EVALUATING THE EFFECTIVENESS OF THE EXISTING BIOSAND FILTERS TO REMOVE PATHOGENS AND SUSPENDED PARTICLES IN WATER AND PROVIDE SAFE WATER OROM SUB-COUNTY (KITGUM DISTRICT).

A FINAL YEAR PROJECT REPORT SUBMITTED TO THE DEPARTMENT OF CIVIL ENGINEERING IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF BACHELOR OF SCIENCE IN CIVIL ENGINEERING OF KAMPALA INTERNATIONAL UNIVERSITY

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MAY 2019

DECLARATION

We the undersigned hereby declare that this project report is our own work and has never been submitted to any university, institution or college of higher learning for the award of any qualification. Any occurrence of a similar project report will be an unfortunate coincidence.

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APPROVAL

This project dissertation was carried out under my supervision and is therefore approved for submission for the partial fulfillment of the University requirements for the award of Bachelor of Science in

Civil Engineering of Kampala International University.

Sign……………………   Date…………………………

Mr. Naliko Issa

DEDICATION

We dedicate this project dissertation to our beloved parents who helped us right from the start of the project till the end.

ACKNOWLEDGEMENT

We wish to extend our sincere word of appreciation to the District Water Officer - KITGUM Mr. PICHO WILLY for allowing us use the District Laboratory and equipment for carrying out the water quality analysis and availing us the necessary information.

We acknowledge the effort of Mr. Naliko Issa Through his guidance, this project dissertation has reached this shape.

Finally, we would like to appreciate our beloved parents, relatives and friends for their great contribution towards my Education both financially and materially.

"May the Almighty God bless you all".

TABLE OF CONTENTS

Contents

LIST OF TABLES

LIST OF FIGURES

ABBREVIATIONS

BSFs:	Biosand sand filters
CAWST:	Centre for Affordable Water and Sanitation Technology
DWO:	District Water Officer
E.Coli:	Escherichia coli
ES:	Effective size
G.I:	Galvanized iron
HDW:	Hand dug well
HR:	High Range
HWT:	Household water treatment
IDPs:	Internally Displaced Persons
NGOs:	Non-Governmental Organizations
NTU:	Nephelometric turbidity units
POU:	Point –of-use
PS:	Protected Springs
PT:	Pool Test
SODIS:	Solar disinfection
UNBS:	Uganda National Bureau of Standards
UNDP:	United Nation Development Programmes
UNICEF:	United Nation Children's Funds
UPS:	Unprotected Springs
UV:	Ultraviolet
WHO:	World Health Organization

ABSTRACT

The project was conducted in Orom Sub-County, Kitgum District to evaluate the effectiveness of the existing Biosand Filters in removing pathogens and Suspended Particles in water. The continuous use of unsafe water for domestic purposes due to limited access to safe water, the increasing demand coupled with the high population growth rate and resettlement of the displaced population has caused outbreak of water related diseases such as typhoid, diarrhea, dysentery and cholera among others especially in the rural areas of Kitgum District. The overall objective was to evaluate the effectiveness of the existing Biosand filters to remove pathogens and suspended particles in water and provide safe water within the Uganda national standards for drinking water. This was made possible by carrying out water quality analysis for raw water and filtered water from the filters, assessing the effects of user practices on the filter performance and lastly assessing the performance of the filter using different water sources. The techniques that were employed in data collection included observations, interview that was supported by use of questionnaires, laboratory tests for some key parameters for drinking water, library search, and internet. The data was then processed and analyzed using Microsoft excel spread sheet, and presented using figures, tables, frequencies and graphs. Biosand filter is 96% effective in removing coliform in water and very effective in removing turbidity since all the filtered water met the National standard of turbidity which is 10NTU. Users' practices affect the performance of the Biosand filters. The type of source water passed through the filter and the level of contamination. The most efficient filters were filters using Borehole water source and was worst with unprotected spring water. Therefore, filters are more effective in treating source water with low turbidity. Biosand filters should continue being used a long side chlorine tablets to remove the remaining 4% of the coliform. Users of BSFs need to be trained on the maintenance of the filters. This should be followed with a monitoring plan to ensure operation and maintenance procedures are followed as this will improve on the performance of the filters.

CHAPTER ONE INTRODUCTION

1.0 Background

Kitgum District is located in northern Uganda with a population of 247,800 (projected population 2012 census) and the water coverage of 58.52% (water sector annual report, June 2015). Kitgum district has a total of 912 water points of which 375 of these water sources have been decommissioned since they were now redundant as people have returned back to their ancestral homes. This has affected the water coverage leading to a drop from 65% to 58.52% (annual report 2015) and this will continue with the increasing population and as more people will be leaving the camps (resettlement). The District has recently (2009) experienced epidemics of hepatitis E outbreak.

Unsafe water sources still prevalent in the District of Kitgum and these include unprotected springs, hand dug wells, shallow wells, and rain water harvesting, streams. The key water quality risks identified in the region include poor microbial quality, high turbidity and high iron content. This has made several water points to be abundant (personal communication with the DWO – Kitgum). According to the DWO, the turbidity of the water sources varies with seasons. Streams, hand dug wells and unprotected springs turbidity ranges from 10 to 100 NTU during rainy season and <5NTU to 15NTU during dry season, the iron content in ground water ranges from 0.2 to 40mg/L and the feacal coliform ranges from 10 to too numerous to count per 100mL. The maximum permissible limits of turbidity, iron content and feacal coliform for drinking water is 10NTU, 1 mg/L and zero count/100mL respectively (UNBS 2008).

Orom Sub-County (project location) is located in Kitgum District with 8 parishes, 153 villages and safe water coverage is only at 47.5% (Water sector annual report, June 2015). Much as government and non-governmental organizations have been implementing Water supply projects in recent years but most of the implementations were in IDP Camps because of the recent wars in Northern Uganda. Today, people have returned back to their ancestral homes but the majority of this returning population from the IDP Camps has settled in areas with inadequate clean and safe water facilities with even limited treatment technologies.

In 2010, a non-governmental organization called Action against Hunger (ACF) carried out an assessment on safe drinking water coverage and distributed a total of 120 Biosand filters to 120 households (returnees) with no access to safe water sources in the sub county. However, outbreaks of water related diseases such as diarrhea, cholera and typhoid among others still prevails in the areas implying the need to evaluate the effectiveness of the Biosand filters.

The World Health Organization estimates that one billion people worldwide lack access to safe drinking water and that 1.8 million people, mostly children, die yearly from water related diseases (diarrheal illnesses). The majority of this disease burden falls on developing countries, especially in remote villages and Indigenous communities. Several technologies have been developed and deployed in communities without or with limited access to safe public drinking water to treat water in their homes to reduce the risk of infection. The Biosand filter (BSF) is one of several such point-of-use (POU) technologies available to treat water in the home to reduce the risk of infection. (Fiore MM, Minningts K, Fiore LD August 2010)

Biosand filters (BSF) are a point of use filtration system, developed from slow sand filters, which remove pathogens and suspended solids from water. As compared to other point of use systems, such as chlorination or solar disinfection, BSFs are easier to operate, and less expensive, which makes them a good alternative, especially in developing countries. The household Biosand filter was first conceptualized by Dr. David Manz in the late 1980s, at the University of Calgary, Canada. The system was developed from the slow sand filter, a technology used for drinking water purification for almost 200 years. Initial lab and field tests were conducted in 1991, and the system was patented in 1993. That same year, the first BSF was implemented in Nicaragua. Subsequent developments on the filters have included circular designs using concrete and plastic housings. In 2001, Dr. David Manz co-founded CAWST (Center for

Affordable Water and Sanitation Technology), as a worldwide distributor of BSFs. It is estimated that over 500,000 BSFs are currently in use worldwide.

1.1 Problem Statement

The continuous use of unsafe water for domestic purposes due to limited access to safe water, the increasing demand coupled with the high population growth rate and resettlement of the displaced population has caused outbreak of water related diseases such as typhoid, diarrhea, dysentery and cholera among others especially in the rural areas of Kitgum District. (Water sector annual report June, 2015).

1.2 Objectives of the Research

1.2.1 General objective

To evaluate the effectiveness of the existing Biosand filters to remove pathogens and suspended particles in water and provide safe water within the Uganda national standards for drinking water.

1.2.2. Specific objectives

- To carryout water quality test for raw water and filtered water from the Biosand filters
- To assess the effects of user practices on Biosand filter's performance
- To assess the performance of Biosand filters using different water sources

1.3 Research Questions

- To what extend does the Biosand filter remove feacal coliform, total coliform, turbidity, pH and iron from water
- Do the users' practices affect the performance of Biosand filters?
- How does the Biosand filter perform with different water sources?

1.4 Justification

Access to safe drinking water in Orom Sub County, Kitgum District is at only 47.5% (Annual sector report, June 2015) implying that majority of the population lack access

to clean water. The project will increase accessibility of safe drinking water to the communities with limited or no access to safe water.
Facilities for treating drinking water, to render it safe to the consumers, are limited. Therefore, there is need to increase and widen the ability of facilities for treating water to render it safe to the consumers.

Unsafe drinking water is a major cause of water-related diseases that predominantly affect people living in developing countries. The WHO estimated diarrhea as being the most prevalent water-related disease to kill 1.8 million children yearly. The provision of appropriate water treatment at household can alleviate the prevalence of these diseases.

1.5 Scope of the Study

1.5.1 Subject scope

The research was limited to carrying out water quality analysis for raw water from the source, stored raw water and filtered water, assessing the effects of the user practices and the use of different water sources on the performance of Biosand filters, and interviewing household owners using Biosand filters and the local leaders.

1.5.2 Geographical scope

The research was limited to households using Biosand filters in the Villages of Orom Sub County, Kitgum District. The District is located in Northern Uganda. It lies between Longitude 32°- 47° East, Latitude 03°-13° North and It is bordered by Gulu District in the West, Lamwo in the North East, Kaabong District in the East, Agago District in the South. The District covers a total area of 3,960 square Kilometer. The District headquarters is 512km accessed by road from Kampala.

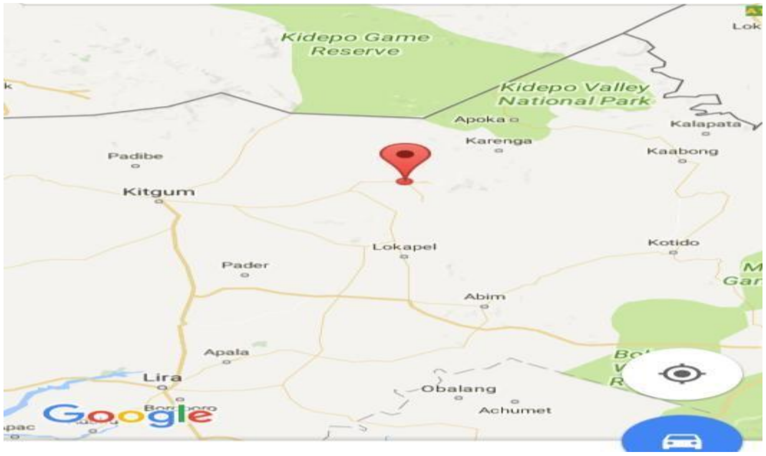


Figure 1.1 Location of Orom (project area) on Google map

1.5.3 Sample size

A total of 25 water sources and filters were considered in carrying out the research. However, this number is the representative samples and was expected to produce a relatively precise result for the study.

1.5.4 Time frame

This project was carried out for a period of 9 months from September 2018 up to May 2019 starting from topic search to the final report presentation and submission.

Details	**Sept**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**March**	**April**	**May**
Topic search	✓								
Proposal draft		✓							
Proposal write up			✓						
Proposal presentation				✓					
Data collection					✓	✓			
Data analysis						✓			
Data presentation							✓	✓	
Conclusion & recommendation								✓	✓

Final report presentation and submission									✓

1.5.5 Financial scope

INCOME	**AMOUNT UG.SHS**
Parents	**350,000**
Friends and relatives	**250,000**
Personal saving	**450,000**
Total income	**950,000**
EXPENDITURES	
Transport	**200,000**
Stationery	**25,000**
Typing and printing	**75,000**
Food and accommodation	**300,000**
Miscellaneous	**150,000**
Total expenditures	**750,000**

1.6 Significance

Having an improved point of use technology (Biosand filters) for water treatment in homes will;

- Improve on the health of the rural communities by increasing access to clean and safe drinking water, thereby enabling them to contribute more towards the country's development and production activities.
- Reduce the Health threats associated with the current consumption of unsafe water since the water quality will be improved. Thus, saving the lives of many people.

1.7 Delimitations

- Some activities were done co-currently to ensure that the project is completed in time.

- Provision of funds by parents and friends to help in running the project.
- Availability of the information required for the study from the internet, journals, books, and existing reports.
- Support from lecturers, District authority, the local council and the communities

1.8 Limitations

- Poor accessibility: the road leading to some of areas were impassable for the vehicles. In this case a motorcycle had to be used.

CHAPTER TWO: LITERATURE REVIEW

2.0 Introduction

The World Health Organization Guidelines for Drinking-water Quality (2006a, 3rd edition, 1st

Addendum) define safe drinking water as water that "*does not represent any significant risk to health over a lifetime of consumption, including different sensitivities that may occur between life stages suitable for all usual domestic purposes, including personal hygiene.*"

Pathogens found in water come in different forms. They may be bacteria, viruses, and protozoa. All the principal pathogens that may be transmitted by water come from human faeces and in a few cases animal faeces. Different micro-organisms survive for different amounts of time in water, have variable susceptibility to chlorine and may cause mild or severe effects. Many pathogens are readily inactivated by the action of chlorine and piped water supplies that have been treated and disinfected should have few pathogens in the final water. However, microorganisms may enter the piped water supply due to failures in the distribution network or local failures.

Most point sources use groundwater, which in its natural state is usually of good microbiological quality. Microorganisms are removed from water by a number of processes that are grouped together under the term attenuation. These processes may lead to the permanent or temporary removal of microorganisms. However, contamination of water may occur because of poor sanitary protection measures due to poor design, siting, construction or operation and maintenance, poor water handling and storage practices. These sources also often show a seasonal variation in quality and quantity that is important for monitoring programs. (WHO 2006)

2.1 Water Quality

2.1.1. Microbiological quality

The principal concern in water quality is the microbiological quality of the water that is being consumed. Microbiological quality may change very rapidly over time and short distances and therefore requires frequent testing.

