Optimisation of Operating Conditions and Field Assessment of Copper Nitrate Impregnated Ceramic Water Filters as Point-Of-Use Water Treatment Device

BY

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DECLARATION

I, Nduvho Milliscent Tshidumo of student number 17002106, hereby declare that this is my work and has not been submitted to any other institution. All references used or quoted have been duly acknowledged and are listed in the list of references.

Signature………… ……………………………..

Date: February 2024

DEDICATION

I dedicate this work to all individuals lost due to lack of access to improved drinking water supplies and sanitation. This work is also dedicated to my parents for their moral support, patience and understanding during the period of the study.

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Gratitude to God almighty for the gift of life and for giving me the opportunity, strength, and ability to complete this work.

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ABSTRACT

Consumption of contaminated water is increasingly becoming a leading problem in developing nations and posing greater threat to human health. Consequently, treating water at the household level is highly recommended for the protection of public health. This research investigates microbial water quality challenges in Tswinga village, focusing on the impact on residents' health, daily life, and socio-economic activities. The primary research question explores the effectiveness of ceramic water filters, particularly those impregnated with copper nitrate, in mitigating waterborne diseases and improving water quality in the region. The study employs a mixed-method approach, combining fieldwork, photovoice methodology, socio-demographic surveys, and laboratory analyses. Fieldwork involves participant interviews, digital photography, and thematic analysis to understand the community's water-related challenges. Socio-demographic surveys gather information on household characteristics, water sources, and daily experiences. Water samples from various sources, in the field, undergo physicochemical and microbial analyses. Ceramic water filters with varying concentrations of copper nitrate were optimised in the laboratory to assess their efficacy in reducing Escherichia coli (*E. coli*) and total coliform. The results from the field and laboratory were compared to evaluate the filters' real-world performance. Key findings revealed significant water quality challenges, such as safety concerns, sanitation issues, and diseases attributable to contaminated water. Photovoice methodology highlighted the community's priorities, emphasising the need for sustainable access to clean water. Physicochemical analysis demonstrated that raw water from Tswinga falls within acceptable standards, but microbial analysis revealed the presence of *E. coli* and total coliform. After optimisation, ceramic filters impregnated with 1 g concentration of ionic copper demonstrated promise in reducing *E. coli* and total coliform bacteria. The weekly results indicated an average reduction of 0.64 log for *E. coli* and 0.16 log for total coliform, showcasing the effectiveness of the filters, attributed to the antibacterial properties of ionic copper. However, challenges arise in translating laboratory success to real-world usage, raising questions about user compliance and proper maintenance. The study sheds light on the complex water quality challenges faced by Tswinga village. While the physicochemical parameters meet standards, microbial contamination poses a severe health risk. Ceramic water filters, particularly those with 1 g of copper nitrate, showed potential in laboratory studies, but their effectiveness in real-world situations depends on addressing user behaviour and maintenance issues.

Keywords: Ceramic water filters, Copper nitrate, Point-of-use water treatment technologies, Photovoice, Waterborne diseases

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AgNPs	Silver Nanoparticles
CBA	Cost Benefit analysis
CBPR	Community Based Participatory Research
CFU	Colony Forming Unit
CMWG	Ceramic Manufacturing Working Group
CWFs	Ceramic Water Filters
DBPs	Disinfection Byproducts
E. coli	*Escherichia coli*
SANS	South Africa National Standards
SODIS	Solar Water Disinfection
WHO	World Health Organization

Chapter one

Introduction

1.1 Background information

The consumption of contaminated water is increasingly becoming a leading problem in developing nations and posing greater threat to human health (Chowdhary *et al*., 2020). This global challenge has resulted in an increase in death rates and illnesses. Consequently, treating water at the household level is highly recommended for the protection of public health.

To improve the quality of drinking water in low-income areas, Point-Of-Use (POU) water treatment devices are not just recommended, but they are the solution in areas where individuals have no access to safe and clean drinking water supplies. In most African regions, access to potable water has been achieved in a few cities and less in rural areas with many lacking basic water supply infrastructure (Edokpayi *et al*., 2018). Due to this, most residents of such rural areas often resort to different sources of water such as a river, lakes, and boreholes. However, some of those alternative sources are polluted with nutrients, trace metals and bacteria (Edokpayi *et al*., 2018). The consumption of microbiologically contaminated drinking water has been reported as the leading threat to public health (Singh *et al*., 2019).

According to the World Health Organization (WHO), the highest number of deaths related to water-borne diseases has been estimated to be due to the consumption of contaminated or unsafe water, particularly in developing countries (WHO, 2019). Hence, it is important to find methods that can be used to reduce the burden of water-borne diseases and treat contaminated water, thus, bringing the levels to permissible limit as stipulated by water quality guidelines. Sing *et al.,* (2019) reported that the WHO proposed the use of low-cost point-of-use treatment technologies, based on their ability to significantly improve the microbial quality in household drinking water and reduce the risk of water-borne diseases. These methods include chlorination, biosand filtration, solar water disinfection (SODIS), UV disinfection, ceramic water filters (CWFs), etc. In most rural areas of South Africa (SA), multiple point-of-use water treatment technologies are being widely promoted with the purpose of reducing the spread of waterborne diseases (Ndebele *et al*., 2021). Hill *et al.,* (2020) reported that the POU water treatment methods are mostly used for treating water in the household before it is consumed, leading to the elimination of the risk of contamination both at the source and during transport to the household.

According to Yang *et al*. (2021), the CWFs are produced from a mixture of locally available materials which includes suitable clays and can reduce the turbidity of water and are effective in the removal of microorganisms from raw water. CWFs are an example of the POU water treatment methods widely used in many parts of the world, especially by rural communities in South Africa to treat unclean water. CWFs are amongst the most practical and sustainable POU technologies with affordable and low-maintenance features for household water treatment in developing countries (Clasen, 2015). The ceramic water filters have been demonstrated to be viable at microbial sterilization and filtration without a residual taste or odour, and socially satisfactory (Jackson *et al*., 2018).

Over the years, small scale treatment devices have been invented in various areas around the world incorporating communities' perspective on raw and treated water. Such methods include charcoal filters and biosand. However, the Community Based Participatory Methods (CBPR), photovoice, has been specifically used as a health promotion tool and the method uses photographs to identify local issues that are observed through the perspective of community members (Mysyuk and Huisman, 2020). In the disciplines of global and public health, photovoice has emerged as an innovative research methodology. According to Kindery *et al.,* (2016), the goals of the photovoice method is to empower individuals to record and represent their community's strengths and concerns. Furthermore, it encourages critical dialogue and awareness about significant community issues through group discussion as well as for its results to reach local officials to spur social change.

There is disparity in access to clean and safe water supply and many residents in the villages such as Tswinga uses water with either unknown quality or poor quality for consumption. Also, due to lack of capital investment in water infrastructure, drinking water from unimproved sources is prevalent and occurs most in rural areas which lack adequate sanitation facilities (Mulenga *et al*., 2017). Hence, to prevent episodes of water borne disease there is a need for water quality improvement.

1.2 Problem statement

The failure to provide clean drinking water and adequate sanitation services to everyone remains one of the most significant shortcomings of the 20th century. This failure has resulted in a high incidence of water-borne diseases, particularly among young children, which has led to a high mortality rate (Mwitwa, 2013).

Water-borne diseases are caused by the consumption of contaminated water. Hence the consumption of such water may cause variety of sicknesses and diseases. WHO (2019) estimated that the consumption of contaminated or unsafe water particularly in developing countries has resulted in the highest number of deaths connected to waterborne infections. Divasha and Ravi (2020) address water-borne infections as the major cause of mortality in non-industrial nations killing around 760, 000 under-age children (< 5 years) in a year. Shaikh *et al*., (2022) reported that about 24 million children in Pakistan experience about 120 million episodes of diarrhoea annually. Jan *et al*., (2022) reported that in 2019, the rural areas of China (with more than 60 million individuals) suffered from the shortage of protected and clean water because of coal mining in Northern China resulting in environmental consequences such as water contamination, water shortage and dust pollution.

Prüss-Ustün *et al*., (2019) addressed that globally in 2016, 485,000 estimated deaths from diarrhoea were reported due to inadequate water access. However, in Sub-Saharan Africa (SSA), the burden of unsafe drinking water is still higher, especially since it recorded higher death rate than any other region in the world in 2015, due to the consumption of contaminated water (Price *et al*., 2022). Soliman (2022) stated that, economically, the absence of clean and safe water has resulted in the loss of lives and a lack of participation from individuals at work and school due to sickness.

In many rural areas of South Africa, there’s a shortage of reliable clean water supply. This has caused a problem for many individuals across the country, leading to consumption of low quality or untreated water. Previous case studies have addressed concerns of water insecurity and a lack of municipal water services within rural South African communities (Lebek *et al*., 2021). In their case study of rural Limpopo province, Mothetha *et al*., (2013) highlighted the challenges of municipal water supplies, such as inadequate operation and maintenance of infrastructure in the development of water facilities, Edokpayi *et al*., (2018) collected samples of household water and evaluated the water-use practices, water treatment technologies as well as the perceptions of water quality among rural households in Limpopo. Results from the study showed that the various water sources used by the residents of the study area was contaminated with faecal matter except tap water. Hence there is a need for interventions to forestall water borne infections. The Department of Water and Sanitation (2019) reported that an estimated 56% of the South Africa’s wastewater treatment plants are dysfunctional leading to the deteriorating in quality of the secondary water sources (rivers, streams, and springs) used by the local communities. Hence, water treatment has been linked to improving the water quality but, in some places, the terrain is bad and there’s poverty contributing to the status quo. Having a centralized water treatment plant may be a challenge but using a very affordable POU treatment system has been reported as a good alternative (Siwila, 2019).

1.3 Motivation of the study

Water security is one of the world’s most exceptional difficulties. Despite advancements and global efforts to develop water infrastructures, over 2 billion people remain without access to safe drinking water (WHO, 2021). Madilonga *et al*. (2021) reported that the consumption of untreated water has been a major cause of water-borne diseases such as diarrhoea and cholera.

Various point-of-use water treatment systems have been used in different studies, Like the use of the silver nanoparticles in ceramic water filters. However, there are some challenges associated with the use of silver nanoparticles, like they can be inhaled and cause heart diseases by the filters manufacturer. It is painted on the filter after firing not mixed with other materials during filter preparation. This affects the filter production because the materials are locally unavailable in South Africa thus driving the cost high. This shows that there is still a need for inexpensive point-of-use technologies in rural areas to decrease the high rate of illnesses triggered by waterborne infections (Dankovich *et al*., 2016). These point-of-use water treatment devices must be highly effective, low cost, easy to operate, with low maintenance requirements, environmentally friendly, as well as socio-culturally friendly (Yang *et al*., 2020). Copper is known as an effective antimicrobial agent that can help kill bacteria such as *E. coli* and total coliforms. Its effectiveness depends on factors such as the quality of the filter and the flow rate of the water through the filter. According to Varkey

and Dlamini (2012), copper can be used as a disinfectant as it is toxic to microorganisms and minimally toxic to humans. Owing to its comparative disinfection efficacy and low cost, it could provide an affordable alternative for water treatment compared with silver (Dankovish and Smith, 2014). In this research, the aim was to try to replace the more costly silver nanoparticles with a low-cost copper nitrate in the filters during production with the intention that it will yield the same bacteria inactivation as that of silver nanoparticles, and it will reduce the cost, to make it more affordable.
Therefore, the research findings could potentially add to the existing knowledge regarding sustainable methods for preventing and minimising the occurrence of water-borne diseases. As such, the public will benefit from the study as they will be educated about the importance of using ceramic filters leading to an improvement in water quality and a decrease in diarrhoea around the community. This is based on positive results from a prior study.

The study will benefit the community of Tswinga, the PureMadi facility, and other organisations advocating for ceramic filters technology by determining whether the use of copper nitrate on ceramic water filters is a more efficient and economically feasible option than other previously used methods to improve community health and ensure environmental sustainability.

1.4 Research objectives

1.4.1 Main objectives

The aim of this study was to optimise the operating conditions of copper impregnated ceramic water filter and to assess the water problems of the community through photovoice methodology.

1.4.2 Specific Objectives

- To assess the perception of community members on water quality issues within the study area.
- To optimise the amount of copper loadings into CWFs to achieve desirable disinfection.
- To determine the effluent quality of the water from the CWFs.
- To evaluate the health risk associated with the consumption of water from the CWFs.

1.5 Research question.

- What are the community members' perceptions regarding water quality issues in the study area?
- What is the optimised amount of copper loadings in the CWFs to achieve desirable disinfection?
- What is the effluent quality of the water from the CWFs?
- What is the health risk associated with the consumption of water from the CWFs?

1.6 Area of study

This study was conducted at Tswinga village located in the Vhembe district, Limpopo Province, South Africa. It is governed by the Thulamela municipality and its geographical coordinates are 23° 1' 0" South, 30° 29' 0" East (getamap.net) *Figure 1.1*.

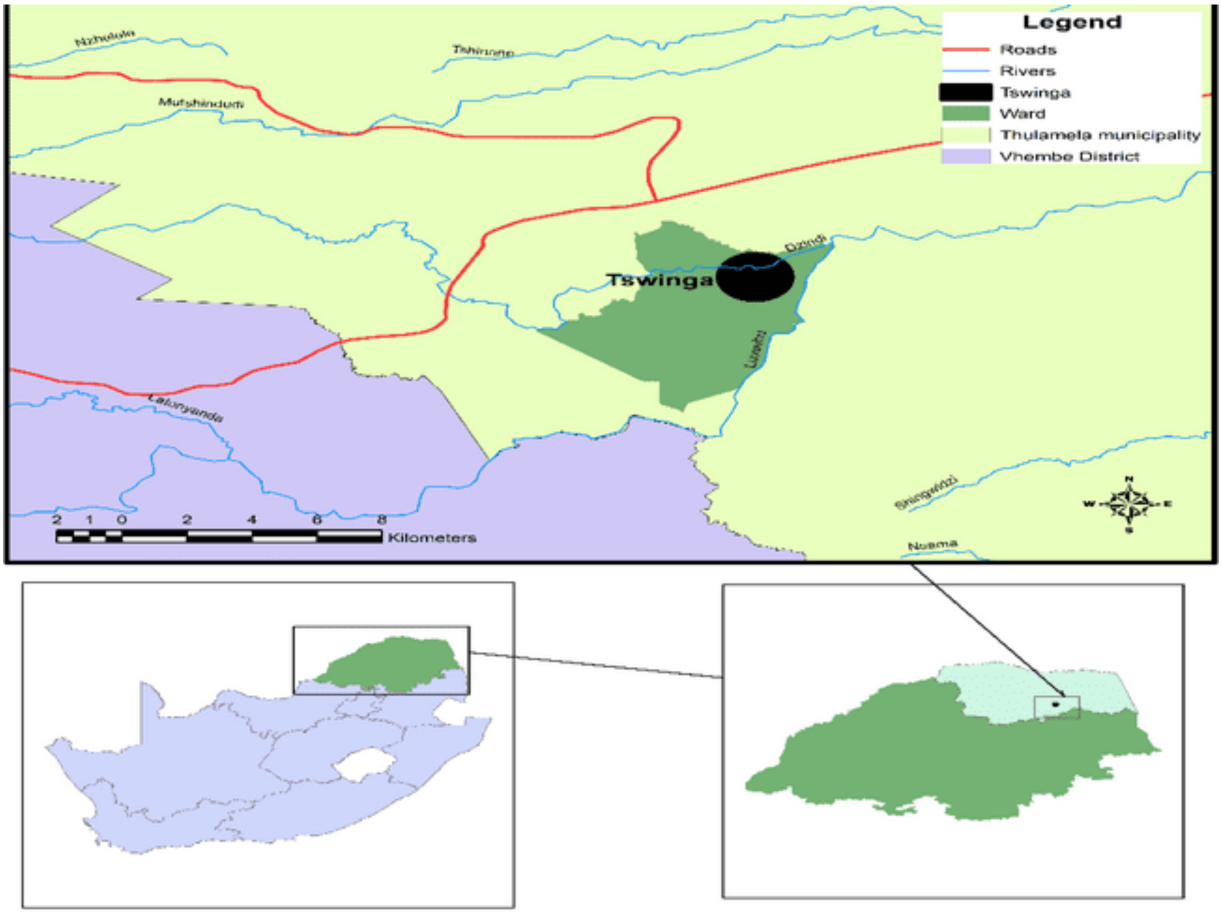

Figure 1.1: Map of the study area

1.6.1 *Population*

Tswinga village has a population of 3948 and 1102 number of households (S.A Stats, 2022).

