS in rural Ethiopia saw a statistically significant reduction in diarrhoea incidences in children below the age of five in the group that administered SODIS compared to the control group. However, a disadvantage of using solar disinfection for household water treatment is that it does not protect the water from recontamination like chemical disinfection hence families should always have enough bottles with treated water until it is consumed (UNICEF, 2008). This method is also not suitable for treating large water volumes and disinfection can take a longer of time during seasons when there is low sun intensity. **• UV light technologies**

Ultra violet technology is a low cost intervention that is effective in the inactivation of bacteria, viruses and other pathogenic microorganisms by using UV light from a lamp (Wagenet *et al.*, 2004). The ultra violet technology is most effective in the inactivation of *Giardia lamblia* cysts or *Cryptosporidium parvum* oocysts, and is recommended to remove these by filtration or distillation (Extension, 2019). Agrawal and Bhalwar (2011) documented that a drawback of this technology is that its effectiveness towards the disinfection of some microbes could be affected by the presence of dissolved organic matter and suspended matter in water that could possibly shield pathogens from being exposed to UV light. Hence, UV light technologies are most effective in providing potable water in instances where the light intensity is high enough to reach pathogens in the water.

- **Thermal (heat) technologies**

Thermal water treatment technologies include boiling and heating to pasteurisation temperatures. Boiling of water is the most commonly used method for household water treatment and has been proven to significantly improve the microbiological quality of drinking water (Engineers Without Borders, 2008). A research carried out by Cohen and Colford, (2017) which aimed to assess the effectiveness of boiling water on diarrhoea and pathogen specific infections in low and middle income countries proved that there was a significant protective effect of boiling for *Vibrio cholerae* infections. On the other hand, some communities do not prefer the boiling method as it is time consuming. Boiling of water and leaving the water to cool down for a while before consumption requires a level of patience. Also, thermal technologies can be hazardous especially in households that have minor children as they might be at risk of getting injured by the boiling water. Another disadvantage of boiling water is that it may lead to indoor air pollution resulting in the inhalation of smoke which might subsequently lead to respiratory infections (Schmidt and Cairncross, 2008). To enhance the effectiveness of boiling, administering a filtration method will aid in the removal of solid materials and particulate matter in the drinking water.

- **Combination (multi-barrier) treatment approaches**

Combination water treatment approaches entail combining chemical purification methods with flocculation, sedimentation and coagulation. These approaches use methodologies similar to those used in wastewater treatment. Souter (2002) has documented that using these methods in combination can reduce about 99.9% of both bacteria and viruses and lead to the reduction in water borne disease incidences. Another study by Crump *et al*. (2005) carried out in Kenya proved the efficacy of combination treatment technologies in preventing diarrhoea in areas with turbid source water. Combination water treatment technologies are not only effective in improving microbial water quality, but are effective in the improvement of physicochemical properties of water such as turbidity and pH (Laurent, 2005). Laurent (2005) further explains that regardless of multi barrier water treatment technologies being reliable in the provision of potable water, they are expensive and provide a low capacity of water for households, which is not so ideal in the underdeveloped world. Also, because chemicals such as chlorine are added, families tend to dislike the smell and taste of drinking water.

2.3 CERAMIC WATER FILTRATION TECHNOLOGY

2.3.1 History of ceramic water filters

Ceramic water filters were originally developed in Guatemala in 1981 by Dr Fernando Mazariegos. The goal was to develop a low cost water filter that could be produced by local community members and could be effective in producing potable water in developing the developing world.

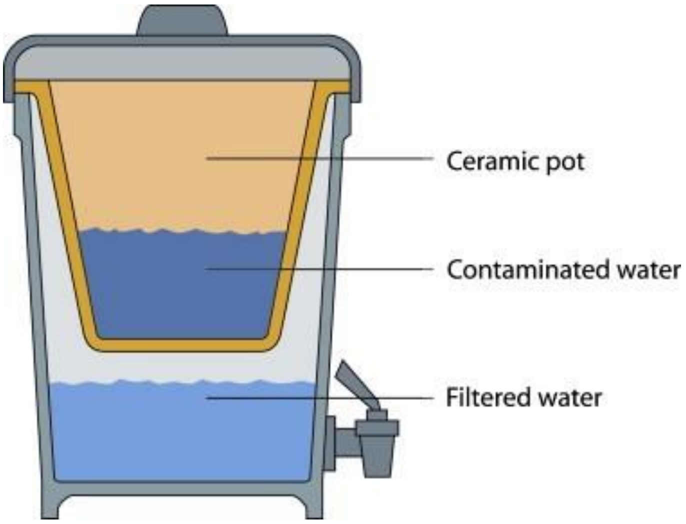

Figure 2.1: Illustration of a ceramic water filter

In 1994, an organisation from Guatemala called the Family Foundation of the Americas (AFA) discovered that other POU water treatment technologies were not very effective in the provision of clean drinking water and this led to a rise in their interest in the ceramic filtration technology. For example, the use of chlorine tablets was not well accepted by communities and had health effects associated with their use (Potters for Peace, 2018). Also, some households failed to boil water long enough and this method of water treatment was ineffective in reducing microbial contamination in drinking water. AFA then decided to carry out a research on ceramic water filters and concluded that this type of POU water treatment technology reduced incidences of water borne diseases in participating households by 50%. These results were in line with initial findings from a similar research carried out by Mazariego.

In October 1998, the second deadliest hurricane, Mitch, hit Central America and affected inhabitants urgently required clean drinking water as the hurricane had damaged water supply systems in that region. The Potters for Peace then adopted the ceramic water filter technology by using previous designs by Mazariego and the AFA and constructed a production facility in Nicaragua. The Potters for Peace distributed more than 5000 ceramic water filters to the affected populations within a period of six months.

Since then, Potters for Peace have been aiding the production of low cost silver impregnated ceramic water filters world-wide. These filters are being produced at over 50 filter manufacturing facilities in more than 30 developing countries. Bouman *et al.* (2010) rated the ceramic water filters are rated as the best POU water treatment device in rural communities.

Potters for Peace work to train other organization implementing the ceramic filtration technology through research and development as well as promotion of the filters. Potters for Peace empower organizations to train local potters to utilise local material to produce and sell water filters so that they are able to be sustainably employed and make profit from the production of these POU water treatment technologies. Potters for Peace are however not involved in the selling of filters and do not operate any filter production facilities.

Potters for Peace and the United Nations carried out some research to assess the effectiveness of silver impregnated ceramic water filters in Nicaragua and results showed that these filters were effective in removing close to 100% of total coliform, *E. coli*, fecal coliform, and streptococcus (Techxlab, 2018). In South Africa, there are currently two operational filter production facilities in North West and Limpopo provinces. These facilities are run by an organization called PureMadi (‘madi’ is a Venda word that means ‘water’) (PureMadi, 2018c).

2.3.2 PureMadi's ceramic water filters

PureMadi is responsible for the operation of filter production facilities that make filters using local materials clay, sawdust and water in rural South Africa. Local community members are educated on how to make ceramic water and are empowered to use those skills to earn a living.

Clay, sawdust and water are mixed in an electric mixer and the mixture is left inside closed buckets so that it is intact the next day. The mixture is then pressed using a mechanised filter press to get the desired flower-pot-like flat bottomed design. Filters are left to dry for between 7-10 days depending on the season. They are then were placed on wooden drying racks and protected from unfavourable conditions such as direct sunlight and rain.

For the filters are then fired using an electric kiln for 8-12 hours at a temperature of 950^0C. After cooling and removal from the kiln, the filters are subjected to two tests (pressure and flow rate tests (*Figure 2.2*) to insure that the filters do not have cracks and large pores that could possibly enable water to pass through the filter walls quickly.

Figure 2.2: Ceramic water filters undergoing the flow rate quality test

After filters have passed all quality tests, they then qualify to be treated with a dilute solution of silver nanoparticles. A paint brush is used to apply the silver chemical that will lodge in the pore spaces of the ceramic matrix and act as a disinfectant towards waterborne microorganisms like total coliform and *E. coli*. When raw water is passed through the filter, it percolates to the bottom of the bucket and is purified in the process. The ceramic water filter costs R350 and can last for up to 3 years. Currently, PureMadi has two operational filter manufacturing facilities in South Africa, one in Mukondeni, Limpopo Province and the other in Dertig, North West Province (PureMadi, 2018a).

2.4 SILVER

2.4.1 Applications of silver

Over the past decades, silver has proven to be effective in inactivating a wide range of microorganisms. Wijnhoven *et al*. (2009) documented how silver has bactericidal characteristics against both gram negative and gram-positive bacteria. Silver has also shown to be effective in the inactivation of antibiotic resistant bacteria. In the case of silver at a nanoscale, its effectiveness is greatly influenced by their small size which is usually between 1-100 nm (Theivasanthi and Alagar, 2011). Because of the minute size of silver nanoparticles, they are very effective in destroying a large size of its host material. Silver has therefore been used in a variety of applications such as in the medical field, food technology, air disinfection, wastewater treatment and household water treatment.

Nano-silver has been reported to be less reactive than silver ions hence it has been successfully applied for medical and dentistry purposes (Kim et al., 2005; Chen and Schluesener, 2008). Also due to the anti-fungal properties of silver, it has been demonstrated that fungi such as *Aspergillus, Candida, and Saccharomyces* are sensitive to silver nanoparticles. Silver possesses antiviral properties and a number of studies have concluded that silver inhibits the replication of viruses such as HIV-1 and hepatitis B (Fewtrell, 2014). Noronha *et al*. (2017) reviewed documents published from 2012-2017 on the application of silver nanoparticles in dentistry and some of the findings concluded that silver nanoparticles had excellent antimicrobial properties in dentistry and may also be used in the treatment of oral cancer.

Silver nanoparticles have also been applied in food technology for example in food storage, food processing equipment and food packaging material. An interesting study by Garde-Cerdán *et al*. (2014) assessed the antiseptic effect of silver nanoparticles in wine storage. Silver nanoparticles in isolation and silver nanoparticles with a small amount of sulphur dioxide were added in the storage of red wines. The study concluded that silver nanoparticles could be used in wine processing and are a promising antiseptic in the storage of young wines.

Another application of silver is in air disinfection. Silver has proved to be a bactericidal agent for microbes in the air stream. For example, a study by Miaskiewicz-peska *et al*. (2011) was carried out to assess the effectiveness of silver nitrate and polypropylene air filters in the removal of microbes and it was concluded that because of antimicrobial properties possessed by silver nitrate, bacteria was unable to inhabit in the air filters. There was a significant decrease in both gram-negative and gram-positive bacterial strains of *Micrococcus luteus, Micrococcus roseus, Pseudomonas luteola and B. subtilis.*

Researchers have recently been focusing on determining the applicability of silver nanoparticles in wastewater treatment. A study by Hu (2010) evaluated how silver nanoparticles would affect wastewater treatment systems and anaerobic digestion. The study was carried out in a laboratory whereby wastewater treatment modular units were fabricated using activated sludge which served to eliminate nutrients and organic matter in the wastewater. The results of this study proved that silver nanoparticles had inhibition effects towards nitrifying bacteria. Que *et al.* (2018) also concluded that silver nanoparticles do not only possess antimicrobial properties but are able to remove pesticides and heavy metals in wastewater.

2.4.2 Silver for point-of-use water treatment

Silver nanoparticles, being the most common type of nanoparticles, have been used in various applications including POU water treatment. Silver nanoparticles have good conductivity, are chemically stable and have good catalytic activity which makes them a good option for use in household drinking water purification (Rus *et al.*, 2017). Due to their welldocumented antibacterial and distinctive properties, they have been applied in POU water treatment technologies such as ceramic water filters.

In the production of ceramic water filters, silver nanoparticles are painted on the inside and outside of the porous ceramic membrane. The silver will lodge onto the pores of the ceramic filter, rendering long term water disinfection to contaminated drinking water.