There are very many different pathogens that may be found in water. It is not feasible to test for pathogens directly, as it is difficult to predict whether they will be present and in what numbers.
Furthermore, for many of the pathogens analytical techniques either do not exist or are expensive and time-consuming. This means that the actions required to remove or prevent pathogen entry into the water supply cannot be taken as quickly as is required and the household consuming the water are put at risk.

As most pathogens are derived from faeces, the approach adopted by most surveillance bodies world-wide to analyze the water for bacteria that show faecal contamination has occurred. These are called *indicator bacteria*. By using indicator bacteria, the number of micro-organisms that are tested for are reduced, which reduces costs whilst retaining good means to assess whether water represents a risk to health of the users. (WHO 2006)

2.1.1.1. Escherichia coli (Faecal coliform):

The indicator bacteria that most surveillance bodies use in routine assessment of the risk of faecal contamination is *Escherichia coli* (*E. Coli*) or as an alternative, thermo-tolerant coliform. *E. Coli* provides the closest match to the criteria for an ideal indicator, however it is not perfect and it is possible to find pathogens in drinking-water supplies when *E. Coli* is absent. In particular, *E. Coli* and thermo-tolerant coliform may not provide a good indication of the presence of protozoa or viruses. However, in general, these indicator bacteria at present provide a reasonably reliable indication of the risk of disease from the water supply. However, given the weaknesses in these indicators, water that has no *E. Coli* or thermo-tolerant coliform should be seen as low risk, rather than as safe (WHO 2006).

2.1.1.2. Total coliform:

This is the group of bacteria that include *E. Coli*, but also other bacteria that come from environmental sources and so their presence does not necessarily indicate a risk to health. (WHO 2006)

2.1.2. Physical tests

These are critical parameters that must be combined the microbiological analysis in every water testing programmes. They include;

2.1.2.1. Turbidity

This is a measure of the suspended solids in the water. Turbidity is important because bacteria are often found attached to suspended particles in the water. In chlorinated supplies, raised turbidity may reduce the effectiveness of disinfection (WHO 2006).

Turbidity is an important parameter for characterizing water quality. Turbidity is caused by the scattering of light by suspended matter such as clay, silt, and finely divided organic and inorganic matter. Knowledge of turbidity facilitates estimation of the concentration of undissolved substances.

2.1.2.2. The pH

This is critical for effective chlorination. Where the pH is too high, chlorine will be consumed in reactions to restore the pH back to neutral. In general, the optimum range of pH for chlorination is 6.5-8.5. All the critical parameters require frequent and routine monitoring. (WHO 2006).

2.1.2.3 Colour

Colour in drinking-water may be due to the presence of coloured organic matter, e.g. metals such as iron and manganese, or highly coloured industrial wastes. Drinking-water should be colourless. For the purposes of surveillance of community water supplies, it is usually simply to note the presence or absence of observable colour at the time of sampling. Changes in the colour of water and the appearance of new colours serve as indicators that further investigation is needed. (WHO 2006)

2.1.2.4. Taste and odour

Odours in water are caused mainly by the presence of organic substances. Some odours are indicative of increased biological activity; others may result from industrial pollution. Sanitary inspections should always include the investigation of possible or existing sources of odour, and attempts should always be made to correct an odour problem. Taste problems (which are sometimes grouped with odour problems) usually account for the largest single category of consumer complaints.

Generally, the taste buds in the oral cavity detect the inorganic compounds of metals such as magnesium, calcium, sodium, copper, iron, and zinc. As water should be free of objectionable taste and odour, it should not be offensive to the majority of the consumers. If the sampling officer has reason to suspect the presence of harmful contaminants in the supply, it is advisable to avoid direct tasting and swallowing of the water. Under these circumstances, a sample should be taken for investigation to a central laboratory. (WHO 2006)

2.1.3. Chemical tests

In some areas chemical tests apart from chlorine and pH may be needed, which will usually be carried out on point sources or sources supplying a piped network. The three chemicals of particular importance are arsenic, fluoride and nitrate. Other chemicals should be tested during source selection or periodic evaluation, unless their presence leads to rejection of water supply for instance iron and manganese, when more frequent analysis may need to be carried out.

Surveillance agencies usually only undertake very limited chemical testing, given the costs and the often stable nature of chemicals in water. However, water suppliers are likely to undertake more frequent chemical analysis and may be required to by the water law. (Theodore B. Shelton, Ph. D. 6th Edition, 2006**)**

2.1.3.1. Nitrate

Nitrate is usually derived from human activity and may come pit latrines, organic solid waste and inorganic fertilizers. Nitrate is of concern to health because it causes methaemoglobinaemia („blue-baby syndrome"). Nitrate is very stable in water with sufficient oxygen (for instance shallow alluvial aquifers) and concentrations will only be reduced through dilution. Therefore, nitrate represents a long-term hazard to the water resource. Nitrate may show seasonal peaks and so timing of sampling is often critical. Usually increases in nitrate are found as a wet season progresses and concentrations decline during dry seasons. If sources contain raised nitrate, the long-term viability of the source is questionable and alternative sources may need to be investigated.

Analysis of nitrate is best done at a laboratory, although there are some accurate field spectrophotometers that provide reliable results. If you use photometers or probes, the results are only semi-quantitative and are probably only useful in trend monitoring. (Theodore B. Shelton, Ph. D. 6th Edition, 2006**)**

2.1.3.2. Arsenic and fluoride

Arsenic and fluoride are often derived from natural sources where minerals bearing these substances are found in bedrock. Excess fluoride causes dental and skeletal flourish which is an extremely painful and debilitating illness.

Arsenic is related to cancers and is of increasing concern in many countries where high levels are found in groundwater and large numbers of people are affected. Both chemicals should be tested when a source is being developed, particularly in areas where there is a suspicion that they may exist because of the underlying geology or where mining or industrial processes are known to release it into the environment.

Arsenic may require more frequent testing as it appears that concentrations may increase when abstraction of groundwater leads to changes in the sub-surface water chemistry. At present, accurate results for both chemicals can only be obtained from laboratory analyses, although some field kits are available for arsenic. When these chemicals are found in water, an alternative source should be found or if this is impossible, the water will need to be blended with water with low concentrations. (WHO 2006**)**

2.1.3.3. Iron and manganese

Iron occurs widely in nature and is found in many natural and treated waters. Iron is an objectionable constituent in both domestic and industrial water supplies. The presence of iron affects the taste of beverages and causes unsightly staining of laundered clothes, plumbing fittings, swimming pool surfaces and the like. The formation of insoluble iron deposits is troublesome in many industrial applications and in agricultural water uses such as drip feed irrigation. In industry iron salts occur through corrosion of plant and equipment, and from industrial processes.

Iron and manganese cause problems with the acceptability of the water and may cause consumers to reject a water source that is otherwise of good quality. Neither iron nor manganese have an impact on health, but cause discoloration or the water, staining of clothes and sanitary ware and may impart an unpleasant taste.

Iron and manganese should be tested during source selection and subsequently tested infrequently in the source waters. Unless the distribution systems is made of iron pipes, routine sampling in distribution systems is not usually carried out, although samples may be analyzed in response to consumer complaints. (Theodore B. Shelton, Ph. D. 6th Edition, 2006**)**

2.2. Health effects of drinking unsafe water or untreated water

Chemicals that are toxic and might be found in drinking water may cause either acute or chronic health effects. An acute effect usually follows a large dose of a chemical and occurs almost immediately. Examples of acute health effects are nausea, lung irritation, skin rash, vomiting, dizziness, and, in the extreme, death.

The levels of chemicals in drinking water, however, are rarely high enough to cause acute health effects. They are more likely to cause chronic health effects, effects that occur after exposure to small amounts of a chemical over a long period. Examples of chronic health effects include cancer, birth defects, organ damage, disorders of the nervous system, and damage to the immune system.

Diseases related to unclean drinking water place a major burden on human health (WHO, 2006a). The WHO attributes 3.2% of global deaths to unsafe water, sanitation and hygiene, of which, over 99.8% occur in developing countries and over 90% are children (Nath et al., 2006). It is thought that more children die from a lack of safe water and a toilet than almost any other cause (UNDP, 2008).

Diarrhea, directly linked to water and sanitation conditions, is the second largest cause of Child hood death (preceded by acute respiratory tract infection), killing 1.8 million children every year (UNDP, 2008). The WHO GDWQ (2006a) declares that drinking water quality interventions can provide significant benefits to health and that every effort should be made to achieve a drinking water quality as safe as practicable.

The majority of water-related diseases are the result of microbial contamination of the water by bacteria, viruses, protozoa or other biological material. Faecal contamination (human or animal) of drinking water supplies signifies the greatest microbial risk due to its potential as a source of pathogenic bacteria, viruses and protozoa. Other contaminants commonly known to compromise the quality of drinking water include toxic cyanobacteria, Legionella and other microbial hazards such as guinea worm. (WHO, 2006a)

Chemical contamination of drinking water, commonly by arsenic or fluoride, is a concern in some regions of the world, particularly where groundwater is used. Radionuclides are another source of drinking water contamination although total exposure is expected to be very small under normal circumstances. Taste, odour and appearance of drinking water can also cause some concern to consumers, however; there may be no direct health effects from these. Concern is raised that consumers may reject safe water on the basis of aesthetic factors in favour of more appealing, but ultimately unsafe water sources. (Theodore B. Shelton, Ph. D. 6^{th} Edition**)**

2.3. Household Water Treatment

In regions where safe water supply is not available or reliable, point-of-use (POU) treatment systems such as household water treatment and safe storage (HWTS) technologies are an effective alternative (Clasen, 2008). Additionally, HWTS can provide safe water more rapidly and affordably than it would take to design, install and deliver a piped community drinking water supply.

2.3.1. Characteristics of an effective POU water treatment technology

A practical and effective POU technology is characterized by;

- The ability to produce sufficient quantities of microbiologically safe drinking water in a reasonably short period of time
- the ability to treat water from different sources that may have high turbidity and organic content
- Low cost to implement, operate and replace and
- It maintains effective and high post-implementation use levels after deployment in the field.

2.3.2. Common POU Water Treatment Technologies

2.3.2.1. Boiling, thermal microbial deactivation;

Boiling water kills bacteria as well as other disease-causing microorganisms like Giardia lamblia and Cryptosporidium parvum which are commonly found in rivers and lakes. At high elevations, though the boiling point of water drops. This reduces the time and energy required to bring water to a boil, but can increase the duration of boiling required to kill certain pathogens. Water temperatures above 70 °C (158 °F) will kill all pathogens within 30 minutes, above 85 °C (185 °F) within a few minutes, and at boiling point (100 °C (212 °F)), most pathogens will be killed, excluding certain pathogens and their spores, which must be heated to 118 °C (244 °F) (e.g.: botulism – Clostridium botulinum). This can be achieved by using *a pressure cooker*, as regular boiling will not heat water past 100 °C (212 °F) at sea level. It is worth noting that not all pollutants are removed from water by boiling, even in a pressure cooker. Boiling cannot remove chemicals having boiling points at or above 100 °C (212 °F), nor heavy metal contamination, e.g., colloidal metal pollutants*. Activated charcoal*, however, can remove many pollutants, but can't remove pathogens. A combination of rolling boiling for one minute at standard atmospheric pressure (i.e., not in a pressure cooker) plus filtering with activated charcoal can neutralize most pathogens and pollutants. (http://en.wikipedia.org/wiki/portablewater-purification. accessed on 26/03/2019 at 09:20am. Boiled water should be stored in the same container in which it was boiled, handled carefully, and consumed within 24 hours to prevent recontamination.

Drawbacks of boiling

Studies in developing countries have documented the following drawbacks of boiling;

- Incomplete inactivation of bacteria in boiled water.
- Lack of residual protection against contamination;
- Lack of epidemiologically confirmed health impact;

- Potential for burn injuries and increased risk of respiratory infections from indoor stoves or fires;
- Potentially high cost of carbon-based fuel source (with concurrent deforestation risk) and the opportunity cost of collecting fuel;
- Potential user taste objections; and,
- Potential for incomplete water treatment if users do not bring water to full boiling temperature.

Appropriateness

Boiling is most appropriate in areas with a good fuel supply, a cultural tradition of boiling, and where water is stored safely after boiling.

2.3.2.2. Solar Water Disinfection (SODIS);

SODIS uses increased temperature, UV light, and oxidative chemistry to inactivate disease causing organisms. Users are trained to place bottles in the sun for 6 hours-2 days, depending on climate. Diarrhea reduction is 9-86%. Aside from initial bottles, SODIS is a zero-cost option. Benefits include acceptability to users because of the minimal cost and ease-of-use. Also, recontamination is unlikely because water is consumed directly from the bottles in which it is treated.

It is very simple, inexpensive and basic method in which transparent polyethylene terephthalate (PET or PETE) bottles are filled with source water and exposed to solar UV and heat energy outside, usually on a dark surface during the hours of sunlight. Drawbacks include the need for pretreatment of turbid water, limited volume of water that can be treated at once, length of time required to treat water, and the plastic bottles supply required. This method requires forward planning and creates problems when large quantities of water are needed for purification as many Africans only have 1-1.5litre bottles.

9http://www.iwawaterwiki.org/xwiki/bin/view/Articles/SolarDisinfection accessed on 27/03/2019 at 09:35am

The benefits of SODIS are:

- Proven reduction of viruses, bacteria, and protozoa in water;
- Proven reduction of diarrheal disease incidence in users;
- Acceptability to users because of the simplicity of use;
- No cost to the user after obtaining the plastic bottles;
- Minimal change in taste of the water; and,
- Although SODIS does not have a chemical residual, recontamination is unlikely because water is served directly from the small, narrow-necked bottles with caps in which it is treated.

The drawbacks of SODIS are:

- The need for pretreatment (filtration or flocculation) of waters of higher turbidity;
- User acceptability concerns because of the limited volume of water that can be treated at once and the length of time required to treat water; and,
- The large supply of intact, clean, suitable plastic bottles required.

