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Showing the efficiency of Bio-Sand filters by setting up a testing program for use with and by Tanzanians.

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Submitted in accordance with requirements for BSc Honours in Environmental Science

I confirm that the number of words is 10000, excluding abstract, acknowledgements, table of contents, tables, figures, references, appendices and quotations from primary data

I declare that this piece of work is all my own and that any work by others has been acknowledged

Signed: Date:

ABSTRACT

In the developed world, access to clean water is the norm. Elsewhere it is often just a dream and even when found is unsafe to drink.

The aim of this project was to investigate the efficiency of Bio-Sand filters in Tanzania. The quality of source water, water after filtration and stored filtered water was tested. Filter efficiency was calculated by comparing levels of *Escherichia coli (E. coli)*. The presence of E. coli provides conclusive evidence of recent faecal pollution and should not be present in drinking water (WHO, 2006).

The project sought to establish that filters provided clean water within WHO guidelines. Further investigations considered removal efficiencies over time from filter installation, the influence of filter age, levels of E. coli in stored filtered water and the effects of different water sources.

A Tanzanian was trained in testing procedures and analysis so monitoring could continue after this research project.

This project showed that 36% of filters tested produced water within WHO guidelines (0 E. coli/100ml). 93% of the filters worked within acceptable range of E. coli (0-10 E. coli/100ml) whatever the water source. Generally, filters produced clean drinking water after 4 weeks, but reached peak efficiency after 8 weeks.

ACKNOWLEDGEMENTS

Thanks to all the people who have helped me through my Independent Research Exercise (IRE) and Years at Birmingham University, including the following:

Dissertation Supervisor, Gillies Pinnay, who offered invaluable advice and guidance all the way from the start of the project till the day this IRE was handed in. Who took the time to read through my various drafts and check my numerous graphs.

Tutor, Melanie Bickerton, whose help throughout my course and support when difficulties have arisen with my unique family conditions has guided me through my choices for modules which have stimulated my learning at this institute.

NGO leaders, Todd and Ann Ziems, for the help in making this project possible and their ongoing support throughout the long and hard write up.

Supporting Technician and Trainee, Emmanuel Abel, who I spent a great 2-3months working with: He was a delight to work with and it was my privilege to offer him the training he needed. His translational skills and knowledge of the local culture were invaluable.

Building and Delivery staff at MCD (Micro Community Developments), for their help throughout this project and the great times we had eating lunch (ugali and beans) and their hospitality toward to me.

To all the Tanzanians who allowed my team to test their filters at their homes and the hospitality we received when entering every house.

To my Sister, Hannah, and Brother in law, Charlie, for their encouragement and support throughout this entire project.

First and foremost, to my Dad and Mum, whose endless love, encouragement and hard work have helped create my final IRE piece; they have spurred me on to do my best and so much more.

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1. Introduction

1.1 General Overview

Our Earth is known to many as the blue planet as 70% of its surface is covered by water. However only 3% of this water is fresh water and can be utilized easily; the other 97% is saline. Furthermore most of the 3% is held within inaccessible or unavailable bodies. This appears to be a very small percentage of the total water on the planet but still equates to 104,620 km^3 which we are able to use.

Access to safe drinking water and basic sanitation are essential human needs. Being able to turn on a tap and fill a glass of water to drink is something we tend to take for granted but the quality of the water at any tap depends on many factors going all the way back to the original source of the water, how it has been treated and how it has been distributed to the tap (Parsons & Jefferson, 2006). People need clean water and sanitation to sustain a healthy life and an established goal of the World Health Organisation (WHO) is that all people, whatever their stage of development and their social and economic conditions, have access to an adequate supply of safe drinking water (WHO, 2004). In 2008 1.1 billion people were unable to reach clean water and 2.6 billion people lacked basic sanitation (UNDP, 2006). Many of these people live in developing countries with limited resources and short life expectancies making it difficult to justify investing heavily in expensive water treatment in preference to other needs. For example, it may be preferable to invest in water distribution or in additional water resources (Binnie, Kimber 2009a).

