IMPROVEMENT OF THE POTABILITY OF SURFACE WATER BY USING THE FILTRATION METHOD

by

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DECLARATION

"I declare that the dissertation hereby submitted to the University of Limpopo, for the degree of Master of Science in Microbiology has not previously been submitted by me for a degree at this or any other university; that it is my own work in design and in execution, and that all material contained herein has been duly acknowledged."

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ABSTRACT

Access to safe drinking water is a major problem globally and it mostly affects people living in low-income countries. The lack of potable water leads to the use of raw water from surface or ground water sources for drinking and other household purposes. A water filtration unit was designed and constructed using fabric, gravel and sand, which were wet-packaged into a 20 L bucket. The efficiency of the filter unit to improve the bio-physicochemical properties of contaminated water was tested using surface waters from rivers in the Sekhukhune area. Physico-chemical parameters tested included turbidity, colour, total suspended solids (TSS), total dissolved solids (TDS), total hardness and pH. Turbidity and colour were the most improved characteristics, where turbidity improved by 69% and colour by 80%. Other parameters such as total hardness, TSS and TDS were non-significantly reduced following treatment with the filtration unit. The amount of soluble solids in raw water was well within allowable limits by WHO standards. Microbiological tests included heterotrophic bacteria, total coliform and faecal coliform counts. The bacterial load was too numerous to count for the untreated water, however, after treatment with the filtration unit, heterotrophic bacterial load decreased to 15×10^{3} CFU/ml, total coliforms to 14×10^{2} CFU/100ml and faecal coliforms to 11×10^{2} CFU/100ml. Further treatment with UV sterilization unit resulted in undetectable amount of bacteria. The unit designed in this study can be beneficial in those rural communities were clean water is not available, it is easy to construct and simple to operate and most importantly it reduced contaminants in surface water. The UV unit incorporated in this study is not cost effective, therefore, other household treatment options such as chlorination and boiling which are easily accessible to most communities can be used to further eliminate remaining microorganisms after filtration. The effective shortest boiling time and minimum dosage of $Na(OCl_2)$ have been previously tested in our laboratory and total elimination of bacteria was achieved within 2 minutes of rolling boil and after 30 minutes following addition of 5ml/20L of liquid chlorine.

Key words: water filtration-unit, UV sterilization unit, bio-physicochemical properties, river water.

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LIST OF ABREVIATIONS

BSF	Biosand filter
CDC	Centre for Diseases Control and Prevention
CFU	Colony forming units
cm	Centimetre
DWA	Department of Water Affairs
FCC	Faecal coliform counts
HPC	Heterotrophic bacterial count
HWTS	Household Water Treatment Systems
JMP	Joint Monitoring Programme
L	Litre
L/h	Litre per hour
MDG	Millennium development goals
MF	Membrane filtration
MRC	Medical Research Council
MS	Mass spectrometry
ml	Millilitre
PCR	Polymerase chain reaction
RSA	Republic of South Africa
SSF	Slow sand filter
TDS	Total dissolved solids
TCC	Total coliform counts
TSS	Total suspended solids
UV	Ultraviolet
UNICEF	United Nations Children's Fund
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNEP	United Nations Environmental Programme
WHO	World Health Organization

TITLE

Improvement of the potability of surface water by using the filtration method.

CHAPTER 1: GENERAL INTRODUCTION

Provision of good quality water is a key element towards sustaining and improving life by reducing incidences of water-borne diseases. However, many people especially in developing countries still depend on untreated water sources. The United Nation's convention on climate change in the year 2000 reported that water is unevenly distributed around Africa. This means that 60% of the water is situated in only 20% of the land (Environmental problems in South Africa, 2013). The Republic of South Africa (RSA) has made satisfactory progress with regard to improving access to safe water, i.e., from 1990 to 2010 most people had access to an improved water source, especially in urban areas whereas in rural areas water provision increased from 66% to 79% (WHO/UNICEF, 2012). Consumption of untreated water due to shortage of clean water leads to a variety of diseases which include cholera, typhoid, hepatitis and gastroenteritis. Sixty percent of rural communities in RSA were affected by water-borne illnesses by 2005. An outbreak of cholera also occurred in RSA between 2008 and 2009 and it affected about 1608 people (OCHA, 2009).

Malakauskas *et al*. (2007) reported that improving the quality of water may significantly reduce the burden of diseases associated with water. Water-borne infections mostly affect immunocompromised people, young children and the elderly. Good quality water is therefore needed on a daily basis (Momba *et al*., 2008). High levels of morbidity and mortality caused by water-borne pathogens led to the development of various household water treatment tools. Water quality describes the physical, chemical, biological and aesthetic properties of water which determines its fitness for different uses and for protecting the health and integrity of users (DWAF, 1996). The South African government published guidelines for domestic use which details four broad categories of water use namely; domestic, agricultural, industrial and recreational purposes; these categories can be subdivided into subcategories such as drinking, bathing, cooking, laundry and gardening (DWAF, 1996). Drinking water must meet specified safety standards which ensure absence of harmful substances in the water and a good aesthetic appeal. The World health statistics published by WHO (2012) reported an average annual decline rate of 9% of population without access to improved water source. This is however, still not sufficient noting that many rural villages are still relying of surface waters.

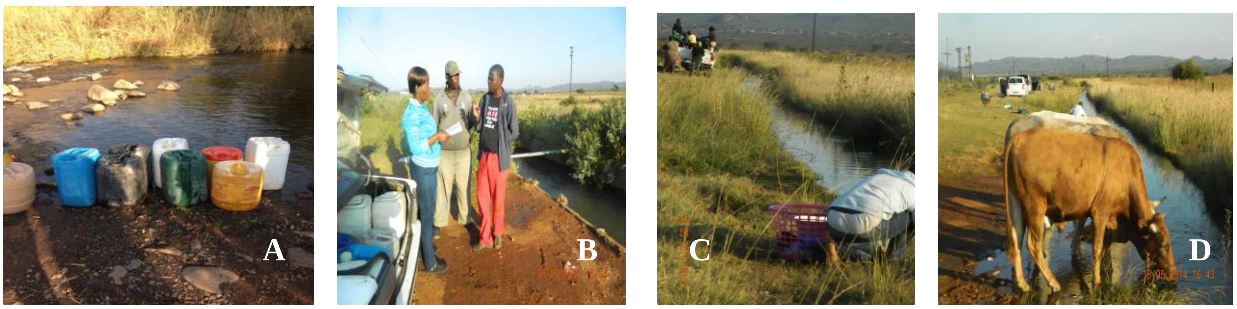

Figure 1 Surface water sources used for domestic purposes in Sekhukhune area. Water collection at Ngwaritsi river is depicted in A and B to D shows human and animal activity at a stream in Ga Masemola village.

Many villages in the Sekhukhune area, Limpopo province, lack a reliable source of potable water; hence many households use surface water as the main source of water for domestic activities such as drinking, bathing and laundry (Fig. 1 A-D). This was established through personal communication with the communities. We established that the water is not treated prior to use either due to lack of knowledge about health hazards of consumption of untreated surface water or due to economic reasons. Treatment of water at consumption point offers communities without access to potable water the opportunity to have safe water. Furthermore, communities can take advantage of small-scale technologies and techniques which can remove chemicals, pathogenic microbes, and improve the taste and physical characteristics of contaminated water in order to improve its potability (Cotruvo *et al*., 2010). One of the oldest methods of water treatment is filtration. Filtration has been shown to remove pathogens from contaminated water (Gray, 2014). The material used for making the filter bed is important for the efficiency of the filtration unit. This study focussed on developing a filtration unit which can be used to remove both microbial and chemical contaminants from water samples and to produce water that meets the RSA specification for potable water. The filtration unit was developed using easily accessible materials such as sand, gravel and cloths, which are readily available in most households and communities.

1.1 PURPOSE OF THE STUDY

1.1.1 Aim

Improvement of the bio-physicochemical properties of surface water for domestic use.

1.1.2 Objectives

The objectives of this study entail:

i. Determination of microbiological quality of surface water in terms of heterotrophic bacteria, total coliforms and faecal coliforms.
ii. Analysis of physico-chemical parameters of surface water with respect to pH, total dissolved solids, total suspended solids, hardness, turbidity and colour.
iii. Identification of common bacterial contaminants in surface water.
iv. Constructing and evaluating a filtration unit for improving potability of surface water in terms of the bio-physicochemical parameters.
v. Coupling of the filtration system with a UV unit to further improve microbiological quality of surface water.

CHAPTER 2: CONSTRUCTION OF A FILTRATION UNIT

2.1 Literature review

2.1.1 Household water treatment strategies

The need to treat water at household level is increasing with an incline in scarcity of potable water in developing countries. Encouraging household water treatment systems (HWTS) can help communities take responsibility of their own water security. Furthermore, if communities are empowered with the knowledge and tools to treat water at home, many microbial diseases will be eliminated. Household-based water treatment and safe storage practice was reported to be associated with a 35% reduction in diarrhoeal diseases as compared to 11% for conventional treatment of water supply (Fewtrell *et al*., 2005). Low cost, safety and efficiency in the removal of contaminants are the desirable qualities of home-based water treatment devices. In RSA the most commonly used methods for treatment of household drinking water are boiling, cloth filtration and chlorination (Anderson *et al*., 2011). Extensive literature is available worldwide about household water treatment options. There is a need to investigate the efficacy of these household water treatment options in removing contaminants under local conditions as well as their potential sustainability (Clasen *et al*., 2007; WHO, 2008).

There is a higher risk of contamination of water sources in rural areas due to limited environmental awareness. A rural community should be empowered with alternative means to treat drinking water in order to meet the challenges of providing safe water for each household. Although there are many household water treatment methods known to date, there is a need to evaluate, redefine and simplify these procedures according to the realities of each community. Point-of-use water purification has emerged as a cost-effective approach to protect the health of communities that lack safe water i.e., treatment of water at consumption point offers consumers who are drinking untreated water or water of poor aesthetic quality the opportunity to have safe water (Clasen *et al*., 2007; WHO, 2008). Institutions like government, academics, NGOs and the private sector formed the international network to promote household water treatment systems after observing that treatment of water at household level reduced the risks of water-borne diseases while increasing base knowledge on water safety within communities (Gundry *et al*., 2004; WHO/UNICEF, 2006; Clasen, 2008). Since then, the World Health Organisation (WHO) stated that its goal is “to contribute a significant reduction in water-borne diseases, especially among vulnerable populations by promoting HWTS as a key component of water, sanitation, and hygiene programmes” (WHO, 2005). Promotion of HWTS had several successful programs which included the ability to achieve quality HWTS components locally, social marketing and availability of implementation materials and technical assistance to support on-the-ground implementers (Lantagne *et al*., 2006). However, HWTS implementation projects have also encountered significant challenges which included aspects about the health impact of these interventions in large-scale situations, long term sustainability of the projects, especially long term access to supplies and scaling up to efficiently reach people without access to improved water sources (Lantagne *et al*., 2006).

Further challenges for implementers included choosing the best HWTS option for a given area and uninterrupted access to the HWTS option is critical. The use of HWTS is most beneficial in instances where supply and quality of drinking water are seldom reliable. Because of increased risk from water-borne diseases, HWTS could potentially be an effective emergency response intervention especially when normal water supplies are interrupted or compromised due to natural disasters, complex emergencies or outbreaks (Lantagne and Clasen, 2012). For poor households daily water use varies temporally and seasonally due to changes in water quality and availability. In urban areas where water supply is sometimes interrupted due to low pressure and irregularity of supply in a piped system, HWTS can be used when households use backup water sources such as shallow wells. Rosa and Clasen (2010) used data from household surveys of 67 middle- and lower-income countries such as Vietnam, Indonesia and Mongolia and reported that an estimated 33% of households or more than 1.1 billion people treat water in their homes before consumption. The acceptability and use of HWTS are yet to be documented in RSA even though local rural communities are facing similar challenges with regard to supply of safe water. In cases where communities receive water from centralised water treatment plants, which involves treating large amounts of water for many households at a single spot, more operation, frequent maintenance and construction of a water distribution system is required (BOULDER, 2011). Centralised systems combine several techniques to purify water. The treatment steps could include aeration, coagulation, flocculation, filtration and disinfection (TULSA, 2011). Centralised systems, unlike household water treatment are not cost effective and require frequent maintenance. Therefore, if these systems are not properly maintained they could lead to partially treated water being distributed to households.

2.1.2 Challenges affecting provision of potable water

Water security is negatively affected globally by factors that include climate conditions, population growth, rural-urban migration, increased per-capita water use and pollution. The global estimation of people who lack access to safe water supply is 1.1 billion and those who lack adequate sanitation is estimated at 2.6 billion (UNESCO, 2009; Onda *et al*., 2012). Jones *et al*. (2009) reported that lack of potable water will affect Africa for the coming several years as it is projected that by 2025, 16% of the population will still be without safe water. Despite all the efforts made to improve water supply and sanitation, which include policies and programs, more people still lack access to safe water. This mostly affects the poor in Asian and African countries (Falkenmark and Rockstrom, 2004). According to WHO (2004) majority of the population in developing countries live in rural and suburban areas where treated drinking water is usually unavailable. Such communities therefore rely on surface water which is often contaminated with pathogens. Water quality is not monitored in rural areas because most communities cannot afford basic treatment facilities for decontamination of water. Rural and developing communities are also situated far from major centres which result in the reduction of management and supervision levels of water supplies. The Republic of South Africa faces a serious challenge with ensuring that its water resources are safe for human consumption and sufficient to meet the demand (September *et al*., 2007). One example is the growing problem of the health risks associated with toxicity of water resources due to increased levels of bacteria which include *Escherichia coli*, *Aeromonas*, *Pseudomonas*, *Salmonella*, *Shigella* and *Vibrio* spp. (September *et al*., 2007). Both urban and rural settlements have been increasing along RSA's rivers and dams and such settlements are often informal and have no water and sanitation infrastructure. Activities within such communities often lead to increased level of pollution in natural water resources. In RSA it was reported that the water sources have high numbers of bacteria, often more than five times the amount that WHO recommends (Mellor *et al*., 2013), and there has been a large growth in biofilm coliforms in the water sources. Mellor *et al*. (2013) further reported that this bacterial growth occurs during the transportation of water through pipes into households. This indicates that the problem of access to safe water is not only the amount which is available but the management and maintenance of water resources as well. Regulations and policies to deliver safe water in RSA were implemented by the national government, however, other local municipalities did not comply. This mostly affected rural communities due to reliance on untreated water (DWA, 2012).