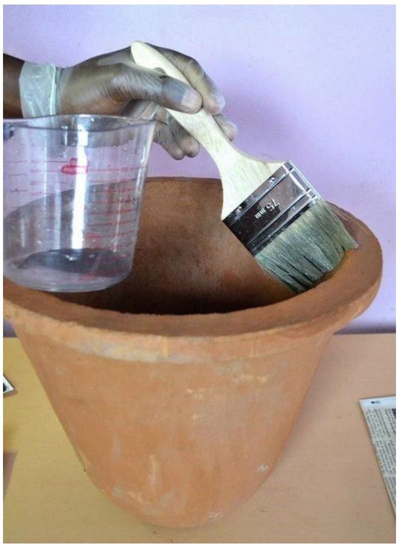

Figure 2.3: Application of aqueous silver nanoparticles onto a ceramic water filter using a paint brush (PureMadi, 2018b).

The mechanisms for contaminant removal by silver impregnated water filters are; size exclusion and inactivation. The size of disease-causing pathogens such as protozoa and some bacteria could be bigger than the ceramic filter pore size and these organisms are removed by exclusion. Inactivation by ionic silver removes smaller bacteria and viruses (Brady *et al.*, 2003, Huang *et al.* 2008, Butkus *et al.*, 2004, Kim *et al.*, 2008).

Theresa *et al.* (2011) carried out a study aimed at assessing silver nanoparticles impregnated bactericidal papers in POU water treatment. Contaminated water filtered through the papers and results proved that the silver nanoparticle papers displayed bacteriostatic properties. *E. coli* log reduction was above log 6 while *Enterococcus faecalis* log reduction was above log 3 in the effluent. Silver release from the silver nanoparticle papers were within the WHO and EPA limits for drinking water, with actual values below 0.1 ppm. The study concluded that silver nanoparticles impregnated papers could treat contaminated water and were effective in the provision of clean drinking water.

Another study by Erin *et al.* (2011) investigated the technological performance and social acceptance of ceramic water filters impregnated with silver nanoparticles for POU water treatment. The research was carried out in a laboratory set up and data was collected from a developing village in Guatemala. Results of the study concluded that ceramic water filters produced using cost effective local materials and local labour have exceptional microbiological performance and are effective in providing clean drinking water for marginalised communities in the developing world. The results also proved that silver nanoparticle impregnated ceramic water filters were socially acceptable in the Guatemalan village.

Rus *et al*. (2017) described how these simple POU water treatment devices had high efficacy in the elimination of water borne microorganisms due to the unique antimicrobial properties of silver nanoparticles. Silver nanoparticles ceramic water filters are able to achieve 99.99% or more bacterial inactivation. Rus *et al*. (2017) further explained how this optimal performance is dependent on factors that include silver nanoparticle retention in the filter structure; *E. coli* bacteria removal; water quality and water flow rate.

New filters with fresh silver coating have been found to be highly effective for disinfection of water. A removal efficiency of 99-100% for *E. coli* was established (OyanedelCraver and Smith, 2008; Brown, 2007). However, over time, as increasing volumes of water are treated, the silver leaches out of the pot into the water decreasing the efficiency of the filter. Hence, a ceramic water filter is effective in the provision of potable water for up to three years.

2.4.3 Limitations of using silver nanoparticles for point-of-use water treatment

Numerous human health and environmental studies have proved that silver nanoparticles are highly effective antimicrobial agents that are not toxic to mammalian cells (Stensberg *et al*., 2011). However, some in-vitro studies aimed at assessing the hepatotoxic and genotoxic potential of silver nanoparticles in albino rats have proved that silver nanoparticles execute nanosilver-related toxic effects towards rat hepatocytes and neuronal cells (El Mahdy *et al*., 2015). Other similar studies by Pinzaru *et al*. (2018) also demonstrated how silver nanoparticles were toxic towards the murine stem cells and human lung epithelial cells of rats.

Another in-vitro toxicity study aimed at investigating the toxicity of silver nanoparticles in rat ears was performed. Results proved that the exposure to silver nanoparticles had effects that include mitochondrial dysfunction and subsequent temporary or permanent hearing loss, depending on the inoculation dose. Retinal cells endured structural disorders due to the absorption of silver nanoparticles even at low concentration (Anthony *et al*., 2015).

Silver has not been proven to possess genotoxic effects towards consumers using ceramic water filters as a POU water treatment technology. Fewtrell *et al*. (2017) asserts that during water purification, silver ions (which do not damage the genetic information of human cells) are eluted from the ceramic water filters and not the actual silver nanoparticles. Fewtrell *et al*. (2017) further explains that the primary exposure to silver nanoparticles in this regard is actually to employees involved in filter production rather than the consumers of ceramic filtered water. In ceramic filter facilities such as the PureMadi Dertig Ceramic Filter Facility, silver is imported from Spain in powder form (PureMadi, 2018a). Filter makers typically prepare an aqueous solution by adding water to the powdered silver nanoparticles almost every week. The aqueous solution of silver nanoparticles is then painted onto the porous ceramic filter membrane. It is highly recommended that employees involved in filter making adhere to all necessary health and safety standards such as covering their nose with dust masks and putting on hand gloves so that their exposure to silver nanoparticles is minimised during handling of the chemical. Adherence to health and safety standards is however a challenge in developing countries and this puts filter makers at high risk of occupational respiratory exposure (Ceramic Manufacturing Working Group, 2011). It is therefore very vital to ensure that all filter making facilities strictly comply with the applicable national and/or global health and safety standards.

Another limitation of using silver nanoparticles for application in POU water treatment ceramic filters is that they are not locally available in South Africa but have to be imported from Spain. Silver nanoparticles are expensive as currently they cost R28 062 (2019 pricing) for 1 kg excluding shipping charges (Laboratorios Argenol, 2019).

2.4.4 The use of silver nitrate for point-of-use water treatment

Because of possible occupational respiratory exposure risk and the pricing/unavailability of silver nanoparticles in the developing world, the substitution of silver nanoparticles by silver nitrate is continually being investigated. Jackson and Smith (2018) made filter discs with silver nitrate and evaluated them using miscible displacement flowthrough experiments with pulse and continuous-feed injections of *E. coli*. Moreover, ceramic filters were made with silver nitrate and tested for their performance in microbial removal in a laboratory in the Limpopo Province of South Africa. Results suggested that adding silver nitrate when making filters is highly effective in the elimination of water borne disease-causing bacteria. Also, it was proven that filters made with silver nitrate improved silver retention in the filter and increased the general lifespan of the filter. Because there is less handling of silver nitrate, (as there is no requirement for painting silver nanoparticles onto the ceramic membrane), the risk of inhalation exposure by workers involved in manufacturing ceramic water filters is eliminated (Jackson *et al.*, 2019).

Another recent laboratory study carried out in Indonesia by Kendarto *et al*. (2019) assessed the effectiveness of ceramic water filters that had silver nitrate added to them in the reduction of *E. coli* and results showed that ceramic water filters could reduce the number of *E. coli* with a significant percentage. The use of silver nitrate solution with a concentration of 0,001M in the production of ceramic water filters was the most effective in removing *E. coli* from raw water with a high removal rate of 99.34% removal rate.

2.5 CONCLUSION

Silver is well known for its distinct characteristics and has been used as an antimicrobial agent for many years. Over the past decades, silver has been applied in various fields such as in medicine and dentistry; food technology; air disinfection wastewater treatment and in POU water treatment technologies. Silver nanoparticles have been applied to ceramic water filters and a wide range of studies have demonstrated how silver nanoparticle impregnated ceramic water filters made using locally available materials and labour are effective in the provision of clean drinking water at POU.

Studies have also been carried out to test ceramic water filters made with silver nitrate. However, because the studies were limited to the laboratory, it is therefore desirable to replicate similar studies in the field and at actual households.

CHAPTER 3: RESEARCH METHODOLOGY

3.1 RESEARCH DESIGN

A field experiment research strategy was adopted. This involved collection of water samples at thirty Dertig village households for water quality assessment and the results were tallied against the WHO guidelines for safe drinking water. The basis of the research was water quality assessment mainly focusing on total coliform and *E. coli* count. The research also focused on comparing the microbial water quality from ceramic filters made with silver nitrate and silver nanoparticle impregnated ceramic filters. Different concentrations of silver nitrate were then measured and an assessment of its effect on the quality of filtrate was done. Microbial water quality tests and measurement of silver levels in effluent were conducted at the PureMadi Dertig Ceramic Filter Facility (PureMadi, 2018a). The exact quantification of silver concentrations was carried out at the Department of Engineering Systems and Environment, University of Virginia.

3.2 FILTER MAKING

3.2.1 Materials

Clay, burn out material (sawdust), grog, water (borehole water), silver nitrate

3.2.2 Method

10 ready-made silver nanoparticle impregnated ceramic water filters were purchased from the PureMadi Dertig Ceramic Filter Facility.
Ceramic water filters made with silver nitrate were then produced by the researcher at the PureMadi Dertig Ceramic Filter Facility (PureMadi, 2018a). The researcher used the method derived from the Ceramic Manufacturing Working Group (2011).

3.2.2.1 Ratio and mixing

Batch 1

50 kg of clay + 22 kg of sawdust + 5 kg grog + 20 litres of water + 39.36 g of silver nitrate to produce 25 ceramic water filters with 1 gram of silver per filter. The researcher used the following calculation in devising the amount of silver nitrate to be added in batch 1; Molecular Weight of silver nitrate is 169.87

Molecular Weight of silver is 107.87, hence,

25 X 1 g Ag X (169.87 g MW of $AgNO_3$ / 107.87 g MW of Ag) = **39.37 $AgNO_3$**

Batch 2

78.74 g $AgNO_3$ was mixed with clay, sawdust, grog and water to produce 25 filters with 2 g of silver per filter (see ratio used in Batch 1).

Mixing times of the clay, sawdust, silver nitrate was 30 minutes for dry mixing in an electrical mixer. After adding water, the wet mixing lasted for an hour in the electrical mixer. The mixture was then left inside closed buckets overnight so that it would be intact the next day.

25 filters in each batch were made to cater for filters that could fail quality tests as well as any possible breakages during the study. Only 15 filters per batch were distributed to the households.

3.2.2.2 Pressing

The mixture was pressed using a mechanised filter press to get the desired flower-potlike flat bottomed design.

3.2.2.3 Drying

The filters were left to dry for between 7-10 days since they were made during the dry and hot season. Filters were placed on wooden drying racks where they were not exposed to unfavourable conditions such as direct sunlight and rain. Monitoring was carried out throughout the drying process to ensure that the filters dried evenly.

3.2.2.4 Firing

For the filters to be fired, they had to be as dry as possible. The filters were fired using VEL50 Front Door kiln for 8-12 hours at a temperature of 950^0C using the following programme;

1. Increase temperature from 20°C at 150°C per hour to 600°C,
2. Increase temperature at 300°C per hour to 950°C,
3. The temperature of the kiln remains constant for 3 hour.

The filters were left to cool before quality tests were carried out.

3.2.2.5 Quality Tests

Pressure tests

Pressure tests were carried out to ensure that the fired filters did not have cracks and large pores that could possibly enable water to pass through the filter walls quickly. The pressure test was implemented as follows:

1. Clean water was poured onto a soak tank
2. The filter base was submerged onto the water with the water level near the rim for ten seconds
3. After ten seconds, no water was supposed to have entered the filter. If there was evidence of water entering the filter, it was discarded and considered a reject.

Flow rate tests

Flow rate tests were performed on all filters that had passed the pressure test. The flow rate test involved placing filters in a soak tank, pouring water to brim and measuring the change in water level for an hour using a calibrated T-device. The recommended flow rate should be between 1.5 to 3 litres of water per hour.