Appropriateness:

SODIS is most appropriate in areas where there is availability of bottles and community motivation and training for users on how to correctly and consistently use SODIS for treating household drinking water. http://www.iwawaterwiki.org/xwiki/bin/view/Articles/SolarDisinfection accessed on 27/03/2019

Figure 2.1 Water disinfection using solar

2.3.2.3. Ceramic Filters (fired clay)

Ceramic filters are made in developing countries where their filtration effectiveness and production methods can vary which can lead to poor quality water being produced by the filter. Also ceramic filters are very expensive and only produce water at a flow rate of 1-4l/hr which poses severe constraints on the amount of water available for family's water requirements (Dies, R, 2003).

Most ceramic filter HWTS systems are based on a filter/receptacle model. To use the ceramic filters, families fill the top receptacle or the ceramic filter itself with water, which flows through the ceramic filter or filters into a storage receptacle. The treated water is then accessed via a spigot embedded within the water storage receptacle (http://www.waterwiki.org/xwiki/bin/view/articles/ceramicfiltration accessed on 27/03/2019 at 10:45am)

Figure 2.2 ceramic filters

Effectiveness of ceramic filters

The effectiveness of ceramic filters at removing bacteria, viruses, and protozoa depends on the production quality of the ceramic filter. Most ceramic filters are effective at removing most of the larger protozoa and bacterial organisms, but not at removing the smaller viral organisms. Studies have also shown significant bacterial contaminations when poor-quality locally produced filters are used, or the receptacle is contaminated at the household level. Because of the lack of residual protection, it is important that users be trained to properly care for and maintain the ceramic filter and receptacle. (http://www.waterwiki.org/xwiki/bin/view/articles/ceramicfiltration accessed on 27/03/2019at 10:45am).

The benefits of ceramic filtration

- Proven reduction of bacteria and protozoa in water
- Acceptability to users because of the simplicity of use
- Proven reduction of diarrheal disease incidence in users
- Long life if the filter remains unbroken
- A low one-time cost.

The drawbacks of ceramic filtration are:

- Lower effectiveness against viruses;
- Lack of residual protection can lead to recontamination if treated water is stored unsafely;
- Variability in quality control of locally produced filters;
- Filter breakage over time, and need for spare parts;
- Filters and receptacles need to be regularly cleans, especially when using turbid source waters;
- A low flow rate of 1-3 liters per hour in non-turbid waters.

Appropriateness:

Ceramic filtration is most appropriate in areas where there is capacity for quality ceramics filter production, a distribution network for replacement of broken parts, and user training on how to correctly maintain and use the filter.

2.3.2.3. Flocculation and disinfection systems

The flocculants/disinfectant powder PUR has been proven to remove the vast majority of bacteria, viruses, and protozoa, even in highly turbid waters. PUR has also been documented to reduce diarrheal disease from 16 to greater than 90% incidence in five randomized, controlled health intervention studies. In addition, PUR removes heavy metals, such as arsenic, and chemical contaminants, such as some pesticides, from water.
http://www.iwawaterwiki.org/xwiki/bin/view/Articles/FlocculantDisinfectant+Powder accessed on 27/03/2019 at 11:00am.

The benefits of flocculants/disinfectant powders are:

- Proven reduction of bacteria, viruses, and protozoa in water;

- Removal of heavy metals and pesticides;
- Residual protection against contamination;
- Acceptable to users because of visual improvement in the water

The drawbacks of flocculants/disinfectant powders are:

- Multiple steps are necessary to use the product, which requires a demonstration to teach new users;
- The need for users to have, employ, and maintain two buckets, a cloth, and a stirring device; and,
- The higher relative cost per liter of water treated compared to other household water treatment options.

Appropriateness:

PUR is most appropriate in areas with a consistent supply chain for sachet resupply and in urban, rural, and emergency situations where educational messages can reach users to encourage correct and consistent use.http://www.iwawaterwiki.org/xwiki/bin/view/Articles/FlocculantDisinfectant+Powder accessed on 27/03/2019 at 11:00am

2.3.2.4. Solar distillation

Distillation is the process of removing salt from water. It is done by applying a heat source to the water to turn it to vapor, thereby purifying the water. Solar distillation uses the sun as the primary source of heat. It is a relatively old technology, with the first solar distillation sill put into service in 1872 in Chile. (http://www.wisegeek.com/what-is-solardistillation.htm#didyouknowout accessed on 28/03/2019 at 16:17).

During distillation, impure water is exposed to heat. The heat causes the water to turn to vapor. The water vapor condenses and turns back into liquid water. The condensed water is free of salt and other impurities.

Solar distillation may use a pre-manufactured and easily portable still, commonly referred to as a solar still, but it has its roots in a makeshift still that can be constructed simply from readily available components, typically being placed over a small pit that is dug into the ground. The solar still relies on sunlight to warm and evaporate the water to be purified. The water vapour condenses, usually on a plastic sheet suspended as an inverted cone, dripping into a collection cup placed beneath its center. For more continuous use, thin tubing or a hose is sometimes routed into the collection cup beneath the inverted cone, permitting repeated removal of water without disturbing the inverted cone upon which water condenses. This is potentially an important method to prevent losing moisture to atmospheric air, such as can occur in the desert, if the inverted cone is removed each time distilled water is removed from the cup. An alternative method based on the same technique is to tie a plastic bag over a branch of vegetation, to capture water released by the vegetation during photosynthesis. Note that while the solar still shares exposure to UV and infra-red radiation with SODIS, along with the use of plastic materials (sheeting in place of a PET bottle), a solar still relies on a completely different mechanism for operation and the two methods should not be confused. In an extreme survival situation, a solar still can be used to prepare safe drinking water from usually unsuitable water sources, such as one's own urine, or even sea water*. (USEPA, Ultraviolet Disinfection Guidance Manual for the final LT2ESWTR, Nov 2006)*

2.3.2.5. Activated charcoal absorption

Granular activated carbon filtering utilizes a form of activated carbon with a high surface area, and adsorbs many compounds, including many toxic compounds. Water passing through activated carbon is commonly used in concert with hand pumped filters to address organic contamination, taste, or objectionable odors. Activated carbon filters aren't usually used as the primary purification techniques of portable water purification devices, but rather as secondary means to complement another purification technique. It is most commonly implemented for pre- or post-filtering, in a separate step than ceramic filtering, in either case being implemented prior to the addition of chemical disinfectants used to control bacteria or viruses that filters cannot remove. Activated charcoal can remove chlorine from treated water, removing any residual protection remaining in the water protecting against pathogens, and should not, in general, be used without careful thought after chemical disinfection treatments in portable water purification processing. Ceramic/Carbon Core filters with a 0.5 micron or smaller pore size are excellent for removing bacteria and cysts while also removing chemicals. (http:// en.wikipedia.org/wiki/portable-water-purification accessed on 27/03/2019 at 12:00pm)

2.3.2.6. Chemical disinfection

Iodine used for water purification is commonly added to water as a solution, in crystallized form, or in tablets containing tetraglycinehydroperiodide that release 8 mg of iodine per tablet adaptation to chronic tetraglycinehydroperiodide. The iodine kills many, but not all, of the most common pathogens present in natural fresh water sources. Carrying iodine for water purification is an imperfect but lightweight solution for those in need of field purification of drinking water. Kits are available in camping stores that include an iodine pill and a second pill (vitamin C or ascorbic acid) that will remove the iodine taste from the water after it has been disinfected, such as those marketed under the Potable Aqua Plus name. The addition of vitamin C, in the form of a pill or in flavored drink powders, precipitates much of the iodine out of solution, so it should not be added until the iodine has had sufficient time to work. This time is 30 minutes in relatively clear, warm water, but is considerably longer if the water is turbid or cold. Iodine treated drinking water, treated with tablets containing tetraglycinehydroperiodide, also reduces the uptake of radioactive iodine in human subjects to only 2% of the value it would otherwise be. This could be an important factor worthy of consideration for treating water in a post nuclear event survival situation. If the iodine has precipitated out of the solution, then the drinking water has less available iodine in solution. Also the amount of iodine in one tablet is not sufficient to block uptake. Tetraglycinehydroperiodide maintains its effectiveness indefinitely before the container is opened; although some manufacturers suggest not using the tablets more than three months after the container has initially been opened, the shelf life is in fact very long provided that the container is resealed immediately after each time it is opened. (http:// en.wikipedia.org/wiki/portable-water-purification accessed on 27/03/2019 at 12:00pm)

Chlorine-based halazone tablets were formerly popularly used for portable water purification. Chlorine in water is more than three times more effective as a disinfectant against *Escherichia coli* than iodine. Sodium dichloroisocyanurate (NaDCC) has largely displaced halazone tablets for the few remaining chlorine based water purification tablets available today. It is compressed with effervescent salts, usually adipic acid and sodium bicarbonate, to form a rapidly dissolving tablets, diluted to 10 parts per million available chlorine (ppm av.cl) when drinking water is mildly contaminated and 20ppm when visibly contaminated. Chlorine bleach tablets give a more stable platform for disinfecting the water than liquid bleach (sodium hypochlorite) as the liquid version tends to degrade with age and give unregulated results unless assays are carried out – not practical on the spot. Still, despite chlorine-based halazone tablets falling from favor in for portable water purification, chlorine-based bleach may nonetheless safely be used for short-term emergency water disinfection. Two drops of unscented 5% bleach can be added per liter or quart of clear water, and then allowed to stand covered for 30 to 60 minutes. After this treatment, the water may be left open to reduce the chlorine smell and taste.

Figure 2.3 some of the chemical water disinfection

Neither chlorine (e.g., bleach) nor iodine alone is considered completely effective against *Cryptosporidium*, although they are partially effective against *Giardia*. Iodine should be allowed at least 30 minutes to kill Giardia. Chlorine is considered slightly better against the latter. A more complete field solution that includes chemical disinfectants is to first filter the water, using a 0.2 micron ceramic cartridge pumped filter, followed by treatment with iodine or chlorine, thereby filtering out cryptosporidium, Giardia, and most bacteria, along with the larger viruses, while also using chemical disinfectant to address smaller viruses and bacteria that the filter cannot remove. This combination is also potentially more effective in some cases than even using portable electronic disinfection based on UV treatment, such as using a SteriPEN UV portable water purifier. (http:// en.wikipedia.org/wiki/portable-water-purification accessed on 27/03/2019 at 12:00pm)

Silver ion/chlorine dioxide based tablets or droplets: this is an alternative to iodine-based based tablets or droplets sold under names such as Micropur Forte, Aquamira, and Pristine; these solutions may disinfect water more effectively than iodine based techniques while leaving hardly any noticeable taste in the water in some usage scenarios. Silver ion/chlorine dioxide based disinfecting agents will kill *Cryptosporidum* and *Giardia*, if utilized correctly. The primary disadvantage of silver ion/chlorine dioxide based techniques is the long purification times (generally 30 minutes to 4 hours, depending on the formulation used). Another concern is the possible deposition and accumulation of silver compounds in various body tissues leading to a rare condition called argyria that results in a permanent, disfiguring, bluish-gray pigmentation of the skin, eyes, and mucous membranes. The cost of chlorine dioxide treatment is about four times higher than the cost of iodine treatment. (http:// en.wikipedia.org/wiki/portable-waterpurification accessed on 27/03/2019 at 12:00pm)

2.3.2.7. Biosand filtration

Biosand filter (BSF) is an adaptation or has been developed from slow sand filter, which has been used for community water treatment and it removes pathogens and suspended solids from water. As compared to other point of use systems, such as chlorination or solar disinfection, BSFs are easier to operate, and less expensive, which makes them a good alternative, especially in developing countries. The Biosand filter is smaller and adapted for intermittent use, making it suitable for households. The filter container can be made of concrete or plastic and is filled with layers of specially selected and prepared sand and gravel. (CAWST Biosand design manual 2010)

2.4. Bio-Sand Filtration

2.4.1. Biosand filter development

Technology of the Biosand filter for household level water treatment has been developed by a

Canadian charity named 'Centre for Affordable Water and Sanitation Technology' (CAWST). Dr.

David Manz developed the household Biosand filter in the 1990s at the University of Calgary, Canada. Dr Manz has trained many organizations on the design, construction, installation, operation and maintenance of the Biosand filter. He also co-founded CAWST in 2001 to provide the professional services needed for the humanitarian distribution of the filter in developing countries. As of June 2009, CAWST estimates that over 200,000 Biosand filters have been implemented in more than 70 countries around the world. (Biosand filter manual, CAWST 2009)

2.4.2. Biosand filter components

Most Biosand filters consist of similar components. At the top of the filter there is a tightly fitted lid, which prevents contamination and unwanted pests from entering the filter. Below is the diffuser plate, which prevents disturbance of the filtration sand layer and protects the bio-layer when water is poured into the filter. Next, is the filtration sand layer. It removes pathogens and suspended solids. Below the sand is a layer of smaller gravels called the separating gravel layer. This prevents filtration sand from entering the drainage gravel layer and clogging the outlet tube. Right below this separating layer is the drainage gravel layer, which supports the separating gravel layer and helps water flow by preventing clogging near the base of the outlet tube.
(Dangol, Bipin, and DorotheeSpuhler. "Biosand Filter." SSWM. Sustainable Sanitation and

Water Management. Accessed on 25th September, 2018 0n <http://www.sswm.info/category/implementation-tools/water-purification/hardware/point-usewater-treatment/bio-sand-filtrat)

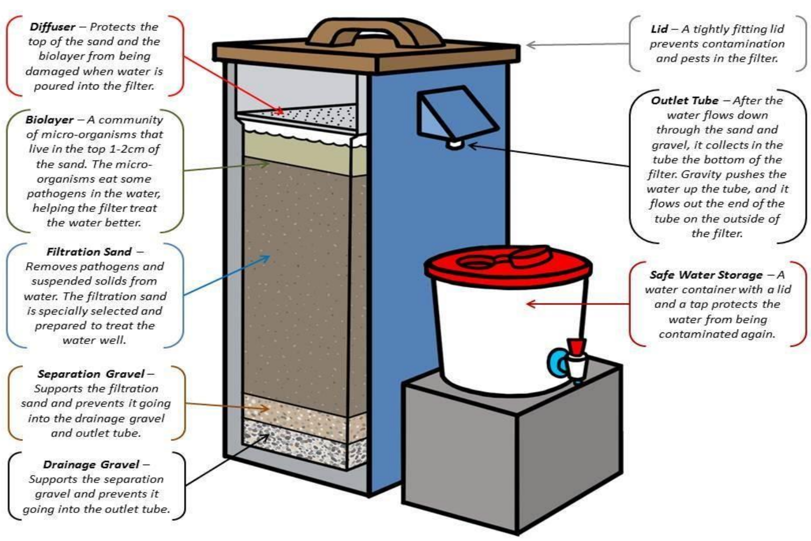


Figure 2.4 Biosand filter components

2.4.3 Types of Biosand filters

2.4.3.1. Concrete filters

Concrete filters are the most widespread type of Biosand filter, consisting of a durable outer core structure of concrete. Concrete is generally preferable to other materials because of the low cost, wide availability, and possibility to be completely constructed on-site. Concrete filter production further allows for entrepreneurship amongst the local community. The plans for the concrete filter are distributed openly by CAWST. Several versions have been developed. The CAWST Version 9 Biosand filter is constructed with a higher maximum loading rate and although the filtered water passes EPA water quality standards it is not optimal. Recent research establishes that contact time between the water and the granular material is the leading determinant in purifying water. The CAWST Version 10 Biosand filter takes this into account as the volume of the water reservoir is equal to the pore space volume of the sand layer, with a maximum loading rate decreased by 33% to ensure stagnant water in constant contact with granular material.