1.6.2 Distrubution of water

A spring serve as Tswinga village's main supply of water. Residents in the Tswinga neighborhood experience water disruption for two to six hours every day when the spring dries up due to water rationing. Families are now compelled by water rationing to save enough water to use during periods when the taps aren't operating. The Tswinga village area's secondary water sources include rainwater, water from tanker trucks, and water from boreholes.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

In developing countries, the consumption of unsafe water is a significant leading problem. Hence, lack of clean and safe water for domestic purposes forces people mostly from the rural area to consume untreated water from any water source. The shortage of safe and clean water has not only been reported as a governance crisis but also as one of the biggest global concerns (Ugya *et al*., 2018; Yan *et al*., 2022).

According to WHO (2018), shortage of clean and safe drinking water in Africa has resulted in an increase in death related to diarrhoeal diseases. Having safeguarded water sources, such as boreholes or standpipes could help reduce the outbreak of the water-borne illness. According to Jeffreys (2012), having treated piped water is very costly to execute and can require a long time in most developing nations across the globe due to the huge initial financial investment. However, in community with such low socio-economic status, the solutions to the provision of safe and clean water are the use of POU water treatment devices. The perception of people towards their water resources have been reported using a pictorial form technique called photovoice.

2.2 Photovoice methodology

Photovoice is a photographic technique that is based on the participatory research of Wang and Burris (1997). The method was developed as a tool for a participatory action and health promotion research while working with rural Chinese women on a program for women's reproductive health and development (Wang and Burris, 1997). According to Sanon *et al*., (2014), the use of photovoice was initially proposed for three different reasons. Firstly, to record and document the strengths and weaknesses of a community. Secondly, to offer a forum for collective and public discourse, as it might empower individuals. Third, to create data and opportunities to advocate for policy change (Manasia, 2017). Basically, photovoice is referred to as a qualitative visual research technique that uses participant-taken photographs to explore and address community needs, strengths, and challenges, and stimulate individual empowerment, while creating critical dialogue to promote community change (Mysyuk and Huisman, 2020).

Researchers and practitioners in the field of health promotion have used the photovoice technique with a range of distinct demographics (Seitz and Orsini, 2022). A few examples include using photovoice to work with: women from rural China (Wang & Burris, 1997), and Latino adults with intellectual disabilities (Jurkowski and Paul-Ward, 2007).

For photovoice projects, a variety of cameras can be used, each having its unique advantages and drawbacks (Campbell *et al*., 2021). The cameras are to be selected with the objectives, participant needs, practical considerations, and available budget. Each type of camera has unique advantages and restrictions that may help or obstruct a photovoice project (Table 2.1).

Table 2.1: Advantages and disadvantages of different types of cameras used in photovoice (Milne and Muir, 2019)

Camera	**Advantages**	**Disadvantages**
Disposable camera	▪ Easily replaceable if lost. ▪ Does not need charger, batteries, or electricity. ▪ Limits number of photos taken, encourages more thought before taking the photo.	▪ Less available in some regions. ▪ Easier to lose. ▪ Lower quality prints ▪ Photographer not able to see the shot taken to verify quality.
Digital camera	▪ Re-usable ▪ No limitations on number of photos captured. ▪ Higher quality images for publishing ▪ Can send images electronically.	▪ Higher cost ▪ Risk of theft or putting the photographer at risk of theft ▪ Need for additional batteries. ▪ Insurance recommended,

		which has a cost implication.
Instant camera (for example Polaroid, or Lomo)	▪ Re-usable ▪ Photos can be shared immediately with other people involved. ▪ Space on the photo to write message. ▪ Does not need to be charged more often.	▪ Plastic likely to break if dropped. ▪ High cost ▪ Paper can be expensive. ▪ Additional time to scan images to jpeg if using older model.
Mobile phone camera	▪ Variety of shooting modes ▪ Smaller and more portable than larger cameras ▪ Can manipulate images with participant	▪ Not all people have mobile phones with cameras, particularly older people, children, and people on low incomes in certain countries

2.3 Point of use water treatment technologies in developing countries

POU treatment devices are defined as any range of technologies utilised for the purpose of treating household drinking water right before consumption (Bitton, 2014). Yang *et al*., (2020) further explained that the treatment technologies should be simple, effective, inexpensive, with low maintenance requirement, environmentally sustainable and should require locally available materials. Various point-of-use water treatment devices are being used by individuals and communities to treat the collected water from various sources with the aim of eliminating water contaminants. In developing countries, point-of-use water treatment systems can be used to overcome the issue of water supplied by pipes which are microbiologically unsafe due to post treatment contamination during the distribution. Also, it can be used to treat ground and surface water before consumption.

2.3.1 Solar water disinfection (SODIS)

The SODIS method is known to be simple, inexpensive, and has been proven to be effective in the removal of water-borne pathogens and bacteria in contaminated water (SODIS, 2018; Chaúque and Rott, 2021). The SODIS system is simple and does not require any installation or maintenance. However, the method requires a placing of clear soft plastic soda bottle with contaminated water not exceeding 2.0 litres on top of the roof to be exposed to direct sunlight (Mosler *et al*., 2013). For better results the contaminated water must be exposed to direct sunlight, since the method works best with direct sunlight for a period of 6 hours, but if exposed to unfavourable weather conditions, it might take 48 hours for the water to be treated (Zinn *et al*., 2018)

2.3.2 Chlorination

Chlorine is a commonly used disinfectant and most favoured for disinfection due to its viability, low-cost and effectiveness, in eliminating microbes from drinking water (Mazhar *et al*., 2020). Levy *et al.,* (2014) further explained that the method is highly effective in treating drinking water and has proven reduction of bacteria and most viruses in drinking water. Numerous studies have proven complete eliminations of microbial contaminants in drinking water using chlorination (Lantagne *et al*., 2018). According to Mohamed *et al.,* (2015), the chlorination method can be used in any climatic condition, the method requires neither maintenance nor any installation. The gradual utilization of this chlorination method can significantly decrease global problems such as water-borne diseases (Clasen, 2015). However, the use of chlorine in water treatment raises apprehensions regarding the possibility of the formation of disinfection by-products (DBPs) due to the interactions between free chlorine and natural organic materials such as fluvic and humic acids which may be present in the water source (Srinivasan *et al*., 2021). DBPs are known to be carcinogenic, common examples include trihalomethanes and haloacetic acids.

2.3.3 UV disinfection

As indicated by Song *et al.,* (2016), UV irradiation has been widely used worldwide in water disinfection for the purpose of inactivating microorganisms and it doesn't create unsafe disinfection byproducts (DBPs). Wu *et al*., (2021) reported that during this method the radiation infiltrates through the microorganism resulting in photochemical harm by impeding their nucleic acids. In any case, it is accepted that such harm further inactivates microorganisms from replication and causing disease (Collivignarelli *et al*., 2017). Ultraviolet technology is especially effective at inactivating Giardia lamblia cysts and Cryptosporidium parvum oocysts, which should be removed via filtering or distillation (Extension, 2019). A draw back to this technology, according to Agrawal and Bhalwar (2011), is that the presence of suspended and dissolved organic matter in water may affect how well it disinfects certain microbes by protecting them from UV light. Therefore, in situations when the light intensity is high enough to reach pathogens in the water, UV light technologies are most efficient in producing potable water.

2.3.4 Biosand filtration

According to Zaman *et al*., (2017), the Biosand is a point-of-use water treatment system known to be one of the simplest systems that require little knowledge to prepare. An advantage of this method is that it has a long-life span, and the materials are locally available or locally made (Zinn *et al*., 2018). The biosand filtration has the potential to remove all pathogens which have contaminated the drinking water (Chaidez *et al*., 2016). Hence, before biosand filtration system is proposed for the treatment of the water, it is important to know the turbidity of the water source. However, for areas where the water source is contaminated with agricultural and industrial toxins, as well as in regions where air reaches freezing temperatures, the method is not recommended to be used. According to Lea (2016), the technique requires the water level to be kept 5-6 centimeters over the sand layer. When using the method of biosand filtration recontamination can occur and results in health complications and death, especially if the bacteria were, not all removed (Zinn *et al*., 2018).

2.3.5 Ceramic Filters

The CWFs are an example of POU water treatment devices mostly used in households to improve the water quality and have been proven to be effective in reducing water-borne diseases (Zinn *et al*., 2018). CWFs are mostly used in rural areas because most of their water sources are usually subjected to water pollution. *Figure2.1* shows an example of the CWFs used for purification of water. According to Abebe *et al*. (2016), the CWFs can remove turbidity, organic matter, as well as microbes in contaminated water. However, the disadvantage of the CWFs is the removal of viruses in water since they are smaller than the porous size of the ceramic filters making the filters to be less effective in removing the viruses from the drinking water (Abebe *et al*., 2016).

Figure 2.1: Example of a ceramic water filter (PureMadi 2021)

2.4 Application of silver-based material in ceramic water filters production

Silver nano particles and silver nitrate have been reportedly used in ceramic filters to enhance its efficacy in inactivating water pathogens as well as producing residual levels of silver for the treated water (Mitelman *et al.,* 2015). A study by Shepardd *et al*., (2020) assessed CWFs filters with and without AgNPs for the reduction of *E. coli* and the results showed that the ceramic water filters can reduce the number of *E. coli* with a significant log reduction. The results showed a 9.5 – 10.9 log reduction for filters with AgNPs, while for the filters without AgNPs the results showed an 8.0 – 9.5 log reduction. However, no residual treatment was guaranteed with the use of CWFs without AgNPs though it recorded good inactivation.

Figure 2.2 shows how silver nanoparticles have been employed in variety of applications, including point-of-use water treatment. Silver nanoparticles poses strong conductivity, chemical stability, and catalytic activity making them a promising choice for drinking water purification (Rus *et al.,* 2017). Owing to their well-established antimicrobial and unique characteristics, AgNPs have been applied in point-of-use (POU) water treatment technologies including ceramic water filters. However, during the filter production as the AgNPs is painted on the filter after firing, it is highly recommended that workers adhere to all the necessary health and safety standards such as covering of noses and wearing gloves to prevent negative health impact.

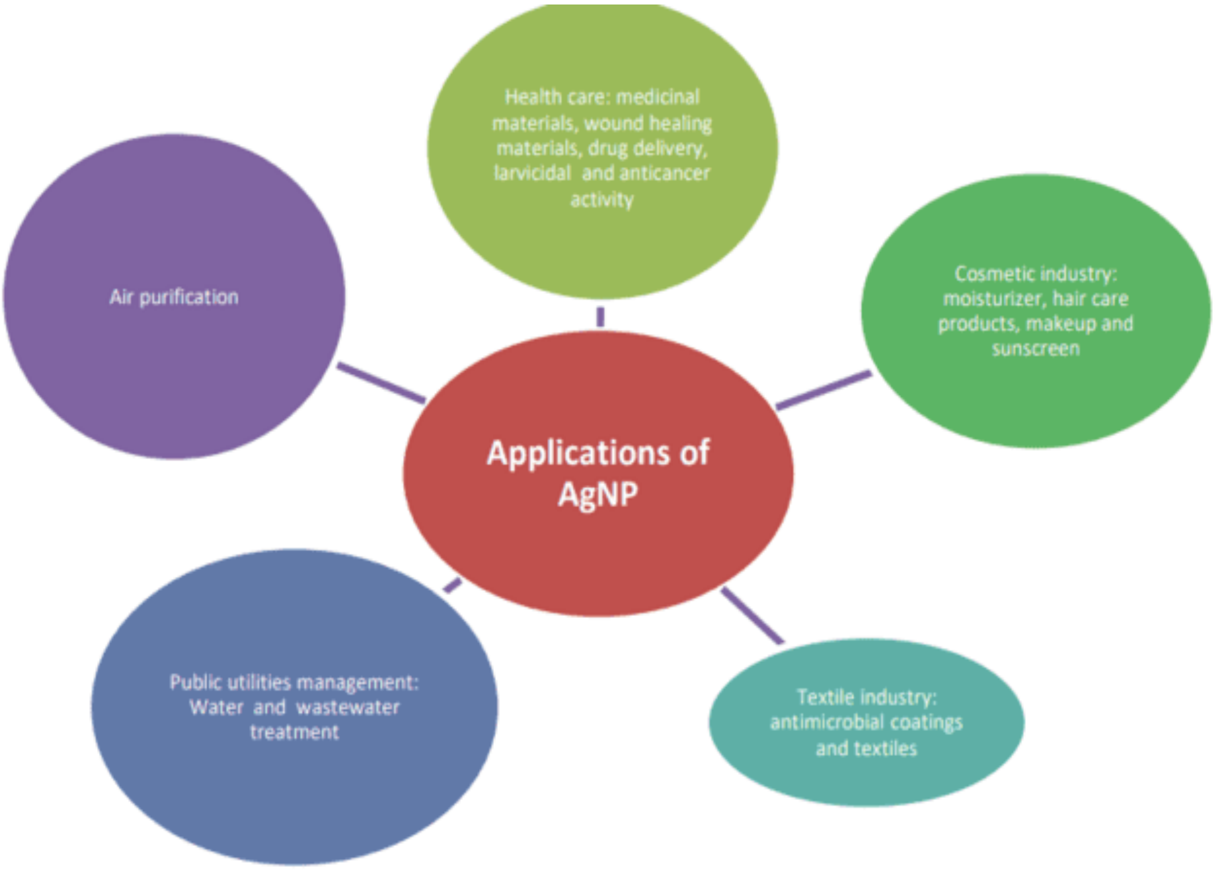

Figure 2.2: Diverse application of Silver nanoparticles

Application of silver nitrate has been proven to enhance the microbiological performance of ceramic water filters (Mitelman *et al.,* 2015). A removal efficiency for total coliforms and *E. coli* of 95% and 99% using ceramic water filters with silver-nitrate was reported by Ndebele *et al.,* (2021). The study showed a comparison performance between silver-nitrate and silver-nanoparticles, the results showed that the different ceramic filters showed similar levels of total coliform and *E. coli* removal. However, CWFs silver nanoparticles recorded an average removal of 85%, whereas the silver nitrate generated the highest average removal of 97%.

2.5 Limitations of using silver nanoparticles in ceramic water filters

Silver nanoparticles (AgNPs) is known to be a powerful disinfectant for waterborne pathogens. The disinfectant has been used in various applications as well as a point-of-use water treatment. According to Jackson *et al*., (2018), the application of the silver nanoparticles has been widely used in many filters production around the world. During its application it is normally painted inside the fired ceramic filters for the purpose of microbial inactivation and to prevent recontamination on the treated drinking water (Mittelman *et al*., 2015).

According to Rus *et al*., (2017), silver nanoparticles have been noted as a good disinfectant in purifying household drinking water because of its good conductivity and chemical stability. However, there are several challenges or limitations associated with the use of the AgNPs application. One of the limitations of using AgNPs is that it is not locally accessible in most developing markets including South Africa and are difficult to obtain, therefore they are imported by filter production facilities and require significant shipping with high costs.

Again, it is highly recommended that when using silver nanoparticle filters during the manufacturing process, the health and safety of the workers are taken into consideration because there could be inhalation of the silver when it’s been painted on the filters after firing which may results in severe health conditions (Fewtrell *et al*., 2017; Ndebele *et al*., 2021). Another limitation is that the silver nanoparticles are expensive which adds to the cost of the CWF produced (Rus *et al*., 2017).

2.6 Copper

2.6.1 Application of copper

Copper is an essential trace element involved in numerous physiological and metabolic processes (Olivares and Uauy, 1996). It has long been known to have antimicrobial activity and is used in drinking water treatment and transportation. The American Environmental Protection Agency (EPA) recognized copper as the first metallic antimicrobial agent in 2008 (Michels, and Anderson, 2008). Rafique *et al.,* (2017) described copper as a non-toxic, affordable antibacterial agent. Subsequently, it is a safe inorganic material that has high potential in a wide range of biological, catalytic and sensors’ applications, more particularly in the form of nanoparticles.