Flow rate can be an indicator of cracks or large pores in the water filter, potential contact time with silver, the ability of the filter to produce sufficient water quantity and production consistency. Filters that failed the quality tests were re-used as grog (fired filters that are crushed into a powder). Grog was added as a raw material so as to increase porosity and reduce filter cracking.

3.2.2.6 Packaging

After filters passed the two quality control tests, they were wrapped using bubble wrap, placed in a plastic bucket with a spigot and boxed. A sheet with filter maintenance and use instructions was put inside the box. They were ready to be delivered to the different households partaking in the research.

3.2.2.7 Health and Safety

The researcher and PureMadi employees followed all the necessary health and safety standards in the production of ceramic water filters. They wore gloves, goggles and dust masks to cover their nose and mouth while sieving sawdust, processing clay, crushing grog, measuring silver nitrate, painting silver nanoparticles onto ceramic filters and mixing the all the inputs.

Hands were washed with soap after handling the materials.

3.2.2.8 Quality Control

Visual Inspections

Visual inspections took place before each major step of the production process so that defective filters could be removed from the production line. Formal visual inspections were carried out before: surface finishing, loading the kiln, flow rate testing, silver application and packaging. Filters were examined for cracks, warping, inconsistent filter walls, large pieces of burn-out material and consistent surface finish. In fired filters, filters were examined for: discoloration, including blackened areas indicating incomplete combustion of the burn-out; warping; cracks; holes or spaces from large pieces of burn-out material; charring; crumbling; and that the base and rim of the filter was at the proper angle to the wall of the filter. The filter rim of fired filters was checked for size and warping by placing a receptacle lid on each filter element. The lid was turned slowly and it was checked that the filter rim meets the lid evenly. If the lid did not fully cover the filter rim, the filter element was grinded using caution not to damage the body of the filter or grind any more material than necessary (The Ceramics Manufacturing Working Group, 2011).

Pressure and Flow Rate Tests

See quality tests in Section 3.2.2.5

3.3 SAMPLING

3.3.1 Household Sampling

Not all households in Dertig were studied. This is due to the fact that sampling 786 households in Dertig was difficult to implement within the required timeframe and also due to limited financial resources. Ideally, non-probability sampling of households was a preferred method for objectivity. A voluntary sample made up of interested households self-selected themselves into the research. These households had a strong interest in the research and volunteered to take part. The short comings of voluntary sampling were noted which include the fact that there is likely to be a degree of self-selection bias. The participating households could have chosen to be part of the study due to the need to own a free water filter, which is usually sold at R350 (PureMadi, 2018c). This could either lead to the results of water samples not being a representative of the water quality in the whole Dertig area or exaggeration of the test results (Sharma, 2017).

Dertig village comprises two wards, namely Ward 14 and 22. Thirty households were sampled (15 from each ward).

3.3.2 Survey Data

Survey data was collected from the participants at the beginning of the research. The survey data questionnaire is attached in *Appendix 1*.

3.3.3 Water quality sampling

Samples of filtered water were taken from 30 households in Dertig Village. 15 households were each given a filter with 1 gram of silver while 15 other households were each given a filter with 2 grams of silver. 10 of these households were given an extra filter impregnated with silver nanoparticles.

Water samples were collected and stored in a sterile 100ml plastics and transported to the PureMadi Ceramic Filter Facility for sample testing. All collected samples were clearly labelled with the name of household, date, time, type of filter (1 g/2 g silver nitrate or silver nanoparticle) and whether the sample contained raw or filtered water.

All aseptic techniques were observed for the water sample to be true representations of the ceramic filtered water. Samples were transported in a cooler box until they reached the PureMadi Ceramic Filter Facility so as to avoid light alteration of microbial parameters.
Analysis of the samples was carried out within 24 hours after sample collection.

3.4 SAMPLE ANALYSIS

3.4.1 Microbial analysis

Water samples from ceramic filters made with silver nitrate and silver nanoparticles were assessed for total coliforms and *E. coli*. Systematic measurement and observation of the two microbial parameters was carried out at the PureMadi Ceramic Filter Facility. The membrane filtration technique was used to detect the presence of microorganisms in water. The membrane filtration technique was adopted for the study because it gives a direct count of total coliforms and *E. coli* present in a given sample of water.

Membrane Filtration Procedure

Total coliform bacteria and *E. coli* were measured in both raw and ceramic filtered household drinking water by membrane filtration.

As a disinfection measure, manifold sample cups were placed in a boiling water bath set to 100°C for 15 minutes. Filter paper disks of 47 mm diameter and 0.45 micropore pore size (4.5 x 10^{-7} m) pore size (EMD Millipore, Billerica, MA, USA) were placed on the surface of the manifold with forceps with following aseptic techniques. 100 ml samples were passed through the filter paper. The filter papers were transferred to a sterile petri dish that had an absorbent pad of selective growth media solution (m-ColiBlue24, EMD Millipore, Billerica, MA, USA). The samples were incubated at 35^0C for 23 to 25 hours. Total coliform and *E. coli* colonies were counted (Edokpayi *et al*., 2018).

3.4.2 Analysis of silver levels in the effluent

Silver analysis on effluent samples was carried out using a HACH visual test kit (this was used as a screening tool). The kit included; one reagent, clippers, forceps, bottle, syringe, comparator chart, pack of filters, filter holder, instruction sheet, and carrying case. The colour chart is used to match the appropriate colour spot to obtain semi-quantitative results on silver levels. Therefore, the HACH visual test kit provides fast and accurate information on silver discharges (HACH, 2019).

3.4.3 Exact quantification of silver

Metals in solution were determined by graphite furnace atomic absorption spectrophotometry (GFAA) (Fig 3.1). 10ml samples from ceramic filtered water (1 g/2 g silver nitrate and silver nanoparticles filters) were collected from each participating household monthly and stored in a refrigerator. The samples were later transported to the Department of Engineering Systems and Environment at the University of Virginia for quantification of silver levels using GFAA. GFAA is a very sensitive method that uses a graphite-coated furnace to vaporize the sample and is simple, quick, and applicable to an enormous number of metals in environmental samples such as domestic water samples. The method used followed 'Determination of Trace Elements by Stabilised Temperature Graphic Furnace Atomic Absorption' by EPA, 1994.

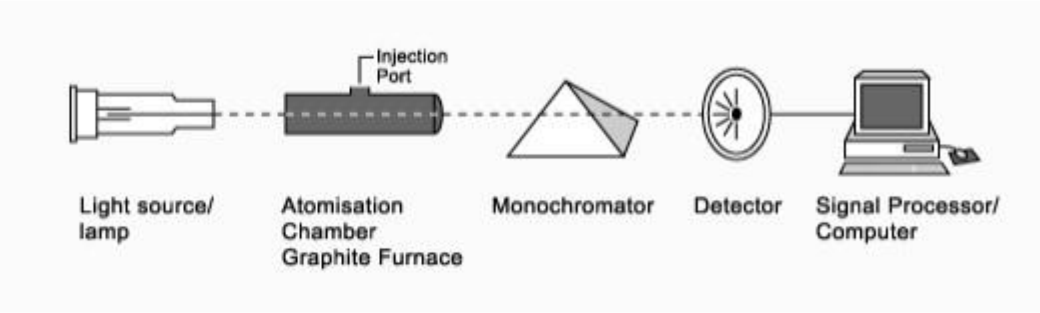

Figure 3.1: Schematic diagram of a graphite-furnace atomic-absorption spectrometer (TAFE NSW, 2020)

3.4.4 Analysis of the economic benefit of silver nitrate

An analysis of the economics involved in production was carried out to assess the economic benefit of using silver nitrate instead of silver nanoparticles in filter making. The final decision was informed by a comparison of costs (measured in rands), expenses, as well as the increased revenue that would come from using silver nitrate.

3.5 SECONDARY DATA ACQUISITION

In South Africa, WHO guidelines for safe drinking water quality are used hence the researcher used these for comparison with the quality of ceramic filtered water. Information on the Dertig area was acquired from the Dertig Tribal Authority. Journals, reports and articles were also reviewed.

3.6 ETHICAL CONSIDERATIONS

Firstly, ethical authorisation was obtained from the ethics committee of the University of Venda. Consent to carry out the study was then requested from PureMadi, the implementers of the ceramic water filter technology in Dertig, South Africa.

Prior to sample collection, permission was requested from the Moretele Municipality and Dertig community leaders. Consent was then requested from the volunteering households where they were also informed about the purpose of the research, details of their participation, how collected data will be used as well as the benefits of the study.

The research involved using different laboratory chemicals in microbial water analysis. Hence there was safe handling and safe disposal of cultures, reagents, and materials and while operating sterilisation equipment so as to protect the health of the individuals working at the filter facility as well as safeguarding the environment at large. Disposal of chemicals and biproducts was done at the University of Venda.

3.7 STATISTICAL INTERPRETATION

Descriptive statistical techniques (using SPSS Version 25) were used in interpreting and presenting data. Quantitative data was organised, summarised and visualised was in order to identify underlying patterns of that data. Graphs and tables were used to illustrate physicochemical properties of raw water; microbial water quality of raw water and ceramic filtered water; a comparison of microbial water quality from silver nitrate and silver nanoparticle filters; silver levels in effluent and a cost analysis of using silver nitrate in filter production. Data was analysed using statistical inference.

CHAPTER 4: RESULTS AND DISCUSSION

4.1 PREAMBLE

This chapter focuses on the presentation of data gathered from field research (within a 13-month period) and secondary sources.

The results of microbial water quality of ceramic filters made with silver nitrate and silver nanoparticles collected from households in Dertig Village, North West Province of South Africa are discussed. A linkage and comparison of findings of other scholars is done and factors linked to the findings are discussed, bringing the study to a conclusion.

4.2 SOCIO DEMOGRAPHIC CHARACTERISTICS OF ENROLLED HOUSEHOLDS

30 enrolled households responded to a survey data questionnaire (*Appendix 1*). The highest range of people per household was between 4 to 6 (n=19, 63%) as shown in *Table 4.1* below;

Table 4.1 Number of people per household

Range	**Number of people per household**	**Percentage**
1 ≤ people ≤ 3	7	23%
4 ≤ people ≤ 6	19	63%
7 ≤ people ≤ 9	4	14%

Adult women are most often responsible for water management (n=23, 77%) at home while adult men are least often responsible for managing water (n=7, 23%). 100% of households have their primary water source piped to their yards with all households reporting the origins of their water to be a municipal treated source (n=30). 100% (n=30) of the households suffer 3-7-day water interruptions weekly. Because of prevailing water supply interruptions in the Dertig area, most enrolled households store their drinking water in plastic buckets (n=24, 81%) whilst a few households store their water in plastic bottles (n=6, 19%).

The majority of households 80% (n=24) fill their storage containers directly from the tap whilst only a fifth of the households (n=6, 20%) use hosepipes to fill their storage containers. Collection of water from storage containers is through cups with handle (n=30, 100%) and none of the households collect water using cups without a handle. All households cover their stored water with a lid. When the stored water is used up, most households (n=17, 57%) have their secondary water source from tanker trucks (delivered at a community central point every 2 days) whilst some (n=7, 23%) households use rain harvested water from their jojo tanks. Only a few households (n=5, 17%) have their secondary water source from nearby boreholes.

100% of the households have gone beyond 24 hours without using their stored water and because water is a scarce commodity, they do not discard the water but rather continue to drink it. None of the households treat their drinking water and the majority (n=14, 47%) (*Figure 4.1*) describe their drinking water quality as average as it is sometimes cloudy and smells bad. Some households (n=12, 39%) describe their drinking water as poor whilst a few households describe their drinking water as very good quality (n=4, 14%).