Rural municipalities lack efficient and effective water cleaning facilities and this result in shortage of potable water. The Department of Water Affairs (2010) stated that 97% of the population had access to basic water supply infrastructure. However, the presence of water supply infrastructure does not always indicate that people have access to safe water because these technologies sometimes do not work due to lack of maintenance (Guardiola *et al*., 2010). Rural communities mostly obtain their water through small community water systems. These systems deliver a defined level of service referred to as a basic water supply service which infers installation of communal taps at a maximum distance of 200 m from each household and minimum quantity of 25 litres per capita per day at a minimum flow rate of 10 l/min and a minimum reliability of 98% (DWA, 2000). An estimated 3, 5% of RSA's population live in the Limpopo province and about 80% live in informal rural settlements or villages. This province is also one of the poorest region in the country and generally regarded as a water-poor area. Due to the relatively dry conditions in the province, 75% of the population is still dependent on ground and surface waters for domestic purposes (Busari and Jackson, 2006).

2.1.3 Water resources and infrastructure in South Africa

Water is an important commodity, hence its physical, chemical and biological characteristics are considered as major health contributing factors (Kazi *et al*., 2009). Acceptable water quality implies the safety of drinking water in terms of its physical, chemical and bacteriological parameters (WHO, 2004). The aim of drinking water quality management is to minimize the health risks associated with either direct or indirect use of water. The need for standards and guidelines in water quality arises from the need to protect human health and RSA is one of the few countries in the world that protects the basic right to sufficient water in its constitution, which states that everyone has the right to sufficient water (Constitution of the Republic of South Africa, 1996). More than 95% of the country’s freshwater resources have already been allocated by 2005. The quality of these water resources has gradually been declining due to increased pollution caused by industry, urbanisation, mining, agriculture and power generation (Ashton *et al.*, 2008).

The increase in population combined with poor sanitation puts a strain on limited water resources which leads to an increase in diseases associated with poor living conditions (Lehloesa and Muyima, 2000). In 2007, the Department of Water Affairs had predicted that water service delivery backlogs would be eliminated by the year 2011 while sanitation backlogs would be eliminated by the year 2013. However, by the end of 2013, it was estimated that 6 million RSA citizens, nearly 14% of the population did not have access to a reliable source of safe drinking water and a further 13 million did not have access to adequate sanitation. The majority of the affected people were in the hard-to-reach communities situated in remote rural areas as well as in unplanned peri-urban settlements (Stats SA, 2014). The percentage of households with access to safe off-site water sources (neighbour’s tap, communal tap or offsite borehole) were 98,7% in the Western Cape, 96,3% Northern Cape and 95,9% in Gauteng. The percentage of households in the Eastern Cape with access to water increased by 24% while in the Limpopo province it declined from 84,0% to 77,5% between 2010 to 2013. The communities with the lowest rates of access to safe water in RSA are in the Eastern Cape, KwaZulu-Natal and Limpopo provinces which are the poor provinces in the country. They all fall below the national average (88.9%) of access to piped water and have a higher proportion of rural communities (Stats SA, 2014). Limpopo province has the greatest proportion of rural communities (90%) followed by Northern Cape (80%), Eastern Cape (62%), Mpumalanga (61%) and lastly KwaZulu-Natal (55%). Overall, approximately 40% of SA’s population resides in rural areas (University of Witwatersrand, 2008). Despite substantial progress in safe water supply nationally, there are concerns regarding lack of effective water purification facilities and this leads to shortage of potable water (WHO/UNICEF, 2010). The available small water treatment plants implemented in rural areas need to be improved regularly for water transfer systems to function at a higher level of efficiency (WHO/UNICEF, 2010). In developing countries similar to RSA, potable water is mostly provided using a communal water source such as a standpipe shared among close households, or a water connection inside the household. These communal sources only provide water at certain time intervals during the day. Even with a connected water supply system, households still have to store water so that sufficient amount of water is available during the non-supply periods. Water storage therefore becomes a necessity for those who are connected to a non-continuous water supply system and those who depend on drinking water sources located outside their household (Heleba, 2012).

2.1.4 Home-based water treatment methods

Point-of-use water treatment and good water storage practices reduce the microbiological contamination of water in households. Various technologies have been reported on and include boiling, solar radiation, chlorination and filtration.

2.1.4.1 Solar radiation

Solar water disinfection is a household treatment method that can significantly improve the microbiological quality of drinking water and therefore prevent water-borne diseases in developing countries (Rose *et al*., 2006). It is a simple, environmentally safe, sustainable and cost effective treatment method for drinking water (WHO/UNICEF, 2005). More than 5 million people disinfect their drinking water with solar disinfection technique. Since 1980 many researchers investigated the mechanisms of solar radiation induced cell death in water and possible enhancement technologies to make it faster and safer. The method has spread throughout the developing world and it is used daily in more than 50 countries in Asia, Latin America, and Africa (Rose *et al*., 2006; Altherr *et al*., 2008; EAWAG, 2012). Limitations related to solar radiation method include inefficiency in treatment of large volumes of water, its ineffectiveness during cloudy or rainy days and it cannot be used on turbid water. However, solar radiation is cost effective and environmentally friendly by not using fossil fuel for disinfection of water (Rose *et al*., 2006; Altherr *et al*., 2008; EAWAG, 2012). Solar radiation is a free method for water treatment, usually applied at the household level and is recommended by WHO as a viable method for household water treatment and safe storage (WHO, 2010).

2.1.4.2 Boiling method

Boiling or heating of water has been used to disinfect household water since ancient times. It is effective in destroying all classes of water-borne pathogens which include viruses, bacteria and bacterial spores, fungi, protozoans and helminth ova. It can also be effectively applied to all types of water including those with high turbidity or dissolved constituents. Research has shown that even heating to as little as 55°C for several hours has been shown to reduce non-spore forming bacterial pathogens as well as many viruses and parasites, including the water-borne protozoans *Cryptosporidium parvum, Giardia lamblia* and *Entamoeba histolytica*. It is recommended that the water be stored in the same container in which it was boiled or heated, preferably one with a lid or other protection in order to reduce chances of recontamination. It is further recommended that boiled or heat-treated water be consumed soon after it has cooled and preferably within the same day (Sobsey and Leland, 2001; Conant, 2005). A major disadvantage of boiling is its consumption of energy, cost and sustainability of fuel. In areas of the world where wood and other biomass fuels or fossil fuels are in limited supply and must be purchased, the costs of boiling water are excessive. The use of wood and wood-derived fuels is also a concern because it contributes to the loss of woodlands and the accompanying ecological damage caused by deforestation. However, where affordable and sustainable sources of fuel are available without causing environmental degradation, heating household water to a rolling boil can be an effective and accessible method of water treatment. Boiling of drinking water though effective, results in water with a bland taste. Handling of large volumes has become a challenge and this may increase incidences of burn accidents within households (Sobsey and Leland, 2001).

2.1.4.3 Ultraviolet sterilization

Ultraviolet (UV) radiation is defined as a physical method where water is exposed to a lamp producing light at a wavelength of nearly 250 nm. The wavelength is located in the middle of the germicidal band and is the one responsible for damaging the DNA of microorganisms (Bolton and Colton, 2008). For poor water quality sources, a pre-treatment method such as filtering is required before using UV as it is only effective in low turbid waters. Ultraviolet is highly effective in the removal of microbes in drinking water, does not introduce chemicals or produce harmful disinfection by-products. Disadvantages of UV treatment of water include lack of disinfectant residual to protect the water from recontamination or microbial regrowth after treatment, turbidity and certain dissolved constituents can interfere with or reduce its disinfection efficiency, high electricity usage is required to power the UV lamps and the cost of a UV unit can also be a deterrent, therefore it may not be suitable to use at household level. Currently, UV units are used as stand-alone treatment systems or as part of a series of other drinking water treatment processes or multiple barrier system (Kowalski *et al.*, 2000).

2.1.4.4 Filtration

2.1.4.4.1 Slow sand filter

Slow sand filtration (SSF) is a common household water treatment method in developing countries. Slow sand filter involves filtering water through fine sand at a very slow rate which allows biological film to develop on top of the sand. The top film serves as a biological filter that is capable of removing almost 99% of all pathogens (Elliott *et al.*, 2008). The advantages of SSF include removal of protozoa and bacteria, it is easy to use, is produced from locally available materials, it involves one-time installation with few maintenance requirements and long shelf life. The drawbacks of SSF include low rate of virus inactivation, lack of residual protection and the current lack of studies proving health impact. Slow sand filters are commonly used for community water supplies but they can also be built to serve individual households. The sand is the commonly used medium, other granular materials such as gravel and burnt rice have also been used. The most important characteristic is the fineness of the sand (Sobsey, 2002).

2.1.4.4.2 Cloth Filtration

Straining water through a cloth has been commonly used in household water treatment for centuries and it has been reported that cloth filters can entrap plankton and reduce the risk of cholera (Colwell *et al*., 2003). This simple method can also filter out helminths and their eggs and larvae (Huq *et al*., 2001). A simple filtration method which employed cotton sari cloth was tested in the filtration of pond and river waters containing *V*. *cholera*. The number of *V*. *cholerae* was effectively reduced by 2 log units (Huq *et al*., 2001; Colwell *et al*., 2003). Advantages of cloth filtration include simplicity, the wide availability of cloth and can be used to treat large volumes of water. Poor households can also benefit due to availability of different cloth materials. Drawback of this method is the filtration capacity of different cloth materials which varies greatly and filtering through multiple layers of cloth can be very slow (Huq, 2010).

2.1.4.5 Nanoparticles

Nanoparticles are currently gaining momentum in water purification (Li *et al*., 2008). Nanoparticles can be used for small scale or point-of-use systems that are not connected to a central network for emergency responses in disastrous situations (Dankovich *et al*., 2011). Silver nanoparticles have been incorporated into a range of cellulosic materials such as bacterial cellulose, filter paper, cotton fabric and cellulose gels (Ferraira *et al*., 2010). Silver and other metals have been used to store potable water for years and the antibacterial properties of these metals are well known (Davies *et al*., 1997). Nanoparticles offer a great potential to create anti-bacterial technologies of low cost and increase access to safe water in the developing world (Li *et al*., 2008). The use of ceramic filters impregnated with silver to remove pathogens from drinking water in rural areas and developing countries is common (Kallman *et al*., 2011). Even with great advantages of using nanoparticles to disinfect water, it is important to determine if nanoparticles leach through treatment technology into finished drinking water. Leaching of nanoparticles may pose potential threats if ingested through drinking water which may result in adverse effects including kidney damage, increases blood pressure, gastrointestinal inflammation, neurological damage and cancer (Kavcar *et al*., 2009).

2.1.4.6 Chlorination

Chlorination is one of many methods that can be used to disinfect water. This method was first used over a century ago and is still used today. It is a chemical disinfection method that uses various types of chlorine or chlorine-containing substances for the disinfection of water. Chlorination was found to be an effective intervention strategy to prevent diarrhoeal diseases (Semenza *et al*., 1998; Quick *et al*., 1999 and Quick *et al*., 2002). Free chlorine inactivates more than 99.99% of enteric pathogens except *Cryptosporidium* and *Mycobacterium* species (WHO, 2002). The treatment requires only a few mg/l and contact time of about 30 minutes. A major advantage of chlorination is that it has proven to be effective against bacteria and viruses, however, it does not inactivate all microbes. In cases where protozoan cysts are not a major concern, chlorination offers a good disinfection method to use because it is inexpensive yet effective in killing microorganisms. One of the disadvantages of water chlorination process is the formation of disinfection by-products (trihalomethanes and haloacetic acids) which may pose a health risk to consumers (Baker *et al*., 2002). Their effects depend on the amount ingested into the body. Due to potential carcinogenicity of these compounds, drinking water regulations across the developed world require regular monitoring of the concentration of these compounds in the distribution systems of municipal water supplies (WHO, 2006). The chlorination process is easy to implement, therefore mostly recommended at household level. It is an effective method in water emergency situations as it can eliminate an overload of pathogens relatively quickly. However, chlorination is not effective on turbid water (Arnold and Colford, 2007).