Many experimental studies have demonstrated in situ that surfaces containing at least 55%-70% copper eliminated many pathogenic seeded microorganisms; bacteria such as *Staphylococcus aureus*, *Escherichia coli (E. coli)* and *Enterococcus faecalis* (Prado *et al.,* 2012). Copper can eliminate pathogenic organisms such as coronavirus bacterial strains, influenza virus, HIV, and fungi after a short period of exposure (Cortes, and Zuñiga, 2020). Copper seems to be an effective and low-cost complementary strategy to help reduce the transmission of several infectious diseases by limiting nosocomial infectious transmission. The antimicrobial property of copper is also used in air conditioning systems.

According to the EPA, contaminated heating ventilation and air-conditioning (HVAC) systems can serve as a breeding ground for microorganisms like viruses, bacteria, and fungi (Vincent *et al,* 2016). Copper destroys the replication and propagation abilities of influenza, and other respiratory viruses, having high potential disinfection in hospitals, communities, and households. Copper oxide or nano compounds may be used as filters, face masks, and hospital clothing, to reduce viruses and bacterial incubation (Fujimori *et al.,* 2012).

2.6.2 Copper for point of use water treatment

Dankovich and Smith, (2014) investigated Copper nanoparticles (CuNPs) as antibacterial drinking water purifiers. *E. coli* bacterial suspensions were passed through a Cu-NP paper sheet and the effluent was analysed for viable bacteria and copper release. The results showed that the CuNP papers with higher copper content showed a high bacteria reduction of log 8.8 and log 4.6 reductions of viable *E. coli* bacteria, in the effluent (Dankovich and Smith, 2014). Moreover, the copper levels released in the effluent were within the recommended limit for copper in drinking water (1.3 mg/L). These results showed comparable performance with the use of AgNPs (Dankovich, 2014). Vincent *et al.,* (2016) also opined that the use of copper may contribute to the quality of water, particularly in developing countries, where there is a direct link between the poor quality of water and the risk of gastrointestinal diseases.

Copper nanoparticles have attracted a considerable amount of interest from researchers due to the properties they possess such as low production cost and antibacterial effectiveness. In comparison with precious metals, for instance, gold, silver, or palladium, copper nanoparticles were reported to have a high surface-area-to-volume ratio, catalytic activity, optical, and magnetic properties (Kanhed *et al.*, 2014). However, their immediate oxidation when exposed to air becomes the main challenge in their preparation and preservation. To overcome the toxicity resulting from the use of reducing agents, CuNPs was synthesised using a purified bioflocculant, to promote green and friendly route (Tsilo *et al.*, 2023). The copper nanoparticles are found to be effective in flocculation, dye removal, COD and BOD removal and possess the antimicrobial activity against both Gram-positive and Gram-negative bacteria (Dlamini *et al.,* 2020).

An interesting study by Dlamini *et al.*, (2019) synthesised copper nanoparticles using a polysaccharide bioflocculant, while its flocculation, removal efficiency, and antimicrobial properties were evaluated. The results reported that the highest flocculation activity (FA) was achieved with the lowest concentration of copper nanoparticles (0.2 mg/mL) with 96% (FA) and the least flocculation activity was 80% at 1 mg/mL (Dlamini *et al.,* 2019). The copper nanoparticle was effective without the addition of the cation as the flocculation activity was 96%. It also worked best at weak acidic, neutral, and alkaline pH with the optimal FA of 96% at pH 7. Furthermore, the nanoparticles were found to be thermostable with 91% FA at 100 °C.

A study by Varkey (2020) reported that copper has antibacterial property to completely disinfect *E. coli* bacteria using moringa-seed-clarified water. Copper does not interfere with the sedimentation process by the seed powder and vice-versa. The combination of the two, the coagulant property of moringa seed powder and the antibacterial effect of copper has been used in developing a simple, efficient, and cost-effective method to disinfect and clean river water for use in rural communities (Varkey, 2020). Apart from its antibacterial property, copper has the advantage that is not harmful to people in low doses or to the environment.

A study conducted by Singh *et al.*, (2020) quantified the effects of chloride ions on silver and copper release from porous ceramic cubes embedded with silver and copper and its effect on *E. coli* disinfection in drinking water. The results showed that for copper-ceramic cubes, log reductions of *E. coli* by copper embedded cubes increased from 1.2 to 1.5 when chloride ion concentration increased from 0 to 250 mg/L. Total copper concentrations in solution increased from 4 g/L to 14 g/L for corresponding chloride ion concentrations (Singh *et al.*, 2020).

A study by Varkey and Dlamani (2012) investigated the technological performance and social acceptance of ceramic water filters impregnated with copper for POU water treatment technology. The filters were tested for their ability to purify raw water obtained from local rivers. The results of the study showed that 10 g of copper, in the form of mesh made of thin wire of diameter 0.65 mm, had the capacity to eliminate *E. coli*, by immersing it in 300 mL of raw water for 5 h, and total coliforms, by immersing it for 10 h. The study showed that copper is a suitable antibacterial agent to combat coliforms in contaminated water. The use of copper as an antibacterial agent in the CWFs is therefore an effective and reliable means for producing clean water for domestic use.

Ceramic water filters have been reported to have a long-life span (2–5 years) if not broken and are relatively low cost due to local production. Jackson *et al.,* (2019) reported that filters made with copper nitrate ($Cu (NO_3)_2$) performed slightly less than silver nanoparticles (AgNPs) filters but were still effective with log reduction in total coliform and *E. coli* removals of 3.33 and 3.54 respectively. According to USEPA (2018) Copper is less expensive than silver and has a higher drinking water standard (1.0 mg/L, which is 10 times higher to that of silver).

This research aims to bridge the gap in knowledge regarding the effectiveness of ceramic water filters impregnated with copper nitrate in disinfecting water contaminated with total coliform and *E. coli*. Specifically, it investigates the impact of varying masses of copper ions on the disinfection capability of these filters over different durations of exposure. Furthermore, the study addresses the practical application of these filters in a real-world setting by evaluating their performance in households within the Tswinga village, providing valuable insights into their efficacy under community-based conditions. Additionally, the research incorporates a participatory approach to understand the health and safety needs of the community.

CHAPTER THREE

METHODOLOGY

3.0 Introduction

Field and laboratory research experiment strategy were adopted in this study. This involved collection of water samples at twenty households at Tswinga village for water quality assessment and the results were tallied against the WHO guidelines for safe drinking water. The photovoice methodology was also adopted in this study to understand the water challenges faced by the community. The research also focused on comparing the microbial water quality results from the field and those done in the laboratory using the same filters with the same concentration. The physicochemical analysis was also done and the results were tallied against the recommended South Africa National Standards (SANS) for Drinking Water.

3.1 Optimisation

3.1.1 Optimisation of copper usage in CWF

In preparation for the optimisation, six filters were prepared to obtain Cu^{2+} masses of 1.0; 2.0; 4.0; 7.0; 10.0 g using copper nitrate salt. A ceramic water filter with neither copper nor silver was used as a control for the experiment. The experiments were run in triplicate for 0, 2, 4, 8, 12, and 24 hours to determine which mass recorded higher disinfection than others. Water samples were collected from Mutale River for this set of experiments which were conducted at the Hydrology Laboratory at the University of Venda.

3.2 *E. coli* stock preparations

The working environment was wiped with 70% ethanol to prevent contamination. Thereafter, Luria-Bertani (LB) broth for *E. coli* stock was prepared using: 0.5 g yeast extract, 0.5 g sodium chloride, 0.25 g tryptone, 50 mL deionised water, all these were mixed in two 250 mL flasks. The 250 mL flasks with the solution were covered with aluminium foil for airflow purposes. Both the broth solutions from the flasks were placed in an autoclave (sturdy sa-232x) and set to 24 minutes with water level filled to bottom plate. After 24 minutes, the 2 flasks were left inside for 2-3 hours before taken out and cooled at room temperature for few minutes. A 50 μL (0.05 mL) of IDEXX aliquot *E. coli* was poured into both flasks using a micropipette. The flasks were then placed in the shaking incubator overnight at 200 rpm speed for 12-16 hours.

The overnight solution (*E. coli* culture) was poured into 50 mL tubes and spun down with a centrifuge at 2500 rpm for 20 minutes. After the solution had settled down (*E. coli* culture), the broth was poured back into the flask and placed back into the autoclave to kill all bacterias so the flasks could be re-used without being contaminated. *E. coli* culture was re-suspended in 50 mL of 10 mM RMB solution (final bacteria concentration = ~ $10^{\wedge 8}$ cfu/mL). The RMB solution (1000 mM in 50 mL tube) was prepared using: 5.6 g K_2HPO_4, 2.4g K_2HPO_4 and 50 mL of deionised water. To prepare 10 mM solutions in 50 mL tube, 500 μl of working stock RMB was poured into 50 mL of deionised water. 40% of glycerol equal to 20 mL of 100% glycerol mixed with 30 mL of 10 mM RMB (300 μL of 1000 mM RMB with 29.7 mL of deionised water). 125 μL *E. coli* from pellet + 125 μL glycerol was placed in small centrifuge tube, label, and frozen for later use. Various dilutions of the levels of *E. coli* and total coliform that was prepared from the stock solution purchased by IDEEX were conducted to get the final concentration that was used in all the filters during optimisation.

3.3 Filter preparations

The following calculations in Table 3.1 were used to calculate the amount of copper nitrate added during filter production in respect of achieving the objective of the optimisation. The methods used in this study were derived from the study by Jackson *et al.,* (2018).

Table 3.1: Different masses of copper nitrate needed for the filter production

Mass (g)	Calculations	$Cu(NO_3)_2$ mass required
1	$1\times 1gCu\ (187.56g\ MW\ of\ \frac{Cu(NO_3)_2}{63.55g\ MW\ of\ Cu})$	2.95
2	$2\times 1gCu\ (187.56g\ MW\ of\ \frac{Cu(NO_3)_2}{63.55g\ MW\ of\ Cu})$	5.90
4	$4\times 1gCu\ (187.56g\ MW\ of\ \frac{Cu(NO_3)_2}{63.55g\ MW\ of\ Cu})$	11.81
5	$5\times 1gCu\ (187.56g\ MW\ of\ \frac{Cu(NO_3)_2}{63.55g\ MW\ of\ Cu})$	14.76
7	$7\times 1gCu\ (187.56g\ MW\ of\ \frac{Cu(NO_3)_2}{63.55g\ MW\ of\ Cu})$	20.66
10	$10\times 1gCu\ (187.56g\ MW\ of\ \frac{Cu(NO_3)_2}{63.55g\ MW\ of\ Cu})$	29.51

The above measured masses of the copper nitrate were mixed with clay, sawdust, grog, and water. The mixing time of the clay, sawdust, and copper nitrate was assessed to be 30 minutes for dry blending in an electrical mixer, thereafter, water was added and mix for 1 hour in the electrical mixer. The mixture was pressed using a mechanised filter press to get an ideal pot moulded. During dry seasons the filters were placed on drying ranks to dry for 7-10 days and 10-15 days to dry if exposed to unfavourable weather conditions such as rain.

After drying, all the filters were fired using a VEL50 front Door furnace for a period of 8-12 hours at a temperature of 950 ºC. After firing the filters were left to cool for a period of 24 hours, then they were placed back into the drying ranks to further cool in the open air before the quality tests were carried out. Flow rate testing is a significant quality affirmation step that demonstrates the rate at which water must go through the water filter. The testing was conducted on every filter that was created to guarantee its suitability. However, the recommended flow rate quality control assessment is expected to be around 1.5 to 3 litres of water per hour. A higher flow rate could however mean a decrease in the effectiveness of the filtration due to cracks or large pores in the water filters and may not eliminate the necessary microorganisms, parasites, and other pollutants (*Figure 3.1*).


(a) (b)

Figure 3.1: Drying racks (a) Flow rate testing (b)

3.4 Photovoice: Community-Based Participatory Method

A community-based participatory method was applied to describe the health and safety needs of the study area (Tswinga). Participants were introduced to the photovoice methodology which helped to identify local factors that affected the health status of community members (Kingery *et al*., 2016). A group of 10 households/participant was chosen to participate in this aspect of the study to encourage in-depth group discussions. Each participant signed a consent, and a release form to share project photographs of their choice in publications and presentations. A group discussion was held with the participants to explain the safety, authority and responsibility that comes with the use of the cameras, as they are needed to achieve one of the study objectives. Participants were given 1 week to take photos of interest concerning water usage, water quality, problems around water in their households and community and anything of interest to them regarding water. The identified themes were matched with the photos taken and quotes on the data. The exhibit was then drafted for participants to review.

3.5 Sample collection

3.5.1 Household sampling

Not every household had the opportunity to participate in this initiative because the sampling of 1102 households in Tswinga village proved challenging to carry out within the limited timeframe and financial resources. To maintain objectivity, a non-probability sampling method was employed. The selected households, demonstrating a keen interest in the research, volunteered to participate. However, their motivation may have stemmed from a desire to acquire a free ceramic water filter. Consequently, only 20 households, actively interested in the project, were included in the study.

3.5.2 Survey questionnaire

At the beginning of the research project, baseline data was gathered from the 20 participants. The survey data questionnaire can be found in *Appendix 1*.

3.5.3 Water sampling

Raw and filtered water samples were collected from selected households in Tswinga Village for analysis. More analysis was done in the laboratory to test the same water sources from the household so to verify the results from the household's samples. Water samples regardless of the source used by the households were collected once a week for a period of two months into 500 mL sterile containers namely whirl pack for laboratory analysis. All the samples collected were clearly labelled with the name of the household, type of water source and whether the sample contained raw or filtered water. The samples were carried in a cooler box to avoid light alteration of microbial parameters. Sample analyses were carried out within 6 hours after sample collections.

3.6 Sample preparation and analysis

3.6.1 Physicochemical parameters of raw and treated water

The physicochemical parameters of the raw and filtered water used by the households were determined in the field using various equipment, the YSI Professional Plus meter (YSI Inc., Yellow Springs, OH, USA) was used to measure the pH, temperature, electrical conductivity (EC), while an Extech multimeter (EC500) was used for the measurement of the total dissolved solids (TDS) and the turbidity was measured using a turbidimeter (10447 EUTECH). All the equipment were first calibrated before use as per the manufacture's guidelines. Estimated levels were contrasted with the South Africa National Standards (SANS) for Drinking Water Quality limits (SANS 241; 2015) (*Figure 3.2)*.

Figure 3.2: Instruments used to measure physicochemical parameters.

3.6.2 Microbiological water analysis

During the period of this study, water samples from the selected households with the copper nitrate impregnated ceramic filters were evaluated for the presence of the total coliform and *E. coli* using a membrane filtration.

The analysis of the samples was carried out within 6 hrs of the sample collection**.** The manifold sample cups used in the membrane filtration were firstly submerged into a hot water bath set at 100 ºC for 30 – 45 minutes for disinfection measures. A stainless-steel forceps was sterilised by passing a forceps through an open flame of an alcohol burner, the forceps were re-sterilised before each use. After disinfecting the manifold cup, a sterile forceps was used to place the filter paper disk of 47 mm diameter with 0.45 micropore size (4.5×10^{-7} m pore size) (EMD Millipore, Billerica, MA, USA) on to the surface of the manifold (Ndebele *et al*., 2021). A volume of 500 mL of the water samples collected from household and 100 mL of it were passed through the filter paper disk in duplicate during membrane filtration.

The membrane filter paper was carefully removed from the manifold with a sterile forceps into an absorbent pad of selective growth solution (m-ColiBlue24, EMD Millpore, Billerica, MA, USA) inside a sterile petri dish. The petri dishes were however labelled with necessary details to avoid confusion. The petri dishes were firmly closed by pressing the top on to the bottom, for the purpose of avoiding growth of interfering microorganisms. The samples were incubated at 37 ºC for a period of 24 hours. After incubation the total coliform and *E. coli* colonies were recorded (Harrigan and McCance, 2014). Deionised water was used as the control experiments.