2.4.3.2. Plastic Biosand filters

Plastic filters are constructed of plastic barrels, usually formed offsite. Plastic filters are easily transportable and come in a variety of sizes. Hydraid is the leading producer in Biosand filter technology and is constructed of medical grade plastic with UV resistance. In 2011, the Tiva Water filter was introduced in Uganda. It has patented several new features that increase the effectiveness of Biosand filtration and include;

- Storage container that prevents cross contamination and increases consumer acceptance.
- This the advantage that the plastic Biosand filters has over concrete filters. design features that slow water filtration and increase water purity
- Use of a filter cloth to prevent clogging.

2.5. Advantages and limitations of using Biosand filters

2.5.1. Advantages;

- Ease of use for the communities
- Produce clean, clear water and good taste of filter water
- Easy to maintain and operate
- Capital cost is relatively low (US$12-30)
- No operation costs or replaceable parts
- Durable and long-lasting, Constructed from local materials
- Reduces diarrheal disease and removes most pathogens
- Removes most sediment including 50-90% of organic and inorganic toxicants
- Can be modified for arsenic removal (Kanchan Arsenic Filter)

2.5.2 Limitations of Biosand filters

- Heavy and difficult to move
- Biolayer takes up to 30 days to develop to maturity
- Source water with high turbidity (> 50 NTU) will cause filter to clog more frequently and require more maintenance
- Cannot ensure pathogen free water
- Cannot remove salt, hardness, and scale (dissolved compounds)
- Suitable for water with low turbidity. High turbidity (> 50 NTU) will cause filter to clog and require more maintenance, cannot remove color or dissolved compounds
- Requires that the filter be used periodically on a regular basis

2.6. Operation and Maintenance

2.6.1. Biosand Filter Operation

Water quality testing can be done to check if the Biosand filter is working well. Testing the levels of microbiological, chemical and physical contamination in the source water and filtered water allows you to calculate the percent removal rates. However, in practice, water quality testing can be complex, time consuming, difficult to interpret, and expensive.

Alternatively, CAWST recommends checking selected key operating conditions to ensure that the Biosand filter is working effectively. If a Biosand filter is not installed or being operated properly, then you can assume that it is not working effectively and producing high quality water on a consistent basis. The key operating conditions for checking includes;

- Filter is used for at least one month since installation.
- Filter is used at least once each day.
- Source water is not too turbid (less than 50 NTU).
- The concrete filter body is not leaking.
- Diffuser is in place and in good condition.
- Water level is 5 cm above the sand during the pause period.
- Top of sand is level.
- Flow rate is 0.4 liters per minute

The Bio-layer

The bio-layer is the key component of the filter that removes pathogens. Without it, the filter removes about 30-70% of the pathogens through mechanical trapping and adsorption. It may take up to 30 days for the bio-layer to fully form. During that time, both the removal efficiency and the oxygen demand will increase as the bio-layer grows. The bio-layer is NOT visible – it is NOT a green slimy coating on top of the sand.

The filtration sand may turn a darker colour, but this is due to the suspended solids that have become trapped.

The water from the filter can be used during the first few weeks while the bio-layer is being established, but disinfection, as always, is recommended during this time. (CAWST 2009)

Filter Loading Rate

The Biosand filter has been designed to allow for a filter loading rate (flow rate per square meter of sand surface area) which has proven to be effective in laboratory and field tests. There is a recommended filter loading rate for each Biosand filter design. For the concrete Version 10 Biosand filter, it has been determined to be not more than 400 liters/hour/square meter. (CAWST 2009)

Pause Period

The Biosand filter is most effective and efficient when operated intermittently and consistently. The pause period should be a minimum of 1 hour after the water has stopped flowing up to a maximum of 48 hours.

The pause period is important because it allows time for the microorganisms in the bio-layer to consume the pathogens in the water. As the pathogens are consumed, the flow rate through the filter may be restored. If the pause period is extended for too long, the microorganisms will eventually consume all of the nutrients and pathogens and then eventually die off. This will reduce the removal efficiency of the filter when it is used again. (CAWST 2009)

2.6.2. Maintaining the Biosand Filter

The bio-layer is an ecosystem that is suited specifically to the source water that is being filtered. If the source water is changed, the bio-layer must be reestablished (CAWST 2010).

Some households use one water source during the wet season and a different water source during the dry season. They must be advised that the bio-layer in their filter will need time to completely reestablish itself when the source is changed.

Regular use, maintenance, and cleaning of the filter will be necessary. Water should be added to the filter at least once a day, but no more than 4 times a day. No more than 3.75 gallons of water should be added to the reservoir each time. Water should not be poured into the reservoir more frequently than once every 2 hours (CAWST 2010).

The frequency of regular maintenance is mainly dependent on the turbidity of the water being filtered. The turbidity of a water source will vary throughout the year and it will be up to the user to monitor and determine the cleaning frequency necessary. During the rainy season, when run off is abundant, water will likely be more turbid requiring more frequent maintenance of the Biosand filter (Fewster 2004).

Over time, particles will accumulate between the sand grains in the filter. Also, as more water is poured a biofilm will form along the top of the diffuser plate. Both of these occurrences cause a decrease in flow rate. Although slower flow rates generally improve water filtration due to idle time [APS1], it may become too slow for the users" convenience. If flow rate goes below an unacceptable rate of 0.1 liter/minute, due to buildup of the bio-layer and suspended solids in the upper layer of sand the Biosand filter will require cleaning. It is recommended by CAWST to perform maintenance. The cleaning method known as the "swirl and dump" or wet harrowing is used to restore flow rate.

CHAPTER THREE: METHODOLOGY

3.0 Introduction

This chapter deals mainly with the means/ways that were used to obtain data, what means were used for processing data and ways of presenting the data.

3.1 Sampling

The population targeted was the households in Orom sub county, Kitgum District using Biosand filters as a point of use technology for water treatment at homes. A simple random sampling was used but in some cases the households were selected basing on the water source they use and from which water was collected. This was to assess if its effectiveness is affected by the use of different water sources.

3.2. Sample size

Determining the sample size that is needed for a particular piece of research is a complex issue. Kent (2007) suggests that for any kind of quantitative analysis, a minimum of 50% sample size is needed even to be able to calculate simple percentages for each variable. In thinking about sample size of this project, it was helpful to draw a distinction between;

- The size of sample that was required to get meaningful results
- The quality and number of responses that would give meaningful results
- The number of usable response

A total of 25 water sources and filters were considered in carrying out the research. However, this number is the representative samples and was expected to produce a relatively precise result for the study. This was determined using kochy's formulae. n= $(N/1+Ne^2)$, where n is the sample size, N is the total number of households and e is the working error. for a confidence of 90% with an error of 10%=0.1 and the total house hold of the sub county is 33

n= $(33/1+ (33x0.1)^2)$ = 25 households

3.3 Data Collection Techniques

3.3.1. Observations:

The researchers visited the households using Biosand filters and several observations were made regarding different aspects of the filter. These observations were important in detecting possible operating problems with the filters. The different aspects of the filter are spouts attachment, diffuser plates, sand layers and cracks in the concrete body.

3.3.2. Interview:

A dialogue between the researcher and the interviewee was held for purpose of gathering primary data. The interviewees included the residents/beneficiaries of Biosand filters and the local council leaders.

3.3.3. Questionnaires;

Questionnaires was prepared and used to conduct the interview to ease the process of obtaining data from the relevant persons who were primarily responsible for using and maintaining the filter. These were typically the females and the responses were noted as the respondents answered the questions. This helped to know how often they check some key operating conditions for effective use of the filter and if they perform "swirl and dump" cleaning according to the "CAWST manual 2010". This was also employed to know the daily number of times they use the filter and determined if the use of Biosand filter has reduced outbreaks of water related diseases in the project area. All these were done to assess the effects of user practices on the BSF performance.

3.3.4. Library search:

The researcher obtained relevant information and data concerning Biosand filters from textbooks, journals, magazines, and existing reports.

3.3.5. The internet:

Relevant information and data were obtained from relevant websites.

3.3.6. Laboratory tests:

3.3.6.1. Water sampling;

Water samples were obtained from four sources for each home. First a sample was collected from the source, drawing bucket or jerry can of each family's well. This bucket of water was then poured into the BSF and a second sample was obtained from the filter spout after approximately 5 minutes of flow. Water samples were collected using disposable 100ml sampling bags. This was because it is safer and less time consuming since it does not require more sterilization which is require when using bottles as collection containers and there is no guarantee that the bottles are 100% sterilized. Each sample collected was then marked with its identity i.e. source ID, filter number, household ID and also the time and date of each sample collection was also noted. The Filter flow rate of each filter was measured.

3.3.6.2. Sample storage:

The samples collected for bacteriological tests and chemical tests were stored in a cool box/container with ice packs to maintain the samples temperature and transported to the District lab.

3.3.6.3. Water quality analysis:

The samples collected were then tested and analyzed for some key physical, biological and chemical water quality parameters using the various test methods adopted from the WHO and UNBS guideline for drinking water quality.

The physical tests;

The physical parameters tests were conducted while in the field (at the source) immediately after the samples collection as they would change during storage and transportation. The physical parameter tested for was only turbidity using a photometer.

Turbidity test;

The turbidity of the water was determined photo electrically using the Palintest. The turbidity results were measured in Nephelometric Turbidity Units (NTU).

Reagents and Equipment

- Palintest Turbidity Set (PM 269)
- Palintest Automatic Wavelength Selection Photometer

Test Procedure

i. The portion of the sample was filtered through a filter paper.

ii. The test tube was filled with filtered sample and retained for use as the BLANK tube.

iii. Another test tube was filled with unfiltered sample to the 10 ml mark.

iv. Phot 48 on photometer was then selected.

v. Photometer reading was then taken in usual manner (see photometer instructions) using the filtered sample as the blank.

vi. The efficiency of the filter in removing turbidity in water was then calculated from; $\frac{Turbidity\ \ of\ raw\ water\ \ (NTU) - Turbidity\ \ (NTU) of\ filtered\ \ water}{Turbidity\ \ of\ \ raw\ water}\ X\ 100\%$

Microbiological quality tests;

Escherichia coli (Faecal coliform) and total coliform tests

Membrane-filtration method was used to test for Escherichia coli (Faecal coliform) and total coliform employed by the wagtech or Del Agua Water testing kit. This test was conducted and concluded within 6 hours from the time of sampling. This was to obtain accurate and reliable results after the 18- 24 hours incubation period. E-coli was incubated at 44°C while total coliform at 37°C

Apparatus used

- 47mm Petri dishes
- Filtration unit consisting of a vacuum pump, filter Funnel with 100ml mark, filter cup and bronze disk
- A lighter
- Car battery
- Incubator
- Magnifying glass

Reagents;

- 45mm Membrane filter papers
- Absorbent pads Methanol
- culture medium / sulfur broth

Procedures

i. Working area was sterilized with disposable cover
ii. Sterilized disposable gloves were put on.
iii. Petri ditches, forceps and the filtration unit were sterilized.
iv. Petri dish was labeled with appropriate information as it was labeled on the sampling bags

    i.e. Filter No. (each filter has its own ID No.), Sample ID and source water type

v. The filter funnel was removed and the membrane filter paper placed.
vi. A minimum volume of 10 ml of the sample (or dilution of the sample) was introduced aseptically into a steriled or properly disinfected filtration assembly containing a steriled membrane filter paper of pore size 0.45mm
vii. A vacuum was then applied using the vacuum pump and the sample was drawn through the membrane filter paper. All indicator organisms are retained on or within the filter paper

viii. The filter paper was then transferred to a suitable selective culture medium in a Petri dish using a sterile forceps. Following a period of resuscitation, during which the bacteria become acclimatized to the new conditions. The Petri ditch was then closed and labeled with the right information of the sample identity

ix. The procedures were repeated for all the samples, the Petri dishes were transferred to an incubator and incubated at a temperature of 44°C and 37°C for E.Coli and total coliform respectively for 18-24hours to allow the replication of the indicator organisms

x. Visually identifiable colonies were formed and counted, and the results were expressed in numbers of "colony forming units" (CFU) per 100 ml of original sample

xi. The efficiency of the filter in removing E.Coli and total Coliform was then calculated from;

$$\frac{CFU\ per\ 100ml\ of\ raw\ water - CFU\ per\ 100ml\ of\ filtered\ water}{CFU\ per\ 100ml\ of\ raw\ water}\ X\ 100\%$$

Chemical tests; pH and iron were tested in the District lab using the pH meter and photometer respectively.