However if this need for clean water is not met then the exposure to polluted water sources will be increased and with the WHO estimating that diarrheal diseases kill 1.6 million people every year, the situation will only get worse (Sobsey, 2008a). The biggest proportion of the 1.6 million people killed every year are children under the age of five who experience multiple episodes of diarrheal disease each year due to their exposure to dirty water through drinking and bathing and are not able to receive adequate hydration and vitamins needed to cope with the extreme amount of water loss experienced. These deaths represent approximately 15% of all child deaths under the age of five in developing countries (WHO, 2000a). It is known that interventions at 'point of use' (POU) can reduce diarrheal diseases by a mean of 40%, which gives a huge incentive to use such point of use filtration units (Sobsey, 2007). These figures are all the more shocking because they reflect the results of at least twenty years of concerted effort and publicity to improve coverage (WHO, 2000b).

The greatest source of contamination in water is from disease bearing human waste. Human waste poses great health risks for the many people who are compelled to drink and wash in untreated water from rivers and ponds (World Bank, 1992). Faecal contamination of source water is aggravated by increase in population, urban growth and expansion which leads to high pollution concentrations which cannot be removed or utilized by local natural removal mechanisms.

Developing countries encounter serious challenges when prioritising their use of available finances, whether raised internally through taxation, received from international donor countries or through NGOs. Common problems include very high per capita water production (water used in an area); a shortage of economic water resources; and low water prices combined with a lack of metering and poor revenue collection, leading to waste by customers and a lack of money for operating and maintaining systems (Binnie, Kimber 2009b). As has been the case in Tanzania, a high demand for water is associated with increasing urbanization, high rates of population growth, and increased wealth leading to wider ownership of water using appliances. Also on a basic level, people used to buying or collecting water by the bucket full and using it sparingly, lack basic education in responsible water usage because often when they first have access to a tap they are overwhelmed at its abundance and use it indiscriminately.

1.2 Tanzania: the test site

Tanzania is situated on the East African coast (see Figure 1) and has a population of 43 million people (TTNW, 2009a). Being situated between 1˚ and 12˚ South parallels, Tanzania covers an area of 881,000 km^2 with an available water resource covering 62,000 km^2, principally from the Lake Victoria, Lake Tanganyika and Lake Nyasa. It is bordered by Kenya and Uganda to the north, Mozambique, Malawi, and Zambia to the south and the Democratic Republic of Congo to the west. The country has a tropical climate with seasonal and varying ranges of temperature and rainfall. Temperatures vary between two seasons – the Hot (Nov–Feb) and Cold (May- Aug) season with highs of over 31˚C and lows of 15-20˚C respectively. With this varying temperature comes a bimodal rainfall regime for Northern Coastal regions of Tanzania. Seasonal rains occur during the months of October-December (Short rains) and March-May (Long rains), with great differences in scale. The coastal regions, including the large offshore islands of Pemba and Zanzibar, have heavier and more reliable rainfall than most of the inland areas. Average annual rainfall is almost everywhere above 1000 mm on the coast and up to 1500 mm in the wetter places. (BBC, 2009) At its peak, the rainfall is so dense that one cannot see through it.

Dar es Salaam, in the Pwani (Coastal) Region of Tanzania (see Figure 2), is the administrative and commercial capital of Tanzania with a population of 2,936,290 (TTNW, 2009b) but only 1 in 4 people have access to clean water sources (Thirst Relief International, 2009). Bagamoyo District has very old historic roots as it contains Bagamoyo Town which served as the main slave port for East Africa and today is home to a population of 248,328 (TTNW, 2009c). Mzenga is a very rural area of Tanzania and one of the poorest with a population of 4600+ and due to it being very isolated does not have any national piped water. All the water comes from shallow wells which are highly contaminated. The Tanzanian Government has stated that 58% of rural population and 15% of urban population do not have access to protected drinking water sources (WaterAid, 2006). Also according to the WHO’s 2009 World Health Statistics, Tanzania’s urban and rural community had 81% and 46% of their population respectively with access to improved drinking water sources (Table 1.1.1 – see appendix