2.1.4.6 Coagulation

Coagulants are known to reduce the time required to settle out suspended solids and it is effective in removing fine particles. Some bacteria and viruses can also attach themselves to suspended particles. The use of coagulation for reduction of turbidity may also improve some microbiological quality such as bacteria, viruses, protozoa and helminths of water (Lea, 2010). The effectiveness of coagulants depends on the type of coagulant used, the nature of the raw water and factors such as temperature and pH (Sancha, 2006). Advantages of coagulants include cost effectiveness and certain contaminants such as lead and barium can also be effectively removed. However, coagulants may be toxic if not properly used (WHO, 2008). In countries like Malawi, Sudan, Egypt and Malaysia, the application of *Moringa oleifera* seeds extract in water coagulation and softening has received a lot of attention (NRC, 2006). Another natural plant coagulant known to clarify turbid surface water is strychnos potatorum. This type of coagulant is reported to be used in countries like Southern and central parts of India, Sri lanka and Burma (Balachandra, 2013). Traditional water purifying methods using herbs and seeds can be used to treat and cleanse the water while retaining its natural benefits (Balachandra, 2013). Aluminum salts are also widely used coagulants in drinking water (Son and Waelkens, 2009). Although chemical coagulants are recognized for their efficiency, they have disadvantages such as inefficiency in low water temperatures, high cost and the large volume production of sludge (Matilainen *et al.*, 2010; Yin, 2010; Yang *et al*., 2011). Aluminium has the potential of increasing the residual cation in solution which causes health problems.

2.1.5 Usage and acceptance of household water treatment methods

To introduce water treatment technologies certain aspects such as considering the socio-cultural aspects of the community, behavioural, motivational, educational and participatory activities within the community must be well understood. This will result in successful and sustainable household treatment technologies. Thus initiatives in water, hygiene and sanitation must include community participation, education and behaviour modification. Affordability and easy access to materials are other important aspects to consider. Differences in local conditions and availability of materials also contribute to the variability and uncertainty of cost estimates for household water treatment and storage technologies. In Bangladesh where diarrheal disease kills approximately 23,000 children annually, mainly due to water-borne infections from use of surface water and unacceptable levels of arsenic, the use of a water purifier called chulli, designed to treat contaminated surface water and to provide an alternative to arsenic-affected tube well water is common (Faruque *et al*., 2005). All the components of the chulli water purifier are made from locally available materials (Islam and Johnston, 2006). Treatment technologies at household level should not have a mechanical base involving mechanical installation and operation and should be indigenous as well such that there is no need to procure raw materials from outside. There is a need to be creative and explore strategies which will easily conform to ideal characteristics of a home-based water treatment which can be beneficial to all people, especially poor communities.

2.2 Methodology

2.2.1 Materials

Cost effective and easily accessible materials such as gravel, cotton cloth, coarse and fine sands were used. Gravel was collected at the University of Limpopo grounds while fabric was purchased at the local store. Coarse and fine sands were collected from households located near the University of Limpopo. Gravel, coarse and fine sands were first washed separately with boiling water, this step was repeated until the water was clear. Each was then baked at 180°C in an oven for an hour and allowed to cool at room temperature prior to construction of the unit. The fabric was immersed in boiling water, washed with detergent and with bleach, rinsed with boiling water and allowed to dry in the sun.

2.2.2 Construction of the filter bucket system

Two plastic buckets (10 L and 20 L) were purchased at a plastic ware shop for R17 and R30 respectively and modified at the University of Limpopo workshop. A faucet was fitted on the side at the bottom of the 20 L bucket and a hole was opened on the opposite side for insertion of a connection tube to the UV sterilization unit (UV Equip) when necessary. Holes of 2 mm diameter were punctured on the 20 L bucket lid. The 10 L bucket was opened at the bottom and glued to the 20 L bucket lid. The modified 10 L bucket was then mounted on top of the 20 L bucket. Provision for connecting the UV sterilization unit was made through the plastic tubing connected at the bottom of the 20 L bucket. A clamp was used when UV unit was not connected.

2.2.3 Preparation of a filter bed

The filter bed was made through wet packaging where the 20 L filter bucket was filled with sterile tap water with continuous stirring to ensure compact packing. Sterile tap water was prepared by autoclaving tap water at 121°C for 15 minutes and sterility was checked by membrane filtration technique using nutrient agar plates. Gravel (5 cm), coarse sand (3 cm) and fine sand (15 cm) were added and packed in separate layers. Lastly a piece of cotton cloth folded 4 times was added. The second bucket (10 L) was then mounted in order to allow addition of water into the filter bucket.

2.2.4 Determination of the flow rate

The flow rate was measured by adding 2 L sterile tap water into the filtration unit. A 2 L measuring cylinder was used to collect water from the unit and a timer was used to measure the time it took for water of a specified volume to flow through the unit. The same procedure was repeated after connecting the UV-water sterilizer.

2.2.5 Determination of microbial quality of the filter bed

The microbiological quality of the filter bed was determined prior to surface water treatment. Sterile tap water was used to clean the filtration unit and prior to surface water treatment, a sample of the eluted water was collected for microbial analysis using the membrane filtration technique. One hundred millilitres of the water sample (10^{-4} dilution) was vacuum-filtered through a 0.45 µm sterile membrane filter. The membrane filters were then transferred to R2A agar (Fluka) plates and incubated at 25°C for 5–7 days and m-Endo agar and incubated at 35°C for 24 hours. Following incubation plates were examined for bacterial growth.

2.2.6 Determination of the life of the filter bed

The life of the filter bed was determined by filtering 30 L of river water collected from Sekhukhune area daily for 14 days and analysing the bio-physicochemical properties with regard to heterotrophic bacteria, faecal coliforms, total coliforms, turbidity, colour, TDS, TSS, total hardness and pH.

2.3 Results and Discussion

2.3.1 Construction of a filtration unit

The main objective of this section was to construct a filtration unit which could be coupled to a UV sterilization unit as an option for home based water treatment. The unit was designed in order to improve the bio-physicochemical quality of surface water to the level of safe drinking water for the communities which do not have access to clean water. The filtration unit has the potential to provide communities with water of better aesthetic quality and taste. The constructed filtration unit coupled with a UV sterilization unit is presented in figure 2. The unit was created using locally available materials such as fabric, gravel, coarse and fine sands which are accessible to every household. The design of the filtration unit was simple and can be easily installed and adapted for household use. The efficiency of household filters to reduce contaminants was also reported by Mwabi *et al*. (2011). Al-Rawi (2009) also reported on the easy access of materials used in the construction of sand filters and their efficiency in removing turbidity and microbial contamination. The filter unit treats the water by mechanical trapping which is related to the size of the pores created between the sand granules and those of the fabric used. The fabric was included as the top layer above the fine sand and filtered out most particulate matter before primary filtration with sand materials. Coarse and fine sands remove pathogens and suspended solids while a layer of gravel prevents sand from entering and clogging the outlet tube (CAWST, 2008). Studies carried out by Jenkins *et al.* (2009 and 2011) on intermittently-operated sand filters has highlighted the importance of sand size in microbial removal. Sand materials have been widely used in conventional water treatment plants as the filter medium because of its wide availability, low cost and the satisfactory results achieved (Al-Rawi, 2009).

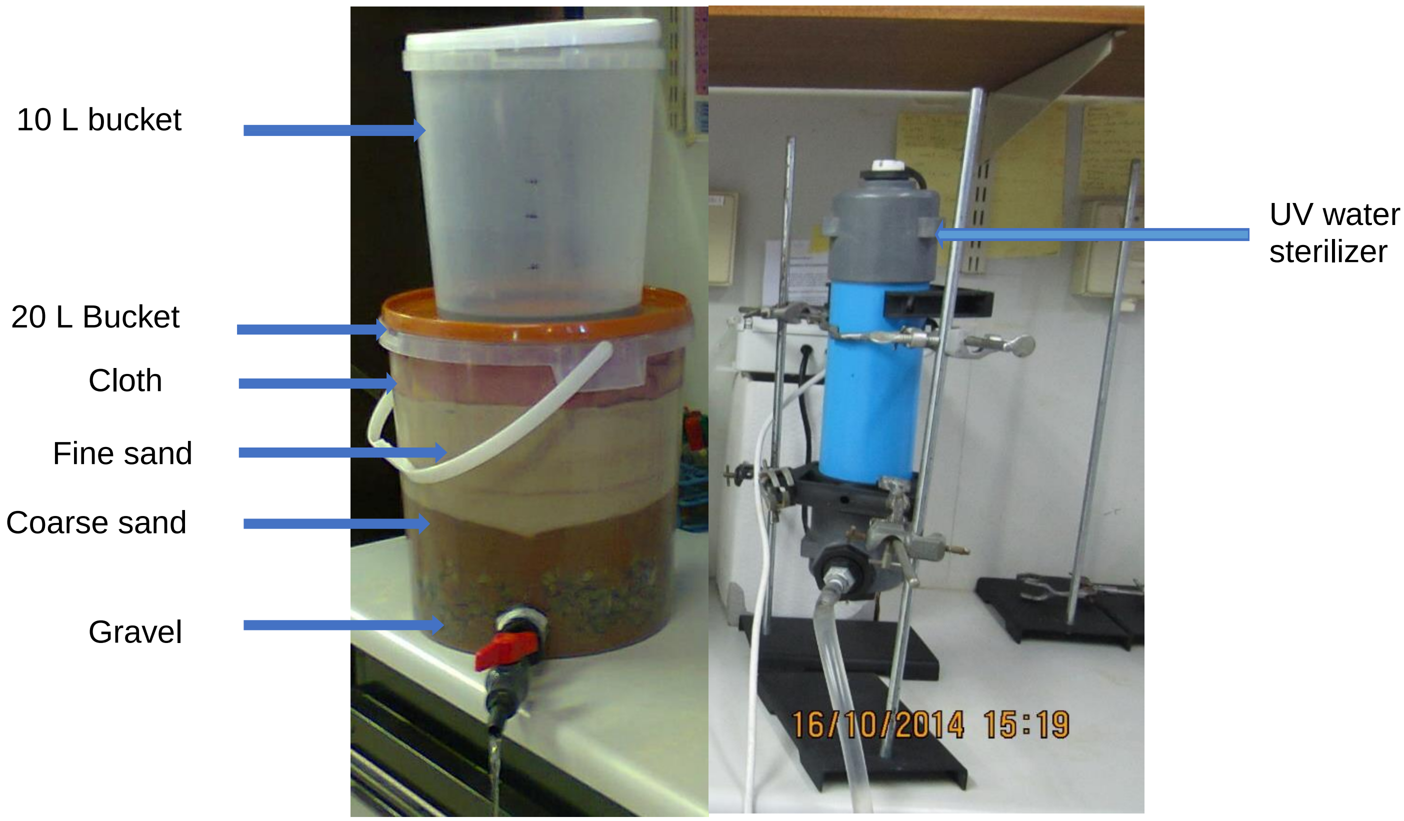

Figure 2 Sand filtration unit with UV unit attached.

More people worldwide rely on homemade water treatment technologies because they are cost effective and use locally available materials. One example of such technologies is the biosand filter (BSF). Several reports have been documented on the BSF about user satisfaction and removal of bacteria (Kaiser *et al*., 2002; Murcott, 2002; Duke *et al*., 2006; Earwaker, 2006; Stauber *et al*., 2006).

2.3.2 Determination of the flow rate

The flow rate of the unit was measured to determine whether the unit was capable of producing enough water for daily use. In South Africa the required minimum quantity of drinking water for each household per day is 25 litres per capita (DWA, 2000). The flow rate can be affected by factors such as the length of the sand column, properties of the fluid (viscosity, density and raw water quality) and the sand characteristics. Higher turbidity raw water can also affect flow rate by clogging the sand pores in the top centimetres of sand. For a good performance by the filters, Brown and Sobsey (2006) recommended flow rates ranging between 1 and 11 L/h for candle ceramic filters, while CAWST (2008) recommended a flow rate of 150 L/h for BSF. The unit provided a flow rate of 25 L/h by adjusting the volume of fine sand. In this study the achieved flow rate can provide enough water for drinking purposes on a daily basis. More finer sand was used in this study when compared to other materials and finer sand is known to affect the flow rate by decreasing the amount of water flow. However, the unit was still able to provide a good flow rate which can provide enough water in the home. Furthermore, for a household with more family members the size of the filter unit and the filter bed can be increased in order to provide more water for the entire family. The flow rate is an important element of water treatment, the retention time directly impacts on the efficiency of the filter bed in removing contaminants from the water. The amount of water that flows through sand filters is controlled by the size of sand media contained within the filter. Higher filtration rate may reduce the efficiency of bacterial removal whereas low filtration rate may result in insufficient amount of treated water available from the filter to meet the needs of the users.

2.3.3 Microbial quality of the filter bed

The filter bed was flushed several times with sterile tap water prior to treatment of surface water. No bacteria were detectable in the eluted tap water on culture. This infers that the rinsing and baking of packaging materials prior to packing of a filter bed achieved no detectable bacteria on culture. Studies by Balke and Griebler (2003) and Pell (1991) reported that sand naturally has a variety of microorganisms involved in the rehabilitation process, therefore it is important to clean and sterilize the sand materials prior to use as filter bed.