Iron tests;

Iron is therefore an important test for the monitoring of natural and drinking waters, for corrosion control in industry and for the checking of effluents and waste waters. The Palintest Iron HR test provides a simple test for the determination of high levels of iron in water over the range 0 –1mg/l Fe. The test responds to both ferrous and ferric iron and thus gives a measure of the total iron content of the water.

Method

The Palintest Iron HR test is based on a single tablet reagent containing an alkaline thioglycollate. The test was carried out simply by adding a tablet to a sample of the water under test. The thioglycollate reduces ferric iron to ferrous iron and this, together with any ferrous iron already present in the sample, reacts to give a pink coloration.

The intensity of the colour produced is proportional to the iron concentration and was measured using a Palintest Photometer.

Reagents and Equipment

- Palintest Iron HR Tablets
- Palintest Automatic Wavelength Selection Photometer
- Round Test Tubes, 10 ml glass (PT 595)

Test Procedure

i. The test tube was filled with sample to the 10 ml mark.
ii. One Iron HR tablet was added, crushed and mixed to dissolve.
iii. It was then allowed to stand for one minute for full colour development.
iv. Phot 18 on Photometer was then selected.
v. The Photometer reading in usual manner (see Photometer instructions) was then taken.
vi. The result was displayed as mg/l Fe. Both the results of the raw water and filtered water were obtained.
vii. The efficiency of the filter in removing iron in water was then calculated from

$$\frac{iron\ content\ \ of\ unfiltered\ \ water - iron\ content\ \ of\ filtered\ \ water}{iron\ content\ \ of\ unfiltered\ \ water}\ X\ 100\%$$

3.4. Data processing:

The data collected was then fed in computer using Microsoft words, excel spread sheet to store and manipulate the data.

3.5. Data analysis:

The data acquired was then analyzed using Microsoft excel spread sheet.

3.6. Data presentations:

Figures, percentage, tables, graphs, and charts have been used in presenting the data.

CHAPTER FOUR FINDINGS AND DISCUSSION OF RESULTS

4.0. Introduction

This chapter looks at all the findings from the laboratory and the analysis of the results. The results are then discussed into details according to the specific objectives of this project and various conclusions on each discussion are provided in this chapter. Various graphs and tables are given to indicate the comparisons of the findings with the National standards and different water sources are looked at differently to analyze how the filters perform with different water sources.

4.1. WATER QUALITY TEST

Due to limited resources, a total of only 25 filters were considered for this study. Out of the 25 filters assessed, 20 (80%) met the key operating conditions for effective use of Biosand filters. Therefore, only the 20 Biosand filters that were functioning properly were considered for evaluation of its effectiveness for pathogen removal. The results of the remaining 5 (20%) that were not functioning properly were not included in evaluation of the filters" performance.

Samples were collected from all the 25 filters. Each set of samples consisted of two individual samples; one sample of water before filtration and one after filtration by the BSF. All 50 samples were tested for pH, turbidity, E.Coli, total coliform and iron.

Table 4.1 week 1 results

HH ID	F ID	source	RAW WATER					FILTERED WATER				
			e-coli	coliform	pH	Iron	Turbidity	e-coli	coliform	pH	Iron	Turbidity
HH 1	F 1	HDW	80	85	7.6	11.6	80.1	3	5	6.5	4.64	7.1
HH 2	F 2	UPS	122	134	8.5	13.5	82	10	12	6.6	4.87	12
HH 3	F 3	UPS	134	149	8.2	8.6	81	11	15	6.8	1.89	15
HH 4	F 4	UPS	107	118	7.4	5.6	78.6	56	57	6.9	2.82	35
HH 5	F 5	BH	105	108	7.1	6.9	58.8	2	3	6.5	0.92	0.7
HH 6	F 6	PS	81	97	7.9	5.7	61.3	35	44	7.4	2.54	19.6

Table 4.2 week 2 results

HH ID	F ID	Source	RAW WATER					FILTERED WATER				
			e-coli	coliform	pH	Iron	Turbidity	e-coli	coliform	pH	Iron	Turbidity
HH 7	F 7	HDW	180	181	6.8	10.2	61	1	1	6.5	2.9	6
HH 8	F 8	HDW	76	80	8.1	7.4	43.6	1	4	7.9	2.4	5
HH 9	F 9	HDW	104	108	8.5	5.8	32.7	3	4	6.8	1.0	5.2
HH10	F10	PS	154	160	7.7	6.3	19	1	3	6.9	0.97	2.8
HH11	F11	HDW	124	126	7.8	9.8	43	1	2	7.2	1.5	3.8
HH12	F12	UPS	215	230	8.5	3.8	38.8	7	15	8.2	1.2	9

Table 4.3 week 3 results

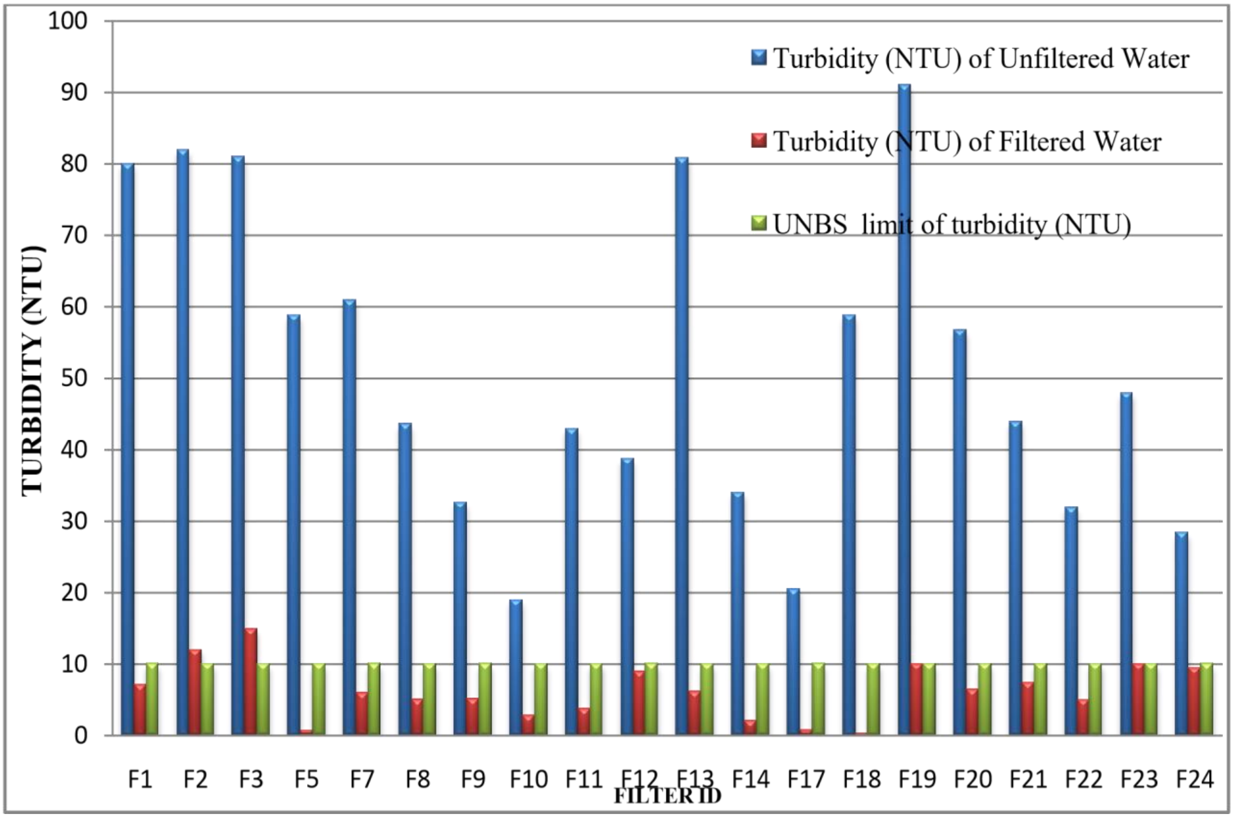
HH ID	F ID	source	RAW WATER					FILTERED WATER				
			e-coli	coliform	pH	Iron	Turbidity	e-coli	coliform	pH	Iron	Turbidity
HH13	F13	BH	69	74	8.5	8.1	80.9	3	5	8.4	2.8	6.1
HH14	F14	BH	89	93	8.3	9.8	34	3	4	8.0	1.0	2.1
HH15	F15	UPS	112	137	7.8	7.3	80.2	58	72	7.3	3.1	39.8
HH16	F16	BH	53	74	7.5	10.3	43.8	14	22	7.1	4.1	9.7
HH17	F17	PS	120	125	6.8	5.1	20.5	3	5	6.8	0.68	0.8
HH18	F18	BH	191	192	8.3	4.7	58.8	1	1	8.2	0.86	0.26

Table 4.4 week 4 results

HH ID	F ID	Source	RAW WATER					FILTERED WATER				
			e-coli	Coliform	pH	Iron	Turbidity	e-coli	coliform	pH	Iron	Turbidity
HH19	F19	PS	25	26	7.2	7.3	91.1	2	3	6.9	1.87	10
HH20	F20	PS	97	112	8.3	14.1	56.8	9	15	8.0	2.7	6.5
HH21	F21	UPS	101	114	8.1	10.9	44	8	13	8.0	1.8	7.4
HH22	F22	BH	114	143	6.8	14.8	32	5	8	6.3	2.9	5.1
HH23	F23	PS	52	57	8.4	5.5	48	3	5	8.2	0.95	10
HH24	F24	UPS	128	131	8.3	4.9	28.4	3	6	8.0	0.68	9.5
HH25	F25	HDW	96	133	7.3	6.8	70.6	33	48	6.9	2.8	28

4.1.2. Discussion of the water quality test results

4.1.2.1. Turbidity



Graph 4.1: shows the turbidity of raw water from the collection container and the filtered water.

The raw water turbidity before filtration ranges from 19 to 91.1 NTU with an average of 51.7 NTU which is above the maximum recommended turbidity limit of less than 50NTU for water to be poured into the filters (CAWST). Only raw water from 11 collection containers (accounting for 45%) out of the 20, met the above requirement whereas the remaining 9 never made above stated condition. This was mainly in surface water sources due to the water coming into contact with soil in the upper layers, where bacteria and particulates are prevalent since the samples were taken during raining seasons. This suggests that the BSFs could be suitable for use during the dry seasons when the turbidity is within the recommended value of less than 50NTU. However, during the raining seasons, it may be necessary to pre-treat the source water.

The turbidity of the filtered water from the BSFs ranges from 0.28 to 15NTU with an average of 6.2 NTU. Out of the 20 filters, 18 (80%) filters produced filtered water within the Uganda National standard for drinking water which requires turbidity not to exceed 10NTU. Filtered water from only two Biosand filters never met this standard. This was possibly because the filters had a high flow rate of $0.15m^3/hr$ and $0.18m^3/hr$ which is quiet greater than the recommended flow rate of $0.1m^3/hr$ and also due to the poor User's practices. The average efficiency of the filters in removing turbidity was 88%.

4.1.3. Microbial Results

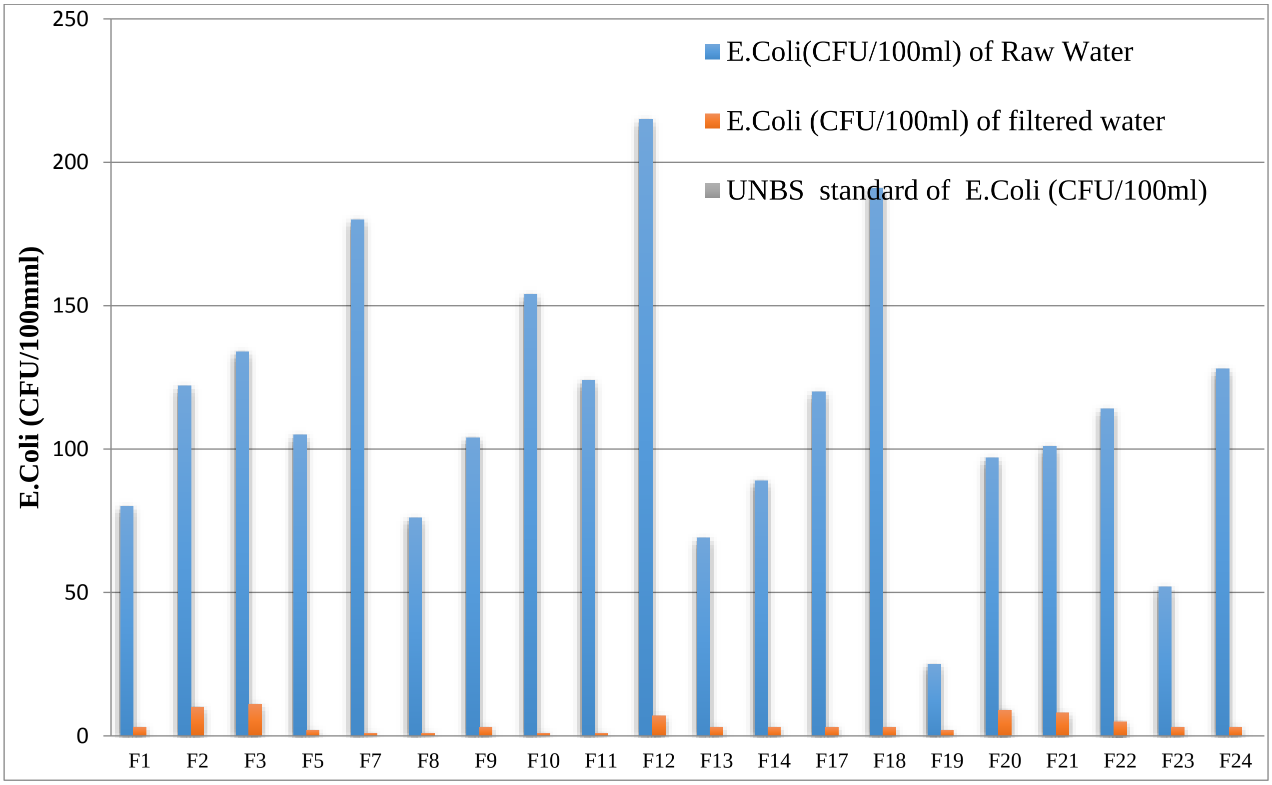
Of the 25 BSFs that were studied, five of them were found to have problems either with the diffuser plate, the resting water level or the maturity of the biofilm. These filters were not considered as the representative of the microbial removal efficiency of the BSF operating under

"good" conditions. Therefore, their results were not included in evaluating the performance of the filters.