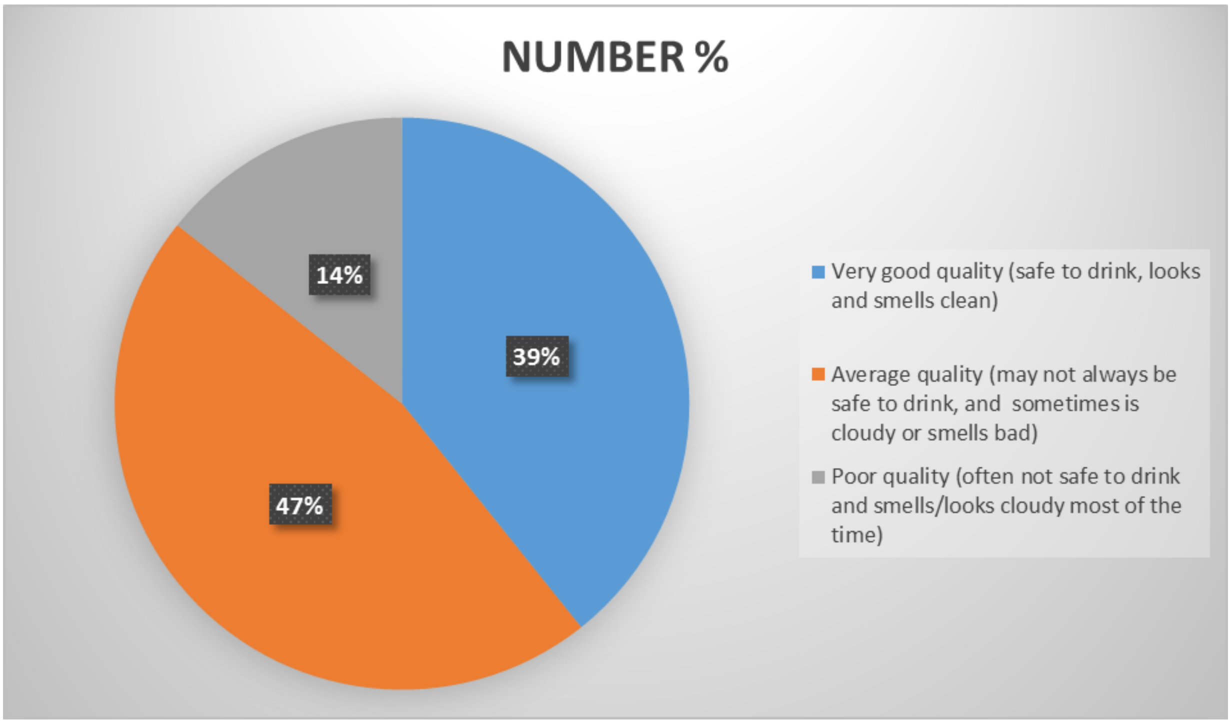

Figure 4.1: Description of water quality by households

4.3 CHARACTERISATION OF RAW WATER

4.3.1 Physicochemical parameters of raw water

Physicochemical tests carried out on all raw water samples at the beginning of the study included conductivity, turbidity, total dissolved solids, colour and pH.

Physicochemical test results showed that raw water from households in the Dertig area had conductivity, total dissolved solids and pH within the recommended South Africa National Standards (SANS) for Drinking Water Quality limits (*Table 4.2*). However, colour and turbidity levels were above the recommended SANS for Drinking Water Quality limits. Analysis of the questionnaire administered to participating households showed that the majority of households (n=14, 47%) described their drinking water quality as average as it is sometimes cloudy. Although these are mere visual observations, the physicochemical test results have proved to be similar. Aesthetically, high colour and turbidity levels render the water unappetizing to consume due to its diminished appearance.

Table 4.2: Results showing average values of physicochemical determinants of raw water used in filter performance tests with reference to SANS for Drinking Water Quality

Water quality parameter	**Average raw water concentration**	**Standard Deviation for raw water concentration**	**Risk**	**SANS Drinking Water Standards**
Conductivity	120 mS/m	21.89	Aesthetic	≤ 170
Total dissolved solids	1150 mg/L	67.72	Aesthetic	≤ 1200
Colour	16 mg / L as Pt-Co	1.145	Aesthetic	≤15
Turbidity	2 NTU	0.695	Operational and Aesthetic	≤ 1
pH	8 pH units	1.083	Operational	≥ 5 and ≤ 9.7

Water meant for human consumption should be ideally colourless. WHO (2017a) asserts that the presence of coloured dissolved organic matter associated to the humic substance fraction of soil may water to have colour. They further explained that high colour levels could be somehow due to the presence of metals such as iron (either naturally occurring or as products of corrosion)

In this study, high colour levels in raw water could be due to the frequent 3-7-day water interruptions in the Dertig area. A policy position statement issued by the Chartered Institution of Water and Environmental Management CIWEM (2012) emphasises that water colour changes in areas where water interruptions are prevalent, are commonly associated with effects occurring within the water distribution network (for example, the re-introduction of flow following an interruption) rather than problems at the water treatment plants.

On the other hand, WHO (2017b) explains that at times turbidity can be an indication of the presence of microbes and therefore an indicator of contamination in the water supply system from source to POU. The findings of a study by Ogutu and Otieno (2003) indicate that the poor execution of water treatment steps (such as coagulation, filtration and chemical disinfection) at the treatment facility may lead to high turbidity levels. Also, the effectiveness of water distribution system management may highly influence turbidity levels. They further explain that leaks within the distribution system can be another factor for a sudden increase in turbidity recorded in household water that is obtained directly from the distribution mains. This is because a difference in atmospheric pressure inside the pipes can cause dirt and particles such as sand to be sucked into the distribution system during times when the water velocity is low.

POU water treatment technologies such as ceramic water filters may be affected by high turbidity levels in the source of water and this may strongly affect their lifespan and effectiveness in water purification (WHO, 2017b). High turbidity levels may be due to the presence of microscopic particles such as clay, silt, heavy metals and biocides. These particles, even at a very minute levels, can promote microorganism growth and inhibit water disinfection. It is therefore important to control turbidity in public water not only for aesthetic reasons but for public health protection (Ogutu and Otieno, 2003).

4.3.2 Microbiological parameters of raw water

Raw water samples were collected and tested together with filtered water throughout the 13month period in order to signal microbial water quality changes after the use of ceramic water filters. *Appendix 2* shows the actual total coliform and *E. coli* count recorded from unfiltered water for the period of the study and a summary of the mean microbiological quality of raw water (before filtration) from different water sources in the Dertig area as a function of time is highlighted in *Figure 4.2*;

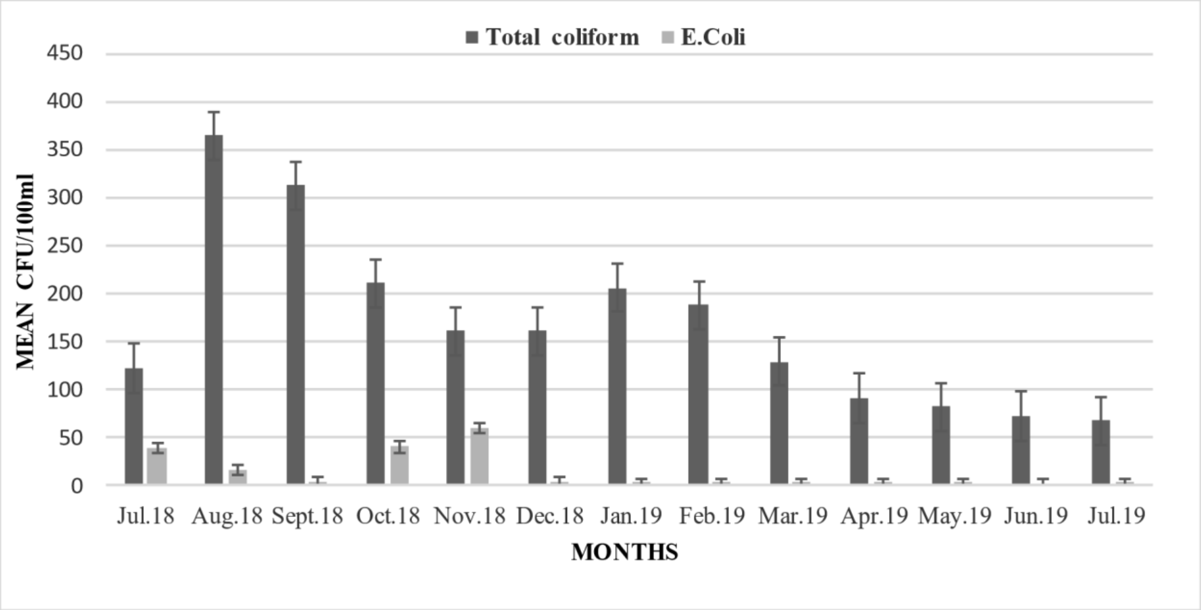

Figure 4.2: Average values of microbiological count of raw water

As shown on *Figure 4.2*, some household raw water samples tested positive for total coliform and *E. coli*, regardless of the source or storage conditions. The presence of both indicator organisms in drinking water is alarming and implies that the water is not safe to drink hence families are at risk of acquiring water borne sicknesses. The Washington State Department of Health (2016) asserts that if drinking water tests positive for total coliform count, there are high chances that the contamination is environmental rather than fecal. They further state that it is a possibility that when environmental contaminants enter the system, microbes can also enter the system hence it is vital to locate and deal with the source of contamination. They also mention that if drinking water tests positive for *E. coli*, this might be an indication of recent fecal contamination. This usually is a serious public health cause for concern as it shows that harmful microorganisms are present in the drinking water and the consumers are at risk of acquiring water borne diseases such as cholera.

At the beginning of the study, 100% households reported their origin of water to be municipal treated water. A possible explanation for the presence of total coliform and *E. coli* in tested raw water could be insufficient water treatment by the responsible authorities. Governments in developing countries are often ineffective, lack capacity and/or show institutional weaknesses (World Bank, 2005). In this instance, the local government institutions responsible for water treatment in marginalised rural areas could be suffering from the lack of resources, lack of professional skills, poor motivation, poor organisational management, and/or inappropriate policies from central authorities, which therefore affects the end-user communities where drinking water quality is concerned.

Because of recurring water interruptions in Dertig, households always store their water and when they run out, they search for alternative sources from tanker trucks, nearby boreholes, etc. *Figure 4.2* also shows that during the first six months of the study (July to December 2018), total coliform levels were the highest and *E. coli* was more prevalent. While doing sample collection, the researcher noted that the Dertig community experienced intense water rationing during the first six months compared to the last seven months of the study where water availability improved in the area. Recontamination of water is a possibility for the poor raw water quality, especially where proper hygiene practices are not followed during water transportation, handling and/or storage (Stauffer, 2019). The improved raw water quality from January could be attributed to the fact that in the North West Province of South Africa, January is immediately after the early rainy season hence the augmentation of water body levels which eventually lead to the minimizing of water rationing in the Dertig area.

Safe storage is a critical factor which could potentially prevent microbiological recontamination of water at household level. Proper storage and continuous use of POU water treatment technologies should therefore be adopted by Dertig households to ensure that they are safeguarded against water borne sicknesses.

4.4 MICROBIOLOGICAL PERFORMANCE OF CERAMIC WATER FILTERS MADE WITH SILVER NITRATE

Filters made with silver nitrate had percentage coliform removal of 94.7% and 99.4% for total coliform and *E. coli* respectively. Mean influent coliform concentrations were not very high, ranging from 68 CFU/100ml for total coliform and 3.4 CFU/100ml for *E. coli*.

Appendices 2 and 3 clearly show the actual total coliform and *E. coli* count of filters made with both 1 g and 2 g silver nitrate.