2.3.4 Determination of the life of the filter bed

The life of the unit was determined to check the volume of contaminated water that can be treated with the unit without losing its effectiveness with regard to improving the bio-physicochemical quality of surface water. Thirty litres of surface water was filtered through the unit daily and the amount of bacteria was monitored by the membrane filtration technique. The filtration unit was able to handle 420 L of raw surface water without any reduction in decontamination efficiency and clogging and hence reducing the flow rate. Heterotrophic bacterial counts, total coliform counts and faecal coliform counts were too numerous to count (TNTC) throughout a 14 day period before the filtration treatment. However, the level of heterotrophic bacteria after filtration averaged at a range of $17 \times 10^3 \pm 10^3$ CFU/ml on day 1 to $16 \times 10^3 \pm 500$ CFU/ml by day 14 ($p=0.77$). For total coliforms after filtration bacterial load ranged from $15 \times 10^2 \pm 100$ CFU/100ml on day 1 to $14 \times 10^2 \pm 100$ CFU/100ml by day 14 ($p=0.57$). With regard to faecal coliforms, bacterial load ranged from $13 \times 10^2 \pm 100$ CFU/100ml on day 1 to $12 \times 10^2 \pm 250$ CFU/100ml by day 14 ($p=0.76$). The filtration unit was able to improve bacterial load noting that the initial bacterial count in raw water could not be determined due to confluent growth at 10^{-4} dilution; however, following treatment with the filter unit only the levels were reduced significantly to the range of 100 cells per 100ml for coliforms. Continuous use of the filter unit showed no increase in bacterial load due to the entrapped bacteria and that the threshold for saturation of the filter bed proved to be high. The filter bed can be refreshed once spent because all the filter materials are freely available in any community and household. With regard to physico-chemical parameters the degree of reduction differed for each parameter. Turbidity was at 10 FAU on average before filtration and after filtration it ranged between 2.3 FAU on day 1 and 2.1 FAU on day 14. Colour, before filtration was recorded at 2.5 l/m on average and after filtration ranged from 0.4 l/m on day 1 to 0.2 l/m by day 14. Total hardness was 4.7 ^{0}dH before filtration and it was between 2.1 ^{0}dH and 1.3 ^{0}dH from day 1 to day 14 respectively. pH changed slightly throughout the analysis, before filtration it was 8.17 and ranged from 8.16 on day 1 to 8.15 by day 14. TDS and TSS were at 1.85 mg/L and 2.52 mg/L respectively on day 1 before filtration and ranged from 1.51 mg/L to 1.94 mg/L respectively by day 14 after filtration.

CHAPTER 3: EFFICIENCY OF THE FILTRATION UNIT IN TREATMENT OF SURFACE WATER

3.1 Literature review

3.1.1 Surface water resources and their quality for domestic use

The absence of water treatment infrastructures in many parts of the world leave rural communities with no other choice than to collect water for domestic purposes from untreated sources such as rivers, boreholes and springs (Sobsey, 2002). Water from these sources is used directly by communities living around them without any prior treatment. Consumption of untreated water may expose households to diseases suchas cholera, salmonellosis, shigellosis and other fungal, viral and parasitic infections (Grabow, 1996). Most of these communities are poor and rely on state intervention for improved water supply. People in rural communities live in close contact with domestic animals and share the same water sources. This increases the risk of faecal contamination of the water (Cloette and Theron, 2002).

The World Health Organization estimated that the number of people affected by diarrhoeal diseases in 2008 due to contaminated water was 2.5 million (WHO, 2011). This means that contaminated water affect the health of many people worldwide each year and the number of diarrhoeal incidences could be reduced by offering communities the tools and knowledge of how to clean water at household level. In many countries including RSA access to safe drinking water for domestic use has become a major challenge for many communities. This demand for clean and safe drinking water has become more serious in the growing global population especially in developing countries (Yongsi and Blaise, 2010). Deterioration of water quality is now a global problem as fresh water resources become polluted at a faster rate. Contamination of water bodies and discharge of toxic chemicals are some of the major causes of water quality degradation (Mahananda *et al.*, 2005). Millions of people are exposed to dangerous levels of biological contaminants and chemical pollutants in their drinking water due to inadequate management of urban, industrial or agricultural wastewater. The dangerously high concentrations of chemical hazards, such as arsenic and fluoride, originating from natural sources affect millions and cause conditions such as cancer and fluorosis (Flanagan *et al.*, 2012). Development and implementation of water quality standards, monitoring of water related disease indicators are critical for protection of water sources. Most water-borne diseases such as diarrhoea can be prevented if interventions are made to increase the availability of clean water. Fewtrell *et al*. (2005) reported that diarrhoeal episodes were reduced by 25% through improving water supply by 32%, sanitation by 45% through hand washing, 39% by using household water treatment and safe storage.

The use of indicator organisms to determine the quality of water is common both in South Africa and worldwide. It is not feasible to screen for every possible pathogens which may be present in water for practical and economic reasons. Indicator organisms are, therefore, generally used for routine monitoring of the potential presence of pathogens in water (DWAF, 1996). Examples of indicator organisms include faecal coliforms, total coliforms and heterotrophic bacteria. Faecal coliforms such as *E. coli* are the most commonly used bacterial indicators of faecal pollution (DWAF, 1996). The total coliform group includes bacteria which exist naturally in soil, water and in warm blooded animals and are used to indicate general safety and contamination of the water body. High HPC in treated water indicate inadequate treatment of the water and post-treatment contamination in the distribution system. WHO/UNICEF (2014) reported that nearly 25% of the global population is consuming faecally contaminated water. This water can contain bacteria, protozoa and viruses which are capable of causing diseases in humans such as gastroenteritis. Most studies focus on bacteria regarding transmission of diseases in water, however, viruses and protozoan pathogens can also cause water related diseases (WHO, 2011). Viruses can cause severe illnesses including meningitis, hepatitis A and E, encephalitis and myocarditis (WHO, 2011). Viruses are rarely tested because it is either impossible or not feasible to detect infectious virus particles in a cost efficient and time saving manner (Gall *et al*., 2015). Protozoans can also contribute to water-borne infections and diseases in humans (WHO, 2004).

3.1.2 Consumption of surface water and associated health risks

Contaminated water can lead to water-borne diseases which are generally characterized by diarrhoea and caused by viruses, bacteria and protozoa (Craun *et al*., 2006). Each year 3.4 million people in Africa, of whom many are children, die because of water related diseases (Fenwick, 2006; WHO, 2014). The United Nations Children's Fund (UNICEF, 2014) reported that about 4000 children die each day as a result of diseases caused by contaminated water. The morbidity and mortality caused by contaminated water are enormous and these must be controlled by improving security of safe water. Gastrointestinal ailments are the most common and well-known health effects associated with contaminated drinking water which is polluted with human and/or animal faeces. Enteric pathogens such as *E. coli, V. cholera* and *S. typhimurium* are commonly found in water sources and transmitted to humans through consumption of contaminated water and foods prepared from contaminated water (WHO, 2008). The faecal oral route is considered to be responsible for the transmission of bacterial and viral diseases as well as for parasitic diseases in poor sanitary conditions (WHO, 2007).

Surface water is commonly contaminated with bacteria and protozoan parasites *Cryptosporidium* and *Giardia* which are the common cause of gastroenteritis in humans. The impact of water-borne diseases such as diarrhoea is significant in RSA. Diarrhoea is responsible for about 20% of deaths in children living in settlements, which lack safe water supply and proper sanitary facilities. In RSA, diarrhoea is the third biggest killer of children under five years and responsible for over 10 000 deaths annually (MRC, 2010). Worldwide diarrhoea is the second most common cause of death in children under five years of age and responsible for 2.4 million deaths each year (Forsberg *et al.*, 2007; Prüss-Üstün *et al*., 2008; WHO/UNICEF, 2009). It is estimated that about 10% of the global burden of disease is associated with lack of access to safe drinking-water, proper hygiene and effective water management (Prüss-Üstün *et al*., 2008). These diseases put a burden on health care systems and economic productivity. Hence there is an urgent need to find sustainable solutions to water shortage and safety in order to improve the health of the community and the economy as well. The current study focuses on the efficiency of the unit to improve microbial load. Bacterial quality of water was determined using indicator organisms in order to assess the level of pollution in surface water as well as level of water improvement after filtration.

3.2 Methodology

3.2.1 Study area

Surface water samples were collected from rivers and streams in the Sekhukhune area of the Limpopo province. These water sources are the main sources of domestic water for communities around them. A total of 5 rivers and dams were sampled namely; Moopetsi river, Motse river, Olifants river, Mariri dam, and Apel cross farrow (from Ngwaritsi dam).

3.2.2 Sample collection

Surface water was collected aseptically from the rivers and dams using sterile 1 L bottles and 20 L buckets. The water was placed on ice and transported to the Microbiology laboratory at the University of Limpopo and processed within 6 hours of sampling.

3.2.3 Enumeration of heterotrophic bacteria

Heterotrophic bacterial counts were enumerated in duplicate as colony forming unit per ml (CFU/ml) using the membrane filtration (MF) technique. The water samples from individual rivers were analysed separately to assess the level of pollution in each river before filtration. One hundred millilitres of the water sample was vacuum-filtered through a 0.45 µm sterile membrane filter of prepared dilutions of 10^{-1}- 10^{-4}. The membrane filters were then transferred to R2A agar (Fluka) plates and incubated at 25°C for 5–7 days until colonies were visible. All visible colonies were counted and those with different morphological characteristics were further purified and reserved for identification.

3.2.4 Enumeration of total coliforms

Total coliform counts were determined in duplicate using the MF technique to indicate the hygienic quality of water. Samples were analysed separately according to each river and sterile distilled water was used to prepare serial dilutions of 10^{-1}- 10^{-4}. Sterile membrane filters of 0.45 µm were used to filter 100 ml of water sample. The membrane filters were first soaked in lauryl sulphate broth (Fluka) for 2 hours at 35°C. Following incubation the filters were transferred to m-Endo agar (Fluka) plates and incubated at 35°C for 24 hours. Red colonies with and without metallic-green sheen were counted.

3.2.5 Enumeration of faecal coliforms

Faecal coliform counts were enumerated in duplicate using the MF technique to check the extent of faecal pollution in the water samples. The water samples from individual rivers were analysed separately before filtration. Sterile distilled water was used to prepare dilutions of 10^{-1}- 10^{-4}. One hundred millilitres of the water sample was filtered through a 0.45 µm sterile membrane filter. The membrane filters were placed on m-FC agar (Fluka) plates and incubated at 44°C for 24 hours. After incubation blue colonies were counted. The identification of *E. coli* was confirmed by MALDI-TOF bio-typing analysis.

3.2.6 Treatment of surface water

Microbial properties of surface water as outlined in sections 3.2.3–3.2.5 were analysed before and after treatment with the filtration unit to assess improvement of water quality. The water samples were pooled together during filtration in order to compare the level of microorganisms before and after filtration with the unit.

3.2.7 Treatment of surface water with the filtration UV sterilization unit

Efficacy of filtration sterilization method was evaluated with regard to the extent and rate of clarifying water and removal of bacteria. A connection tube was used to connect the filtration unit and the UV water sterilizer. Surface water was added to the filtration unit and passed through the connected tube into the water sterilizer. The water was then collected at the outlet of the water sterilizer and further analysed for microbial properties as outlined in section 3.2.3–3.2.5. The water samples were exposed to UV dose of 30 mJ/cm^2 and UV transmission $T_{10,}$ of 80% (UV Equip).

3.2.8 Data analysis

Statistical analysis could not be performed for evaluating the significance of the degree of microbial load reduction due to heavy contamination of the untreated water samples, wherein the actual microbial load could not be determined i.e., enumeration of bacteria before filtration was too numerous to count. Enumeration of bacteria is considered reliable when performed on plates that have between 30 to 300 CFU.

3.3 Results and Discussion

3.3.1 Removal of heterotrophic bacteria

Collected surface water was analysed before and after treatment with the filtration unit to document the removal of heterotrophic bacteria. Results showed that surface water was heavily contaminated with heterotrophic bacteria before treatment with filtration unit. The values were recorded as too numerous to count (TNTC). However, after filtration with the unit the amount of bacteria declined to $15 \times 10^3 \pm 14 \times 10^2$ CFU/ml. Further treatment with UV unit eliminated the remaining bacteria to an undetected level. Surface water commonly contains high amount of heterotrophic bacteria, as also observed by Pritchard *et al*. (2009), animal and human wastes are commonly implicated as sources of contamination. The recommended level of heterotrophic in drinking water set by both WHO and South African drinking water quality guidelines is <1000 CFU/ml (SABS, 2011; WHO, 2011). Although the recommended standard for heterotrophic bacteria in drinking water could not be reached, the degree of reduction of bacterial load was significant noting that the bacterial load of raw surface water was measured at too numerous to count per millilitre of water sample and it reduced to $15 \times 10^3 \pm 14 \times 10^2$ CFU/ml. When the filtration unit was coupled with UV unit, total disinfection was obtained. High levels of heterotrophic bacteria in a system indicate ideal conditions for bacterial growth. Bacterial regrowth can encourage slime growth, increase the cost for disinfectants, cause foul-tasting water and harbor secondary respiratory pathogens such as *Legionella*. Therefore, heterotrophic bacterial count can serve as an indicator for the underlying causes of aesthetic problems (WHO, 2002). Keynan (2007) reported that the presence of heterotrophic bacteria in drinking water distribution systems is usually not considered harmful to the general consumer. However, precautions must be taken for the immune compromised people. There is no evidence that heterotrophs can be harmful especially when ingested by healthy people. Hence heterotrophic bacterial tests generally provide information on treatment efficiency, the extent of after growth in distribution networks as well as adequacy of disinfectant residual (WHO, 2011). In water treatment, an increase in the heterotrophic bacteria indicates post-treatment contamination or growth within the water conveyed by the distribution system or the presence of deposits and biofilms. A sudden escalation in the heterotrophic bacterial counts above standard values requires actions to investigate and remediation if necessary (Kusnetsov *et al*., 2003; Edagawa *et al*., 2008; Moritz *et al*., 2010).