4.1.3.1. Escherichia Coli (Faecal Coliforms) Results.

The WHO and UNBS Guidelines recommend protection of the water source and treatment techniques to ensure the absence of biological contaminants. The presence of fecal coliform in drinking water indicates pollution. The degree of treatment required is a function of the source water and level of faecal contamination of the source.

The Escherichia coli (faecal coliform) of the raw water from the collection container before filtration range from 25 to 216 CFU/100ml with an average count of 114 CFU/100ml implying that the raw water deserved to be treated before use since they never met the required minimum standard for water to be used for domestic purposes according to the WHO and UNBS guidelines. The Escherichia coli (Faecal coliform) of the filtered water from the BSFs ranged from 1 to 11 CFU/100ml with an average count of 4 CFU/100ml. The average efficiency of the filters in removing E. Coli was 96.1%.

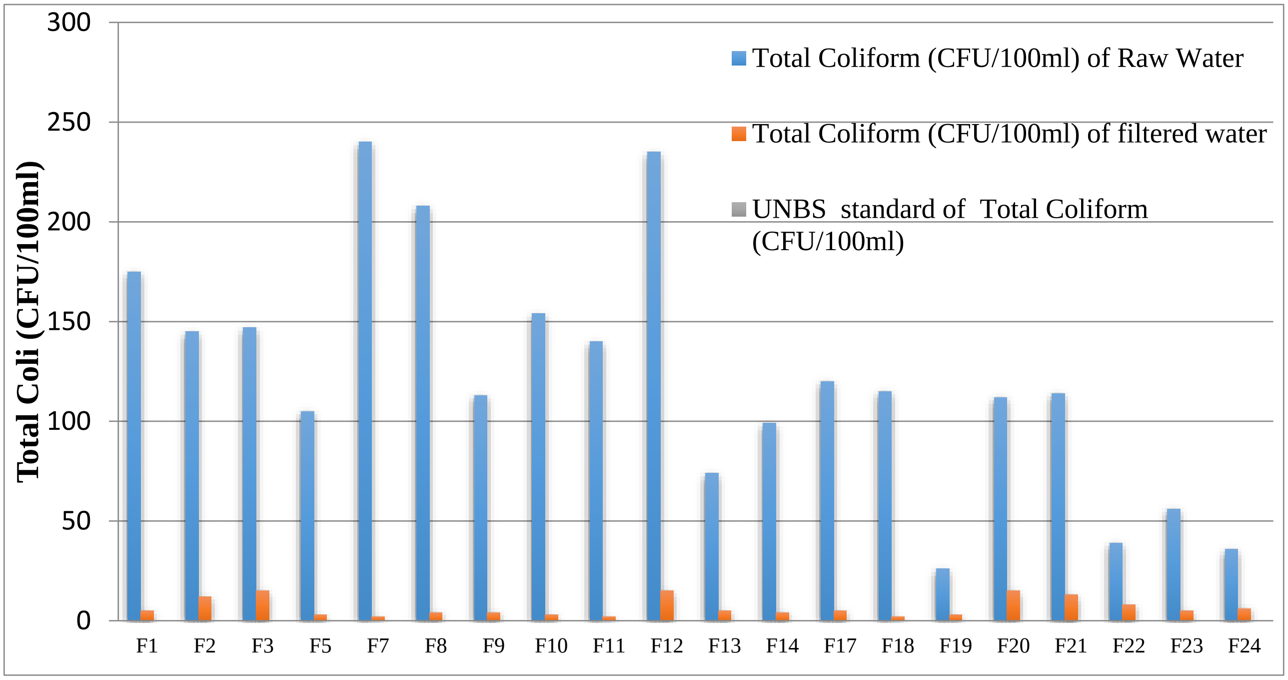


Graph 4.2: shows the E. Coli of raw water from the collection container before filtration and after filtration

All the filtered water from the 20 filters considered for this study never the met the Nation standard which requires E. Coli not to be detected in drinking water. They still had E. Coli in the range of 1 to 11CFU per 100ml implying that there is still risk of diseases from the filtered water. However, this can easily be removed by chlorination since their turbidity was reduced to the required standard.

4.1.3.2. Total Coliform Results

The total coliform of the raw water from the collection container before filtration ranged from 26 to 240 CFU/100ml with an average count of 127 CFU/100ml and that of filtered water from the BSFs ranged from 1 to 15 CFU/100ml with an average count of 6 CFU/100ml and average percentage removal of 9



Graph 4.3: shows the total coliform of raw water from the collection container and that of the filtered water.

All the filtered water from the 20 filters considered for this study never the met the National standard which requires Total Coliform not to be detected in drinking water. They still had total coliform in the range of 1 to 15CFU per 100ml implying that there is still risk of diseases in the filtered water if consumed without further treatment. However, this can easily be removed by chlorination since their turbidity was reduced to the required standard.

4.1.4. Chemical Test Results

4.1.4.1. pH

The results show that, all the filtered water met the Uganda national standard for drinking water with an average of 7.26 against the range of 6.5-8.5 (UNBS) and the filters removed an average of 7.4% of the pH. This also implies that, there is little significant change in the pH before and after filtration, as shown in the Table below

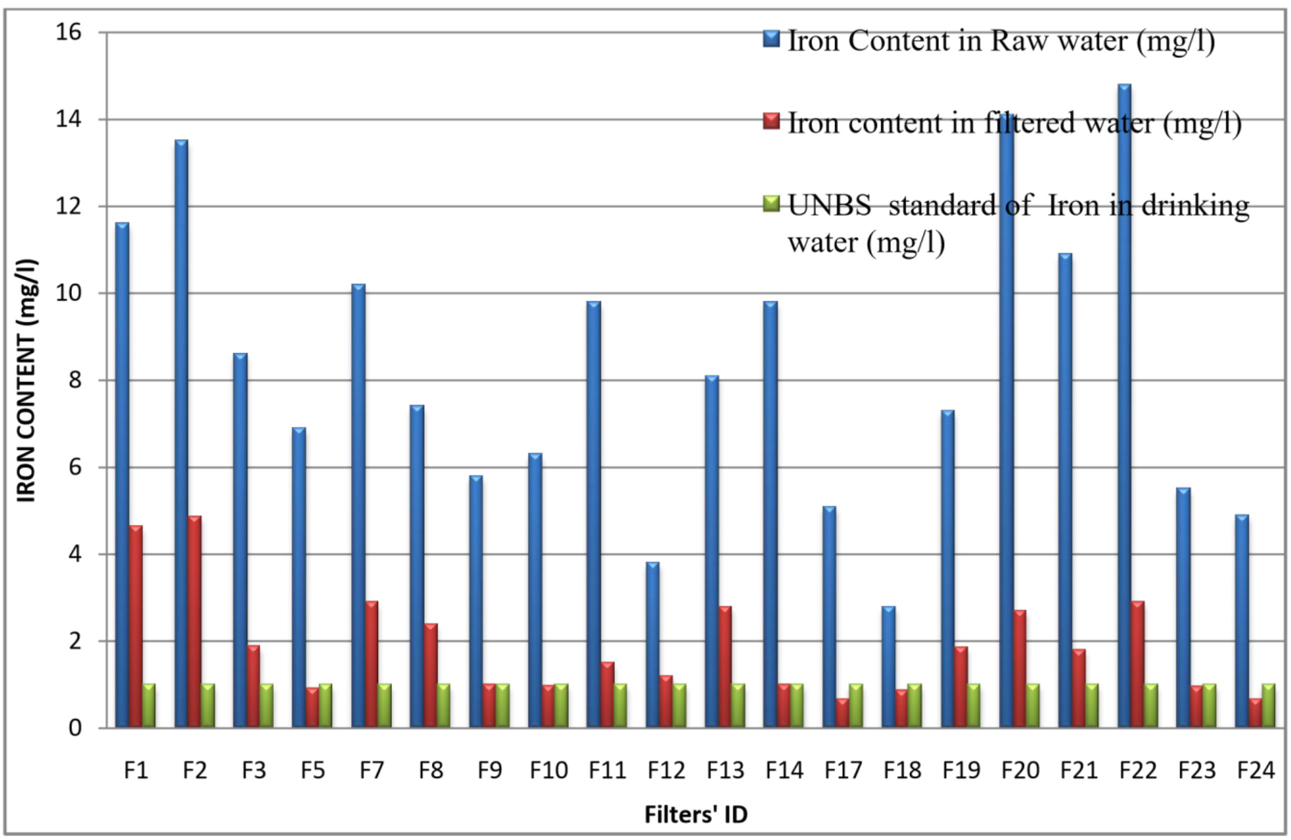
Table 4.5 pH values of water before and after filtration

Raw water before pH filtration values	**Filtered water from the BSFs pH values**	**Percentage removal of pH after filtration**	**Raw water before pH filtration values**	**Filtered water from the BSFs pH values**	**Percentage removal of pH after filtration**
7.6	6.5	14.5	8.3	8	3.6
8.5	6.6	22.4	6.8	6.8	0.0
8.2	6.8	17.1	8.3	8.2	1.2
7.1	6.5	8.5	7.2	6.9	4.2
6.8	6.5	4.4	8.3	8	3.6
8.1	7.9	2.5	8.1	8	1.2
8.5	6.8	20.0	6.8	6.3	7.4
7.7	6.9	10.4	8.4	8.2	2.4
7.8	7.2	7.7	8.3	8	3.6
8.5	8.2	3.5			
8.5	8.4	1.2			
Average results			**7.85**	**7.26**	**7.4%**

Source: the researcher

4.1.4.2. Iron Test Result

The filters' average efficiency removal of iron in water was 78% with only 8 filters (40%) out of the twenty producing filtered water within the recommended maximum permissible limit for drinking water according to the WHO and the Uganda National standards which requires iron content in water not to exceed 1mg/l. Filtered water from the remaining 12 filters (60%) never met this condition. However, Iron does not have an impact on health, but cause discoloration of the water, staining of clothes and may impart an unpleasant taste which cause problems with the acceptability of the water and may cause consumers to reject a water source that is otherwise of good quality.



Graph 4.4: shows the iron content in water before and after filtration

4.1.5. Conclusion for the water quality test results

The results show that, the Biosand filter is more effective for removing Turbidity in water with an average efficiency of 88% and 18 filters (90%) out of twenty filters produced filtered water with turbidity within the maximum allowable limit of turbidity in water for domestic purposes as per the Uganda National standard which requires turbidity not to exceed 10NTU.

Biosand filters removed Total Coliform and E. Coli to a reasonable level. Although, its average efficiency in removing E. Coli and Total Coliform was 96.1% and 96.3% respectively, the filtered water from all the 20 filters still had coliform with an average of 7CFU per 100ml. This implies that Biosand Filter is not 100% effective in removing coliform and risks of outbreak of diseases still exist if the filtered water is consumed without further treatment. However, it can still be used alongside any of the disinfection methods since the turbidity of the filtered water is within the required limit.

Biosand filters is also not very effective in removing iron in water with an average removal percentage of 78% with only 08 filters which producing filtered water that met the Uganda National and the World Health Organization standards which require iron content in water not to exceed 1mg/l.

There is little significant change in the pH before and after filtration with an average percentage reduction of 7.4%. However, all the pH values both before and after filtration were within the required maximum permissible limits which is in the range of 6.5-8.5 as the WHO and National standards.

4.2. EFFECTS OF USERS' PRACTICES ON THE PERFORMANCE OF BIOSAND FILTERS

The technical performance of the BSF can be influenced by many factors, from technology design to manufacturing quality to operation and maintenance.

CAWST recommends checking selected key operating conditions to ensure that the Biosand filter is working effectively. If a Biosand filter is not being operated properly, then you can assume that it is not working effectively. The eight key operating conditions for checking include;

- Filter is used for at least one month since installation.
- Filter is used at least once each day.
- Source water is not too turbid (less than 50 NTU).
- The concrete filter body is not leaking.
- Diffuser is in place and in good condition.
- Water level is 5 cm above the sand during the pause period.
- Top of sand is level.
- Flow rate is 0.4 liters per minute

4.2.1. Physical Observation Results

The following were the observation results;

- 19 filters out of 25 had either wooden or metal plugs attached to the spout.
- 05 filters had floating diffuser plates
- 05 filters had diffuser basins
- 2 filters had its top fine sand layer disturbed
- 02 filters had standing water and their resting water level were greater than 5cm above the top fine sand.
- Two filters had cracks on its body
- One filter never had its lid

Discussion of the physical observation results

4.2.1.1. Spouts Attachment

Of the twenty-five BSFs that were investigated, nineteen had spigots or wooden/metal plugs attached to the spout and six had no such attachments. Presence of a spigot does not mean blocked flow; it merely gives the user the option to stop the flow of water. Stopping the flow for extended periods of time (especially when water has just been poured in) is not favorable to the growth or sustenance of the biology in the filter since oxygen diffusion is reduced.

On the other hand, users of the filters like the flexibility afforded by a tap; they do not have to constantly attend to the filter or worry that water might overflow and flood their homes. To solve this conflict of interest, some have come up with the idea of an intermediate, storage container as shown in Figure 5. The spout leads directly into the intermediate storage container which has a tap allowing the users to dispense water when needed. This solution removes the need to plug the spout and the need to constantly attend to the filter. However contamination could occur during storage, particularly if the containers are not cleaned and occasionally disinfected.

Figure 4.1 BSFs with spout attachment

4.2.1.2. Diffuser Plate and basin

Of the 25 BSFs that were investigated, 20 had diffuser plates and the remaining five had diffuser basins. All the diffuser plates were made of LDPE and the diffuser basins were made of metal; of the diffuser plates, 5 were found to float when water was poured in, as shown in Figure 6. This is an undesirable condition because a floating diffuser plate is not supported by the inner ledge of the BSF and thus has the additional degrees of freedom on the horizontal plane. Thus, when more water was poured in at one side of the filter, the diffuser plate would be free to tilt downwards in response to the force derived from the weight of the water. This allows more significant numbers of harmful organisms, suspended solids to pass through the filter and this may damage the top sand layer and the bio-layer. Such a condition reduces the effectiveness of the BSFs.