4.4.1 Removal efficiency of Total Coliform

Water samples were collected from 30 households and tested for total coliform before and after the use of ceramic water filters made with silver nitrate. Results show that ceramic water filters made with silver nitrate have a high removal efficiency for total coliforms at **94.7%**. This implies that incorporating silver before firing the filters is effective in removing total coliform on contaminated water. A previous study carried out by Mwabi *et al*. (2012) proved that ceramic water filters impregnated with silver were efficient in producing water that is microbiologically safe to drink, regardless of the type of water source. This silver impregnated ceramic water filters had better performance than other point-of-use water treatment devices such as bucket filters, bio-sand filters and ceramic candle filters (Mwabi *et al*., 2012). The high performance of ceramic water filters made with silver nitrate could be attributed to the antibacterial properties of the silver chemical that is mixed with clay, sawdust, grog and water during the manufacturing process. *Table 4.3* statistically shows total coliform removal by ceramic water filters made with silver nitrate;

Table 4.3: One-Sample Statistics showing total coliform removal by ceramic water filters made with silver nitrate

	N	Mean	Std. Deviation	Std. Error Mean
Raw water total coliform	13	68.0	14.7	4.1
Filtered water total coliform	13	3.6	5.3	1.5

Mean difference (total coliform) = Mean inflow - Mean outflow

= 68.0 - 3.6

= 64.4

Percentage of total coliform removal = (Mean difference / Total) * 100%

= (64.4/ 68.0)* 100%

$$= \mathbf{94.7\%}$$

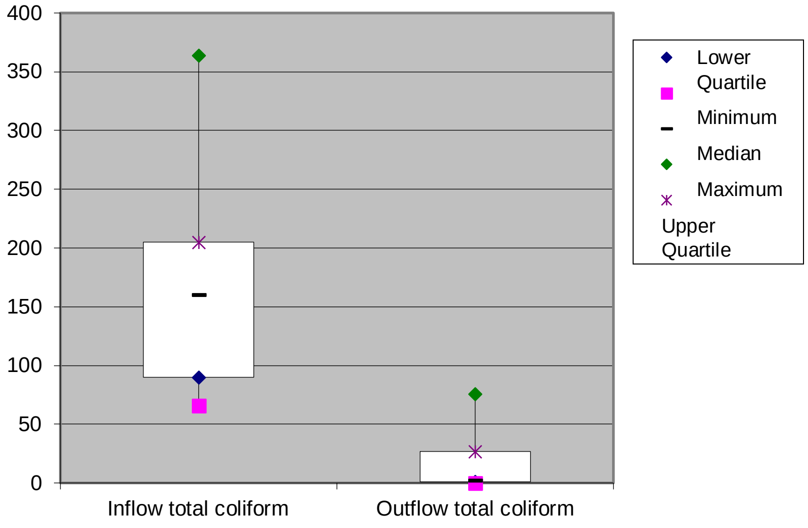

Figure 4.3: Box and Whisker Plot highlighting differences of inflow and outflow total coliform count

Ceramic water filters made with silver nitrate were effective in reducing total coliform throughout the 13-month period and their longer disinfection capacity could be due to the presence of the silver ion since a similar study by Nangmenyi *et al*. (2009) has documented the effect of silver in fibreglass water treatment. Silver has antibacterial properties that inactivate bacteria by disrupting the disulphide bond formation of proteins in the cell membrane or by inhibiting DNA synthesis (Oyanedel-Craver and Smith, 2008). It is thus possible that silver is a major contributing factor towards the removal of bacteria in drinking water consumed by Dertig families participating in the study.

4.4.2 Removal efficiency of *E. coli*

Water samples from the 30 participating households were collected and tested for *E. coli* prior and after treatment by ceramic water filters made with silver nitrate. The removal efficiency of *E. coli* proved to be very high at **99.4%**. A similar study assessing the effect of activated silver on water quality in a laboratory setup was reported by Meierhofer *et al*. (2019) where fecally contaminated tap water containing more than 1000 CFU/100 ml of *E. coli* was used. Results showed that *E. coli* was completely inactivated in batches containing silver after about 12 hours and *E. coli* coliform was not inactivated in the control configurations, which contained no silver. Table 4.4 below statistically shows *E. coli* removal by silver nitrate ceramic water filters;

Table 4.4: One-Sample Statistics showing E. coli removal by ceramic water filters made with silver nitrate

	N	Mean	Std. Deviation	Std. Error Mean
Raw water *E. coli*	13	3.4	7.0	1.9
Filtered water *E. coli*	13	0.02	0.1	0.02

Mean difference (*E. coli)* = Mean inflow - Mean outflow

= **3.4 - 0.02**

= **3.38**

Percentage of *E. coli* removal = (Mean difference / Total) * 100%

= **(3.38/ 3.4) * 100%**

= 99.4%

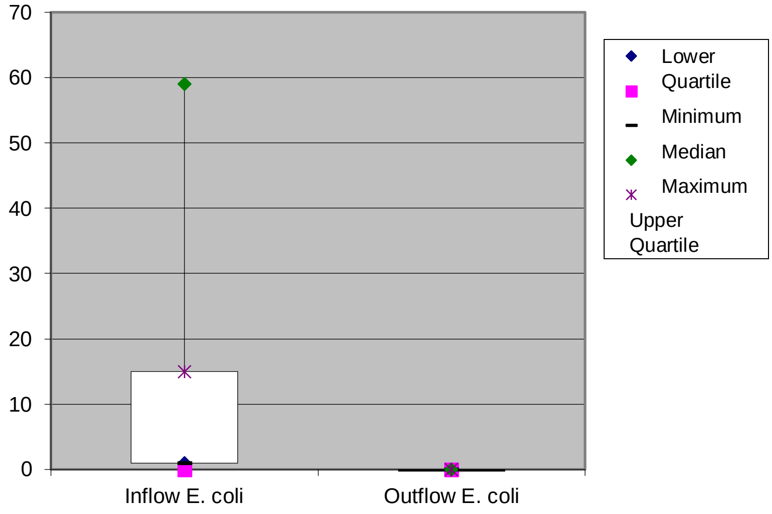

Figure 4.4: Box and Whisker Plot highlighting differences in inflow and outflow E. coli count

Participating Dertig households were thoroughly advised on the importance of properly maintaining the ceramic water filter and were issued with printed filter use instructions during inception of the research. Proper water handling, hygiene practices and safe storage are essential in the provision of good water quality as they prevent recontamination and offer longtime inactivation of bacteria by silver during storage. Whenever the researcher visited households for sample collection, water was continuously stored in the ceramic filter receptacles. A possible factor contributing to the high removal efficiency of *E. coli* by the ceramic water filters made with silver nitrate could be the contact time with silver during storage. Van der Laan *et al*. (2014) carried out a study to determine the role of silver during filtration and subsequent storage. Results showed that storage time in the receptacle contributed to the inactivation of *E. coli* by silver, to a greater extent. The study concluded that water storage time after filtration, determined *E. coli* inactivation efficacies rather than ceramic water filter characteristics such as sawdust and clay.

4.5 COMPARISON OF MICROBIOLOGICAL QUALITY OF SILVER NITRATE AND SILVER NANOPARTICLES IMPREGNATED CERAMIC WATER FILTERS

Out of 30 households participating in the study, 15 households had ceramic water filters with 1 g of silver nitrate added during the manufacturing process whilst 15 households had ceramic water filters with 2 g of silver nitrate added during the manufacturing process. 10 of those 30 households were randomly selected and given an extra filter with painted silver nanoparticles. A comparison of the microbiological quality of the three types of ceramic water filters within a 13-month period was carried out.

The effectiveness of both filters in improving microbial water quality could be due to the fact that the filters were still new and had only been used for 13 months (they have a life span of 3 years). New filters with fresh silver coating have been found to be very effective in water purification. A removal efficiency of 99-100% for *E. coli* was established in new filters (Oyanedel-Craver and Smith, 2008; Brown, 2007). They further explain that, over time, as the amounts of water to be treated increases, silver leaches out of the ceramic water filter into the water reducing the efficiency of the filter as a POU water treatment device.

Figure 4.5 highlights that both methods of silver application (i.e incorporating silver nitrate before the firing stage and painting-on silver nanoparticles after the firing stage) are effective in total coliform and *E. coli* removal. This proves the influence of silver on microbial removal efficiencies. Silver ions are highly effective in the disinfection of a wide range of waterborne microorganisms (Singh *et al*., 2019).

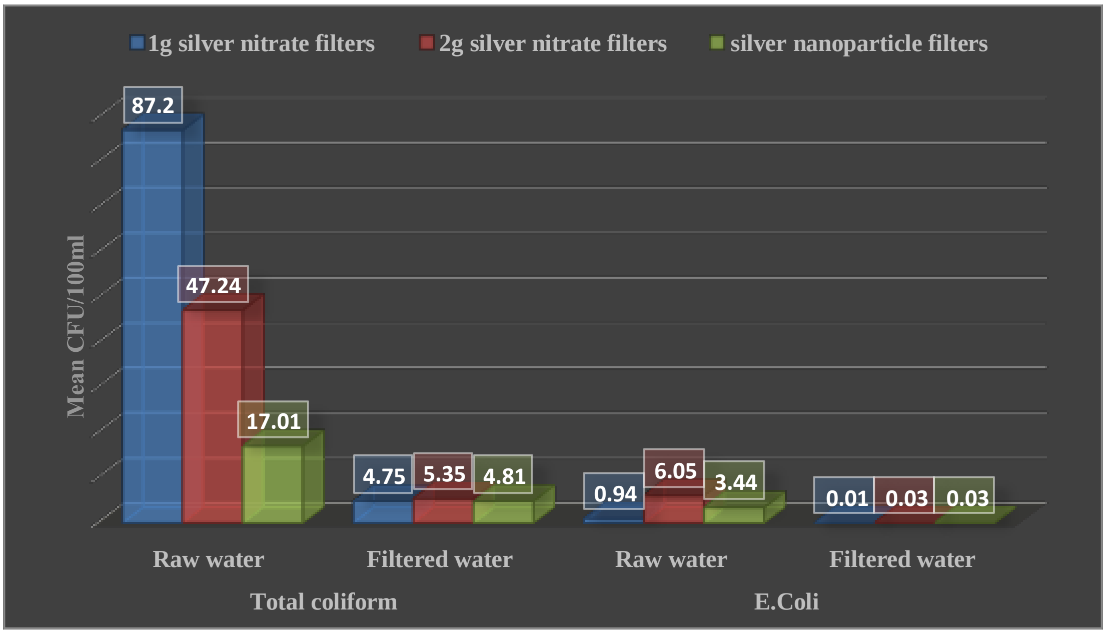

Figure 4.5: Counts of total coliforms and E. coli in raw water and ceramic filtered water

A calculation of the percentage total coliform and *E. coli* removal by 1 g, 2 g and silver nanoparticle filters is carried out and results show that the different filters result in similar levels of total coliform and *E. coli* removal, although the 1 g silver nitrate filters produced the highest average removal of 97.23% (Table 4.5). It is noted that silver nanoparticle filters had a slightly lower removal efficiency of total coliform (71.72%) compared to 1 g and 2 g silver nitrate filters.

Table 4.5: Percentage coliform removal for total coliform and E. coli by 3 filter types over 13-month period

Filter type	**Total coliform removal**	***E. coli* removal**	**Average removal**

1 g silver nitrate	95.55%	98.94%	97.23%
2 g silver nitrate	88.67%	99.50%	94.09%
Silver nanoparticles	71.72%	99.13%	85.43%

The results are in line with Jackson *et al*. (2018) who carried out laboratory studies which recorded that ceramic water filters made using silver nitrate had higher total coliform and *E. coli* removal (log reductions of 4.06 and 4.11) relative to silver nanoparticles impregnated ceramic water filters (log reductions of 3.85 and 3.92). Actual count of indicator bacteria in raw and filtered water for the 3 filter types is shown in *Appendices 2, 3 and 4*.