3.3.2 Removal of total coliforms

Similar results as heterotrophic bacteria were obtained with regard to total coliform. Before filtration, results showed high bacterial contamination (TNTC) while after filtration a reduction of $14 \times 10^2 \pm 141$ CFU/100ml was observed. The recommended WHO and RSA amount for total coliform is <10 CFU/100ml (SABS, 2011; WHO, 2011). When the filtration was combined with the UV unit the total coliforms were eliminated. Nogueira *et al.* (2003) evaluated the microbiological quality of treated and untreated water samples and observed that high levels of contamination by total coliforms (83%) and faecal coliforms (48%) were found in untreated waters. The presence of coliforms indicates that the water has been contaminated biologically and has the potential risk of containing pathogens. Total coliforms can originate from a number of sources including air, soil, handling of water with dirty hands, dead animals or insects which fall into the water sources. Symptoms which are usually observed when contaminated water is consumed are nausea, vomiting, diarrhoea and stomach cramps (WHO, 2008). Baumgartner *et al*. (2007) reported total coliform removal by biosand filter ranges between 58.3–99.7% under different operating conditions and at different sample collection points.

3.3.3 Removal of faecal coliforms

Both the RSA and WHO set the recommended limit for faecal coliforms for drinking water at 0 CFU/100ml (WHO, 2011; SABS, 2011). Results obtained before treatment with the filtration unit showed high bacterial contamination (TNTC). However, after filtration with the unit a bacterial reduction to $11 \times 10^2 \pm 141$ CFU/100ml was observed. Further treatment with UV unit resulted in undetectable levels of faecal coliforms. Yokata *et al*. (2001) reported that sand filters can reduce both coliforms and general bacteria, but it may not remove 100% of pathogens from heavily contaminated surface water. The presence of faecal coliforms in the water is an indication that the water is polluted with faecal matter from warm blooded animals including humans. Presence of faecal coliforms infers poor microbiological quality of the water sources hence unacceptable for human consumption. The symptoms of illness associated with faecal coliforms are bloody and non-bloody diarrhoea, fever, abdominal cramps and nausea (WHO, 2008). These effects may be more severe and possibly life threatening for children, the elderly or people with immune deficiencies or other illnesses (Vaccari *et al*., 2006; WHO, 2008).

The combination of filtration and UV methods is a potential household water treatment option for those communities which lack access to treated water. The observed results suggest that, despite improvement in the quality of water after filtration, there is still a need to include another treatment method to further eliminate remaining microorganisms. Yongabi *et al*. (2011) used a combination of coagulation and sand filter to remove microbial load and physico-chemical contaminants from surface water. They found that coagulation alone did not reduce microbial load to acceptable levels, but use of sand filtration after coagulation reduced the HPC, FCC and TCC to acceptable levels. This observation is contrary to the results observed in this study where sand filtration did not reduce bacterial levels to acceptable levels. Other studies reported on bacterial reduction by filters (Lantagne, 2001; Campbell, 2005; Van Halem *et al*., 2009) such as ceramic silver pot filters to counts between 2 and 7 logs. Choice of sand filters for home water treatment is based on the fact that it incorporates various purification functions such as straining, entrapment, settlement and adsorption in removal of organisms from water. In situations where the water is heavily contaminated with suspended particles and microorganisms, filters serve as a pre-treatment method by removing most contaminants thereby making disinfection easy and effective. In developing countries such as RSA where access to potable water is a challenge, the use and implementation of household filters combined with a sound knowledge of how to operate and clean this filters can make a positive impact on the health of the communities. Jenkins *et al*. (2011) reported that to further achieve bacterial removal by 0.050 to 0.063 log per hour in sand filters, an increase in idle time by each hour is necessary. Furthermore, a longer idle time can decrease turbidity by 3.85%, bacterial removal by 0.29 log and viruses by 0.77 log (Jenkins *et al*., 2011). In this study a fabric was used to trap out particulate matter and microbes. Huq *et al*. (2001) studied the efficiency of simple sari cloth material in trapping phytoplankton and microorganisms from raw water and concluded that cloth filtration achieve decontamination by removing microorganisms and other particulates attached to phytoplankton. It was further reported that folding of the cloth material provides the thickness thereby yielding good efficiency for filtration and retaining smaller sized particulates. However, further increase in folds may increase the probability of clogging and slow passage of the water without improving efficiency of removal of plankton and particulates (Huq *et al*., 2001).

CHAPTER 4: IDENTIFICATION OF COMMON BACTERIAL CONTAMINANTS IN SURFACE WATER

4.1 Literature review

Water has always been one of the most important natural resource, therefore to ensure the safety of water supplies, identification of the microbial contaminants is imperative in public health and water management programs. Conventional methods for identification of microorganisms can take days or weeks to yield results. Furthermore, some organisms like E. *coli* can easily transform from culturable state to a viable but non-culturable state, hence become undetected using culture methods (Yang *et al*., 2008). Most microorganisms in water remain unidentified due to lack of understanding of the real conditions under which these organisms survive. Fast, reliable and cost effective techniques such as polymerase chain reaction (PCR) and mass spectrometry have currently been employed for the identification of microorganisms in water (Yang *et al*., 2008). Polymerase chain reaction is the most used molecular technique, furthermore PCR protocol allows the detection of microorganisms in different types and sources of water samples (Shaban and Malkawi, 2007). This technique permits accurate detection of large groups of organisms using target specific primers (Wasseneger, 2007). Advantages of PCR include high sensitivity which makes it possible to identify one cell in 100 ml of water sample, specificity for the target microorganisms, rapid analysis and the ability to detect multiple bacteria simultaneously (Hongying *et al.*, 2008).

Mass spectrometry is an analytical technology that identifies the chemical composition of a compound or a sample on the basis of mass-to-charge ratios of ions formed (Yang *et al*., 2008). With the mass spectrometer the ion source transforms the molecules into ions with specified masses and charges, therefore charged ions are easily produced in matrix assisted laser desorption/ionization (MALDI). The use of MALDI has become one of the most powerful ionization techniques for mass spectrometry analysis and imaging studies of biological tissues as well as characterization of bacteria, viruses, parasites and fungi. In Microbiology, MALDI spectra are used for the identification of microorganisms such as bacteria or fungi. Species diagnosis by this procedure is much faster and more accurate and compared to other procedures based on immunological or biochemical tests. Disadvantages of MALDI includes that the commercially available MALDI database of whole cells cover a minor part of water-borne bacteria and that sometimes several species of microorganisms may be present together. Advantages of MALDI includes that it is fast and reliable, little sample material required and it can be used for bacteria, yeasts and fungi (Seng *et al*., 2009).

4.2 Methodology

4.2.1 Cultivation of microorganisms

Bacteria isolated from the water samples mentioned in 3.2.1 were grown on nutrient agar at 37°C for 18 to 24 hours, on m-FC agar and incubated at 44°C for 18 to 24 hours, on m-Endo agar and incubated at 35°C and on R2A and incubated at 25°C for 5–7 days.

4.2.2 Sample preparation

A 300 µl of deionized water was pipetted into a microcentrifuge tube. Carefully isolated colonies from the different agar medium (m-FC, m-endo, nutrient agar and R2A) were placed into different microcentrifuge tubes containing deionized water and mixed thoroughly by vortexing, followed by the addition 900 µl ethanol. The mixtures were further vortexed and centrifuged for 2 minutes at 15,000 rpm. The supernatants were discarded and the pellets were centrifuged again. The residual ethanol was removed by carefully pipetting without disturbing the pellets. The pellets were allowed to dry at room temperature for 3 minutes. A 1 µl of 70% formic acid was added to the pellets and the solution was mixed thoroughly, followed by the addition of 1 µl pure acetonitrile (ACN) and centrifugation for 2 minutes at 15,000 rpm.

4.2.3 Biotyping procedure

Cells from a single bacterial colony grown on an agar medium were transferred in duplicates to a target spot on a 48-well stainless steel FLEXImass™ target plate and allowed to dry at room temperature. The entire spot was overlaid with 1 µl of hydroxycinnamic acid (HCCA) solution and allowed to dry at room temperature. The MALDI target plate was placed into the MALDI-TOF for identification of organisms. To evaluate the accuracy of the MALDI-TOF, The following strains were included as reference controls: *Escherichia coli* (ATCC® 25922), *Salmonella enterica* (ATCC® 13311™) and *Shigella boydii* (ATCC® 9207™).

4.2.4 Differentiation of the *E. coli* isolate

The isolated *E. coli* strain were further characterized to delineate virulence using EHEC-specific PCR assay. *E. coli* isolates from culture were pooled together for total genomic DNA isolation following the method of Goldenberger *et al*. (1995). The DNA was used as template in a 40 cycle PCR assay which was performed under the following conditions: denaturation step at 94°C for 15 seconds, annealing step at 64°C for 30 seconds and extension step at 72°C for 40 seconds. The EHEC specific *rfb*E primers used in this study are described in Bertrand and Roig (2007). *E. coli* O157 was used as a positive control. The resulting amplicons were analysed on 2% agarose gel electrophoresis using the 50bp DNA ladder.

4.3 Results and discussion

4.3.1 Identification of bacterial contaminants

Contamination of drinking water sources with microbial pathogens is a serious problem. More than three million people die every year from water-related disease and 43% of water-related deaths are due to diarrhoea (WHO, 2008). The majority of diseases are caused by bacteria, fungi, viruses and parasites, excreted in human faeces either by animals or humans which lead to contaminated water supplies (Tambekar and Hirulkar, 2007).

Table 1: Predominant bacteria isolated from surface waters.

Identified organisms	**Dominance of isolates**
Acinetobacter baumannii	55%
Escherichia coli	44%
Bacillus cereus	33%
Cronobacter sakazakii	11%
Bacillus muralis	11%
Bacillus megaterium	11%
Acinetobacter pittii	22%
Pseudomonas azotoformans	11%
Bacillus simplex	11%

In this study, the most dominating organisms identified in surface water were found to be *E. coli* and *Acinetobacter baumannii*. Identified bacterial species are presented in table 1. Of the *E. coli* isolates identified with the biotyping assay, none was found to belong to the enterohaemorraghic *E. coli* (EHEC) strain as indicated in fig. 3 below

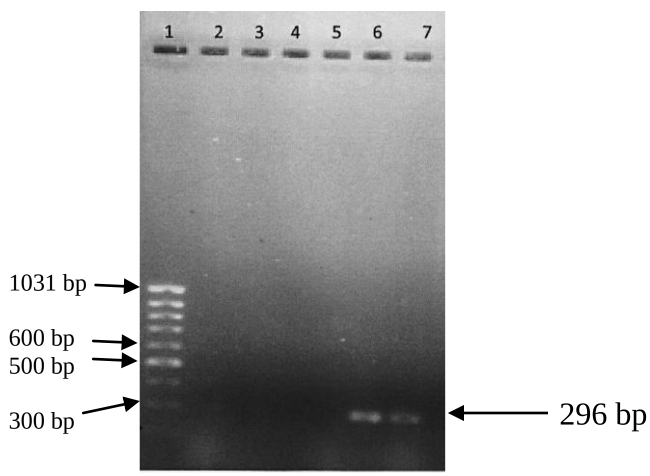

Figure 3 Enterohaemorraghic *E. coli* specific PCR assay. Lane 2, pooled Moopetsi river samples; lane 3, pooled Motse river samples; lane 4, pooled Olifants river samples; lane 5, *E. coli* ATCC 25922; lane 6 and 7, *E.coli* O157 isolates.

Although the pathogenic EHEC could not be detected in this study, this does not preclude the presence of O157 and non-O157 strains considering that this study conducted a single spot analysis. Routine monitoring of the water system is important for public health purposes.

4.3.2 Health effects of bacterial contaminants on humans

Bacterial contamination of water may pose a significant risk to public health. Pathogens associated with water-borne diseases are excreted in the faeces of humans and animals and transmitted via the direct consumption of water. Bacterial contamination of surface water generally originate from sources such as municipal waste charges and agricultural and forestry runoffs, livestock and wild animals (Kay *et al*., 2005). In many cases contamination of water by microorganisms is caused by limited environmental awareness in rural areas (Lehloesa and Muyima, 2000).

4.3.2.1 *Acinetobacter* spp.

Acinetobacter baumannii is a typically short, almost round, rod-shaped Gram-negative bacteria. This organism has been reported to represent 1.0–5.5% of the heterotrophic bacterial flora in drinking water samples and have been isolated from 5–92% of distribution water samples (Bartram *et al*., 2003). *A. baumannii* can be an opportunistic pathogen in humans, affecting people with compromised immune systems. *Acinetobacter baumannii*, also known for its antibiotic resistance, is responsible for the majority of nosocomial infections (Rice, 2008). Some of the diseases caused by *A. baumannii* include pneumonia, meningitis and urinary tract infections (Fournier and Richet, 2006). It has previously been isolated from environmental soil and water samples (Yeom, 2013). Another type of *Acinetobacter* spp. identified in this study was *Acinetobacter pittii.*

4.3.2.2 *E. coli*

E. coli is a faecal coliform commonly found in the lower intestine of warm blooded animals. Water-borne transmission of pathogenic *E. coli* has been well documented from recreational waters and contaminated drinking water. Although most strains are not harmful, a limited number of enteropathogenic strains such as *E. coli* O157:H7 and *E. coli* O111 can cause acute diarrhoea (O'Connor, 2002). Enterohaemorraghic *E. coli* strains could not be specifically detected in this study. Pathogenic *E. coli* strains cause intestinal disease by a variety of mechanisms and the infections may resemble cholera, dysentery or gastroenteritis (WHO, 2002; CDC, 2009). The presence of *E. coli* in water indicates faecal contamination and implies that the water may contain many types of disease causing organisms.