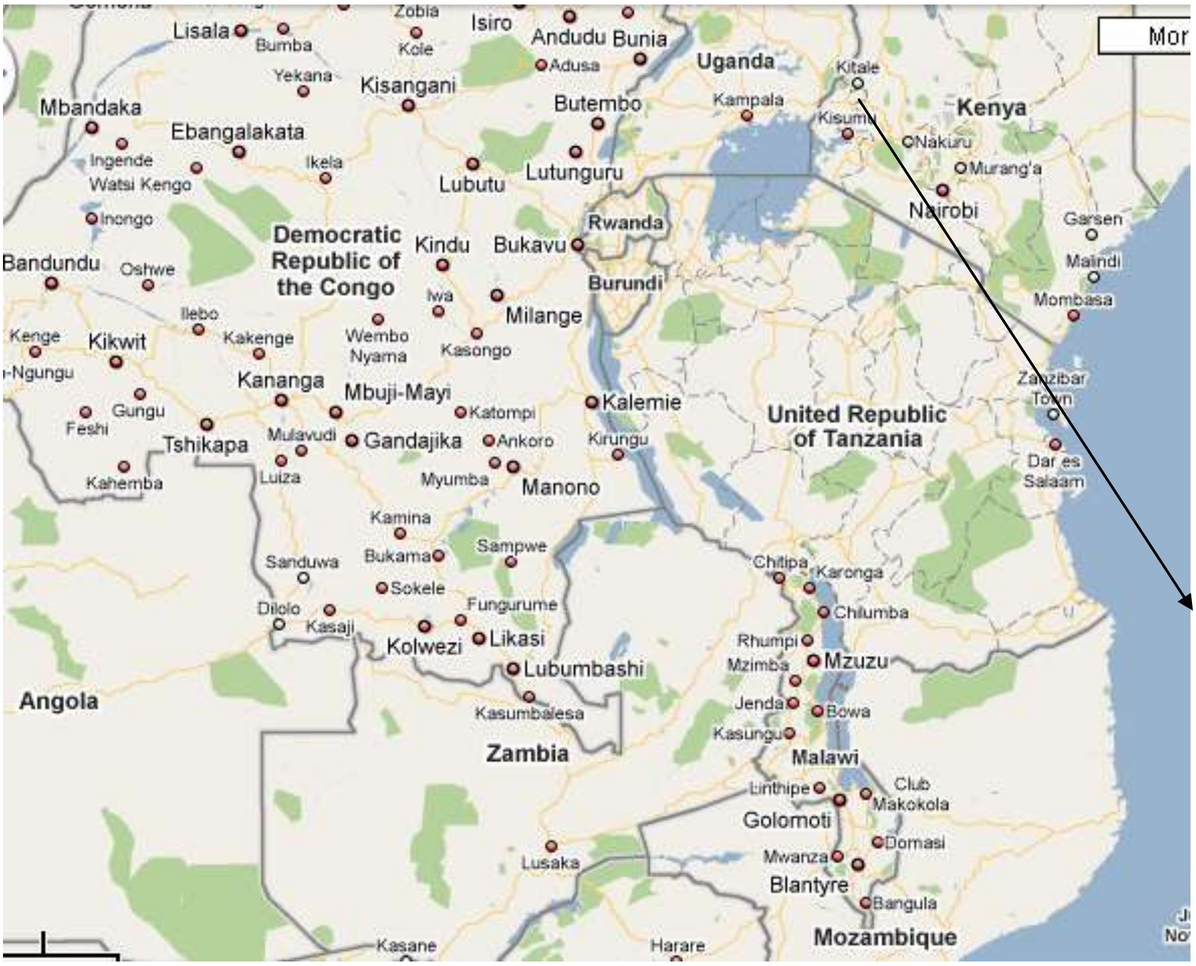

Fig 1: Map of Tanzania with its seven bordering countries (source: Google Maps, 2009)