Therefore, it can be concluded that ceramic water filters made with both 1 g and 2 g silver nitrate perform better than silver nanoparticles impregnated ceramic water filters. It is also noted that there is no significant improvement in performance for filters made with 2 g silver nitrate relative to filters made with 1 g silver nitrate.

4.6 SILVER LEVELS IN EFFLUENT

This study has proved that applying both silver nitrate and silver nanoparticles to ceramic water filters improves microbiological efficacy in household water treatment. Application of silver to ceramic water filters also prevents stored water from recontamination. Lyon-Marion *et al*. (2018) asserts that if silver added to the ceramic water filter during production is above the recommended standard, silver release in ceramic water filters may lead to undesirable health effects. It is therefore very vital for filter manufacturing facilities to add the right amount of silver in order to achieve the goal of POU water treatment at the same time not exceed the maximum recommended silver levels of drinking water.

Water samples from filtered water effluent (1 g, 2 g and silver nanoparticles filters) were collected every month and stored in a refrigerator for preservation until they were transported to the University of Virginia (Department of Engineering Systems and Environment) for silver analysis. Due to transportation constraints, not all samples were analysed. Only 15 samples after 2-month intervals were randomly selected and transported for analysis using the GFAA. Average effluent silver levels were 0.07±0.04mg/L, 0.6±1.10 mg/L and 0.8±1.0mg/L for 1 g, 2 g and silver nanoparticle filters, respectively (below the EPA and

WHO standard of 100 mg/L). Actual silver levels determined per household throughout the study for all 3 types of filters are shown in *Appendices 5, 6 and 7.*

It is noted that silver levels in all filters decrease throughout the study. A possible explanation for this could be the frequency of use of ceramic water filters by households. A study on silver nitrate filters by Kendarto *et al*. (2019) recorded that the amount of silver in ceramic walls and filtered water is affected by the frequency of filter use. Hence, silver levels decrease with continual filter use. *Figure 4.6* shows the silver concentrations for each type of filter decreasing over the extent of the research;

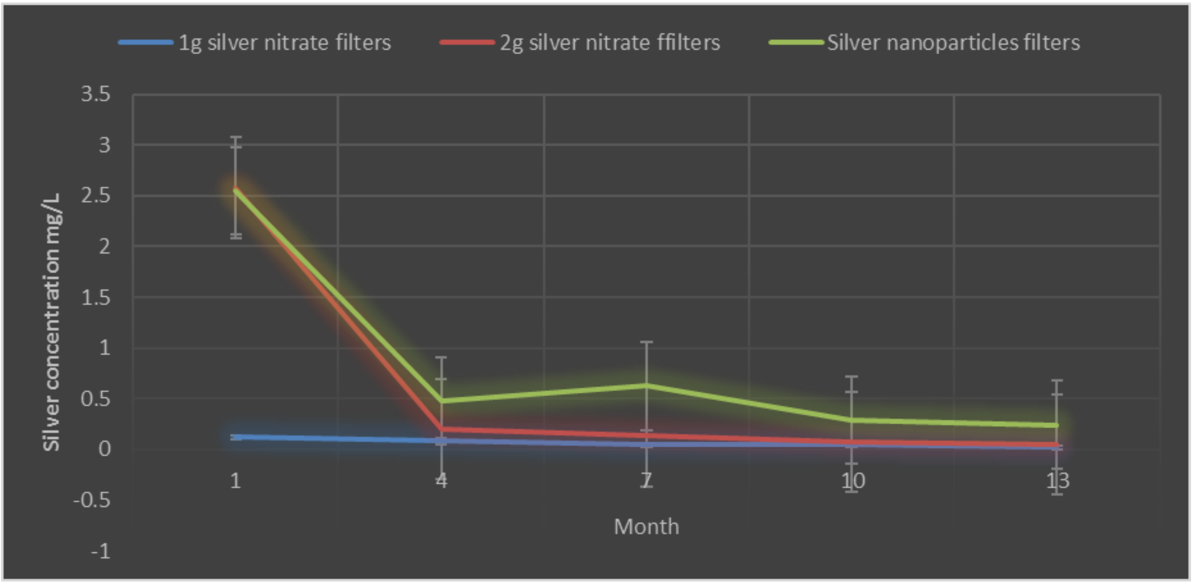

Figure 4.6: Results of experiments showing silver concentration in effluent over a 13 month period

The above figure shows that silver nitrate filters release extremely low levels of silver ions and it has been proven in previous studies that ionic silver is not genotoxic at different concentrations (Lantagne *et al*., 2017). Therefore, ceramic water filters made using silver nitrate are effective in both improving microbiological drinking water quality while releasing extremely low levels of silver for water disinfection that are within the recommended EPA and WHO silver concentration levels for drinking water.

A similar study by Jackson *et al.* (2018) performed under laboratory conditions proved that adding silver nitrate in filter production releases low silver levels to the drinking water and performs consistently in microbial inactivation over time. The results indicated that silver nitrate is a viable substitute that ceramic filter production facilities could adopt. Jackson *et al.*

(2018) further attributed the surface chemistry mechanism between the ceramic and the silver nanoparticle versus the silver nanopatch to have an effect on the differences in silver release.

Jackson *et al*. (2018) further explains that in contrast, silver nanoparticle filters seemed to perform better at the beginning of the study but decreased in microbiological performance over time. Also, silver nanoparticle impregnated ceramic water filters regularly released silver levels above the drinking-water standard as compared to filters made with silver nitrate.

In conclusion, since the 1 g silver nitrate filters proved to release extremely low silver levels compared to 2 g and silver nanoparticle filters during water treatment, they are the best option to adopt. Ceramic water filters made with silver nitrate do not only make water safe for human consumption (microbiologically and in terms of silver release) but also reduce the risks of occupational exposure (to silver) to workers involved in filter making. Silver nitrate is mixed with clay, sawdust, grog and water during the manufacturing process whilst silver nanoparticles are painted to the filters after firing. Using silver nitrate therefore eliminates the possibility of inhalation exposure to the filter manufacturing workers.

4.7 ECONOMICS OF THE PROCESS

4.7.1 Cost analysis

A cost analysis of the economic benefit of substituting silver nanoparticles with silver nitrate in the production of ceramic water filters is carried out. Overall, the silver nitrate chemical costs less than silver nanoparticles in terms of the purchasing price per kilogram and considering that silver nitrate is locally available in South Africa there are no shipping costs incurred (2019 pricing). Silver nanoparticles are purchased and shipped from Spain implying that there is additional shipping cost associated with the purchase of silver nanoparticles as shown in *Table 4.6;*

Table 4.6: Summary of costs related to the purchase of silver nitrate and silver nanoparticles

	Silver nitrate	**Silver nanoparticles**

Price per kg	R9,085	R28,062
Shipping Cost	R0	R4,502
TOTAL	R9,085	R32,564

Besides the above-mentioned purchasing costs, using silver nitrate eliminates one stage labour costs as the painting step is removed because silver nitrate is added during the manufacturing process instead. The use of silver nitrate during the manufacturing process also eliminates health risks for workers as some research suggests that inhalation of silver nanoparticles may result in genotoxic effects (Aktepe *et al*., 2015; Fewtrell *et al*., 2017). Elimination of these health risks will therefore avoid occurrences such as down time at the workplace, lack of productivity and compensation claims by employees.

However, one drawback as noted by Jackson *et al*. (2018) is that silver nitrate filter production requires the application of silver before quality tests (pressure and flow rate tests) and if a filter fails to pass one or both tests, the silver will be wasted.

4.7.2 Sensitivity analysis

During the manufacturing of different types of filters under study (1 g silver nitrate, 2 g silver nitrate and silver nanoparticles), the quantity of all other inputs essential in filter making remains constant i.e. clay, sawdust, grog and water. Only the type, quantity and application method of chemical differs. Therefore, sensitivity analysis is carried out to determine how the volume of filters produced affects total costs. A random example showing the costs of producing 1000 filters using the different chemicals is highlighted in *Figure 4.7*;

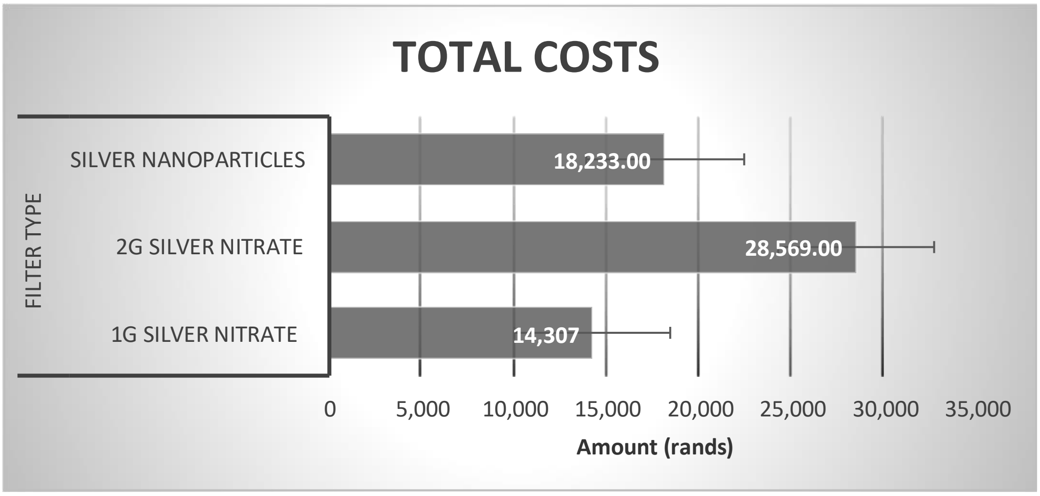

Figure 4.7: Costs associated with producing 1000 filters

The sensitivity analysis therefore concludes that it is more economic to manufacture ceramic water filters with 1 g silver nitrate as they are cheaper to produce than both 2 g silver nitrate and silver nanoparticle filters. Because of this lower production cost, filter manufacturing facilities might consider reducing the current selling price of ceramic water filters thus improving affordability to the underprivileged communities that lack clean water supplies.

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

Water filters made using silver nitrate perform better in removing microorganisms from drinking water compared to the conventional silver nanoparticles impregnated ceramic water filters. Therefore, ceramic water filters made with silver nitrate can be adopted in providing safe drinking water at household level. Water filters made using silver nitrate are effective in removing total coliform and *E. coli* from polluted raw water.

Both filters made using silver nitrate and silver nanoparticles release silver concentrations that are below the recommended drinking water standards (100 ppb) for silver levels. However, the study proves that 1 g silver nitrate filters release lower silver levels in the effluent than 2 g silver nitrate and silver nanoparticle filters, at the same time performing better in reducing microorganisms from drinking water.

Because silver nitrate is mixed with clay and sawdust during filter manufacturing, there is less handling of the chemical by workers (in comparison to the application of silver nanoparticles which involves painting the chemical onto the ceramic filter using a paint brush). Using silver nitrate therefore reduces the risk of inhalation of the chemical by workers thus improving their occupational safety and health.

Making filters with 1 g silver nitrate is a viable option because the filters are cheaper to produce. Silver nitrate can be purchased locally in South Africa hence there are no importing costs associated with its use (compared to silver nanoparticles). It is therefore economical to adopt the use of silver nitrate in the production of ceramic water filters.

In summary, adopting silver nitrate in ceramic filter production could potentially improve microbiological performance; reduce the cost of filter production; increase occupational health and safety of workers involved in filter making; and also increase the safety of consumers using ceramic water filters for household water treatment.

5.2 RECOMMENDATIONS

Filter manufacturing facilities could substitute using conventional silver nanoparticles with using silver nitrate as the disinfecting agent in ceramic filtration. This is due to the lower cost price, microbiological performance and moderate silver releases in drinking water and improved worker safety that is associated with the production of filters made using silver nitrate.