Figure 4.2 A floating plastic diffuser plate

Figure 4.3 Diffuser basin made of steel

4.2.1.3. Sand Layer

Out of the 25 BSFs that were investigated, two had disturbed top sand layer (see Figure 7). Such a condition affects the effectiveness of the filter because it is the sand layer that removes the pathogens and suspended solids. The disturbed sand could be as a result of hydraulic scouring of the sand or human hands.

Figure 4.4 disturbed top layer of fine sand

4.2.1.4. Water level

Out of the 25 filters, there is always standing water in 02 filters and its resting water level is greater than 5cm above the top fine sand and one filter had its water depth less than 5cm.

According to the CAWST, water depth of greater than 5 cm (2″) results in lower oxygen diffusion and consequently a thinner bio-layer. This can be caused by a blocked outlet tube, an insufficient amount of sand installed in the filter. On the other hand, a water depth of less than 5 cm (2″) may evaporate quickly in hot climates and cause the bio-layer to dry out. A low water level may be caused by too much sand being put into the filter during installation. Therefore, both of these conditions affect the filters" effectiveness.

Figure 4.5 Water level at rest greater than 5cm above the topmost sand level

4.2.1.5. Cracks in Concrete Body

Only 2 BSFs out of the 25 investigated had cracks in the concrete shell. One was mended using cement paste while the other was not mended. This means that the sand and the gravel layers are not held tightly since it is the filters' body that holds the sand and gravel layers whose purpose is to remove pathogens and suspended solids. Therefore, the filters' effectiveness is reduced when these two layers are disturbed and not held properly.

4.2.1.6. Filters' lids

One filter never had the lid. The concerned community claimed that it was supplied without the lid. This condition also affects the filter's effectiveness since the filter is always left uncovered and this allows other contaminants and insects into the filter.

4.2.2. Questionnaire Results

- All the filters were in use for 1 -3 years
- 22 filters out of 25 were used daily for at least 2 weeks before the research

- Filtered water taste better than the unfiltered water due to the cooling property of the filter
- 19 households used water from the same source for their filters whereas 6 Households do not because some water points are seasonal
- The water sources used are boreholes, Hand dug wells, Protected and Unprotected springs
- The bio-layers in the filters were not given time to re-established when the source water is changed.
- 6 Households lack the technical knowledge to check the 8 key good operating conditions for the filters.

Discussion of the questionnaire results

All the twenty-five filters investigated for this study have been in used for 1-3 years. 22 filters (88%) have been used daily for the past 2 weeks while the remaining three have not been used daily for the past two weeks. This condition affects the effectiveness of the filter since these filters are supposed to be used daily. According to CAWST 2010 BSF manual, Water should be added to the filter at least once a day, but not more than 4 times a day and not more than 3.75 litres of water should be added to the reservoir each time.

Of the 25 households visited for this study, 19 households used water from the same source for their filters (76%) and the remaining six (24%) do not use water from the same source for their filters. This is because some water points are seasonal and they dry up especially during dried seasons, this forces the households to look for an alternative source of water. However, these communities do not always allow the bio-layer in the BSFs to re-establish when they change their source water. Such condition affects the filter's effectiveness because bio-layer is the key component of the filter that removes pathogens and it is an ecosystem that is suited specifically to the source water that is being filtered. If the source water is changed, the bio-layer must be reestablished (CAWST 2010). During that time, both the removal efficiency and the oxygen demand will increase as the bio-layer grows. Therefore, they must be advised that the bio-layer in their filter will need time to completely reestablish itself when the source is changed.

Out of the 25 Households visited, 19 HHs occasionally checks some key components of the Biosand filters for its effective use (maintenance) where as six households do not because they lack the technical knowledge. Regular use, maintenance, and cleaning of the filter are necessary for its effective use. The frequency of regular maintenance is mainly dependent on the turbidity of the water being filtered. The turbidity of a water source will vary throughout the year and it will be up to the user to monitor and determine the cleaning frequency necessary. During the rainy season, when run off is high, water will likely be more turbid requiring more frequent maintenance of the Biosand filter. 03 households out of the 25 HHs visited, reported that, the filter does not produce enough water for their families and therefore, they occasionally drink unfiltered water because the filters' flow rates had gone so low. These HHs do not know how to perform the regular maintenance of their filters to restore the flow rate. A decrease in the flow rate is caused when particles accumulate between the sand grains in the filter and also, as more water is poured a biofilm will form along the top of the diffuser plate. Although slower flow rates generally produce filtered water of better quality due to idle time, it may become too slow for the users' convenience. The flow rate may go below an unacceptable rate due to buildup of the bio-layer and suspended solids in the upper layer of sand, therefore the Biosand filter will require cleaning. It is also recommended by CAWST to perform maintenance, the cleaning method known as the "swirl and dump" or wet harrowing is used to restore flow rate.

4.2.3. Performance of the Biosand filters that never met any of the eight good Operational Conditions (improperly functioning).

Table 4.6 Performance of the Biosand filters under bad operating conditions against the ones with good operating conditions

parameters	Average Efficiency of the filters under poor operating conditions (%)	Average Efficiency of the filters under good operating conditions (%)
Turbidity	62.4	87.1
E.Coli	58.2	96.1
Total Coli	57.6	94

These Biosand filters were less effective in removing Turbidity, E. Coli, and Total coliform in water with average percentage removal of 62.4%, 58.2%, 57.6% respectively compared to the

Biosand filters that were considered to be in "good operational conditions" with average percentage removal of 87.1%, 96.1%, 94% respectively. (Adopted from table 1)

All the filtered water from these BSFs (bad operational conditions) never met both the National and the World Health Organization's standards for drinking water which requires the turbidity not to exceed 10NTU, zero E. Coli and total coliform per 100ml. This implies that, the users' practices greatly impact on the performance of Biosand filters. Mistakes might also occur at the construction phase and this will in the long run affect the filter's effectiveness.

During the construction phase, there may be technical failures that would cause the cast concrete body to leak or crack as it was in two cases, a faulty (floating) diffuser plate that would reduce its protective function and this was observed in 5 BSFs, the use of inappropriate sand type would cause the flow rate of the filter to deviate from the recommended range, Installing insufficient amount of sand in the filter would cause a water depth of greater than 5 cm (2") in the filter which results in lower oxygen diffusion and consequently a thinner bio-layer. This can also be caused by a blocked outlet tube. This was observed in 2 filters. Installing too much sand in the filters would lead into a water depth of less than 5 cm (2") which may evaporate quickly in hot climates and cause the bio-layer to dry out. This was observed in only one filter out of the 25 filters.

4.3. PERFORMANCE OF THE FILTER WITH DIFFERENT TYPE OF WATER SOURCES.

Water samples were collected from four different types of water sources and tested for turbidity, E. Coli, Total coliform and iron. These water sources were; Boreholes, Hand dug wells, protected springs and unprotected springs. For each of the type of the water source, a minimum of five samples were taken and water quality analysis was done both before and after filtration. This was done to determine the performance of Biosand filters with different water sources.

4.3.1. Boreholes:

Table 4.7 Results of the filters using Borehole water

HH ID	Raw water from the source					Filtered water					Efficiency of the filters				
	Turbidity(NTU)	E.Coli (CFU/100ml)	Total Coli (CFU/100ml)	Iron (mg/l)	Ph	Turbidity(NTU)	E.Coli (CFU/100ml)	Total Coli (CFU/100ml)	Iron (mg/l)	Ph	Turbidity	Ph	E.Coli	Total Coli	Iron
HH18	58.8	191	192	4.7	8.3	0.26	1	1	0.86	8.2	99.6	1.2	99.5	99.5	81.7
HH13	80.9	69	74	8.1	8.5	6.1	3	5	2.8	8.4	92.5	1.2	95.7	93.2	65.4
HH22	32	114	143	14.8	6.8	5.1	5	8	2.9	6.3	84.1	7.4	95.6	94.4	80.4
HH5	58.8	105	108	6.9	7.1	0.7	2	3	0.92	6.5	98.8	8.5	98.1	97.2	86.7
HH14	34	80	93	9.8	8.3	2.1	3	4	1	8.0	93.8	3.6	96.3	95.7	89.8
	Average removal efficiency of the filters using borehole water (%)										**93.8**	**4.4**	**97.0**	**96.0**	**80.8**

Source: Researcher

4.3.1.1. Turbidity;

The result shows that, the turbidity of three (3) Boreholes" water after filtration met the Uganda national of standard for drinking water which requires turbidity not to exceed 10NTU whereas 2 didn't meet the standard and this maybe because of presence of inorganic particulate and non-soluble metal oxides. The average efficiency removal of the turbidity in borehole water is 93.8%

4.3.1.2. E. Coli and Total Coliform;

The filters removed E. Coli and total Coliform in borehole water with an average efficiency removal of 97.0% and 96.0% respectively. But all the filtered water never met the National standard that requires both E. Coli and total coliform not to be detected in water for drinking.

Iron:

The average efficiency of filters in removing iron in water is 80.8% with filtered water from 3 filters meeting the National standard that requires iron content in water not exceed to 1mg/l.

4.3.2 Hand dug well

Table 4.8 Results of filters using Hand dug well water

HH ID	Raw water from the HDW					Filtered water					Efficiency of the filters				
	Ph	Turbidity (NTU)	E.Coli (CFU/100ml)	Total Coli (CFU/100ml)	Iron	Turbidity	Ph	Iron	E.Coli	Total Coli	Ph	Turbidity	E.Coli	Iron	Total Coli
HH1	7.6	80.1	80	85	11.6	7.1	6.5	4.64	3	5	14.5	91.1	96.3	60	94.1
HH7	6.8	61	180	181	10.2	6	6.5	2.9	1	1	4.4	90.2	99.4	71.6	99.4
HH8	8.1	43.6	76	80	7.4	5	7.9	2.4	1	4	2.5	88.5	98.7	67.6	95.0
HH9	8.5	32.7	104	108	5.8	5.2	6.8	1	3	4	20	84.1	97.1	82.7	96.3
HH11	7.8	43	124	126	9.8	3.8	7.2	1.5	2	2	7.7	91.2	98.4	84.7	98.4
	Average removal efficiency of the filters using Hand dug well										**9.8**	**89.0**	**96.1**	**73.3**	**96.6**

4.3.2.1. Turbidity;

The results show the turbidity of water from Hand dug well before filtration never met both the National and the World Health Organization's standard for drinking water. However, after filtration, all the Biosand filters using Hand dug wells were capable of removing turbidity in water to the required National standard which is 10NTU. The average efficiency of these filters in removing turbidity in Hand dug well water was 89.0%.

4.3.2.2. E. Coli and Total Coliform;

The filters removed E. Coli and total Coliform in Hand dug wells" water with an average efficiency removal of 96.1% and 96.6% respectively. But none of these filters using Hand dug well removed E. Coli and Total Coliform to the required National standard that requires both E.Coli and total coliform not be detected in water. This implies that the filters are not 100% effectively in removing coliform in water from hand dug well. The users" practices also contributed to its ineffectiveness.

4.3.3. Unprotected spring

Table 4.9 Results of filters using Unprotected spring's well

HH ID	Raw water from UPS					Filtered water					Efficiency of the filters (%)				
	Iron	Ph	Turbidity	E.Coli	Total Coli	Turbidity	E.Coli	Ph	Iron	Total Coli	Turbidity	Iron	Ph	E.Coli	Total Coli
HH 2	13.5	8.5	82	122	134	12.0	10	6.6	4.87	12	85.4	63.9	22.4	91.8	91.0
HH 3	8.6	8.2	81	134	149	15.0	11	6.8	1.89	15	81.5	78.0	17.1	91.8	89.9
HH21	10.9	8.1	44	101	114	7.4	8	8.0	1.8	13	83.2	83.5	1.2	92.1	88.6
HH12	3.8	8.5	38.8	215	230	9.0	7	8.2	1.2	15	76.8	68.4	3.5	96.7	93.5
HH24	4.9	8.3	28.4	128	131	9.5	3	8.0	0.68	6	66.5	86.1	3.6	97.7	95.4
	Average Efficiency removal of the filters' using unprotected spring water (%)										**78.7**	**75.9**	**9.6**	**94.0**	**91.7**

Source: Researcher

4.3.3.1. Turbidity;

The average efficiency of the filters in removing turbidity in unprotected springs" water was 78.7%. 03 filters out of five using UPS water were capable of removing turbidity in water to the required National standard which is 10NTU. Filtered water from the remaining two filters had turbidity of 12.0 and 15NTU with removal efficiency of 85.4% and 81.5% respectively. These filters were less effective because their diffuser plates were found to be floating.

4.3.3.2.*E. Coli and Total Coliform;*

The filters removed E. Coli and total Coliform in UPS water with an average efficiency removal of 93.5% and 91.2% respectively. But none of these filters using water from unprotected springs removed E. Coli and Total Coliform to the required National standard that requires both E. Coli and total coliform not be detected in water. Therefore, the filtered water from all these Biosand filters using unprotected springs as their sourced water should be disinfected before use to render it safe for human consumption.

4.3.4. Protected springs

Table 4.10 Results of the filters using protected spring's water

HH ID	Raw water from PS					Filtered water					Efficiency of the filters (%)				
	Ph	Turbidity	Iron	E.Coli	Total Coli	Turbidity	Ph	Iron	E. Coli	Total Coli	Turbidity	Ph	Iron	E.Coli	Total Coli
HH23	8.4	48.0	5.5	52	57	10	8.2	0.95	3	5	79.2	2.4	82.7	94.2	91.2
HH20	8.3	56.8	14.1	97	112	6.5	8.0	2.7	9	15	88.6	3.6	80.8	96.7	93.5
HH10	7.7	19	6.3	154	160	2.8	6.9	0.97	1	3	85.3	10.4	84.6	99.4	98.1
HH17	6.8	20.5	5.1	120	125	0.8	6.8	0.68	3	5	96.1	00	86.7	97.5	96.0
HH19	7.2	91.1	7.3	25	26	10	6.9	1.87	2	3	89.0	4.2	74.4	92.0	88.5
Average Efficiency of the filters' using protected spring water (%)											**87.6**	**4.12**	**80.84**	**96.0**	**93.5**

Source; Researcher

4.3.4.1. Turbidity;

All the Biosand filters using water from protected springs produced filtered water with turbidity of less than 10NTU. The National standard requires turbidity in water for domestic purposes not to exceed 10NTU. Therefore, filtered water from all these filters met the above stated condition with an average efficiency of 87.6%.