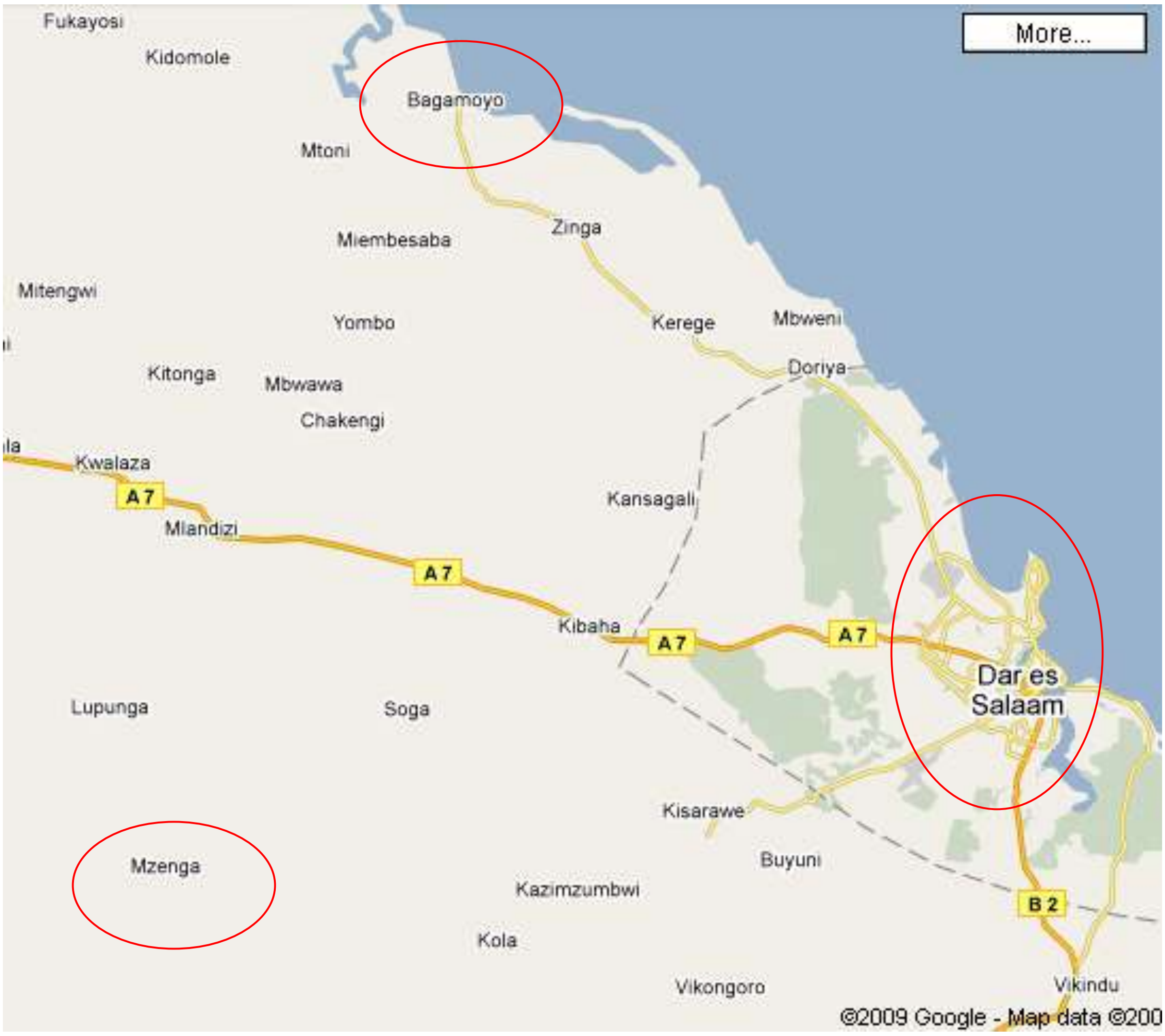

Figure 2: Highlighting the three main areas at which sampling of the Bio-Sand filters occurred (source: Google Maps, 2009)

A). Substandard water distribution systems, intermittent water pressure due to power outages and other disruptions, and illegal connections to the distribution system often lead to the introduction of faecal contamination and therefore, microbiologically contaminated water at the consumer's tap or collection point (Sobsey, 2002).

Table 1.1.2 (overleaf) shows statistics from the surrounding countries and helps to indicate where Tanzania stands relative to other developing countries. Tanzania has the 2nd highest population but has the 5th lowest percentage of the total population with access to improved water sources. This shows the country has a huge deficit resulting in a large number of Tanzanians living in conditions which are despicable and needs to be addressed. These statistics show that Tanzania is an ideal case study, to see whether a POU household method of water treatment is effective and will help to increase the availability of clean water in the rural community. POU household water treatment technology allows people to improve the quality of their water by treating it in the home (Stauber et al., 2006a).

Having lived in Tanzania for 5 years, and seen the desperate need at times of the Tanzanians, how they struggle to obtain water or access safe drinking water; this can be rectified easily by bringing in cost effective methods of water treatment and piped water/ boreholes to every area so that everyone has a fresh supply of water.