Community members in the Dertig area and other affected areas may need to disinfect their drinking water before consumption regardless of the water source. Affordable disinfection methods may include the use of ceramic water filters. There is also need for relevant authorities to protect contamination of drinking water sources by devising policies for communities that lack POU water treatment.

Further Research

Other factors affecting the microbial water quality of ceramic filtered water such as general household hygiene practices, inadequate cleaning and maintenance of the filters, loss of disinfectant residual could be studied. Because it was beyond the scope of this research, it might be essential for further studies to be carried out on whether ceramic filters improve chemical water quality.

As the ceramic filtration technology is not yet a widespread water purification technique in Africa, it might be imperative to carry out a study on the community and stakeholder perceptions of the technology. In addition, experience of other organisations with the ceramic filtration technology should be compiled to understand the sustainability of the system in different regions.

The study was limited to the North West province. It might be essential to carry out further studies on silver nitrate ceramic water filters in different geographic environments such as Eastern Cape, Free State and Kwazulu Natal provinces of South Africa. The source and quality of water differs from province to province hence it might be interesting to evaluate the performance of ceramic filters made with silver nitrate using water from a wide variety of sources.

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APPENDIX 1 - Survey Data Questionnaire

1. What is the name of the head of your household?

2. Please provide the best phone number to reach you to schedule future visits for water sampling.
3. How many people currently live in this home?
4. What are the ages of the people who currently live in this home?
5. What is the gender of each person currently living in this home?
6. What is the source of drinking water for members of your household that you use most frequently in the current season? Choices: Piped into house; piped to yard/plot; Neighbour's pipe; Public tap/standpipe; Tanker truck; Buy bottled water; other.
7. How long does it take you to retrieve water for your home?
8. Who is the main person responsible for filling water containers from this source? Choices: Adult woman; Adult man; Female child under 15; Male child under 15; other.
9. Where does this water originate? Choices: Municipal treated source; Community-level system for surface water; Community level system for ground water; Pond; Spring; River; Borehole; Other; Not known.
10. Is your main water supply continuous or interrupted?
11. If interrupted, how long was the last interruption?
12. During interruptions, where do you most often get water instead? Choices: Same as question 5.
13. If there are interruptions, how long does it take you to retrieve water from a secondary source?
14. How often do you have to get water from the secondary source?
15. Do you treat your water in any way to make it safer to drink?
16. If you do, how do you treat it? Choices: Let it stand so particulates settle; Solar disinfection; Use a water filter; Pass the water through a piece of folded fabric; Add bleach/chlorine; Boil; Other.

17. What do you use to store your drinking water? Choices: Ceramic pots; Metal buckets; Plastic buckets; Jerry can; Small pans; Cooking pots; Plastic bottles; Other.

18. Are your storage vessels covered?

19. What do you use to bring water to the storage container? Choices: Fill directly from tap; Use another container to fill (please specify type of container); other.

20. What do you use to remove water from the storage container for consumption? Choices: Use spigot to discharge water into a cup; Use hands to scoop out water; Use a cup with a handle to scoop out water; Use a cup without a handle to scoop out water; other.

21. In the last month, has there been a time when no one was drinking household water for periods of time greater than 24 hours? If so, please give the duration of each event.

22. At the end of a period of 24 or more hours without using water, do you continue to drink the water in your storage container or do you discard it and fill it up again with new water?

23. How would you describe your drinking water most of the time? Choices: Very good quality - it is safe to drink, looks and smells clean; Average quality - it may not always be safe to drink and sometimes is cloudy or smells bad; Poor quality - It probably is often not safe to drink and it smells bad or looks cloudy most of the time; I don't know.

APPENDIX 2- Microbiological quality of raw water and water from ceramic filters made using 1 g silver nitrate Key

T.C - total coliform count

E.C - *E. coli* count

H/H – Household label

■ - No water samples collected

**measured in CFU/100ml*

Results from July 2018 to September 2018

	July 2018	August 2018	September 2018

	Raw		Filtered		Raw		Filtered		aw		Filtered	
H/H	**T.C**	**E.C**	**T.C**	**E.C**	**T.C**	**E.C**	**T.C**	**E.C**	**T.C**	**E.C**	**T.C**	**E.C**
D	8	0	0	0	15	0	3	0	0	0	0	0
E	121	0	10	0	1000	0	3	0	119	17	10	0
F	42 19	0 0	57 14	0 0	29	0 0	17	0 0	[redacted]	[redacted]	[redacted]	[redacted]
G					4		4		1000	0	8	0
H	37	0	3	0	153	0	1	0	31	0	0	0
L	0	0	0	0	74	0	1	0	7	0	0	0
M	0	0	0	0	34	0	1	0	71	0	6	0
N	138	0	0	0	196	0	0	0	254	0	1000	2
O	31	0	0	0	29	0	0	0	209	22	1	0
T	147	0	0	0	131	0	0	0	168	1	1	0
U	2	0	0	0	103	0	0	0	8	0	1	0
V	1000	0	1000	0	1000	0	1000	0	1000	0	1000	0
W	171	0	2	0	1000	0 0	0 0	0 0	1000	0 0	0	0 0
Y	[redacted]	[redacted]	[redacted]	[redacted]	1000	0	5	0	1000 5	0	11	0
CC	48	0	26	0	106						0	

Results from October 2018 to December 2018

	October 2018				November 2018				December 2018			
	Raw		**Filtered**		**Raw**		**Filtered**		**Raw**		**Filtered**	
H/H	**T.C**	**E.C**	**T.C**	**E.C**	**T.C**	**E.C**	**T.C**	**E.C**	**T.C**	**E.C**	**T.C**	**E.C**
D	0	0	0	0	0	0	0	0	8	0	0	0
E	0	0	0	0	233	0	0	0	300	0	0	0
F	131	0	14	0	215	0	111	0	276	0	79	0
G	138	0	94	0	2	0	0	0	294	0	104	0
H	217	0	0	0	63	0	0	0	47	0	0	0
L	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
M	0 102	0 0	0 0	0 0	[redacted]	[redacted]	[redacted]	[redacted]	1000	49	0 0	0 0
N					15	0	0	0	87	0		
O	1000	1000	2	0	67	0	0	0	98	4	0	0
T	112	0	31	0	39	0	0	0	0	0	0	0

U	0	0	0	0	6	0	0	0	8	0	0	0
V	1000				341				1000	0	0	0
W	1000	0 0	52 35	0 0	146	0 0	0 0	0 0	[redacted]	[redacted]	[redacted]	[redacted]
Y	1000	0	33	0	349	0	2	0	78	0	0	0
CC	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

Results from January 2019 to March 2019

	January 2019				**February 2019**				**March 2019**			
	Raw		**Filtered**		**Raw**		**Filtered**		**Raw**		**Filtered**	
H/H	**T.C**	**E.C**	**T.C**	**E.C**	**T.C**	**E.C**	**T.C**	**E.C**	**T.C**	**E.C**	**T.C**	**E.C**
D	2	0	0	0	16	0	0	0	1	0	0	0
E	1000	2	1	0	143	0	0	0	63	0	0	0
F	165	0	0	0	1000	0	0	0	107	0	0	0
G	43	0	0	0	165	0	0	0	25	0	0	0
H	101	0	0	0	85	0	0	0	120	0	0	0
L	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
M	12	0	0	0	1000	4	0	0	132	0	2	0
N	1000	3	0	0	354	1	0	0	157	0	0	0
O	321	0	0	0	113	4	0	0	1000	1	0	0
T	32	0	4	0	21	0	0	0	67	0	0	0
U	13	0	0	0	14	0	0	0	0	0	0	0
V	456	0	3	0	1000	2	0	0	1000	1	0	0
W	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Y	1000	0	1	0	87	2	1	0	67	0	0	0
CC	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

Results from April 2019 to June 2019

	April 2019				**May 2019**				**June 2019**			
	Raw		**Filtered**		**Raw**		**Filtered**		**Raw**		**Filtered**	
H/H	**T.C**	**E.C**	**T.C**	**E.C**	**T.C**	**E.C**	**T.C**	**E.C**	**T.C**	**E.C**	**T.C**	**E.C**

D	6	0	0	0	15	0	0	0	6	0	0	0
E	110	5	1	0	87	1	0	0	267	0	0	0
F	68	1	0	0	143	0	0	0	76	2	0	0
G	223	1	1	0	19	0	0	0	44	0	0	0
H	23	0	0	0	42	0	0	0	31	0	0	0
L	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
M	87	0	1	0	65	2	1	0	88	0	0	0
N	101	7	1	0	364	10	0	0	35	1	3	0
O	134	4	2	0	46	0	0	0	57	0	0	0
T	123	0	7	0	33	0	0	0	21	0	1	0
U	41	0	0	0	12	0	1	0	0	0	0	0
V	454	0	0	0	232	0	3	0	123	0	0	0
W	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Y	178	0	1	0	456	0	0	0	657	0	0	0
CC	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

Results for July 2019

	July 2019			
	Raw		**Filtered**	
H/H	**T.C**	**E.C**	**T.C**	**E.C**
D	1	0	0	0
E	41	0	1	0
F	44	1	1	0
G	23	0	0	0
H	13	0	0	0
L	[redacted]	[redacted]	[redacted]	[redacted]
M	111	3	2	0
N	67	1	1	0
O	378	0	7	0

T	0	0	0	0
U	9	0	0	0
V	24	0	0	0
W	■	■	■	■
Y	123	0	0	0
CC	■	■	■	■

APPENDIX 3- Microbiological quality of raw water and water from ceramic filters made using 2 g silver nitrate Key

T.C - total coliform count

E.C - *E. coli* count

H/H – Household label

■ - No water samples collected

**measured in CFU/100ml*

Results from July 2018 to September 2018

	July 2018				**August 2018**				**September 2018**			
	Raw		**Filtered**		**Raw**		**Filtered**		**Raw**		**Filtered**	
H/H	**T.C**	**E.C**	**T.C**	**E.C**	**T.C**	**E.C**	**T.C**	**E.C**	**T.C**	**E.C**	**T.C**	**E.C**
A	1000	3	0	0	1000	0	0	0	238	0	0	0
B	2	0	0	0	66	76	3 0 0	0 0 0	1000	5 0 0	1 0 0	1 0 0
C	■	■	■	■	0	0			0			
J	17	1000	0	0	1000	289			44			
K	0	0	0	0	37	0	1	0	2	0	0	0
P	28	0	0	0	30	0	0	0	8	0	0	0
Q	2	0	5	0	50	0	0	0	58	0	0	0

R	26	0	0	0	9	0	0	0	83	0	0	0
S	26	0	0	0	292	0	0	0	1000	1	2	0
X	14	0	13	0	1000	0	22	0	1000	0	22	0
Z	0				23				13	0	0	0
AA	267	0 0	0 1	0 0	184	0 0	0 0	0 0	[redacted]	[redacted]	[redacted]	[redacted]
BB	111	0	0	4	1000	0	1	0	101	1	0	0
DD	[redacted]	[redacted]	[redacted]	[redacted]	1000	71	0	0	[redacted]	[redacted]	[redacted]	[redacted]
I	0	0	0	0	[redacted]	[redacted]	[redacted]	[redacted]	11	0	1	0