3.7 Ethical consideration

Ethical clearance approval was obtained from the Research Ethical Committee of the University of Venda before the commencement of the field study (FSEA/22/ES/13/1707). Permission to collect samples or conduct the study was also obtained from the Chief of Tswinga Village. Then consent forms were distributed to all volunteering participants and the purpose of the study was carefully explained to them. Highlights on how the community would benefit from the study was explained as well as how the data will be collected and used in this study.

3.8 Statistical analysis and interpretations

Data interpretation and presentation employed descriptive statistical methods using SPSS Version 25. The data was well organised, summarised, and visualised to find any underlying trends in quantitative data, while graphs and tables were illustrating the physical and chemical characteristics of raw water.

CHAPTER FOUR

Results and discussion of baseline data and photovoice analysis

4.1 Preamble

This chapter present the baseline data generated from the survey questionnaires at the selected households. Photovoice analysis from ten volunteering households from the 20 selected households, are well discussed in this chapter accordingly.

4.2 Socio demographic characteristics of enrolled households

A total number of 20 households from Tswinga village were enrolled and included in the survey (*Appendix 1*). Majority of the people in the households is between 1-4 (n=15, 75%), while in terms of age, the highest age group is n=17 which is 85% as presented in *Table 4.1*.

Table 4.1: Number and age of people in the households

Demographic	Range	Frequency	Percentage (%)
Number of people in the household	1 ≤ people ≤ 4	15	75%
	5 ≤ people ≤ 9	13	65%
	10 ≤ people ≤ 14	2	10%
Age	<21 years	0	0
	22-40 years	17	85%
	41-60 years	11	55%
	61>years	2	10%

Adult women have been reported to be responsible for managing water (n=19, 95%) in the household, while adult men are least often responsible in managing the water (n=1, 5%). Most of the enrolled households (n=18, 90%), depend on spring as their primary source of drinking water, while others depend on borehole water (n=2, 6.70%). The participants shared that they must travel 10 - 15 minutes to get to their primary water source. Ninety percent (90%, n=18) of the households reported that sometimes the spring dries up and would take up for 2-6 hours due with no water in it and this really disrupt their livelihood. Due to these interruptions all the enrolled households (n=20, 100%), store drinking water in plastic buckets, whilst a few (n=13, 65%) use drums as storage containers. One hundred percent (100%, n=20) of the households collect water from storage containers using cups with handle. All the enrolled households (100%) have a lid to cover their stored water. Findings reveal that water is often stored for more than 24 hours and are not usually discarded after a long time in all the households. Rather, newly collected waters are added to the previous ones, this is because water is a scarce commodity. Eighty percent (80%, n=16) highlighted that they do not use anything to purify their drinking water except to allow the particles to settle before consumption, while (n=3, 15%) boil their water to kill of the bacteria before consumption and 5% (n=1) shared that they use domestos to treat their own drinking water.

The absence of potable water supply to this community has made them to resort mainly to spring for their basic water needs. When the spring is interrupted majority of the respondents (n=16, 80%) have their secondary water supply from trucks (the trucks are often hired to go to the nearest communities with sufficient water supply to collect water in 210 L drums). *Figure 4.1* illustrates that when spring water availability is disrupted, individuals who depends on the spring as their main water source resort to purchasing water from trucks as their alternative, resulting in an increase from 40% to 80% in truck water purchases. Meanwhile, 20% of the population unable to afford truck water opt for dam water while awaiting the spring to replenish.

(a) (b)

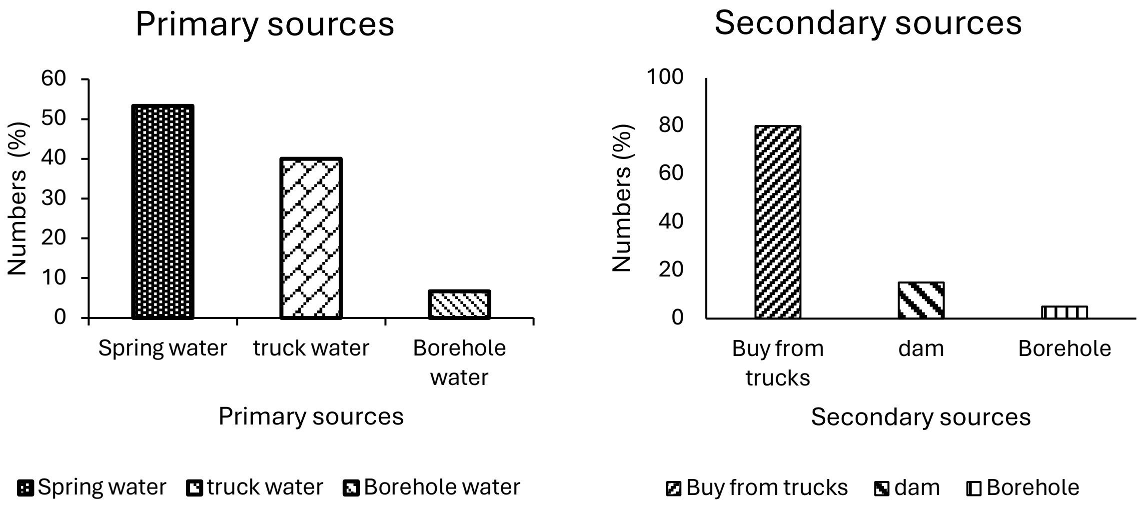

Figure 4.1: Primary and secondary sources of water used by the respondents

The perception of the quality of the collected water varies across respondents. Some believe the water is of good quality (n=9, 45%), others (n=7, 35%) feel it is of average quality as it can sometimes be cloudy and have a bad smell mostly after rainfall events, only a fewer households described their water as having poor quality and often not safe to drink (n=4, 20%) (*Figure 4.2)*

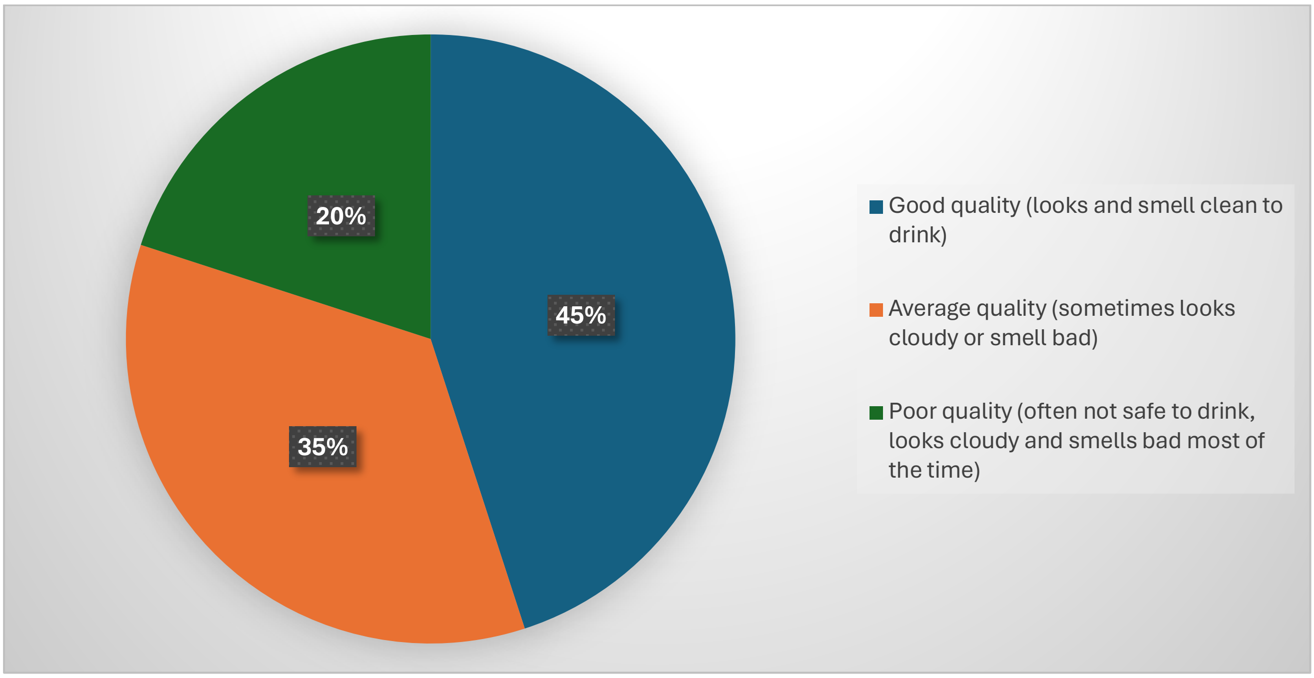

Figure 4.2: Respondents perception of their water quality

4.3 Water quality challenges using photovoice in the study area.

Photovoice has been developed as a valuable research method in the global and public health (Walker & Early, 2010). This innovative approach uses photography to uncover local concerns from the point of community members. The primary objectives of photovoice are to empower individuals to document and contemplate the strengths and challenges within their community as well as facilitate meaningful group discussions and understanding about key community issues. It also ensures that the findings are conveyed to local policymakers, spurring them to drive social transformation (Wang and Burris, 1997).

A total of 10 households were recruited and provided with instruction in digital photography and ethical photography practices based on their perceptions of their water sources.

After a week of taking pictures, participant underwent both one-on-one and collective interviews, all the interviews were audio recorded and they were conducted in their home language (Tshivenda) and the entire data was transcribed and subjected to a collaborative thematic analysis conducted by both the participants themselves and the researcher. There were no specific guidelines regarding the minimum or maximum number of photographs the participants were meant to capture, but they were informed that during the interview day there would only be limited time to discuss a handful of the photos.

The top 5 meaningful photographs from each participant were selected with the participant’s consent, accompanied by a summary written from the interviews transcripts and displayed to the community. The aim of this was to give the participant a chance to verify if what was written accurately reflects their intended message. The photographs displayed showed a wide range of concerns including what people of Tswinga village are suffering from. Table 4.2 shows a breakdown of the themes from the photographs shared during the interviews with the participants. The concerns were ranked in order of importance in the community.

Table 4.2: Themes identified in the photographs.

Themes	Individual interviews (n = 10)

Water problems	80%
Safety	60%
Sanitation	60%
Water purification before use	40%
Presence of diseases	30%
Loss of income	20%

4.2.1 Water problems

The participants identified multiple sources of water in their community, including rivers, dams, springs, and boreholes. Some community members face challenges accessing water, walking about 15 minutes to reach the dam and river and 10-15 minutes to arrive at the springs. The respondents thus expressed a strong desire for sustainable access to clean and safe water.

Due to water scarcity, some participants resort to reusing bath and laundry water for their vegetables, despite concerns about potential contamination. They believe this practice helps conserve the limited water supply. Another issue raised is the disposal of trash near water sources, causing an unpleasant odor and imparting color to the water. Participants suggested implementing solid waste management as a solution to mitigate this problem (*Figure 4.3*).

Figure 4.3: Water collection from a depleted spring

4.4.2 Safety

During the interview, participants expressed their concern about their compromised safety due to water shortages. Some reported waking up as early as 3-4 am to secure a spot in long queues at the spring, fearing that water would run out quickly. Participants also shared worries that they don't feel safe when doing laundry at the rivers because if they leave the clothes there to dry, they might be stolen. Furthermore, if they were to stay there till the clothes were dried, their safety is also compromised hence, they must carry the wet laundry on top of their heads to dry at home which is a big burden.

Participants highlighted the risk of encountering dangerous wildlife and mentioned incidents of crocodiles and hippos moving onto land areas, posing a threat to children. Additionally, concerns about personal safety, including the risk of assault or kidnapping, were linked to dense vegetation around water sources. Participants suggested that the municipality should provide water to mitigate these safety risks (*Figure 4.4*).

Figure 4.4: Gathering water at a precarious water source

4.4.3 Sanitation

During sanitation-related interviews, several subthemes were constructed, including toilets, reuse of dirty water, and solid waste disposal. Some Participants revealed that they lack functioning sanitation facilities at home and often resort to using nearby bushes when their pit latrines are full, and they cannot dig new ones due to financial constraints. Due to the fear of diseases like the coronavirus, some neighbors are reluctant to share their toilets. Despite the awareness of the risk of wild animal attacks, some participants feel compelled to use open areas. However, despite shortage of water in their areas they try to practice hygiene by washing their hands after using the toiles to avoid infections. Respondents recommended government assistance for the poor in building sustainable toilets in their land (*Figure 4.5*).

Figure 4.5: Pit latrine used by one of the respondents.

4.4.4 Water purification

Many of the participants mentioned that they hardly use anything to purify their drinking water except to allow the particles in the water to settle first then use the water, some added that they also boil the water to kill the bacteria, while those who can afford buy chemicals like bleach and domestos uses them to treat the water before consumption. However, the participants stated that they don’t often measure the amount of chemicals added to the water because they don’t have the requisite knowledge. They were advised not to use domestos as it has not been recommended for treating drinking water and may cause health risk to them.

4.4.5 Presence of diseases

During interviews, participants highlighted the presence of diseases linked to the consumption of unsafe water. One woman emphasised the adverse effects of consuming untreated water and how this is affecting their children, connecting this issue to broader themes such as water problems, sanitation, and water purification.

Children were reported to experience sickness such as itching, and skin rashes after consuming poor-quality water or using river water for bathing. Some children faced difficulties with urination, requiring the genital area to be moistened for them to urinate, and this is often associated with excruciating pain. Cases of hospitalisation due to malaria, believed to be contracted while fetching water from the river and dam, were also mentioned. Participants expressed the belief that these diseases could be prevented with sustainable access to clean water. They suggested community outreach programs by Community Health Workers and Nurses to educate the community on disease prevention methods (*Figure 4.6*). Edokpayi et al. (2018) reported the contamination of several water sources in Vhembe district due to inadequate access to safe drinking water and sanitation. Their study showed water studies contamination with microbes and the water use practice showed that majority residents of Dzimauli valley do not treat their drinking water sourced from various water bodies before consumption thus leading to an increased disease burden.

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Figure 4.6: Open-source water collection by one of the respondents

4.4.6 Loss of income

During the interviews, some members mentioned that they use to run small businesses at their home, such as selling chickens which requires significant amount of water which is hard to find. Others sold vegetables at their homes, but stopped as it is labour intensive fetching from the river. Hence, they now only use small portion of their gardens to plant vegetables which they consume. Participants highlighted that they face challenges of Hippos traveling at night, destroying people’s small scales businesses, including those making clay bricks along the river and those with small farms. This wildlife interference is causing financial losses for the community. Some participants expressed a desire for decent jobs that would enable them to drill boreholes at their homes (*Figure 4.7*).

Figure 4.7: Small businesses alongside the riverbank

The objective of the photovoice was to identify local factors that affects the day-to-day life and health using photography. From the identified problems the participants were able to develop creative solutions, and the data can be used to develop public health interventions and educational needs suitable for them. There are lots of small businesses along the riverbanks around Thohoyandou, Limpopo province. Aniyikaiye et al. (2021) reported the prevalence of small-scale informal brick making industries along waterfronts (Mvudi and Luvuvhu rivers) in Thohoyandou. These industries greatly enhance the socio-economic status of the rural dwellers.

CHAPTER 5

Results and discussion of optimisation, field, and laboratory studies

5.0 Preamble

This chapter presents the optimisation and the field results which was obtained using the optimal ceramic filter from the optimisation analysis. Laboratory analysis results are also presented for verification of the field work results.