Location	Population total (in 1000's), 2006	Deaths among children under 5 yrs of age due to diarrheal diseases (%), 2000	Population with sustainable access to improved drinking water sources (%) rural, 2006	Population with sustainable access to improved drinking water sources (%) total, 2006	Population with sustainable access to improved drinking water sources (%) urban, 2006
Democratic Republic of the Congo	60644	18.1	29	46	82
Kenya	36553	16.5	49	57	85
Malawi	13571	18.1	72	76	96
Mozambique	20971	16.5	26	42	71
Uganda	29899	17.2	60	64	90
United Republic of Tanzania	39459	16.8	46	55	81
Zambia	11696	17.5	41	58	90

Definitions:

Deaths among children under 5 yrs of age due to diarrheal diseases (%) - http://www.who.int/whosis/indicators/compendium/2008/1ms5

Population with sustainable access to improved drinking water sources (%) rural - http://www.who.int/whosis/indicators/compendium/2008/2wst

Table 1.1.2 Summary of WHO statistics on surrounding countries in comparison to Tanzania

1.3 Project: Aims and Objectives

In this Independent Research Exercise one method of obtaining clean safe water – Bio-Sand Filters – will be considered and testing its removal efficiency in a Tanzanian context using membrane filtration. Incorporated into this project was the training of a Tanzanian so that the water monitoring process could be continued in the future.

Hypotheses for the project were:

1. **The filters will have a removal efficiency that provides clean water within WHO and NGO guidelines:**
   WHO guidelines state that for water to be safe to drink there should be no trace of E. coli per 100ml of water (see Table 1.3, Appendix B). NGO guidelines state that there may be between 0-10 E. coli/100ml of water, which falls within the range classed as "reasonable" by the WHO.
2. **There is no correlation between the age and efficiency of a filter;**
   It has been assumed that as filters increase in age there is no effect on E. coli removal efficiency. A recent post-implementation study of Bio-Sand filters undertaken in Cambodia (2006) also documents high levels (88%) of continued filter use for as long as 8 years post-implementation (Stauber et. al, 2008a)
3. **The E. coli levels increase once the water is stored:**
   Many of the Tanzanians do not understand that if the method of storage is not kept clean it will contaminate the clean filtered water.
4. **The type of water passed through the filter does effect the removal efficiency of the filters:**
   Different types of water have higher levels of source E. coli and therefore it would be beneficial to research at what level of E. coli the filter can produce safe drinking water.
5. **The filters are able to reach required levels of E. coli removal within 1month of installation.**
   After one month, the filters should be capable of producing water within the guidelines set if used and maintained properly.

1.4 Alternative water treatment methods

Bio-Sand filtration is not the only type of POU household water treatment available. Four other methods have been suggested;

1. Simple Chlorination with safe storage – using free chlorine
2. Combined Coagulant – Chlorine Disinfection Systems which combine dry coagulant flocculent and chlorine as a tablet which is a simple-to-use method
3. SODIS – a 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. 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
4. Ceramic Filters (fired clay) – these are made in developing countries where their filtration effectiveness and production methods can vary (Sobsey, 2008b) 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 a family's water requirements (Dies, R, 2003).

Bio-Sand filtration however has developed from a long running system and this will be discussed in the next section

2. Bio-Sand Filtration

2.1 Background and development

The Bio-Sand filter has developed from the principle of slow sand filtration. Slow sand filtration is a process involving passage of raw water through a bed of sand at low velocity (generally less than 0.4 m/hr) resulting in substantial particulate removal by physical and biological mechanisms (NSC, 2005). “Biological filtration” or “slow sand filtration”, “slow” because of how it operates under low loading rates, has been in continuous use since the beginning of the nineteenth century, and has proved effective under widely differing circumstances (Huisman & Wood, 1974a). It is simple, inexpensive, and reliable and is still the chosen method of purifying water supplies for some of the major cities in the world – London, Paris and Amsterdam. This water treatment process, the oldest of them all, is one of the least understood and the least scientific research has been carried out into its theoretical and practical application than into any other more recent but less effective methods.

The first instance of filtration as a means of water treatment dates from 1804, when John Gibb designed and built an experimental slow sand filter for his bleachery in Paisley, Scotland (Lenntech, 2008). He and others improved on the practical details, and in 1829 the method was first adopted for a public supply when James Simpson constructed an installation to treat the water supplied by the Chelsea Water Company in London. By 1852 the practise had become established, and its advantages so evident, that the Metropolis Water Act (Binnie and Kimber, 2009c) was passed requiring all water derived from the River Thames within 5miles of St Paul’s Cathedral to be filtered before being supplied to the public. In this era in time scientific understanding of pathogenic bacteria was still not realised and the slow sand filtration was merely seen as a physical strainer of suspended solids and turbidity. The idea of pathogenic bacteria came from the study by John Snow on cholera transmission. He concluded that there must be the presence of *materies morbi*, - a material derived from previous cases that could transmit infection to those who ingested it (Huisman & Wood, 1974b).