4.3.2.3 *Bacillus* spp.

Bacillus spp. are spore-forming, aerobic-to-facultative aerobes. They are Gram-positive rods which naturally inhabit fresh and marine waters, decaying organic matter, soil, vegetables and the intestinal tract of invertebrates (Bottone, 2010). *Bacillus* spp. are heterotrophic organisms known to induce bacteremia in immunocompromised hosts. Symptoms associated with *Bacillus* spp. are vomiting and diarrhoea. These species can produce resistant endospores which help them survive chlorination (Rice *et al.,* 2005), exposure to high temperature, low pH and other environmental conditions. Several previous studies have reported the isolation of *Bacillus* spp. in drinking water (Pavlov *et al.,* 2004; Stelma *et al.,* 2004; Burtscher *et al.,* 2009). In the gastrointestinal tract, vegetative cells ingested as viable cells or spores produce and secrete a protein enterotoxin and which has the potential to induce a diarrheal syndrome. Other types of Bacillus bacteria identified in this study included *Bacillus cereus*, *Bacillus muralis*, *Bacillus simplex* and *Bacillus megaterium*.

4.3.2.4 *Cronobacter sakazakii*

Cronobacter sakazakii is a Gram-negative bacteria commonly found in plant material. However, it has also been found in wastewater and brought into contact with humans through food and environmental exposure. *Cronobacter sakazakii* is a coliform bacteria which is implicated in various life-threatening diseases in humans such as meningitis, necrotizing enterocolitis, septicemia, and pneumonia which affects a wide range of age groups (FAO/WHO, 2004*). Cronobacter* infections are not common, but they are often fatal in infants and can be serious among people with immunocompromised systems and the elderly (FAO/WHO*,* 2008*)*.

4.3.2.5 *Pseudomonas azotoformans*

Pseudomonas spp. are heterotrophic bacteria found naturally in the soil and in drinking water sources such as aquifers. Conventional drinking water treatment systems can remove or inactivate these bacteria, but they may continue to multiply within finished drinking water attachments and can cause negative health effects in humans under certain conditions. High numbers of *Pseudomonas* may indicate the development of a bacterial layer on surfaces within a distribution system. Such surface areas may include home water treatment devices that utilize carbon filters or membranes*. Pseudomonas azotoformans* is a Gram negative bacterium which is widespread in nature occurring commonly in water and soil. When the organisms gain access to treated water they may proliferate (Xie *et al*., 2006). Health risks usually involve colonization of damaged sites such as burn and surgical wounds, the respiratory tract of people with underlying disease and physically damaged eyes. Invasion of the body may also occur causing destructive lesions or septicaemia and meningitis. Cystic fibrosis and immunocompromised patients are prone to colonization with these species which may lead to serious progressive pulmonary infections (De Victorica and Galván, 2001). Organisms identified in this study such as *Cronobacter sakazakii* and *E. coli* can be detrimental to the health of the communities which rely on this type of water for drinking purposes. It is worth noting that such communities that rely on raw waters for household use are commonly poor and lack financial resources to purchase safe water or to invest in home-based water treatment machines, hence they consume the raw water without any prior treatment. The observation in this study indicates the extent of health risks such communities are exposed to, i.e., the high risk of contracting water-borne infections. Therefore the quality of such water need to be assessed before communities can consume it. Furthermore, steps should be taken to promote awareness on the use of untreated water for domestic purposes as well as to share knowledge with the communities on how to take responsibility of their own water security. Simple techniques for treating water at household level such as filters, chlorination and solar disinfection, combined with safe storage water can reduce the burden of diseases associated with consumption of untreated water (WHO/UNICEF, 2005).

CHAPTER 5: IMPROVEMENT OF PHYSICO-CHEMICAL QUALITY OF SURFACE WATER BY FILTRATION

5.1 Literature review

Water quality measures the condition of water in relation to the requirements of one or more biotic species and or to any human need or purpose (Diersing, 2009). Therefore, good quality water should have desirable properties which include low organic content, neutral pH value, adequate amount of dissolved oxygen, moderate temperature, absence of infectious agents as well as toxic substances (Adeniyi, 2004). It is important to know the quality of water before consumption. Contaminants such as particulate matter and colour imparting chemicals can be easily identified only by assessing the appearance, taste and odour of the water. However, most cannot be easily detected and require testing to reveal whether any contamination is present. Selection of parameters is dependent upon what purpose the water is used for and the extent of water quality and purity needed. Unlike microbial contamination, chemical contamination of water leads to health problems primarily through long term exposure. Therefore, water that is chemically contaminated may persist for years before detection. Contaminants reach drinking water supplies from various sources, including municipal and industrial discharges, urban and rural runoff, natural geological formations, drinking water distribution materials and the drinking water treatment process (Okonko *et al*., 2008).

Physico-chemical contamination of drinking water may pose health problems such as cancers, adverse reproductive effects, cardiovascular and neurological diseases (Okonko *et al*., 2008). Physical properties that are monitored for drinking water include colour, odour, turbidity, total suspended solids while chemical properties include biological oxygen demand, chemical oxygen demand, dissolved oxygen, alkalinity, total dissolved solids and hardness (UNEP, 2009). Water that has an unpleasant taste or odour but potable can often lead consumers to use unsafe but more appealing water resources. Therefore safe drinking water should be available at all times (UNICEF, 2008). A growing number of contaminants are being detected in water for two reasons which include that new chemicals are being introduced into the agricultural and industrial sector which may contaminate water intended for household use. These contaminants can enter and persist in the environment, therefore new testing techniques allow contaminants to be detected at lower levels (Carr and Neary, 2008).

5.2 Methodology

5.2.1 Sampling

Surface water was collected aseptically from the rivers and dams mentioned in section 3.2.1 using sterile 1 L bottles and 20 L buckets. The water was placed on ice and transported to the Microbiology laboratory at the University of Limpopo and processed within 6 hours of sampling. Water samples from rivers were analysed separately before and after filtration. The results for each parameter before and after filtration were pooled together for statistical analyses.

5.2.2 Determination of water colour, turbidity and total water hardness

Water colour was measured by first filtering the water to remove suspended materials, then a UV nanocolor® spectrophotometer (Macherey-nagel) was used following manufacturer's instructions. Total water hardness was determined using a total water hardness kit (Macherey-nagel) and further measured with a UV nanocolor® spectrophotometer (Macherey-nagel). Turbidity was also measured using a UV nanocolor® spectrophotometer (Macherey-nagel).

5.2.3 Analysis of total suspended solids

Hundred millilitres of water was filtered through a pre-weighed glass fiber filter membrane. The filter was dried at 105°C, allowed to cool at room temperature and weighed again. TSS was calculated in mg/l as (A-B)/C x 1000, where A is the final weight of membrane after filtration, B is the initial weight of membrane before filtration and C is the volume of water sample filtered.

5.2.4 Analysis of total dissolved solids and pH

Total dissolved solids and pH were measured using a multiparameter analyser (Consort C860).

5.2.5 Treatment of surface water with filtration unit

Physico-chemical properties of surface water as outlined in sections 5.2.2–5.2.4 were analysed before and after treatment with the unit to assess improvement of water quality.

5.2.6 Statistical analysis

A pair size t-test method was performed to test for significant difference before and after treatment. A p-value of <0.05 was considered statistically significant.

5.3 Results and Discussion

5.3.1 Improvement of water colour

Water colour may result from a variety of sources which includes natural metallic ions (iron and manganese), humus and peat materials, plankton, weeds, and industrial wastes. Metallic ions such as iron and manganese typically impart a reddish-brown colour to water. Figure 3 shows the average water colour of surface waters. The unit was effective in terms of reducing colour from water samples. The colour of raw water before treatment with the unit was 2.48I /m and after filtration it reduced to 0.50 I/m. This constitutes 80% removal of colour in raw water by the filter unit. Colour in water is primarily a concern of water quality for aesthetic reason, coloured water give the appearance of being unfit to drink. It can also indicate the presence of organic substances, such as algae or humic compounds. Recently, colour has been used as a quantitative assessment of the presence of potentially hazardous or toxic organic materials in water. The recommended limits for colour in potable water which is 15 I/m have traditionally been based on aesthetic considerations. Harun and Kabir (2013) showed that pond sand filters were efficient in removing colour by 53-69%. This observation agrees with our findings where 80% improvement in hue of raw water to the apparent colour of tap water was achieved.

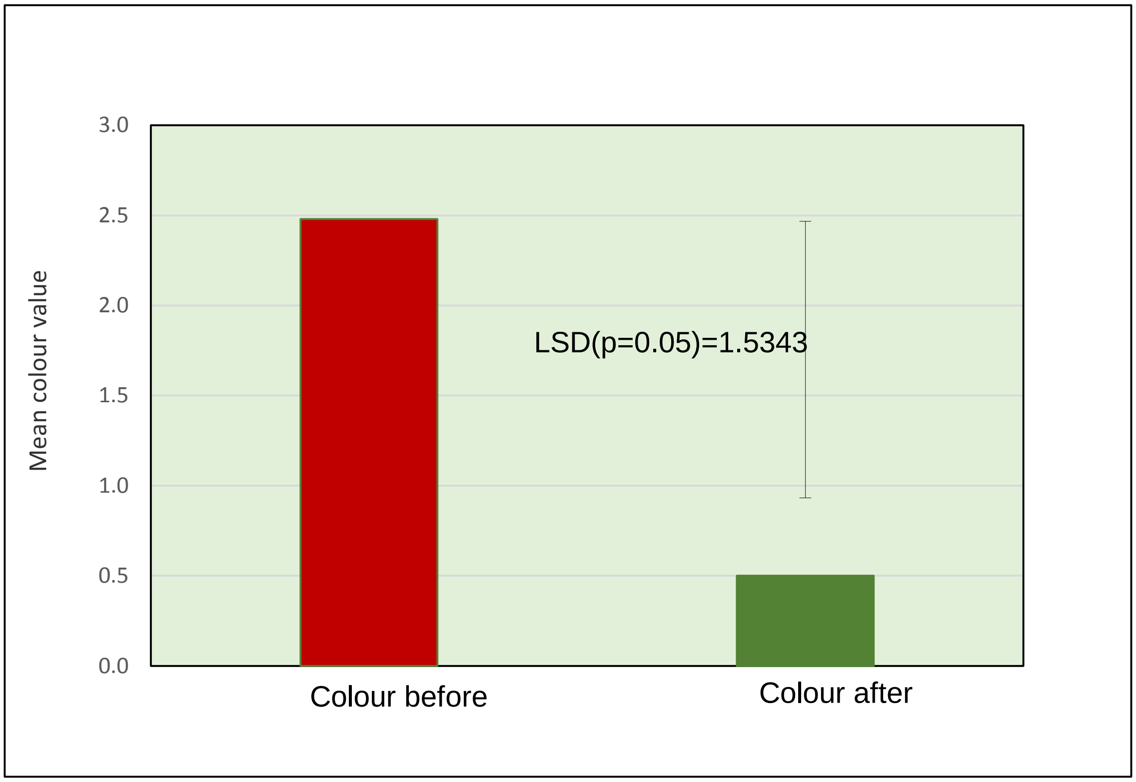

Figure 4 Mean colour of surface water before and after filtration

5.3.2 Improvement of turbidity

Turbidity is a measure of the cloudiness of the water and it is commonly used to measure the risk of microbial contamination and the effectiveness of the treatment method used. High turbidity in water is a matter of concern, as this shows the presence of suspended material which can promote the growth of microorganisms especially during storage for household use (Momba and Notshe, 2003). Turbidity of raw surface water samples before treatment in this study was 9.8 FAU which exceeded the recommended limit of <5 FAU. A 69% improvement in clarity of water was achieved following the filtration treatment of raw water, and this falls within the recommended limit by WHO (2011). Figure 4 shows the statistical analysis of turbidity before and after filtration. The p-value for turbidity was 0.01, which implies that the filtration treatment was significant and effective in terms of clarifying the water.