5.1 Optimisation of copper nitrate in the ceramic water filters at the laboratory

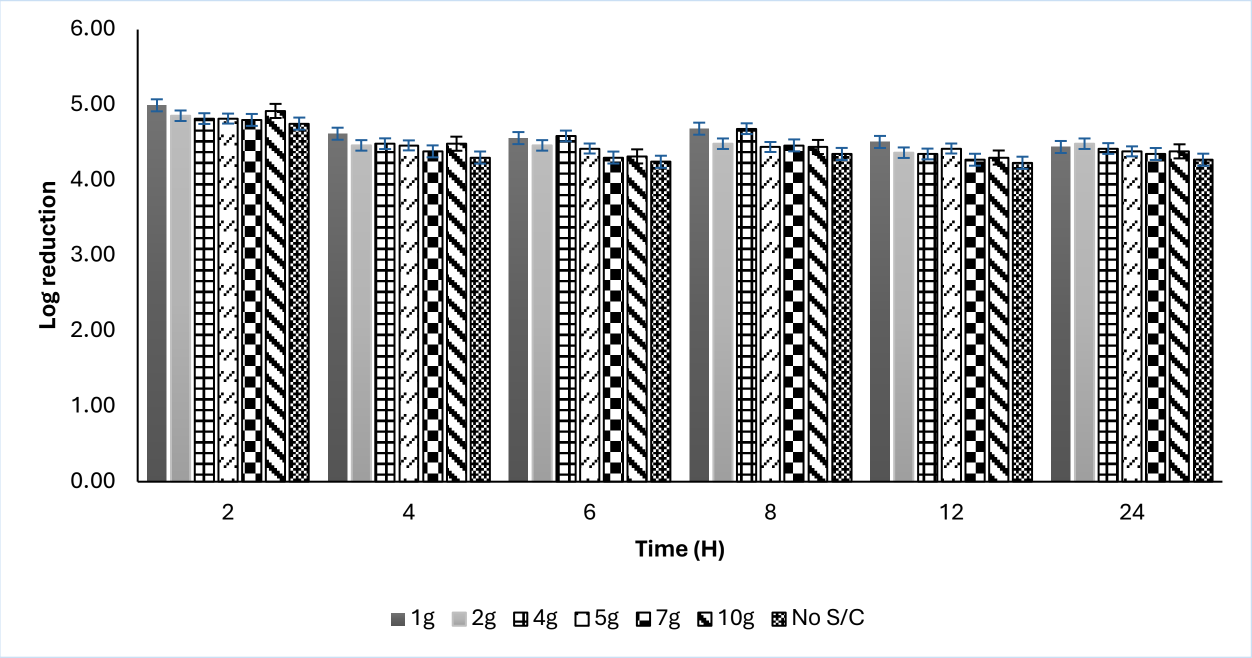
Raw water samples were collected from the Mvudi river using a sterile 25 L water container. The raw water was tested for *E. coli* and total coliform before and after transfer to the ceramic water filters made with ionic copper. *Table 2* presents the levels of *E. coli* and total coliform that was prepared from the stock solution purchased by IDEEX as outlined in section chapter three 3.1.2 of this document. The prepared E. *coli* and total coliform stocks were labelled 4.83 x 104 and 2.43 x 105 cfu/100 mL, respectively and preserved for the spiking of the raw water for optimisation studies. The average *E. coli* and total coliform levels recorded was used to spike the river water for the optimisation studies using varying masses of copper nitrate to arrive at 1-10 g of ionic copper in the CWF.

Table 5.1: The concentration of E. coli and total coliform that was prepared.

Trials	*E. coli*	Total coliform
1	5.0×10^4	2.1×10^5
2	4.0×10^4	2.6×10^5
3	5.50×10^4	2.6×10^5
Average conc.	4.83×10^4	2.43×10^5

Thereafter the concentration of the raw water with *E. coli* stock solution was tested to compute the log reduction for both the *E. coli* and the total coliform. For optimisation, 8 filters were used to observe the level of ionic copper which performs well when applied for the treating of river water in ceramic filters made of copper nitrate in various masses (1; 2; 4; 5; 7, and 10 g), and the last one with no silver and copper (No S/C).

The results showed that all the ceramic water filters with different concentrations performed well (*Figure 5.1)*.



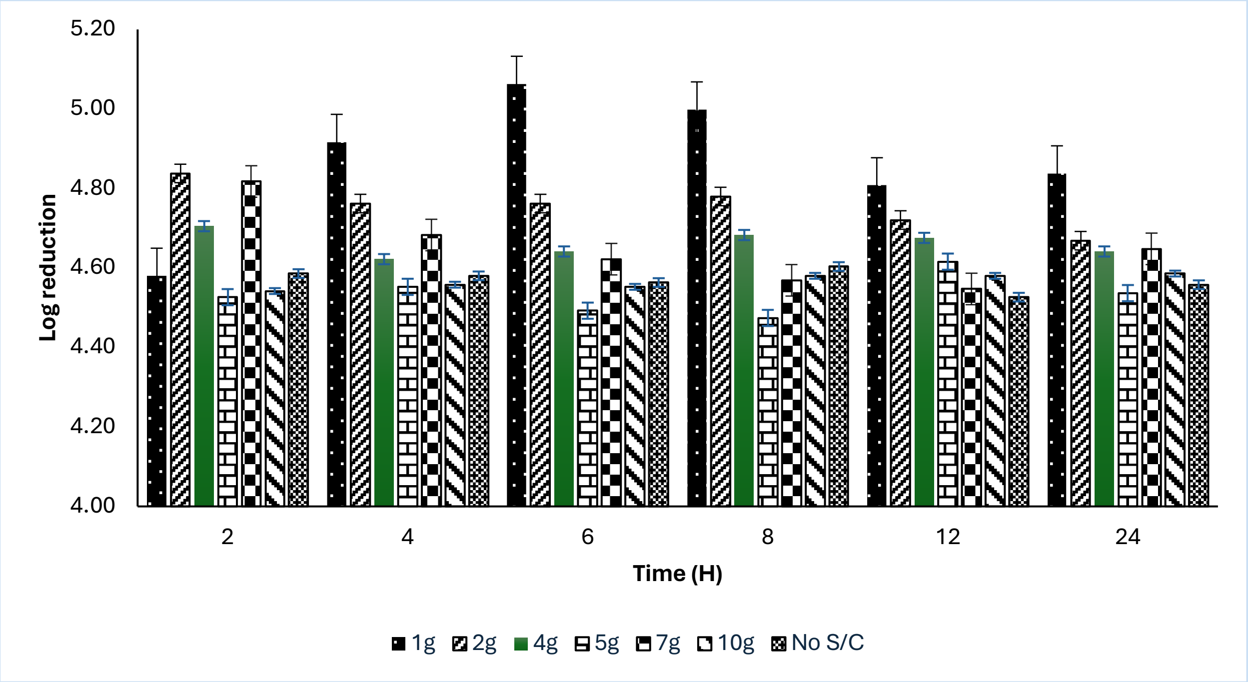
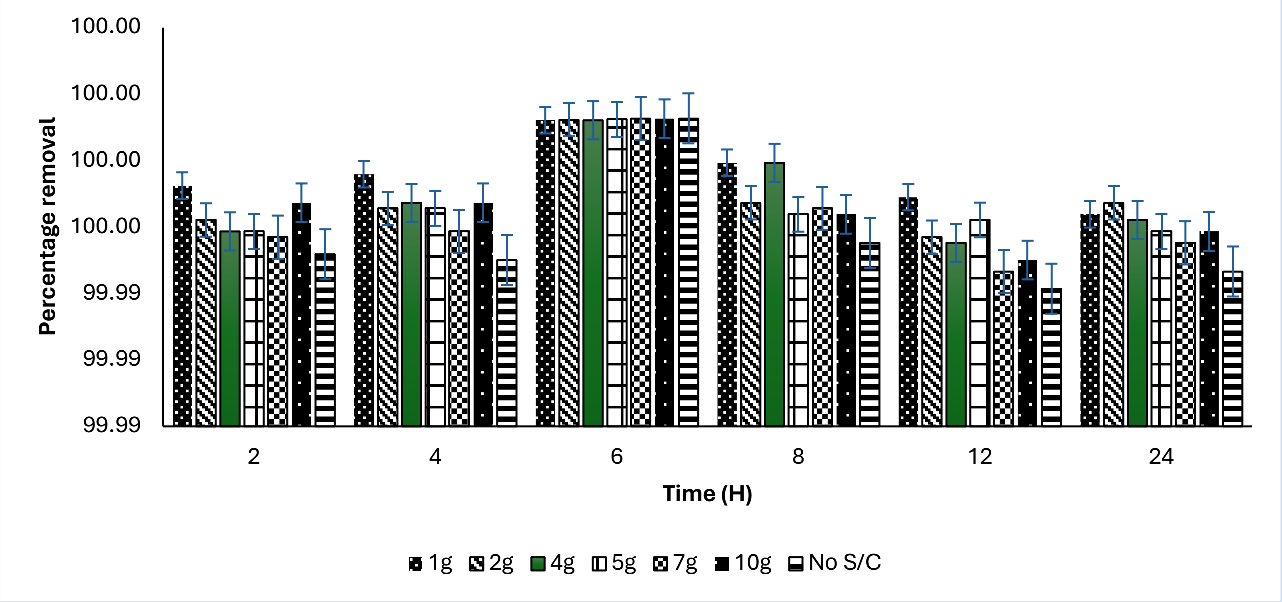


Figure 5.1. Log reduction of *E. coli* (top) and total coliform (bottom) during optimisation

Agrawal *et al*., (2018), reported also that when disinfecting a wide range of microorganisms in water, silver ions are highly recommended due to their effectiveness. However, from the results of the filters made of ionic copper conducted in the laboratory, a 4.99 log reduction and 100% of the initial *E. coli* concentration was observed with the 1 g filter at 2 hours of disinfection. At 2 hours all the filters behaved similarly as there wasn't much difference through the time point and having *E. coli* log reduction and percentage removal in the range of 4.23-4.99 and 100%. Looking at the performance on the graph of the filter with No silver/copper (No S/C) at 2-24 hours the inactivation of the filter was a bit lower compared to other filters throughout the various time scale. *Appendix 2 and 3* shows the log reduction and percentage removal throughout all the filters.

It was observed that the inactivation of *E. coli* decreases with an increase in time interval in practically all the filters. The 1 g filter had a slightly decrease of log reduction (4.56) at 6 hours with 100% removal then after filtering for another 2 hours there was an increase at 8 hours with the log reduction and percentage removal of 4.68 and 100%. However, it was a bit different with the log reduction and percentage removal of total coliform. From 2 hours, 1 g increased with the increase in time interval from 2-6 hours with 4.54-5.06 log reduction and 99.99-100%. From 8-12 hours a slight decrease was observed, just like with other filters the inactivation was changing at different time point. The performance of ceramic water filters made with 1 g of ionic copper could be attributed to the antibacterial properties of the copper that is mixed with clay, sawdust, grog, and water during the manufacturing process. Therefore, it can be concluded that the CWFs made with 1 g of ionic copper behaves slightly better compared to other ceramic filters (*Figure 5.2*).



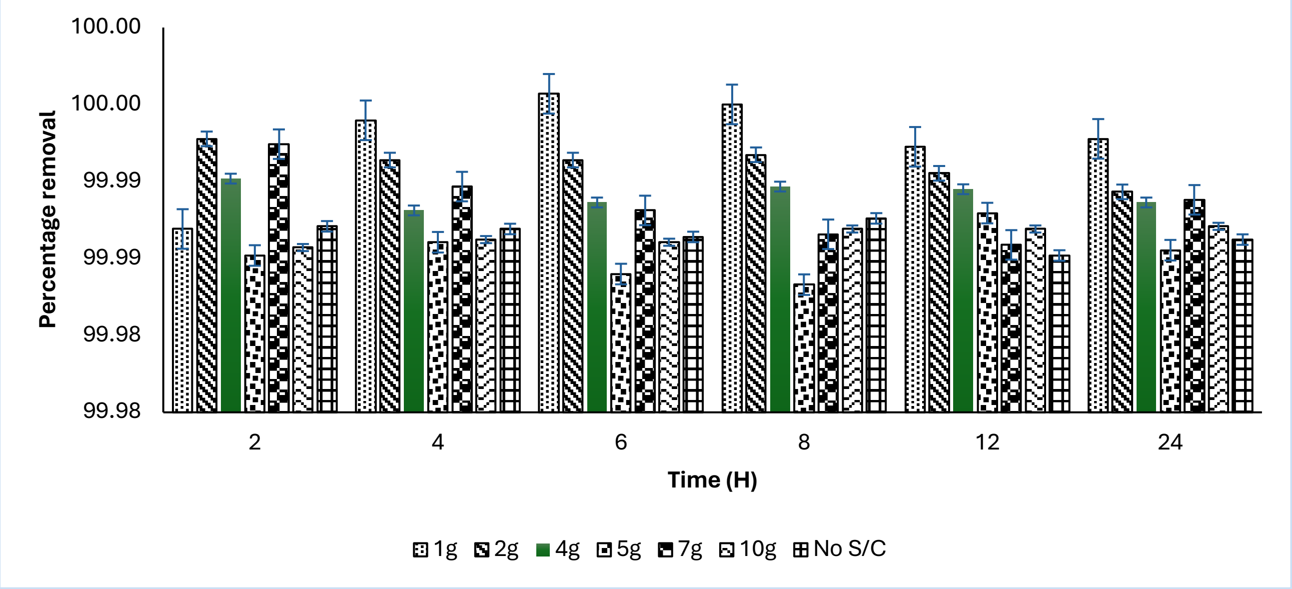


Figure 5.2: Percentage removal of E. coli (top) and total coliform (bottom) during optimisation

5.2 Characteristics of raw water

5.2.1 Physicochemical Parameters of raw water

The physicochemical analysis was carried out in all raw water for a period of 8 weeks in the households, and they include pH, electrical conductivity, total dissolved solids, and turbidity.

The physicochemical results showed that raw water, from the household in the Tswinga village, had pH, TDS, and EC within the recommended South African National Standard (SANS, 2015) for drinking water quality (*Table 5.2*). From the findings on the questionnaire administered to participating households showed that most households (n=7, 35%) described their drinking water quality as average as it is sometimes cloudy and have a bad smell mostly after rainfall events. Without concluding the mere observation of the participant, physicochemical tests were carried out and the results conforms to the observations of the participants.

Table 5.2: Average values of physiochemical water quality parameters of raw water samples with SANS for Drinking Water Quality recommendations

Parameters	**MIN**	**MAX**	**AVERAGE**	**STDEV**	**SANS (2015)**
pH	5.19	9.34	7.98	0.79	≥ 5 to ≤ 9.7
Turbidity (NTU)	0.05	7.42	1.49	1.39	≤ 1
TDS (mg/L)	44.04	863	277.41	209.88	≤ 1200
EC (μS/cm)	38.64	894	293.61	237.26	≤ 1700

The pH values for the raw water fell within the recommended standard set by SANS for drinking water quality (*Figure 5.3*).

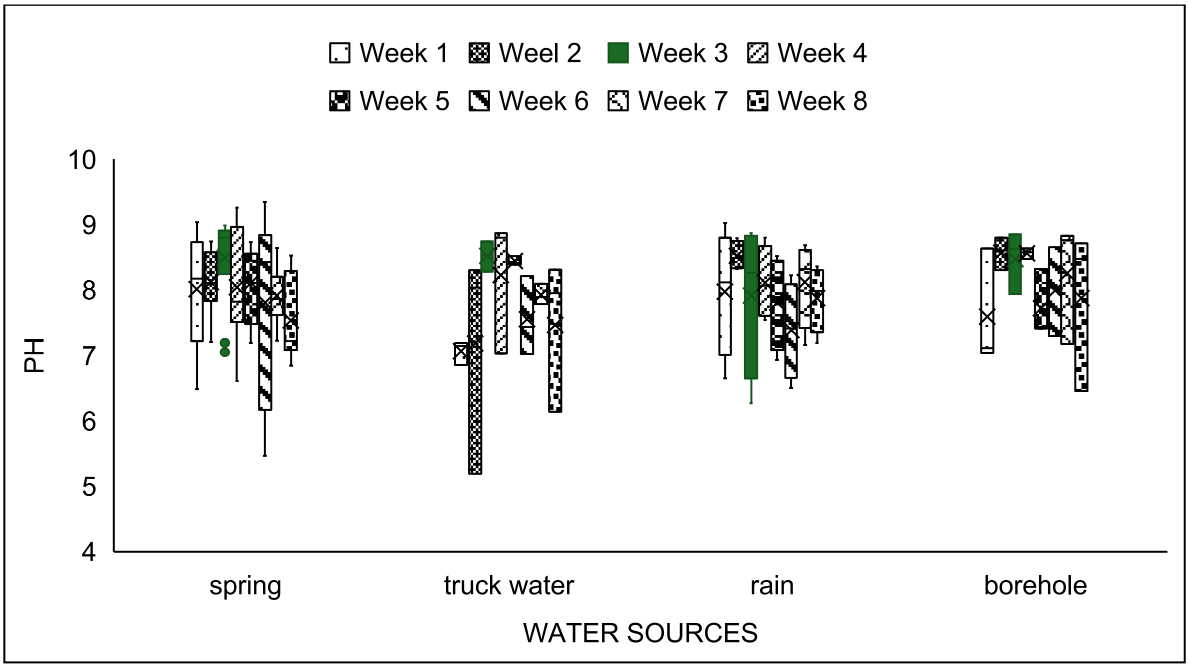


Figure 5.3: pH of the various water sources

Electrical conductivity is a measure of the ability of water to conduct an electrical current, which is directly related to the concentration of dissolved ions in the water (Nazir *et al*., 2015). In this study, the conductivity of all different water sources recorded at a normal range fall within the SANS for drinking water quality limits (*Figure 5.4*).