Having seen these results and conclusions, the first water tests where run in London in 1858, but did not include bacteriological parameters. Following work done by other scientists, such as Pastuer and Kock - just to name a few, these bacteriological parameters were introduced in the 1860’s and 1870’s.

However this understanding did not immediately lead to the extensive use of slow sand filtration globally. It took a clear illustration of the effectiveness of this method for the U.S.A and the United Kingdom to invest. This proof of the effectiveness of water filtration was provided in 1892 by the experience gained in two neighbouring cities, Hamburg and Altona, which drew their drinking-water from the River Elbe. Hamburg delivered its water untreated except for settlement, while Altona filtered the whole of its supply. When the river became infected from a camp of immigrants, Hamburg suffered from cholera epidemic that infected one in thirty of it population and caused more than 7500 deaths, while Altona escaped almost unscathed. (Huisman & Wood, 1974c)

Eventually, in 1914 drinking water standards were implemented for drinking water supplies in public traffic, based on coliform growth. This led to Dr Manz of Calgary University developing a practical and portable slow sand filter by making several modifications to allow for point of use water treatment and inconsistent flow through the filter. Bio-Sand filters work by water passing through the stratified layers of sand and granite. Micro-organism such as bacteria and parasites collide with and adsorb onto sand particles. These organisms collect in the top layers of the sand, gradually forming a biological zone (Biosandfilter, 2004). This zone in turn acts as an active food chain to consume disease causing coliforms, such as faecal coliforms, which can cause diarrhoea. This can lead to death in young children by dehydration.

There are two main types of sand filters which are differentiated by the way the raw water is passed through the sand medium: Pressure and Gravity fed filters.

Pressure filters are those which are used for industrial situation where large quantities of clean water are needed in a short period of time and so the water is forced through the sand medium at high pressures. These have however high initial costs, especially when the components need to be imported. Therefore these forms of sand filtration are found in the industrialized countries where they are manufactured (Huisman & Wood, 1974d).

Gravity filters consist of an open topped container which has an outlet or drainage point at its base which is then filled to a certain level with the filtration sand. Water is added and due to the force of gravity it passes down through the filter medium being purified as it passes through the sand grains (Huisman & Wood, 1974e).

There are four main elements of a sand filter which Huisman and Wood (1974f) states as the most essential elements:

1. **A raw water reservoir**, the principal function of which is to maintain a constant head of water above the filter medium... providing the pressure that carries the water through the filter.
2. **A bed of filter medium** (fine sand) within which the various purification processes take place
3. **An under drainage system** which fills the dual purpose of supporting the filter medium posing minimal obstruction to the emerging filtered water
4. **A system of control** to regulated the velocity of flow through the bed so that the water level does not drop below the highest point of the filter medium.

The above constitute the physical characteristics of slow sand filtration. It is also imperative that the purification of water is understood i.e. the mechanisms by which the purification process is carried out.

2.2 The Filtration Process

Figure 3: An example of a Bio-sand Filter (Duke et al. 2006a)

As water is added to the Bio-Sand filter the heavier suspended solids start to settle. An alga which is naturally found in water starts to absorb carbon dioxide, nitrates and phosphates and creates cell material and oxygen. This oxygen dissolves into the water where it can then be used in chemical reactions which assimilate organic impurities in the water for further algae use. Lying on top of the sand medium is an organic slimy layer, known as the schmutzdecke – filter skin, which the raw water must pass through before it reaches the sand medium. The schmutzdecke is made up of threadlike algae and a variety of species such as plankton, diatoms, protozoa and bacteria (Huisman & Wood, 1974g). This area is extremely active with the various micro-organisms trapping, digesting and breaking down organic matter. Living bacteria as well as dead algae are all consumed within this layer. With depth there is a reduction in food and therefore competition within the bacteria in the sand is extremely high and so as a consequence water having passed through 40-60cm of sand will have most of the particles and bacterium removed. Within this 40-60cms of filter medium, the water starts to pass through the sand and 4 different mechanisms have been identified with which particles in a flow of water, through a filter, may come in contact with a particle of a filter media (Binnie, Kimber, 2009d).