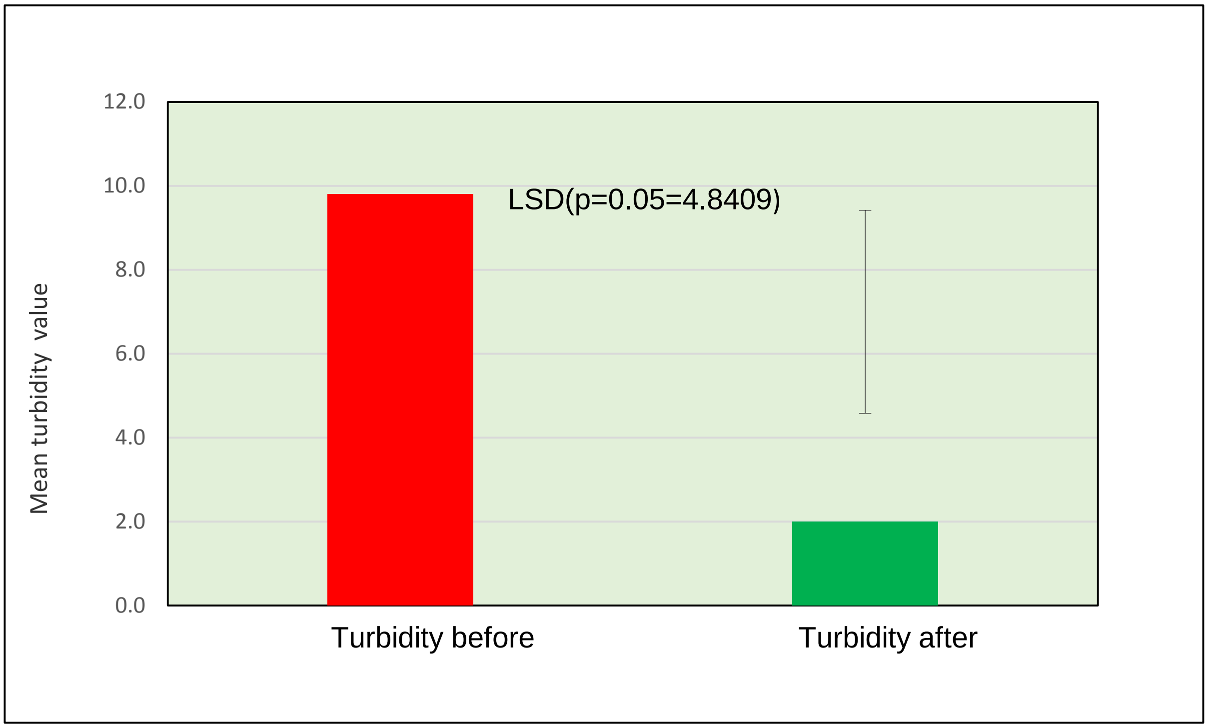

Figure 5 Mean turbidity of surface water before and after filtration

In a similar study by Burt (2012) treatment of water with BSF achieved an average efficiency of 83% for turbidity where 100% of the filtered water samples were within the WHO recommended levels. Turbidity or cloudiness, if present in high amounts in drinking water, is aesthetically unappealing and may also represent a health concern. Even though turbidity is not a direct indicator of health risk, a strong relationship between removal of turbidity and removal of protozoa has been reported (EPA, 1999). Figure 5 depicts the difference in water clarity before and after filtration with the unit. In another study by Naddafi *et al*. (2005) the efficiency of clay pots filters were evaluated and showed that the filter pots were efficient in removing turbidity to acceptable levels of less than 1 NTU.

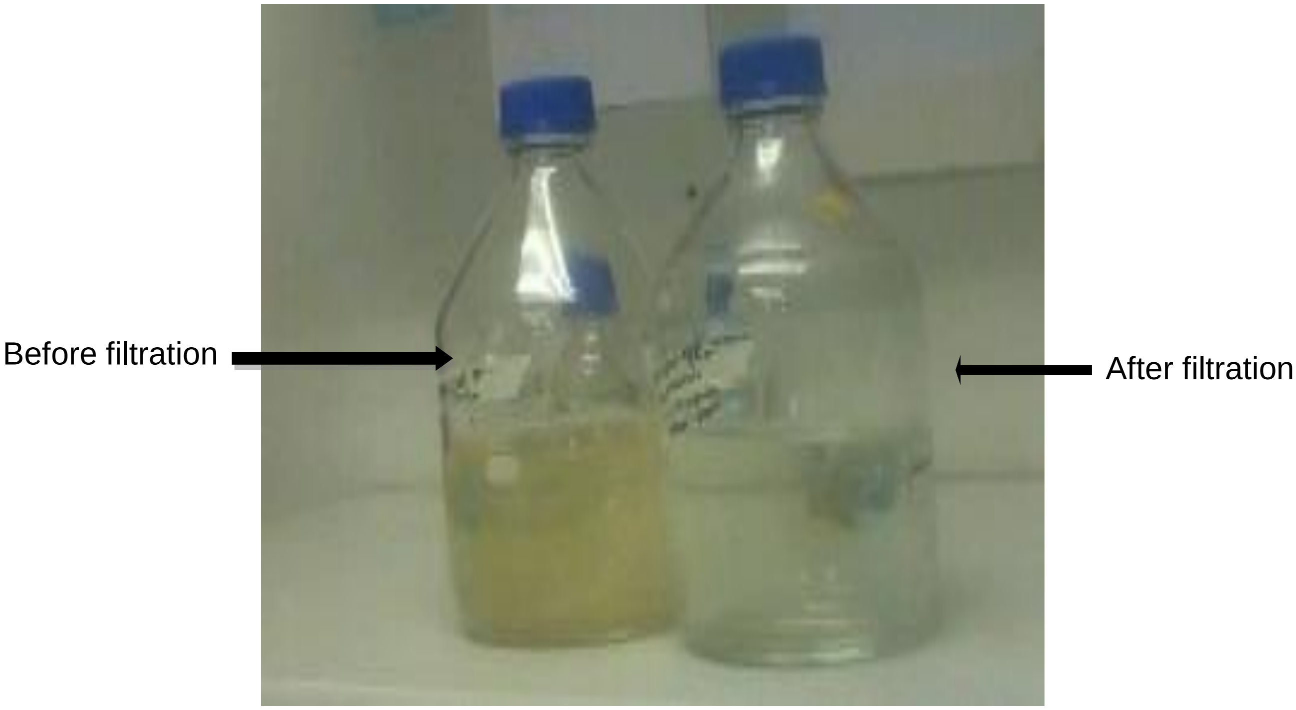

Figure 6 Water samples before and after filtration

5.3.3 Reduction of total water hardness

Hardness in water is generally caused by dissolved calcium and magnesium. Hard water can lead to scale deposition, particularly on heating. The World Health Organization indicated no adverse health effects of hard water on humans due to consumption of hard water (WHO, 2003) while on the other hand intake of soft water was implicated in deprivation of minerals. In this study total hardness of water was reduced by 50% from 4.6 ^{0}dH to 2.3 ^{0}dH after treatment with the filtration unit (figure 6). However, the difference in water hardness before and after treatment was not statistically significant with a p-value of 0.12. Hard water is a common factor in surface waters as also observed by Shittu *et al*. (2008) with well, stream and river waters in Nigeria.

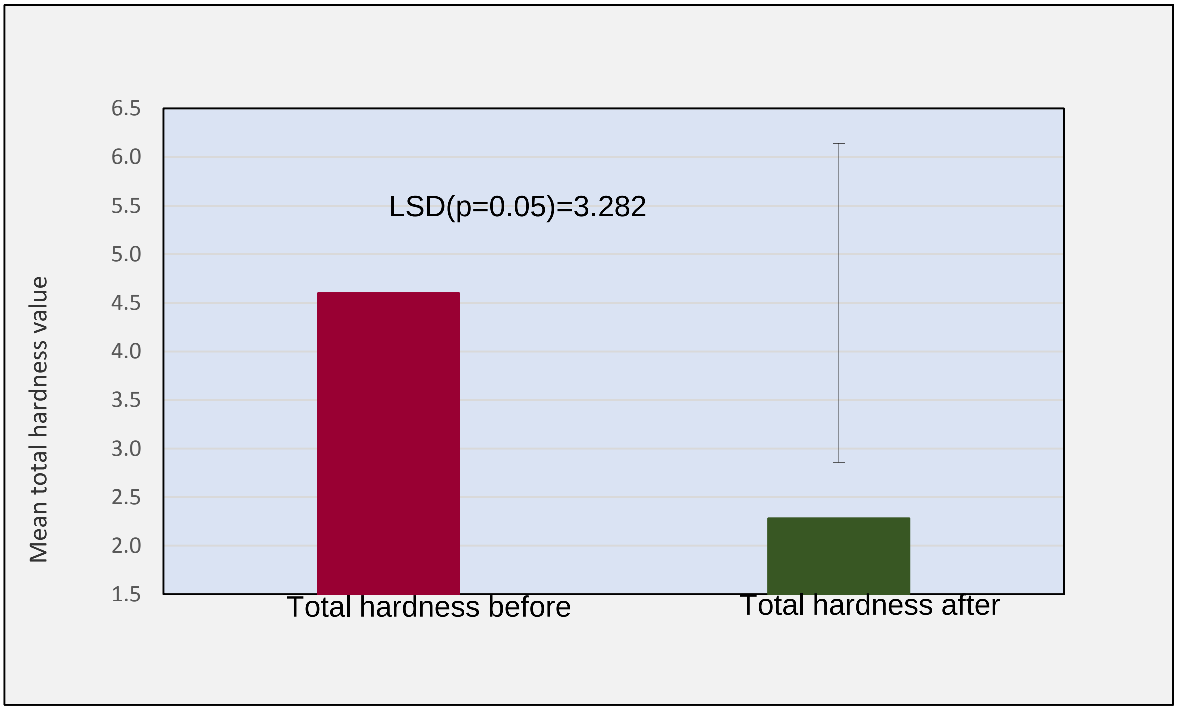

Figure 7 Mean total hardness of surface water before and after filtration

5.3.4 Improvement of levels of total suspended solids and total dissolved solids

High levels of suspended solids produce water that is not acceptable for drinking. Total suspended solids contribute to turbidity of water. The TSS content of the raw surface water was 2.3 mg/L, which was well within recommended limit of less than 1200 mg/L (WHO, 2011). Filtration reduced the level of TSS by 22% to 1.8 mg/L; this improvement was not statistically significant. Similar results as for TSS were observed for TDS, although not significant, the filtration unit was able to reduce the amount of TDS from 1.7 mg/L for raw surface water to 0.9 mg/L after filtration, which was a 47% reduction. Total suspended solids may originate from soil erosion, runoff discharge and algal blooms. Pathogens and other dissolved metals can attach to suspended particles in water therefore make it difficult to disinfect the water (Kemker, 2014). In most cases suspended solids are made up of inorganic materials, though bacteria and algae can also contribute to the total solids concentration. However, organic particles from decomposing materials can also contribute to the TSS concentration. As algae, plants and animals decay, the decomposition process allows small organic particles to break away and enter the water column as suspended solids (Murphy, 2007).

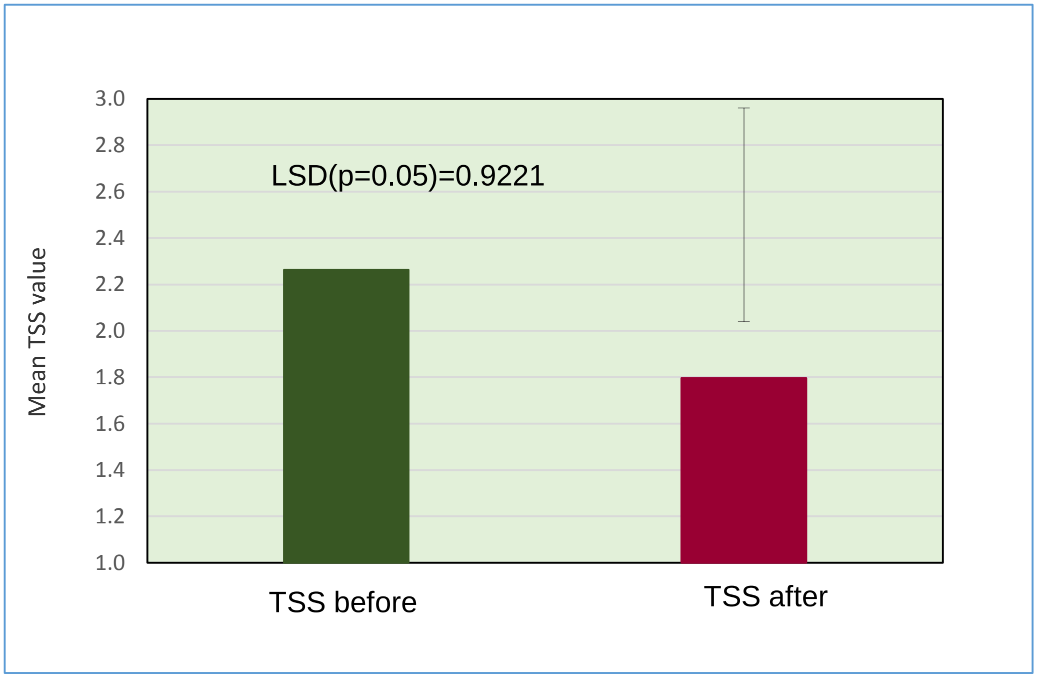

Figure 8 Mean TSS of surface water before and after filtration

High levels of TDS in drinking water can give water a murky appearance, therefore unappealing to consumers. Erhuanga *et al*. (2014) observed a reduction in TDS and TSS following treatment of raw water with ceramic filter. Dissolved solids in water commonly originate from increased weathering of minerals by acids in the soil, process water and fissure water effluents (Atekwana *et al*., 2004). Consumption of water high in TDS and TSS may results in health effects such as gastrointestinal irritation in some individuals. Therefore, if the amount of these parameters can be reduced in water, health risks will be minimal due to cumulative effects. Total dissolved solids can also interfere with treatment devices and it is an important consideration when choosing a treatment system (Atekwana *et al*., 2004). Total suspended solids can impact the quality of water because they reduce water clarity and may also be a contributing factor to water-borne disease outbreaks due to microorganisms associated with organic fractions (Wilson, 2010).