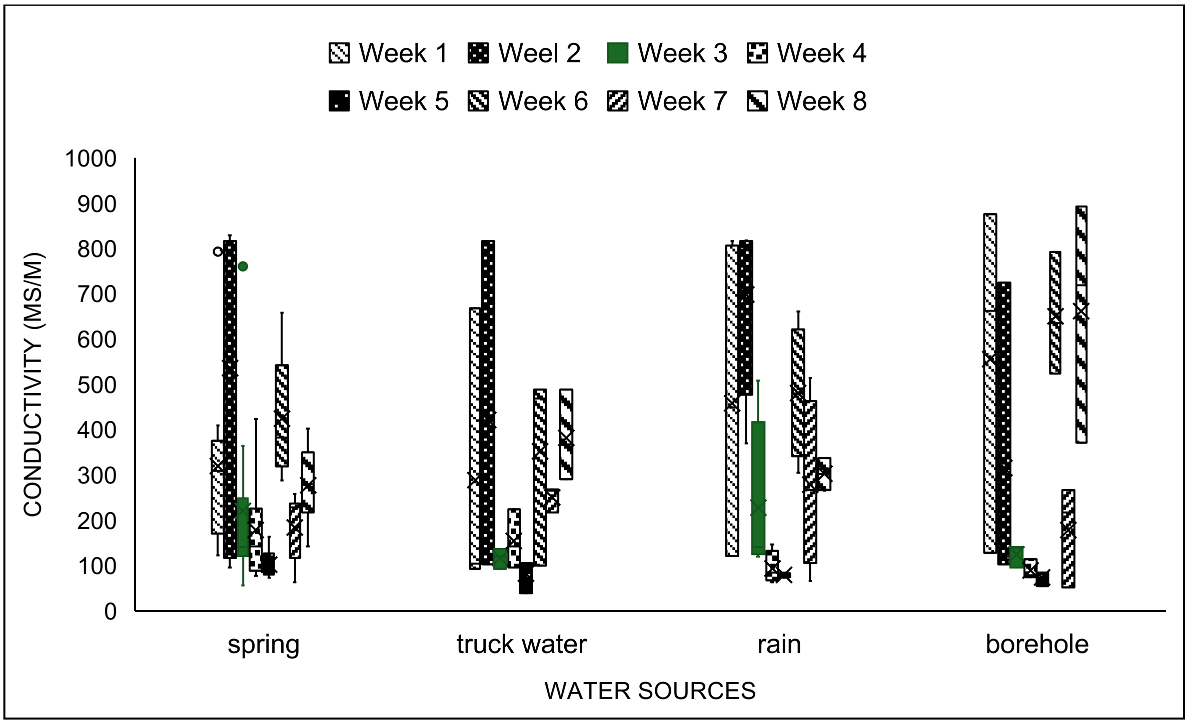


Figure 5.4: Electrical conductivity of the various water sources

Turbidity is referred to as the degree to which water loses its transparency over time due to the presence of suspended particles and other microorganisms (Kitchener *at al*., 2017). However, rainwater had higher turbidity (7.10) compared to others, the nature of their roof catchment as well as the harvesting containers could both contributes to the turbidity of the water even though rainwater is the purest form of water. However, it is also important to note that not all rainwater in the household recorded higher turbidity and this was due to a variety of factors.

Looking at other sources, the spring water also recorded high turbidity (5.05), and this could be due to the surroundings where the spring is located as well as the land use activities around it. Also, it was noted at the Tswinga spring that some of the residents do laundry and do agricultural activities next to the spring causing runoff of various pollutants into the spring increasing its turbidity. Additionally, springs can contain dissolved minerals, such as calcium and magnesium, that can contribute to the cloudiness of the water (Jankulovska-Petkovska *et al*., 2022) (Figure *5.5)*.

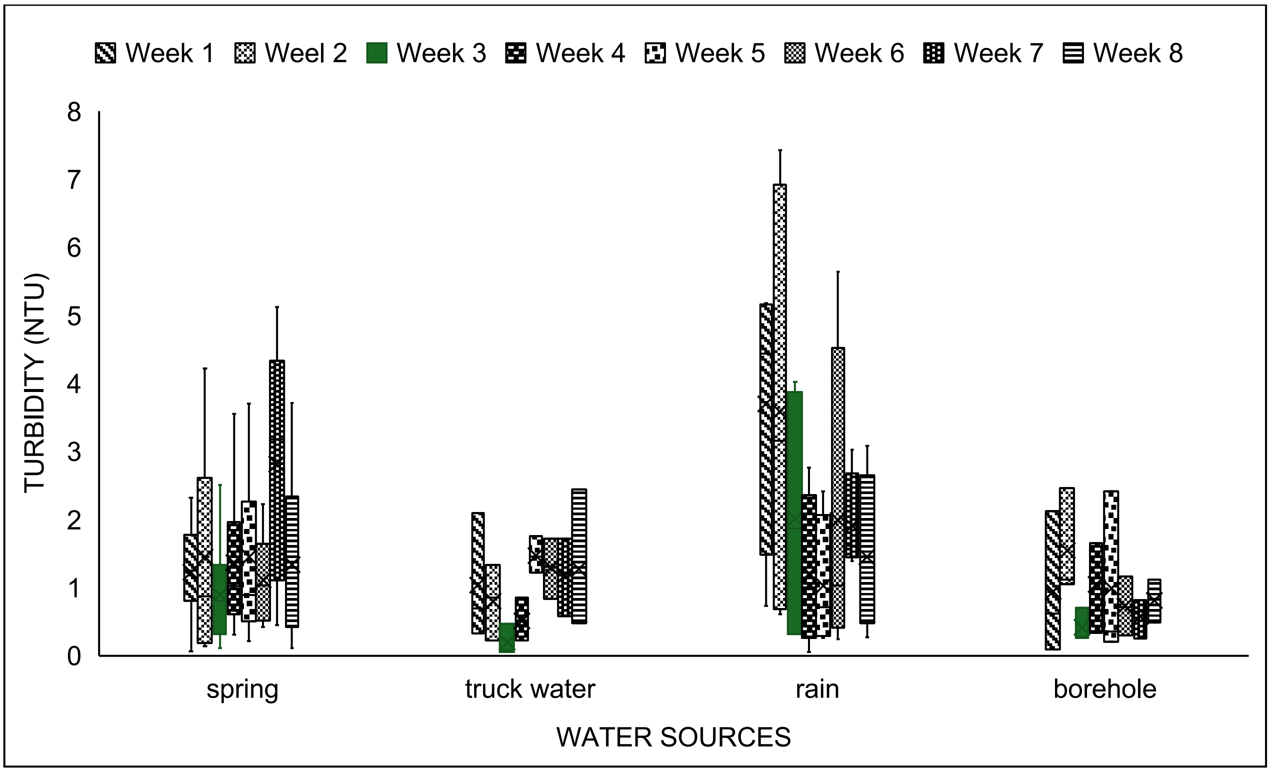


Figure 5.5: Turbidity of the various water sources

5.2.2 Microbial Analysis of raw water

Raw water samples were collected from the participant's homes and tested for a period of 2 months (8 weeks) at the University of Venda Hydrology laboratory. *Appendix 2* shows the actual *E. coli* and total coliform count recorded from the raw water for the period of the study from different water sources. For accurate results the samples were tested on the same day of collection, using the membrane filtration method. Regardless of the type of water source tested, *E. coli* and total coliform were present in the raw water. *Appendix 4* shows the microbial quality of the raw water. The presence of these indicator organisms imply that people are at risk of waterborne infection as they often consume this water in its untreated form. Water samples from boreholes had higher *E. coli* in week 1 as compared to other water sources (*Figure 5.6.*)

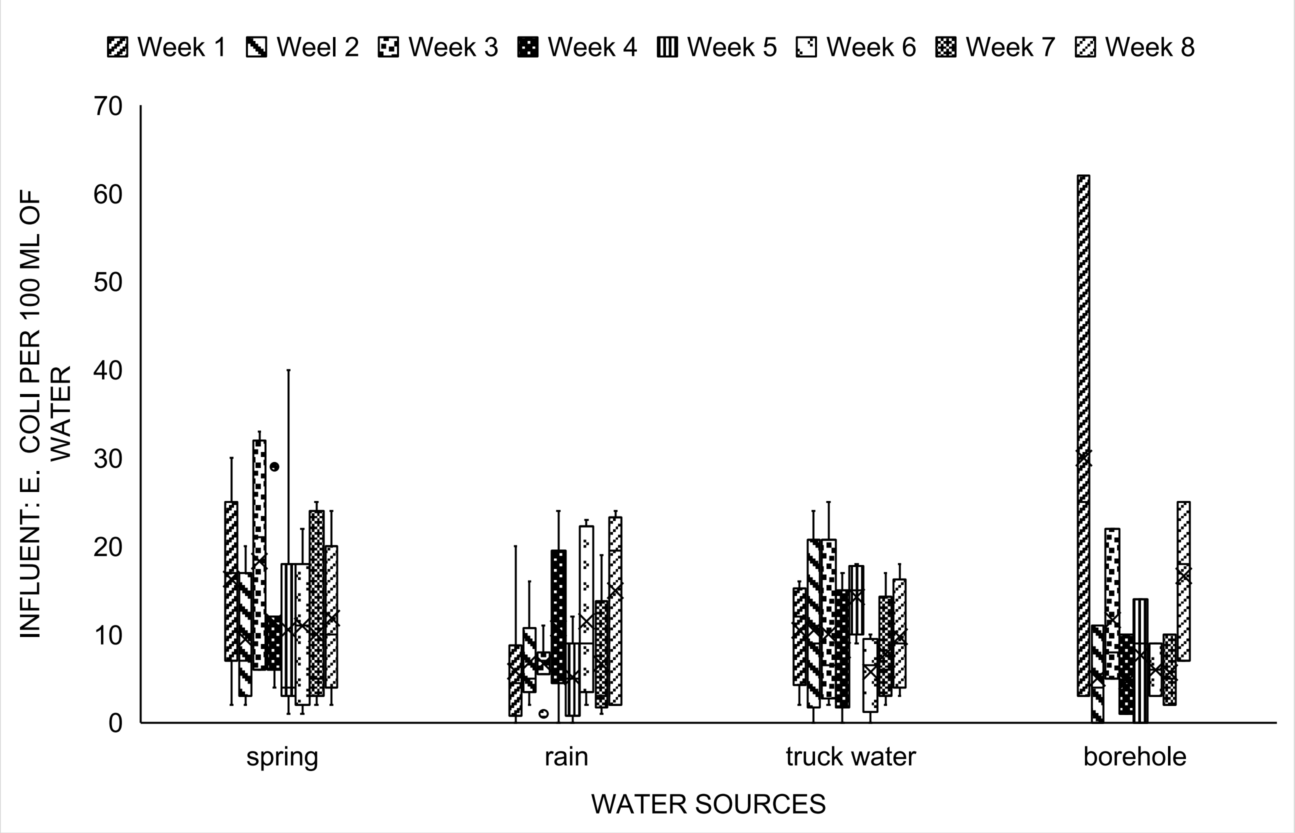


Figure 5.6: E. coli in the influent water

E. coli in spring water seems to have been caused by environmental contamination than the other sources, as the springs are subjected to some non-point sources of pollution which results in higher levels of water contamination than other sources (Kostyla *et al*., 2015). The relatively higher levels of total coliform and *E. coli* in spring water could be due to runoff from agricultural and human activities, whenever it rains where animal waste and waste disposed of by residents are washed into the spring, leading to higher levels of *E. coli* and total coliforms (*Figures 5.6-5.7*).

It is also important to note that total coliform bacteria are commonly found in soils (Seo *et al*., 2019) and in this study, they can be present in the soil surrounding the spring contributing to the levels of total coliforms recorded. From the findings, due to high levels of contamination, the various water sources should be treated before consumption to prevent residents from contracting waterborne diseases. Households at Tswinga village should adopt the use of point-of-use water treatment devices to protect them against waterborne diseases and other risks.

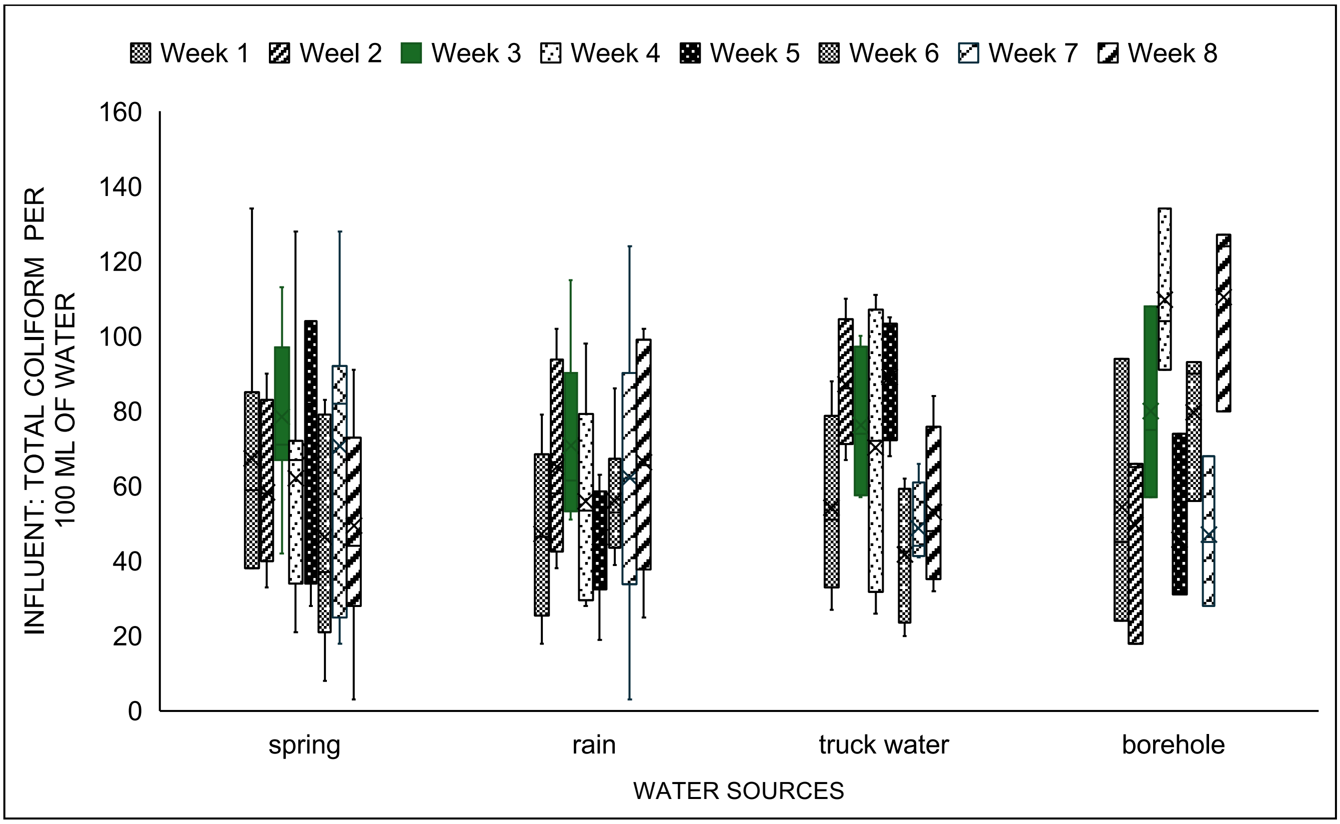


Figure 5.7: Present Total coliform in the influent water

5.3 Performance of the ceramic across water sources

5.3.1 Log reduction of using optimised ceramic water filter across various water sources

The filters were produced and optimised in the laboratory and 1 g was chosen from the optimisation results. Afterwards, field work was conducted where 1 g ionic copper CWFs was given to 20 selected households for use in the study area. Filtered water samples from the selected households were collected weekly and tested for *E. coli* and total coliform for a period of 8 weeks. *Appendix 5* shows the log reduction of *E. coli* and total coliform for water from the optimised ceramic filters. An average of 0.64 log reduction for *E. coli* was obtained while 0.16 log reduction of the total coliform was recorded, respectively. The log reduction shows that the filters were effective at removing bacteria in water, and this could be partly attributed to the antibacterial properties of the ionic copper added to the filter (Figure 5.8).