Results from October 2018 to December 2018

	October 2018				**November 2018**				**December 2018**			
	Raw		**Filtered**		**Raw**		**Filtered**		**Raw**		**Filtered**	
H/H	**T.C**	**E.C**	**T.C**	**E.C**	**T.C**	**E.C**	**T.C**	**E.C**	**T.C**	**E.C**	**T.C**	**E.C**
A	85	1 0	1 3	0 0	87 27	0 0	0 1	0 0	87	0	0	0
B	1								[redacted]	[redacted]	[redacted]	[redacted]
C	0	0	0	0	1	0	0	0	41	0	0	0
J	94	0	0	0	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
K	0	0	0	0	32	0	0	0	104	0	0	0
P	0	0	0	0	0	0	0	0	0	0	0	0
Q	0	0	0	0	251	0	0	0	33	0	0	0
R	[redacted]	[redacted]	[redacted]	[redacted]	0	0 0 0	0 0 0	0 0 0	59	0	0	0
S	76	0 0	2 0	0 0	1000				[redacted]	[redacted]	[redacted]	[redacted]
X	173				96				37	0	0	0
Z	47	0	0	0	17	0 0			17	0	0	0
AA	[redacted]	[redacted]	[redacted]	[redacted]	117	530	0 0 0	0 0 0	[redacted]	[redacted]	[redacted]	[redacted]
BB	164	0	164	0	31				31	0	0	0
DD	124	5	0	0	1000	1000	578	0	59	0	0	0
I	0	0	0	0	11	0	0	0	4	0	0	0

Results from January 2019 to March 2019

	January 2019				February 2019				March 2019			
	Raw		**Filtered**		**Raw**		**Filtered**		**Raw**		**Filtered**	
H/H	**T.C**	**E.C**	**T.C**	**E.C**	**T.C**	**E.C**	**T.C**	**E.C**	**T.C**	**E.C**	**T.C**	**E.C**
A	3	0	0	0	43	0	0	0	0	0	0	0
B	76	0	5	0	87	0	2	0	15	0	1	0
C	1	0	0	0	0	0	0	0	2	0	0	0
J	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
K	2	0	0	0	12	0	0	0	0	0	0	0
P	4	0	0	0	0	0	0	0	1	0	0	0
Q	12	0	0	0	0	0	0	0	9	0	0	0
R	78	0	0	0	36	0	0	0	43	0	0	0
S	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
X	78	0	7	0	35	0	0	0	76	0	1	0
Z	23	0	0	0	12	0 0 0	0 0 1	0 0 0	23 54 87	0 0 0	0 0 0	0 0 0
AA	[redacted]	[redacted]	[redacted]	[redacted]	113							
BB	134	0	1	0	98							
DD	350	23	24	0	235	13	20	0	145	34	23	0
I	1	0	0	0	0	0	0	0	1	0	0	0

Results from April 2019 to June 2019

	April 2019				May 2019				June 2019			
	Raw		**Filtered**		**Raw**		**Filtered**		**Raw**		**Filtered**	
H/H	**T.C**	**E.C**	**T.C**	**E.C**	**T.C**	**E.C**	**T.C**	**E.C**	**T.C**	**E.C**	**T.C**	**E.C**
A	1	0	0	0	0	0	0	0	2	0	0	0
B	111	0	3	0	12	0	0	0	16	0	0	0
C	3	0	0	0	9	0	0	0	0	0	0	0
J	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
K	4	0	0	0	1	0	0	0	0	0	0	0
P	5	0	0	0	0	0	0	0	2	0	0	0
Q	2	0	0	0	0	0	0	0	1	0	0	0

R	12	0	0	0	2	0	0	0	17	0	0	0
S	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
X	23	0	0	0	145	0	0	0	23	0	0	0
Z	13	0	0	0	4	0	0	0	34	0	0	0
AA	9	0	1	0	12	0	0	0	17	0	0	0
BB	66	0	0	0	178	0	0	0	128	0	4	0
DD	456	12	13	0	143	2	8	0	123	0	0	0
I	3	0	0	0	0	0	0	0	0	0	0	0

Results for July 2019

	July 2019			
	Raw		**Filtered**	
H/H	**T.C**	**E.C**	**T.C**	**E.C**
A	2	0	0	0
B	24	0	1	0
C	0	0	0	0
J	[redacted]	[redacted]	[redacted]	[redacted]
K	13	0	0	0
P	0	0	0	0
Q	14	0	0	0
R	56	0	0	0
S	[redacted]	[redacted]	[redacted]	[redacted]
X	68	0	1	0
Z	5	0	0	0
AA	12	0	0	0
BB	56	0	0	0
DD	567	25	7	0
I	1	0	0	0

APPENDIX 4- Microbiological quality of raw water and water from silver nanoparticles impregnated ceramic filters Key

T.C - total coliform count

E.C - *E. coli* count

H/H – Household label

■ - No water samples collected

**measured in CFU/100ml*

Results from July 2018 to September 2018

	July 2018				**August 2018**				**September 2018**			
	Raw		**Filtered**		**Raw**		**Filtered**		**Raw**		**Filtered**	
H/H	**T.C**	**E.C**	**T.C**	**E.C**	**T.C**	**E.C**	**T.C**	**E.C**	**T.C**	**E.C**	**T.C**	**E.C**
C	TMC	3	0	0	TMC	0	0	0	238	0	0	0
D	2	0	0	0	66	76	3	0	TMC	5	1	1
H	■	■	■	■	0	0	0	0	0	0	0	0
K	8	0	0	0	15	0	3	0	0	0	0	0
N	121	0	10	0	TMC	0	3	0	119	17	10	0
O	44	0	50	0	29	0	17	0	■	■	■	■
S	19	0	14	0	4	0	4	0	TMC	0	8	0
V	37	0	3	0	153	0	1	0	31	0	0	0
X	0	0	0	0	■	■	■	■	11	0	1	0
Z	19	TMC	0	0	TMC	289	0	0	44	0	0	0

Results from October 2018 to December 2018

	October 2018				**November 2018**				**December 2018**			
	Raw		**Filtered**		**Raw**		**Filtered**		**Raw**		**Filtered**	
H/H	**T.C**	**E.C**	**T.C**	**E.C**	**T.C**	**E.C**	**T.C**	**E.C**	**T.C**	**E.C**	**T.C**	**E.C**
C	85	1	1	0	87	0	0	0	87	0	0	0
D	1	0	3	0	27	0	1	0	■	■	■	■
H	0	0	0	0	1	0	0	0	41	0	0	0
K	0	0	0	0	0	0	0	0	8	0	0	0

N	0	0	0	0	233	0	0	0	300	0	0	0
O	131	0	14	0	230	0	111	0	276	0	79	0
S	138	0	94	0	2	0	0	0	294	0	104	0
V	213	0	0	0	63	0	0	0	47	0	0	0
X	0	0	0	0	11	0	0	0	4	0	0	0
Z	94	0	0	0								

Results from January 2019 to March 2019

	January 2019				**February 2019**				**March 2019**			
	Raw		**Filtered**		**Raw**		**Filtered**		**Raw**		**Filtered**	
H/H	**T.C**	**E.C**	**T.C**	**E.C**	**T.C**	**E.C**	**T.C**	**E.C**	**T.C**	**E.C**	**T.C**	**E.C**
C	3	0	0	0	43	0	0	0	0	0	0	0
D	76	0	5 0	0	87	0	2	0	15	0	1	0
H	1	0		0	0	0	0	0	2	0	0	0
K	2	0	0	0	16	0	0	0	1	0	0	0
N	1000	2	1 0 0	0	143	0	0	0	63	0	0	0
O	165	0		0	1000	0	0	0	107	0	0	0
S	43	0		0	165	0	0	0	25	0	0	0
V	101	0	0	0	85	0	0	0	120	0	0	0
X	1	0	0	0	0	0	0	0	1	0	0	0
Z												

Results from April 2019 to June 2019

	April 2019				**May 2019**				**June 2019**			
	Raw		**Filtered**		**Raw**		**Filtered**		**Raw**		**Filtered**	
H/H	**T.C**	**E.C**	**T.C**	**E.C**	**T.C**	**E.C**	**T.C**	**E.C**	**T.C**	**E.C**	**T.C**	**E.C**
C	1	0	0	0	0	0	0	2	0	0	0	1
D	111	3	0	12	0	0	0	16	0	0	0	111
H	3	0	0	9	0	0	0	0	0	0	0	3
K	6	0	0	15	0	0	0	6	0	0	0	6
N	110	1	0	87	1	0	0	267	0	0	0	110

O	68	0	0	143	0	0	0	76	2	0	0	68
S	223	1	0	19	0	0	0	44	0	0	0	223
V	23	0	0	42	0	0	0	31	0	0	0	23
X	3	0	0	0	0	0	0	0	0	0	0	3
Z	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

Results for July 2019

	July 2019			
	Raw		Filtered	
H/H	T.C	E.C	T.C	E.C
C	2	0	0	0
D	24	0	1	0
H	0	0	0	0
K	[redacted]	[redacted]	[redacted]	[redacted]
N	13	0	0	0
O	0	0	0	0
S	14 56	0	0	0 0
V		0	0	
X	[redacted]	[redacted]	[redacted]	[redacted]
Z	68	0	1	0

APPENDIX 5 SILVER LEVELS IN EFFLUENT Filters made using 1 g silver nitrate Key

H/H- Household label

**measured in mg/L*

	SILVER CONCENTRATION				
H/H	**July 2018**	**October 2018**	**January 2019**	**April 2019**	**July 2019**
D	0.099	0.093	0.092	0.033	0.072
E	0.109	0.046	0.074	0.071	0.042
F	0.055	0.060	0.029	0.044	0.007
G	0.082	0.095	0.092	0.039	0.000
H	0.07	0.092	0.029	0.000	0.023
L	0.104	0.126	0.036	0.026	0.032
M	0.136	0.092	0.066	0.004	0.019
N	0.124	0.058	0.046	0.084	0.022
O	0.112	0.122	0.026	0.062	0.025
T	0.144	0.092	0.056	0.087	0.012
U	0.178	0.089	0.063	0.049	0.020
V	0.166	0.124	0.000	0.044	0.16
W	0.193	0.138	0.063	0.014	0.037
Y	0.139	0.091	0.018	0.058	0.000
CC	0.149	0.062	0.000	0.044	0.001

APPENDIX 6 SILVER LEVELS IN EFFLUENT Filters made using 2 g silver nitrate Key

H/H- Household label

**measured in mg/L*

	SILVER CONCENTRATION

H/H	July 2018	October 2018	January 2019	April 2019	July 2019
A	2.540	0.231	0.163	0.072	0.077
B	2.568	0.236	0.178	0.061	0.088
C	2.597	0.179	0.137	0.121	0.110
I	2.594	0.150	0.097	0.106	0.041
J	2.587	0.166	0.163	0.085	0.069
K	2.533	0.215	0.106	0.072	0.090
P	2.532	0.139	0.077	0.098	0.065
Q	2.578	0.198	0.132	0.070	0.050
R	2.624	0.257	0.187	0.042	0.035
S	2.623	0.181	0.158	0.068	0.000
X	2.569	0.230	0.101	0.055	0.031
Z	2.562	0.246	0.167	0.034	0.059
AA	2.559	0.217	0.127	0.019	0.000
BB	2.588	0.160	0.086	0.079	0.012
DD	2.612	0.165	0.101	0.068	0.023

APPENDIX 7 SILVER LEVELS IN EFFLUENT Silver nanoparticles filters Key

H/H- Household label

**measured in mg/L*

	SILVER CONCENTRATION				
H/H	**July 2018 (mean 2.548)**	**October 2018 (mean 0.48)**	**January 2019 (mean 0.624)**	**April 2019 (mean 0.29)**	**July 2019 (mean 0.242)**
C	2.571	0.516	0.575	0.285	0.258
D	2.529	0.486	0.587	0.306	0.267
H	2.592	0.550	0.623	0.271	0.197
K	2.497	0.486	0.651	0.275	0.267

	-		–		
N	2.461	0.545	0.625	0.335	0.239
O	2.635	0.415	0.623	0.245	0.245
S	2.599	0.474	0.597	0.305	0.217
V	2.504	0.410	0.625	0.309	0.287
X	2.576	0.474	0.661	0.274	0.217
Z	2.525	0.444	0.673	0.295	0.226