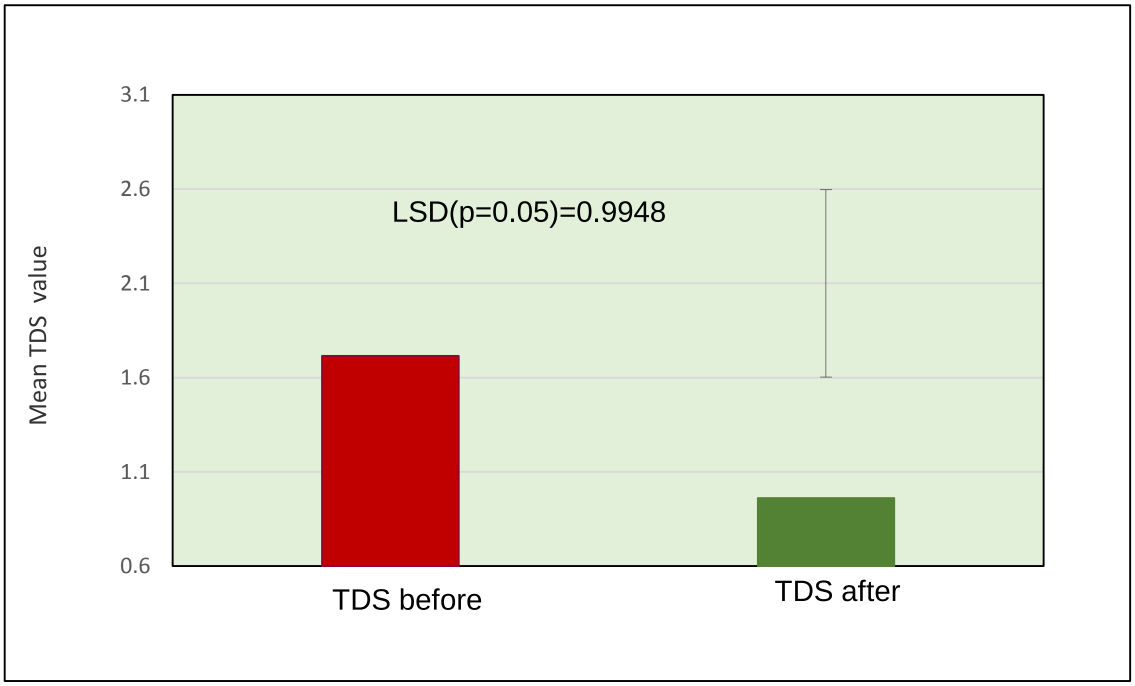

Figure 9 Mean TDS of surface water before and after treatment

5.3.5 Analysis of pH

pH, which is the degree of acidity and alkalinity is the most important parameter for test of water quality and useful tool for interpretation of water chemistry. The pH in water has an important influence on living organisms and the surrounding environment of the water. Sources of pollution that could change the pH of surface water include acid mine drainage and industrial processes. The pH of raw surface water was at pH 8.17 before treatment and pH 8.10 after treatment. The p-value for pH was 0.06, this shows the treatment did not reduce the pH significantly. pH is the most important parameter in determining the corrosive nature of the water. Acidic water usually indicates higher levels of corrosion (WHO, 1996). Exposure to low pH levels may result in irritation of the eyes, skin and mucous membranes. In this study the pH values before and after filtration were within the WHO recommended level. The pH required for normal bodily function is about 7.4 which is slightly alkaline (Waugh and Grant, 2007). The World health Organisation recommends a pH of 6.0-8.5 in water. This suggests that in terms of pH the water is fit for human consumption, therefore pose no harmful effects. Similar studies by Ahammed and Davra (2011) evaluated the performance of BSF modified with iron oxide coated sand and found no significant differences for pH, calcium and magnesium between the modified BSF and the conventional BSF.

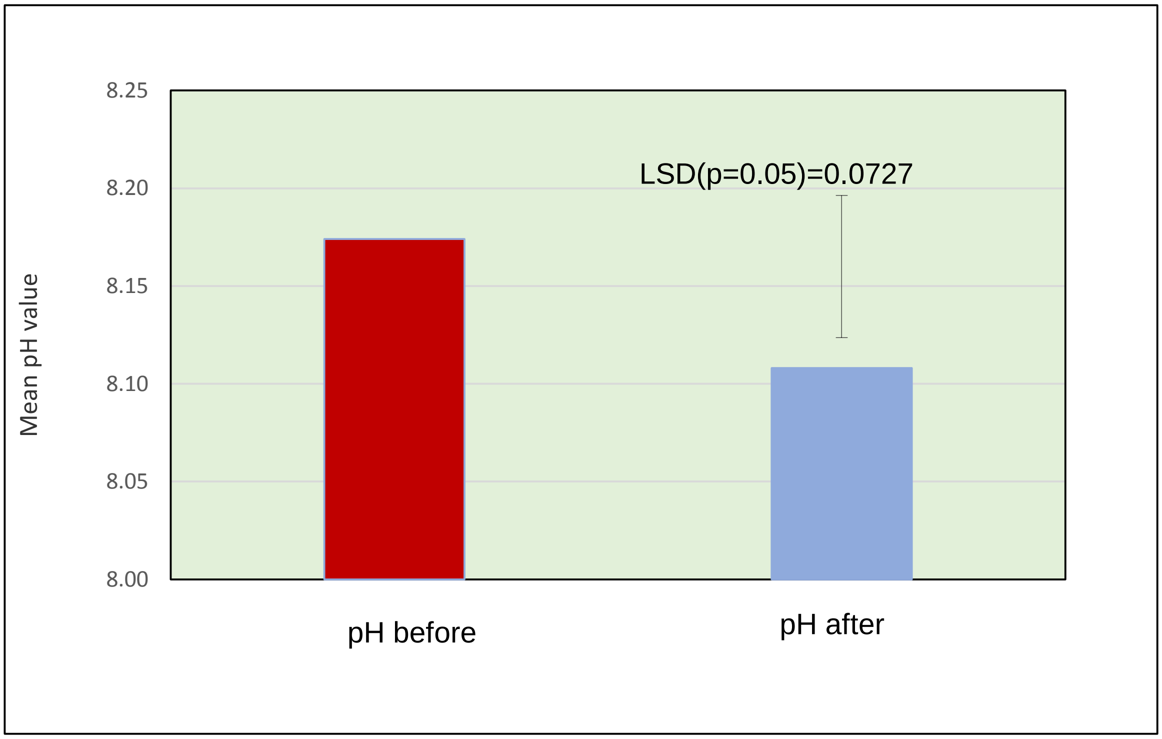

Figure 10 Mean pH values of surface water before and after filtration

Klaman (2009) also investigated a ceramic pot filter using local river water for the removal of microbes and physico-chemical parameters and found that there was no significant difference in terms of pH between pre- and post- treatment analyses. These results were similar to the findings observed in this study. The water sources in Sekhukhune area are used by the communities for domestic purposes. Therefore, their results have been compared with the WHO guidelines to assess their suitability for consumption. A summary of the physico-chemical properties of surface water analysed before and after treatment with the filter unit are presented in table 2. Parameters such as pH, TSS and TDS were within the recommended limit set by WHO.

Table 2: Physico-chemical properties of surface water before and after filtration

parameter	Mean before	Mean after	P-value	WHO Standard
pH	8.17 ± 0.11	8.11 ± 0.08	0.065	5.0-9.7
Colour (l/m)	2.48 ± 1.44	0.50 ± 0.30	0.023*	<15 (l/m)
Turbidity (FAU)	9.80 ± 3.77	2.00 ± 0.71	0.011*	<5 (FAU)
Total hardness (^{0}dH)	4.60 ± 3.59	2.28 ± 1.08	0.121	4-8 (^{0}dH)
TDS (mg/L)	1.71 ± 2.69	0.96 ± 1.94	0.103	<1200 (mg/L)
TSS (mg/L)	2.26 ± 2.04	1.795 ± 1.32	0.232	<1200 (mg/L)

*Significant differences were declared when P<0.05.

CHAPTER 6: GENERAL DISCUSSION

Provision of potable water especially in rural areas can prevent illnesses, lead to improved health and reduce poverty as well. The importance of providing potable water is not only a national priority but an international priority as well. Substantial efforts are made to increase domestic water supply and sanitation globally and in RSA. Such efforts are seen through the implementation of MDG target by the United Nations. South Africa like many developing countries is experiencing shortage of water and the situation is made worse by recurrent droughts, rapid population growth and contamination of existing water resources. Inadequate provision of potable water results in communities consuming contaminated water, hence being exposed to water-borne infections and diseases. People who are mostly affected by shortage of water are the ones situated in the rural parts of RSA. This is mainly caused by low income. Sullivan (2002) reported that income is a strong predictor of availability of potable water. Lawrence *et al. (*2002) further reported that most people in rural areas cannot access safe water because of poor income. For this reason many choose to go for freely available water regardless of its quality.

Consumption of contaminated water may expose consumers to water-borne diseases like hepatitis A and E, cholera, typhoid and poliomyelitis. Improvement of water quality has proven to play a substantial role in reducing diarrhoea and mortality in different countries (Cutler and Miller, 2005; Arnold and Colford, 2007; Clasen *et al*., 2007; Kremer *et al*., 2009; United Nation, 2010; WHO/UNICEF, 2012). In order to reduce the level of bacterial contamination in drinking water, there is a need to educate communities particularly on causes, modes of transmission and prevention of water-borne diseases. Furthermore, proper storage of treated water will also have a significant improvement on the health of consumers. The detection of bacterial contamination of surface water in relation to the study area in the current study could be attributed to the fact that the water sources in Sekhukhune area are mainly rivers and dams which are open and therefore susceptible to contamination by excreta from either human or animals. Surface and ground waters in the Sekhukhune area are primarily the most common sources of water and most households do not carry out any treatment prior to use. This study has emphasized the need for provision of potable water which will have an impact on the social well being of the community. Different treatment strategies that are tailor made and can be easily adopted must be explored to improve provision of potable water to these communities. Rural areas in developing countries often adopt simple water treatment technologies capable of serving either the whole community or individual households. While some of these technologies can remove certain particles and microbial contaminants, they may not provide water that meets the WHO water quality guidelines. Therefore a further simple method of disinfection may be necessary to yield potable water. Water treatment at household level can reduce the risk of water-borne diseases when combined with knowledge about the importance of safe water. The implementation of HTWS will offer communities advantages because such strategies are easy to implement, use locally available materials, cost effective and do not require any mechanical installation.

Currently RSA promotes household water treatment methods such as boiling, chlorination and cloth filtration. Although these methods are efficient in removing microorganisms, they have few documented disadvantages highlighted in this study such as high burn rates with boiling, production of chlorine by-products and certain cloth materials being inefficient in removing microorganisms. This study aimed at designing a cost effective and easy to use filtration unit which can be used by communities in RSA who do not have access to potable water. The unit was designed using a combined filtration method using cotton cloth and fine sand for entrapment and absorption of contaminants. The filtration unit used in this study was efficient in improving turbidity, colour and bacterial load. The unit also offers several advantages such as simplicity, cost effective and availability of materials. However, the only shortcoming of our filter unit was its inability to remove all bacteria. The UV sterilisation method was incorporated after filtration to further remove remaining microorganisms. Use of UV units is not cost effective for most households and hence does not provide an option for total disinfection of raw water. However, secondary disinfection of water especially during storage is important in preventing recontamination or regrowth through handling.

Secondary water treatment methods that can be used by households include boiling and chlorination. These methods are cost effective, hence generally recommended. Studies by fellow students in the water quality laboratory at the University of Limpopo improved the efficiency and cost-effectiveness of the boiling (Mathipa, 2012) and chlorination (Makhuvhele, 2013) methods through optimisation and efficacy analysis. Howard and Bartman (2003) reported that bringing water to a rolling boil for 2 minutes showed a 97% reduction of heterotrophic bacteria and complete elimination of coliforms while 5 and ten minutes showed complete elimination of all bacterial contaminants. The shortcoming of chlorination is the formation of disinfection by-products, this aspect still being analysed, while boiling produces water with a blunt taste. Flowing from the results obtained in this study, we recommend that secondary disinfection of filtration-treated water be performed without changing of containers to minimise recontamination. Furthermore, less amount of disinfectant will be used as most contaminants will have been removed by filtration already. The importance of raw water improvement through reduction of bacterial counts can be viewed as a significant attribute to reduce the risk of water-borne diseases. Most household filters reported are made using locally available materials in order to accommodate the poor communities. However, promotion and use of such filters are almost non-existing in RSA even though several studies have reported on the use and efficiency of household filters in removing contaminants (Murcott, 2002; Earwaker, 2006; Elliott *et al*., 2008), and their effectiveness in preventing diarrhoea and other water-borne diseases with an average of 63% (Wright *et al*., 2004).

CHAPTER 7: CONCLUSION AND FUTURE PROSPECTS

Based on the result of the study the filtration unit was able to reduce the amount of contaminants in surface water. However, the unit alone was not able to reduce the amount of microbial contamination to acceptable levels. Furthermore, future studies must assess the health aspects of household water treatment instruments such as the contribution of the filter bed materials in terms of release of chemicals and the effect of such chemicals to the ultimate quality of treated water. In Sekhukhune area where surface water is mainly used for domestic purposes, there is a need to enlighten the communities about the dangers of consuming untreated water and to give advice on how to treat water in their homes. This will result in households taking responsibility of the safety of the water they consume. However, this must go hand-in-hand with a monitoring plan to ensure correct construction, and that operation and maintenance procedures are followed. This study documented the use of unsafe water sources for domestic use, health risks associated with the use of contaminated water resources, available household water treatment technologies as well as providing a potential household water treatment unit. The findings documented in this study are important in order to have proper understanding of the shortage of water and its implication on the well being of the people. More cost effective technologies are urgently needed to circumvent the risks associated with consumption of untreated natural waters and to mitigate the shortfalls on provision of treated water by the government authorities, especially for rural areas which are generally impoverished and can thus not afford buying bottled water for drinking purposes.

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