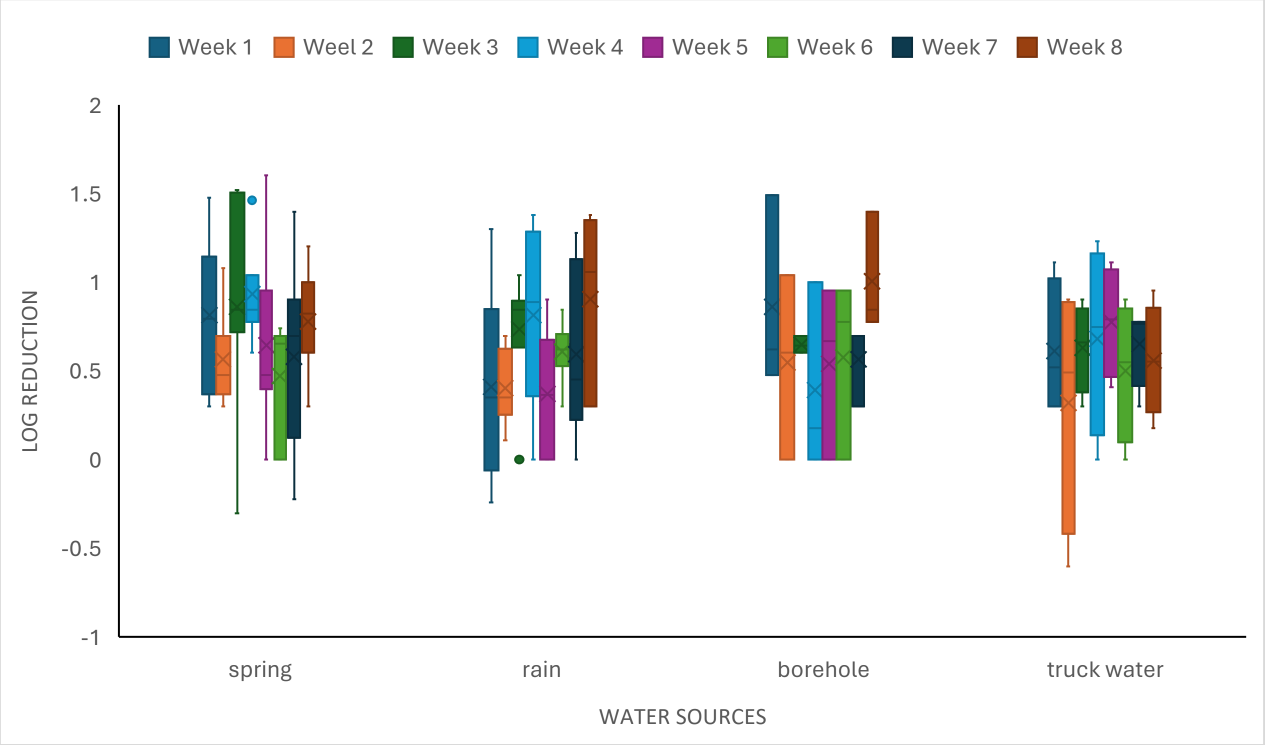


Figure 5.8: Log reduction of E. coli counts after filtration through the ceramic water filters with 1 g of copper nitrate

Looking at the various water sources, higher bacterial inactivation was recorded with spring when compared to other water sources. This is because spring water from the influent results showed a higher level of *E. coli,* than others. An average of 0.71 log reduction of *E. coli* and 0.12 log of total coliforms were recorded for the spring water sources (*Figure 5.9*). Borehole water recorded an average of 0.64 log reduction for *E. coli*, and 0.27 log reduction of total coliform, respectively. Generally, the lower log reduction recorded was due to the lower levels of *E. coli* and total coliform in the influent water.

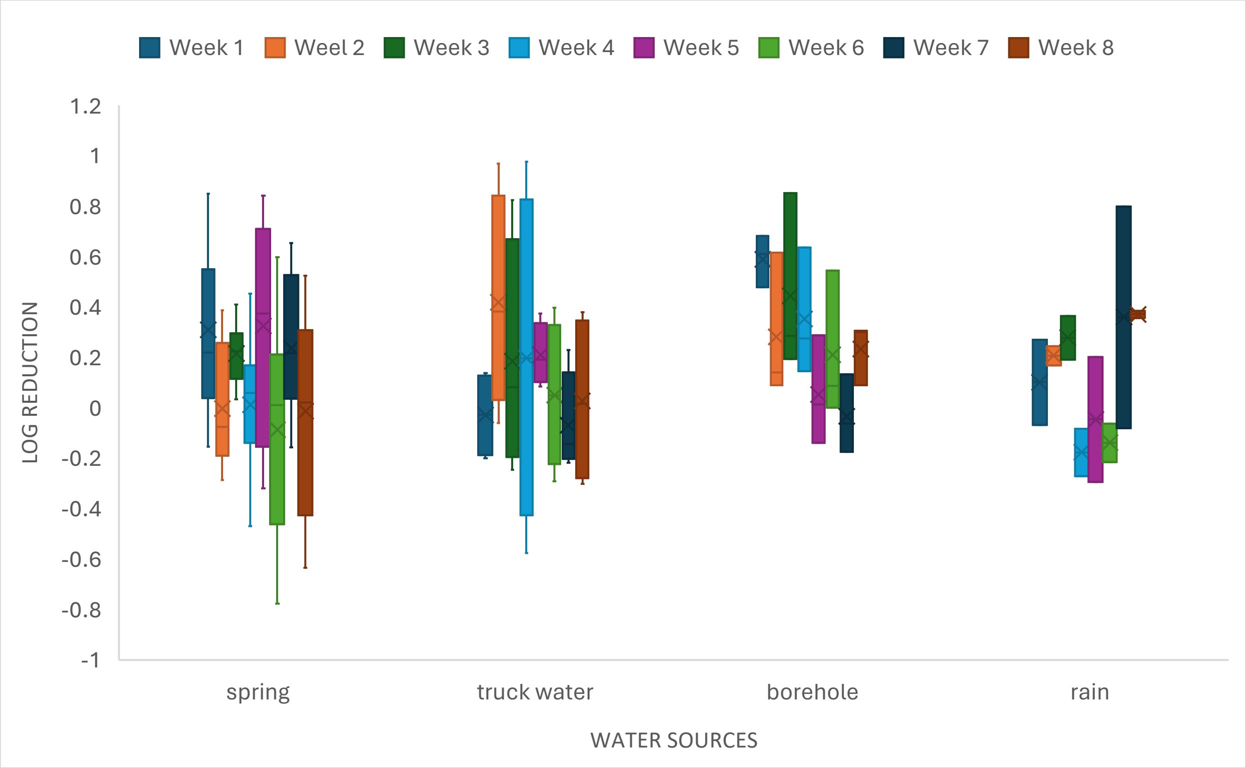


Figure 5.9: Log reduction of total coliform counts after filtration through the ceramic water filters with 1 g of copper nitrate

5.3.2 Log reduction across participants households

Varying average levels of *E. coli* removal in the ranged of 55.71-92.76% was recorded in various households (Table 5.2). The optimised CWFs was efficient in reducing most of the *E. coli* counts recorded from the raw water in the various water types of the residents. Majority of the households recorded *E. coli* removal of over 80%. Conversely, low levels of total coliform were removed from the filter in the range of -3.90-49.85%. Although the presence of total coliform does not indicate presence of pathogenic organisms, it was however unexpected. In some households' higher levels of total coliform was recorded in the treated water than in the raw water, this shows that human factors could have resulted in this finding.

During the distribution of the ceramic water filters the participants were taken through the importance of maintaining their filters, how to handle them, hygiene practices, and safe storage to prevent recontamination of the treated water. When a filter is not maintained properly, it can contribute to the presence of *E. coli* and total coliform in the treated water. According to Varkey and Dlamini (2012), copper is an effective antimicrobial agent that can help kill bacteria such as *E. coli* and total coliforms, the effectiveness of the copper coating can depend on factors such as the quality of the filter and the flow rate of the water through the filter.

The participant was carefully advised that if the ceramic filter is not properly cleaned or maintained, bacteria can accumulate on the surface and create a biofilm that can reduce its effectiveness. In the case where the flow rate of the water through the filter was too high, the participants were advised to report it so the filter can be changed as this will compromise their effectiveness. However, it was also noted that in some households the effluent levels of both *E. coli* and total coliform did not reduce consistently throughout the period of 8 weeks. The reasons for this trend were carefully examined. It was noted from observation that members of some households used the CWFss bucket for other purposes such as for making juice during parties, for irrigating the vegetables in their yards and for carrying other materials the bucket was not designed for. This could be because of their socio-economic status as they feel the bucket should be used for multiple purposes rather than for treating water. This finding shows that human factors can influence the effectiveness of a point-of-use water devices.

To eliminate other potential causes of the poor performance recorded in some households an additional experiment was conducted in the laboratory using the same source water as the households with some 1 g CWFs. This was also ascertained if the CWFs is working below the expected outcome.

Table 5.3: Average of each household for 8 weeks

HOUSEHOLDS	AVERAGES OF EACH HOUSEHOLD FOR 8 WEEKS							
	INFLUENT		EFFLUENT		% REMOVAL		LOG REDUCTION	
	E.C	T.C	E.C	T.C	E.C	T.C	E.C	T.C
1	19.00	77.50	1.38	49.00	92.76	36.77	1.14	0.20
2	11.50	52.38	1.25	46.75	89.13	10.74	0.96	0.05
3	14.00	46.75	1.75	32.13	87.50	31.28	0.90	0.16
4	9.75	65.50	1.88	35.63	80.77	45.61	0.72	0.26
5	9.88	64.00	1.13	56.88	88.61	11.13	0.94	0.05
6	5.00	67.88	0.88	44.88	82.50	33.89	0.76	0.18
7	6.50	55.88	1.50	58.88	76.92	-5.37	0.64	-0.02
8	6.63	55.88	0.63	35.88	90.57	35.79	1.03	0.19
9	8.75	57.50	3.88	43.00	55.71	25.22	0.35	0.13
10	9.88	76.25	1.88	61.63	81.01	19.18	0.72	0.09
11	7.50	72.38	1.75	44.13	76.67	39.03	0.63	0.21
12	15.50	71.25	1.50	50.63	90.32	28.95	1.01	0.15
13	9.75	72.50	1.00	36.38	89.74	49.83	0.99	0.30
14	14.13	44.63	1.88	54.25	86.73	-21.57	0.88	-0.08
15	13.25	63.25	2.13	51.13	83.96	19.17	0.79	0.09
16	8.38	57.50	1.13	52.00	86.57	9.57	0.87	0.04
17	9.00	69.38	0.88	60.88	90.28	12.25	1.01	0.06
18	8.50	79.25	1.25	51.63	85.29	34.86	0.83	0.19
19	8.88	54.50	3.25	56.63	63.38	-3.90	0.44	-0.02
20	13.13	64.13	1.38	52.57	89.52	18.02	0.98	0.09

Where EC is E. coli and TC is total coliform

5.4 Laboratory analysis based on participant’s influent water.

For the laboratory analysis only six filters were used. The water samples were measured in duplicate, two filters were used for each water source and the average counts was calculated. The truck water was included as it is the most used water source amongst the participants. *Appendix 6* shows the average microbiological quality of raw water and filtered water tested in the laboratory from ceramic filters made with 1 g of copper nitrate. Looking at the results, it was noted that the *E. coli* removal in all the water sources during the laboratory analysis was within the same range with the field results with removal percentages ranging from 77.17 – 88.24%, while the log reduction ranged from 0.63 – 0.93 due to the low initial concentration of the raw water.

From the laboratory results total coliform recorded percentage removal ranging from 74.38 - 84.24% (Table 5.4). This was significantly higher than what was recorded during the field studies (-3.90-49.85%) using same source water and CWFs. The laboratory test showed that if the filter is properly used, more desirable results would be obtained, otherwise, there might be interference leading to the filter not performing to its potential. This proves that human interference was involved during field work leading to the inconsistent reduction in removal of total coliform in most households. The study showed the effectiveness of the optimized copper nitrate filter in improving the water quality of the source water in the study area. The levels of total coliform in the treated water from the laboratory studies conformed to the South African National Standards of <10 cfu/100 mL.

Table 5.4: Average of water sources for period of 8 weeks

WATER SOURCES	**AVERAGES FOR ALL 8 WEEKS**							
	INFLUENT		**EFFLUENT**		**% REMOVAL**		**LOG REDUCTION**	
	E.C	**T.C**	**E.C**	**T.C**	**E.C**	**T.C**	**E.C**	**T.C**
1. Borehole	4.25	19.00	0.50	3.00	88.24	84.24	0.93	0.80
2. Borehole	6.13	17.00	1.00	5.00	83.67	72.35	0.79	0.56
1. Spring	12.06	23.00	1.88	5.00	84.46	79.30	0.81	0.68
2. Spring	14.38	23.00	1.88	6.00	86.96	75.34	0.88	0.61
1. Truck water	5.75	25.00	1.31	7.00	77.17	74.38	0.64	0.59
2. Truck water	6.50	21.00	1.06	4.00	83.65	80.61	0.79	0.71

Where EC is *E. coli* and TC is total coliform

CHAPTER 6

CONCLUSION AND RECOMMENDATION

6.1 Conclusion

This research investigated the challenges of microbial water quality in Tswinga village, unfolding a narrative of profound implications for the health, daily lives, and economic activities of its residents. The primary aim revolves around the efficacy of ceramic water filters, specifically those infused with copper nitrate, in addressing waterborne diseases and enhancing water quality within this community. Through participant interviews and photovoice methodology, safety concerns during water collection, sanitation issues, and diseases linked to contaminated water emerge as predominant issues. The community's struggle for sustainable access to clean water was vividly captured through poignant photographs, emphasising the urgency of addressing these challenges. Physicochemical analysis of raw water from various sources, suggests compliance with acceptable standards. However, microbial analysis paints a different picture, uncovering the presence of *E. coli* and total coliform, signalling potential health risks.

Laboratory optimisation of ceramic water filters, particularly those impregnated with ionic copper, yields promising results. However, 1 g of ionic copper behaved slightly better compared to other ceramic filters, with an increase in total coliform log reduction and percentage removal in time interval for 2-6 hours with log reduction of 4.54-5.06 and 99.99-100% removal. Field studies using the optimised 1 g filter was conducted. Fieldwork involved distributing these filters to 20 households, where water samples were collected weekly over an 8-week period and tested for *E. coli* and total coliform. Results indicated an average reduction of 0.64 log for *E. coli* and 0.16 log for total coliform, showcasing the effectiveness of the filters, attributed to the antibacterial properties of ionic copper. Notably, spring water exhibited higher bacterial inactivation. Inconsistencies in reduction were observed across households, partly due to human factors such as improper maintenance and alternate use of filter buckets. laboratory experiments confirmed the efficacy of CWFs when properly utilised, with consistent removal percentages for *E. coli* across various water sources. Total coliform removal was higher in laboratory tests compared to field results, thus emphasising the impact of human interference during field studies. This study highlights the significance of user compliance and adherence to instructions, noting that even advanced technology may not yield expected results if people do not follow proper procedures.