4.3.4. 2. E. Coli and Total Coliform;

The filters removed E. Coli and total Coliform in protected springs" water with an average efficiency removal of 96.0% and 93.5% respectively. But none of these filters using water from protected springs removed E. Coli and Total Coliform to the required National standard that requires both E.Coli and total coliform not be detected in water. This implies that there is still risk of outbreak of water related diseases if the filtered water is consumed without further treatment.

4.3.5. The conclusion of the performance of the filters using different water sources.

There are high levels of contamination in all the four water sources with E. coli and total coliform reaching levels of over 200 CFU/100ml being observed. Surface water sources (Hand dug well, springs) is more contaminated than the ground water source (Borehole).

In all the four different water sources, Biosand filter was more effective in removing Turbidity in water with an overall average efficiency removal of 87.3%. Filtered water from 90% of the filters met the national standard which requires turbidity not to exceed 10NTU.

Biosand filters using Water from Boreholes performed better than the other three types of water sources followed by Hand dug wells and then protected springs whereas the Biosand filters using unprotected springs, water had the worst performance.

It can be concluded that the type of source water passed through the filter and the level of contamination does affect the efficiency of the filter. The most efficient filters were filters using Boreholes" water. Therefore, Biosand filters are more effective in treating source water with low turbidity.

4.4. Chlorine Tables

Chlorine tablets are used to disinfect settled and filtered water. Chlorine tablets containing the necessary dosage for drinking water disinfection can be purchased in a commercially prepared form. These tablets are available in drug shops and even sporting goods stores and should be used as stated in the instructions. When instructions are not available, it is recommended to use two chlorine tablets for every 20 liters of water to be purified and allow it stand for at least 30minutes before use. The residue chlorine after the 30minutes stand by will be 0.2mg/l which is the recommended chlorine content in water for human consumption.

4.5. Cost Analysis

Cost of the Biosand filter = 150,000/=

A household use about 20 liters of water for drinking daily. This means that, they need 2 chlorine tablets to disinfect the 20litres of filtered water for drinking.
Each chlorine tablet costs shs. 250/=

The total cost of chlorine tablets per Household per annual = (2*1*250*365) = 182,500/= p.a

The Total cost of the Biosand filters and chlorine tablets = (150,000 +182,500) = 332,500/=

Estimated Cost of medication and other related expenses per household per annual is 1,000,000/= (one million)
Therefore, Savings = (1,000,000-332,500) = 667,500/= in the first year.

However, after the first year, each household will only be spending about 182,500/= per annual on the chlorine tablets. Hence saving about 817,500/= per annual.

CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS

5.1. Conclusion

The Biosand Filter is well accepted by users, shows a high rate of adoption, and contributes to water safety in a multi-barrier approach. Biosand filter is 96% effective in removing coliform in water but very effective in removing turbidity since all the filtered water met the National standard of turbidity which is 10NTU and less effective in removing iron since 80% of the filters never met the WHO"s standard for drinking water which requires the iron content not to exceed 1 mg/l.

The users' practices affect the performance of the Biosand filters since all the filtered water from the filters were under "bad operational conditions" never met both the National and the
World Health Organization's standards for drinking water.

It can be concluded that the type of source water passed through the filter and the level of contamination does affect the efficiency of the filter. The most efficient filters were filters using
Boreholes" water. Therefore, Biosand filters are more effective in treating source water with low turbidity.

5.2. Recommendations for Action

Basing on the result of the study, namely, the effective removal of turbidity, reduction of E. Coli and total coliform in water to a small number ranging from 1-15CFU per 100ml, the Biosand filter should continue being used and extended to rural communities with no access to improved water sources. However, this needs to go hand in hand with adoption of any of the chlorine tablets to remove the remaining 4% of Coliform in filtered water. Hence improving the water quality further.

Households that use different water sources depending on the seasons should be advised to always allow the bio-layer in their filter to completely reestablish itself when the source water is changed.

Users of BSFs need to be trained on the maintenance of the filters. This should be followed with a monitoring plan to ensure operation and maintenance procedures are followed as this will improve on the performance of the filters.

Further study to upgrade the system and redesigning of the Biosand filter by using other medium rather than sand as the filter medium is also recommended.

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APPENDICES

APPENDIX 1: WATER QUALITY ANALYSIS RESULTS FOR TURBIDITY AND pH

HOUSEHOLDS' ID	RAW WATER FROM THE C0LLECTION CONTAINER		FILTERED WATER FROM THE FILTER'S SPOUT				PERCENTAGE REMOVAL	
	Turbidity (NTU)	pH	Filter ID	Filters' flow rate (m^3/hr)	Turbidity (NTU)	Ph	Turbidity (NTU)	pH
HH 1	80.1	7.6	F1	0.08	7.1	6.5	91.1	14.5
HH 2	82	8.5	F2	0.15	12	6.3	81.7	25.9
HH 3	81	8.2	F3	0.18	15	6.8	81.5	17.1
HH 5	58.8	7.1	F5	0.09	0.7	6.5	98.8	8.5
HH 7	61	6.8	F7	0.1	6	6.5	90.2	4.4
HH 8	43.6	8.1	F8	0.12	5	7.9	88.5	2.5
HH 9	32.7	8.5	F9	0.1	5.2	6.8	84.1	20.0
HH 10	19	7.7	F10	0.11	2.8	6.9	85.3	10.4
HH 11	43	7.8	F11	0.09	3.8	7.2	91.2	7.7
HH 12	38.8	8.5	F12	0.07	9	8.2	76.8	3.5
HH 13	80.9	8.5	F13	0.11	6.1	8.4	92.5	1.2
HH 14	34	7.5	F14	0.1	2.1	6.8	93.8	9.3
HH 17	20.5	8.3	F17	0.07	0.8	8	96.1	3.6
HH 18	58.8	6.8	F18	0.1	0.26	6.8	99.6	0.0
HH 19	91.1	8.3	F19	0.12	10	8.2	89.0	1.2
HH 20	56.8	7.2	F20	0.123	6.5	6.9	88.6	4.2
HH 21	44	8.3	F21	0.065	7.4	8	83.2	3.6
HH 22	32	8.1	F22	0.05	5.1	8	84.1	1.2
HH 23	48	6.8	F23	0.098	10	6.3	79.2	7.4
HH 24	28.4	8.4	F24	0.13	9.5	8.2	66.5	2.4
AVERAGE	**51.725**	**7.85**		**0.08**	**6.368**	**7.26**	**87.1**	**7.4**

APPENDIX 2: WATER QUALITY ANALYSIS RESULTS FOR MICROBIAL AND IRON

HH ID	RAW WATER FROM THE COLLECTION CONTAINER			FILTERED WATER FROM THE FILTER'S SPOUT				FILTERS' EFFICIENCY		
	E.Coli (CFU/100ml)	Total Coliform (CFU/100ml)	Iron (mg/l)	Filters' flow rate (m^3/hr)	E.Coli (CFU/100ml)	Total Coliform(CFU/100ml)	Iron (mg/l)	E.Coli	Total Coliform	Iron (mg/l)
HH 1	80	85	11.6	0.08	3	5	4.64	96.3	94.1	60.0
HH 2	122	134	13.5	0.15	10	12	4.87	91.8	91.0	63.9
HH 3	134	149	8.6	0.18	11	15	1.89	91.8	89.9	78.0
HH 5	105	108	6.9	0.09	2	3	0.92	98.1	97.2	86.7
HH 7	180	181	10.2	0.1	1	1	2.9	99.4	99.4	71.6
HH 8	76	80	7.4	0.12	1	4	2.4	98.7	95.0	67.6
HH 9	104	108	5.8	0.1	3	4	1	97.1	96.3	82.8
HH 10	154	160	6.3	0.11	1	3	0.97	99.4	98.1	84.6
HH 11	124	126	9.8	0.09	1	2	1.5	99.2	98.4	84.7
HH 12	215	230	3.8	0.07	7	15	1.2	96.7	93.5	68.4
HH 13	69	74	8.1	0.11	3	5	2.8	95.7	93.2	65.4
HH 14	89	93	9.8	0.1	3	4	1	96.6	95.7	89.8
HH 17	120	125	5.1	0.07	3	5	0.68	97.5	96.0	86.7
HH 18	191	192	4.7	0.1	1	1	0.86	99.5	99.5	81.7
HH 19	25	26	7.3	0.12	2	3	1.87	92.0	88.5	74.4
HH 20	97	112	14.1	0.123	9	15	2.7	90.7	86.6	80.9
HH 21	101	114	10.9	0.065	8	13	1.8	92.1	88.6	83.5
HH 22	114	143	14.8	0.05	5	8	2.9	95.6	94.4	80.4
HH 23	52	57	5.5	0.098	3	5	0.95	94.2	91.2	82.7
HH 24	128	131	4.9	0.13	3	6	0.68	97.7	95.4	86.1
AVERAGE				**0.08**				**96.0**	**94.1**	**78.0**

APPENDIX 3. QUESTIONNAIRE FOR HOUSEHOLD USING BIOSAND FILTERS

KAMPALA INTERNATIONAL UNIVERSITY
SCHOOL OF ENGINEERING AND

APPLIED SCIENCE

P.O BOX 20000, KAMPALA

Dear respondent,

We are students of Kampala International University in our final year of study pursuing a bachelor's degree of Science in Civil Engineering. We are carrying out a research study entitle
"***Evaluating the effectiveness of Biosand filter"*** a case study of Orom Sub County. This study is part of the requirements leading to the award of above stated degree programme.

It is upon this, that we kindly request you to respond to this questionnaire with all the honesty and sincerity. The information you will provide will be entirely for study purposes and it will be treated with utmost confidentiality.

The researcher does not have enough funds to pay you for responding to the questions in this form but your positive response is highly appreciated.

Thank you.

1. What is your name? (Optional)____

2. Age bracket ☐ 10-25 ☐ 26-30 ☐ 31-35 ☐ 36-above

3. Gender ☐ Male ☐ female

4. For how long have you used the filter? ☐ <1yr ☐ 1-3yrs ☐ 3-5yrs ☐ 5yrs -above

5. Do you occasionally drink your water without filtering it? ☐Yes ☐No

6. Have you used your filter each day for the last 2 weeks? ☐Yes ☐No

7. Do you ever use your storage bucket to carry unfiltered water? ☐Yes ☐No

8. Is there always standing water in your filter? ☐Yes

   ☐No

9. Does filtered water taste better than unfiltered water? ☐Yes

   ☐No

10. Do you always use water from the same source for your filter? ☐Yes ☐No

11. If yes, which water source do you always use? ☐Borehole ☐Protected spring

    ☐ unprotected spring ☐Hand dug well ☐shallow well ☐piped water

12. If no, do you always allow the bio-layer in the filter to reestablish when you change the water source? ☐Yes ☐No

13. Has anyone in your family had water related diseases such as diarrhea, cholera, typhoid in the past 1 month? ☐ Yes ☐ No. (please note the diseases)

14. How often do you use the filter? ☐ daily ☐ weekly ☐ monthly

15. Do you occasionally check some key components of the biosand filters for its effective use (maintenance)? ☐ Yes ☐ No

If yes, explain____
____

16. Does the filter produce enough clean water for the entire household? ☐ Yes ☐ No

17. Have you had any problems with the filter? ☐ Yes ☐ No

If yes, what were the problems? ____
____

18. Since you started using the filter, do you think your family's health has improved, stayed the same, or became worse? ☐ improved ☐ remained the same ☐ worsen

PHYSICAL OBSERVATION BY THE RESEACHER

19. Does the filter have attachments to the spout? ☐ Yes ☐ No

If yes, please specify the kind of attachment___________________________________

21. Does the filter have diffuser plates? ☐Yes ☐No

If yes, please specify the materials they were made of _________________________

22. Does the diffuser plate float when water is being poured in the filter? ☐Yes ☐No

23. At water level does the water level rest below or above the top layer of the fine sand?

☐ below 5cm ☐above 5cm

24. Does the filter concrete Body have Cracks? ☐Yes ☐No

APPENDIX 4. WATER QUALITY SAMPLING AND ANALYSIS FORM FOR RAW WATER FROM THE COLLECTION CONTAINER/ JERRICANS

NAME OF THE SAMPLE COLLECTOR________________________ SAMPLE No.________

SAMPLING DATA

SOURCE NAME________________________SOURCE TYPE_________________________

HOUSEHOLD ID_________________________

DATE OF SAMPLING_______________________________

TIME OF SAMPLING_______________________________

DATE OF ANALYSIS_______________________________

TIME OF ANALYSIS_______________________________

RESULTS:

pH_________________________________

TURBIDITY______________________________NTU

E. Coli______________________________ CFU/100ml

TOTAL COLIFORM_______________________CFU/100ml

IRON______________________________/mgl

REMARKS;

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APPENDIX 5 WATER QUALITY SAMPLING AND ANALYSIS FORM FOR FILTERED WATER

NAME OF THE SAMPLE COLLECTOR________________________ SAMPLE No.________

SAMPLING DATA

SOURCE NAME________________________SOURCE TYPE_______________________

HOUSEHOLD ID_______________________

FILTER ID_______________________

DATE OF SAMPLING________________________________

TIME OF SAMPLING________________________________

DATE OF ANALYSIS________________________________

TIME OF ANALYSIS________________________________

RESULTS:

pH__________________________________

TURBIDITY______________________________NTU

FILTER FLOW RATE__________________m^3/hr

E. Coli_______________________________ CFU/100ml

TOTAL COLIFORM_______________________COUNTS/100ml

IRON_______________________________/mgl

REMARKS;

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