6.2 Recommendation

Community members should be part of the implementation of the effective community engagement strategies to enhance user compliance and adherence to filter usage instructions before commencing any project. There should be a proper investigation on culturally sensitive approaches and educational programs to ensure the proper maintenance and utilisation of water treatment technologies. From the findings the community members of Tswinga village should consider disinfecting their drinking water before consumption irrespective of their source water.

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APPENDICES

APPENDIX 1: Survey data questionnaire

1) Name of the head of your family?

2)How many people are currently living in this household?

3) For the following visit, can you please give the number we can reach out.

4) In your household, what is the gender of everyone currently living there?

5) Please provide the name of the primary source of water you frequently use.

6) Which of the following sources of drinking water does your household utilize?

- ❖ Public tap; open well; borehole; piped into houses; buy bottled water; neighbors piped or tanker trucks.

7) To retrieve water for your household, how much time does it requires?

8) The water you get from your main source, is the quality adequate?

- ❖ Yes or no or maybe.

9) The water containers in your household, who is accountable for filling them up?

- ❖ Female child; male child; adult woman; adult man or others

10) Is your water supply continuous or interrupted?

11) Just how long does the interference last if interrupted?

12) If the interference last for long, where do you regularly get the water?

- ❖ Public tap; open well; borehole; piped into houses; buy bottled water; neighbors piped or tanker trucks.

13) The water you consume do you treat it in any way before consuming it?

- ❖ Yes or No.

14) If so, which strategy do you use to treat the water you use?

- ❖ Let it settle.

- Solar disinfection
- Use a cloth as a filtration.
- Use chlorine or add bleach.
- Boil the water.
- Other

15) Your drinking water, where do you store it?

- Cooking pots.
- Plastic bottles or buckets.
- Water tank.
- Ceramic pots or Plastic buckets.
- other

16) For consumption, what is it that you use to remove drinking water from the containers?

- Use hands to scoop out the water.
- Use a cup that has no handle.
- Use a cup with a handle to scoop out water.
- A spigot to discharge drinking water into a cup.
- other

17) Your drinking water, how would you portray it most of the time?

- Good quality –looks and smells clean to drink.
- Average quality –the smell is bad, sometimes it looks cloudy and may not always be safe to drink.
- Poor quality –it looks cloudy most of the time, often not safe to drink, smells so bad.
- I don’t know.

APPENDIX 2: Log reduction of E. coli and total coliform during optimisation analysis.

T.C – total coliform count, E.C – *E. coli* count, No S/C – No silver/Copper

Results of filters with 1, 2, 4, and 5 g

	Filters							
	1 g		**2 g**		**4 g**		**5 g**	
Hours	**E.C**	**T.C**	**E.C**	**T.C**	**E.C**	**T.C**	**E.C**	**T.C**
2	4,99	4,58	4,86	4,84	4,82	4,71	4,82	4,53
4	4,62	4,92	4,46	4,76	4,49	4,62	4,46	4,55
6	4,56	5,06	4,46	4,76	4,59	4,64	4,42	4,49
8	4,68	5,00	4,49	4,78	4,68	4,68	4,44	4,47
12	4,51	4,81	4,37	4,72	4,35	4,68	4,42	4,62
24	4,44	4,84	4,49	4,67	4,42	4,64	4,38	4,54

Results of filters with 7 g, 10 g and No S/C

	Filters					
	7 g		**10 g**		**No S/C**	
Hours	**E.C**	**T.C**	**E.C**	**T.C**	**E.C**	**T.C**
2	4,80	4,82	4,92	4,54	4,75	4,59
4	4,38	4,68	4,49	4,56	4,30	4,58
6	4,30	4,62	4,32	4,55	4,25	4,56
8	4,46	4,57	4,44	4,58	4,35	4,60
12	4,27	4,55	4,30	4,58	4,23	4,53
24	4,35	4,65	4,38	4,59	4,27	4,56

APPENDIX 3: Percentage removal of E. coli and total coliform during optimisation analysis.

Results of filters with 1, 2, 4, and 5 g

	Filters							
	1 g		**2 g**		**4 g**		**5 g**	
Hours	**E.C**	**T.C**	**E.C**	**T.C**	**E.C**	**T.C**	**E.C**	**T.C**
2	100,00	99,99	100,00	99,99	100,00	99,99	100,00	99,99
4	100,00	99,99	100,00	99,99	100,00	99,99	100,00	99,99
6	100,00	100,00	100,00	99,99	100,00	99,99	100,00	99,98
8	100,00	100,00	100,00	99,99	100,00	99,99	100,00	99,98
12	100,00	99,99	100,00	99,99	100,00	99,99	100,00	99,99
24	100,00	99,99	100,00	99,99	100,00	99,99	100,00	99,99

Results of filters with 7 g, 10 g, and No S/C

	Filters					
	7 g		**10 g**		**No S/C**	
Hours	**E.C**	**T.C**	**E.C**	**T.C**	**E.C**	**T.C**
2	100,00	99,99	100,00	99,99	100,00	99,99
4	100,00	99,99	100,00	99,99	100,00	99,99
6	100,00	99,99	100,00	99,99	100,00	99,99
8	100,00	99,99	100,00	99,99	100,00	99,99
12	99,99	99,99	100,00	99,99	99,99	99,99
24	100,00	99,99	100,00	99,99	99,99	99,99

APPENDIX 4: Microbiological quality of raw water and filtered water from ceramic filters made using 1 g of copper nitrate.

Results from week 1 to 3

	Week 1				Week 2				Week 3			
	Raw		Filtered		Raw		Filtered		Raw		Filtered	
H/H	**E.C**	**T.C**	**E.C**	**T.C**	**E.C**	**T.C**	**E.C**	**T.C**	**E.C**	**T.C**	**E.C**	**T.C**
spring	30	85	1	24	17	59	4	72	32	113	1	44
rain	0	28	0	28	9	38	7	29	7	62	1	71
spring	25	38	4	23	3	58	0	32	33	42	0	25
truck water	2	27	0	38	24	67	3	77	2	100	0	15
truck water	13	51	0	81	0	84	4	9	5	57	0	63
rain	1	18	0	15	4	44	1	64	7	82	0	18
rain	4	52	7	28	2	54	0	17	7	54	0	117
rain	5	79	1	31	5	91	1	92	11	61	0	42
spring	17	71	4	44	20	90	8	94	6	67	12	62
truck water	11	88	2	64	7	110	1	38	25	89	6	55
borehole	3	24	0	5	0	66	0	16	22	108	5	69
borehole	62	94	2	23	4	18	1	13	8	75	2	39
borehole	25	45	6	15	11	65	1	53	5	57	0	8
spring	14	59	0	84	12	33	0	64	21	71	4	51
rain	20	41	1	22	16	102	8	58	7	51	1	22
rain	5	65	0	76	5	62	2	42	1	115	0	74
spring	19	134	2	19	5	83	0	99	6	69	0	36
spring	2	47	0	43	7	40	3	62	9	97	0	49
truck water	16	51	8	41	11	88	8	44	8	59	1	104
spring	7	62	3	23	2	46	0	12	21	90	3	69

Results from week 4 to 6

	Week 4				Week 5				Week 6			
	Raw		Filtered		Raw		Filtered		Raw		Filtered	
W/H	E.C	T.C	E.C	T.C	E.C	T.C	E.C	T.C	E.C	T.C	E.C	T.C
spring	7	21	0	62	3	104	1	15	22	83	4	21
rain	24	73	0	6	2	51	0	97	14	61	2	52
spring	29	72	1	63	1	28	1	18	11	71	3	61
truck water	7	95	2	10	18	98	7	69	8	20	0	8
truck water	17	111	0	47	9	85	0	36	0	51	0	100
rain	0	28	0	10	0	63	0	63	22	86	5	40
rain	10	98	1	63	1	19	0	116	4	56	0	48
rain	18	40	0	32	8	57	3	21	2	39	0	33
spring	12	34	2	38	4	82	1	19	5	26	1	16
truck water	0	26	1	98	13	105	1	62	10	62	2	65
borehole	3	104	2	24	9	32	1	44	3	90	3	90
borehole	10	91	1	65	14	74	3	72	9	93	1	76
borehole	1	134	1	71	0	31	0	16	6	56	0	16
spring	4	44	0	38	18	51	2	73	18	37	4	67
rain	6	30	2	56	12	51	3	32	4	50	0	82
rain	6	67	0	81	8	37	1	73	23	45	5	52
spring	11	68	0	94	5	34	2	71	1	8	0	48
spring	11	128	1	87	3	82	0	16	2	21	2	61
truck water	9	49	0	47	17	68	4	56	5	34	2	26
spring	6	54	0	22	40	104	1	44	18	79	4	77

Results from week 7 to 8

	Week 7				Week 8			
	Raw		Filtered		Raw		Filtered	
H/H	E.C	T.C	E.C	T.C	E.C	T.C	E.C	T.C
spring	25	82	0	118	16	73	0	36
rain	12	52	0	3	24	54	0	88
spring	3	25	5	23	7	40	0	12
truck water	6	66	0	39	11	51	3	29
truck water	17	41	3	55	18	32	2	64
rain	4	124	0	65	2	98	1	84
rain	1	72	1	3	23	42	3	79
rain	2	3	0	18	2	77	0	18
spring	4	87	3	63	2	3	0	8
truck water	6	46	0	76	7	84	2	35
borehole	2	28	0	42	18	127	3	63
borehole	10	45	2	52	7	80	0	65
borehole	5	68	0	50	25	124	0	62
spring	2	18	0	4	24	44	5	53
rain	19	79	1	95	22	102	1	42
rain	2	44	0	7	17	25	1	11
spring	5	92	0	56	20	67	3	64
spring	24	128	3	38	10	91	1	57
truck water	2	42	1	61	3	45	2	74
spring	7	62	0		4	28	0	121

APPENDIX 5: Log reduction of E. coli and total coliform for water from the ceramic filters made using 1 g of copper nitrate.

Results from week 1 – 4

	Week 1		**Week 2**		**Week 3**		**Week 4**	
W/H	**E.C**	**T.C**	**E.C**	**T.C**	**E.C**	**T.C**	**E.C**	**T.C**
spring	1,48	0,55	0,63	-0,09	1,51	0,41	0,85	-0,47
spring	0,63	0,21	0,40	-0,02	-0,30	0,03	0,78	-0,05
spring	0,80	0,22	0,48	0,26	1,52	0,23	1,46	0,06
spring	0,98	-0,15	0,70	-0,29	0,78	0,14	1,04	0,06
spring	0,30	0,46	0,37	0,39	0,95	0,12	1,04	0,45
spring	1,15	0,85	1,08	-0,08	0,72	0,28	0,60	-0,14
spring	0,37	0,04	0,30	-0,19	0,85	0,30	0,78	0,17
truck water	0,70	0,27	0,70	0,25	1,04	0,37	1,26	-0,27
truck water	1,30	-0,07	0,30	0,17	0,85	0,19	0,48	-0,08
truck water	0,70	0,08	0,40	-0,16	0,00	0,66	0,78	0,45
truck water	0,00	0,27	0,60	0,50	0,85	-0,34	0,00	0,19
borehole	-0,24	0,41	0,30	0,00	0,85	0,16	1,00	0,10
borehole	0,00	0,00	0,11	0,12	0,85	-0,06	1,38	1,09
borehole	0,62	0,61	1,04	0,14	0,70	0,28	0,00	0,15
rain	0,48	0,48	0,00	0,09	0,64	0,85	0,18	0,28
rain	1,49	0,68	0,60	0,62	0,60	0,19	1,00	0,64
rain	0,30	-0,15	0,90	-0,06	0,30	0,82	0,54	0,98
rain	0,74	-0,20	0,85	0,97	0,62	-0,04	0,00	0,37
rain	0,30	0,14	0,14	0,46	0,90	0,21	0,95	-0,58
rain	1,11	0,09	-0,60	0,30	0,70	-0,25	1,23	0,02

Results from week 5 – 8

	Week 5		Week 6		Week 7		Week 8	
W/H	**E.C**	**T.C**	**E.C**	**T.C**	**E.C**	**T.C**	**E.C**	**T.C**
spring	0,48	0,84	0,74	0,60	1,40	-0,16	1,20	0,31
spring	0,60	0,64	0,70	0,21	0,12	0,14	0,30	-0,43
spring	0,00	0,19	0,56	0,07	-0,22	0,04	0,85	0,52
spring	0,40	-0,16	0,00	-0,26	0,70	0,65	0,82	-0,08
spring	0,48	0,37	0,00	0,01	0,90	0,23	1,00	-0,64
spring	0,95	-0,32	0,65	-0,78	0,30	0,22	0,68	0,02
spring	1,60	0,71	0,65	-0,46	0,85	0,53	0,60	0,20
truck water	0,43	0,20	0,30	-0,21	0,30	-0,08	0,30	0,39
truck water	0,60	-0,30	0,60	-0,06	1,28	0,80	1,34	0,36
truck water	0,90	0,00	0,66	0,33	0,30	0,28	1,23	0,07
truck water	0,00	-0,79	0,64	0,07	0,60	1,38	0,30	-0,27
borehole	0,00	0,43	0,60	0,07	0,00	-0,78	0,88	0,63
borehole	0,30	-0,28	0,85	0,07	1,08	1,24	1,38	-0,21
borehole	0,00	0,01	0,78	0,09	0,70	-0,06	1,40	0,09
rain	0,95	0,29	0,00	0,54	0,30	0,13	0,78	0,30
rain	0,67	-0,14	0,95	0,00	0,70	-0,18	0,85	0,30
rain	0,41	0,15	0,90	0,40	0,78	0,23	0,56	0,25
rain	1,11	0,37	0,70	-0,29	0,78	-0,13	0,54	-0,30
rain	0,63	0,23	0,40	-0,02	0,30	-0,22	0,18	0,38
rain	0,95	0,08	0,00	0,12	0,75	-0,16	0,95	-0,22

APPENDIX 6: Average microbiological quality of raw water and filtered water tested in the laboratory from ceramic filters made using 1 g of copper nitrate.

Results of week 1 to 6

	Week 1				**Week 2**				**Week 3**			
	Raw		**Filtered**		**Raw**		**Filtered**		**Raw**		**Filtered**	
W/H	**E.C**	**T.C**	**E.C**	**T.C**	**E. C**	**T. C**	**E. C**	**T. C**	**E. C**	**T. C**	**E. C**	**T. C**
Borehole	3	21	0	5	4	10	0	1	1	13	0	7
Borehole	7	15	1	2	7	16	1	3	0	8	0	3
Spring	17	27	0	6	3	6	1	2	3	6	0	2
Spring	22	33	1	5	11	19	1	3	2	6	0	3
Truck water	1	6	1	6	1	6	1	2	2	39	0	2
Truck water	4	9	3	2	0	3	1	1	10	23	1	1

	Week 4				**Week 5**				**Week 6**			
	Raw		**Filtered**		**Raw**		**Filtered**		**Raw**		**Filtered**	
W/H	**E.C**	**T.C**	**E.C**	**T. C**	**E. C**	**T. C**	**E. C**	**T. C**	**E. C**	**T. C**	**E. C**	**T. C**
Borehole	3	24	0	4	2	14	1	3	13	40	1	2
Borehole	1	18	0	9	4	12	2	7	21	34	4	11
Spring	6	12	2	6	23	40	6	13	25	63	4	5
Spring	7	12	1	3	30	42	2	10	17	29	5	15
Truck water	16	40	0	5	15	70	6	20	8	26	3	16
Truck water	19	38	0	7	11	52	2	15	4	16	2	5

Results of week 7 - 8

		Week 7				**Week 8**			
		Raw		**Filtered**		**Raw**		**Filtered**	
Filters	**W/H**	**E.C**	**T.C**	**E.C**	**T.C**	**E.C**	**T.C**	**E.C**	**T.C**
1 g	Borehole	6	14	2	2	4	21	0	3
1 g	Borehole	6	11	1	1	4	18	0	3
1 g	Spring	13	21	2	2	8	13	1	5
1 g	Spring	13	27	4	4	13	19	3	6
1 g	Truck water	2	8	1	1	2	10	1	2
1 g	Truck water	2	9	0	1	2	15	1	2