These are

- Coagulation and Sedimentation
- Interception
- Diffusion
- Hydrodynamic action

These mechanisms are driven by electrical forces, chemical bonding and mass attraction. Throughout the filtration process adsorption is taking place along the whole vertical and horizontal columns as the water passes slowly through the pore areas in the sand. An example of how much area there is for the water to adsorb – $1m^3$ of sand have a surface area of $15000m^2$ (Huisman & Wood, 1974h).

Coagulation and Sedimentation involves the loss of electro-chemical charges on particles in the water. When the articles become neutral they have a greater potential to clump together and settle out of the water. Pollutants and bacteria aggregate on the sediment particles as they cannot exist in solution. When the particles are moved via this method the bacteria, such as E. coli, are also removed from the water.

Interception is where a uniformly moving particle in the water flow collides with a grain of the filter media and, due to Van der Waals forces and adhesion, it sticks to the grain.

Diffusion in contrast to sedimentation involves small particles that, flowing in the stream line of water, are pulled across the water line to be removed from the solution. The removal of such small particles does not influence the total overall removal it to any great extent.

Hydrodynamic action, although not considered to be of any great significance is due to the velocity gradient formed by the moving particles in the water and the filter medium. The particle will preferentially rotate down the velocity gradient and therefore be moved towards the filter media.

3. Methodology

3.1 Membrane Filtration

Many different methods can be used to test for bacteria in water sources as has been discussed in the previous chapter. Membrane filtration has been used over a long period and has given accurate counts to bacterium (E. coli and total coliform) with E. coli being an indicator for faecal coliforms. It was used in World War II to check water quality after bombardments but was a very time consuming task. In 1947 Müller designed a membrane based method for analysis of water which produced results within 12 to 24 hrs (Madaeni, 1999). It has been developed into easy and cost effective methods which were used in this project.

The reasons this method was chosen are due to its simplicity to administer, small number of resources needed to actually run the tests successfully and it's the cost of these resources. The financial viability had to be taken into account as systems for testing and monitoring, established during the project, were to be conducted by the Tanzanians themselves in the future. Also our European educational heritage equips us to handle complex systems. In Tanzania, where the vast majority only achieves a primary education, it was important that the testing programme and procedure were simplified, clear and straightforward so that accuracy could be ensured. Once solid scientific foundations had been established and understood then other skills and tests can be developed later as part of their ongoing training.

3.2 Project Setup

Over a 3-month period in Tanzania, 300 individual samples of water were taken for two specific and different purposes. Two separate areas of the project were set up:

- the first was to test 3 new filters over a 2-month period and see how the efficiency of the filters developed over the two months.
- the second was to make spot check on 30 filters ranging in age and located in different areas and using a variety of water sources.

This was so that not only the efficiency of the filters could be verified but also to see whether after filtration the water was becoming re-contaminated. There had been reports from local people that the water coming out of a certain filter was causing illness, but it was also suspected that the individual was using dirty buckets to store her water and by doing so was re-contaminating the water.

3.3 Sample Collection

The filters were selected on the basis of the water source from which water was collected (to see if the efficiently was affected by different source waters), the age of the filters (to see if the filters maintain a high efficiency or deteriorate with age) and also they were chosen for reasons of practicality and accessibility i.e. being within 6 hrs travel of the testing site. This was because membrane filtration must be conducted within 6hrs after sampling has taken place for accurate and reliable results to be obtained after the 24hr hour incubation period.

The collection was made using Whirlpak 100ml sampling bags, by simply dipping the bag into the water and filling it to just over the 100ml black line on the bag. This method of collection was chosen due to the simplicity of use, availability of the bags, ease of transportation and the higher cost of sterilizing re-useable bottles. With the time it would take to sterilize bottles and with no real way of making sure they are 100% sterile, it was easier and less time consuming to use disposable 100ml sampling bags.

The numbers of individual samples taken per filter were 3 samples of pre-filtered source water, 3 samples post-filtration and 3 samples of the stored filtered water. This was so that an average reading could be taken for each of the three stages, the data could interrogated to see if there were any correlations between the different types of source water and final filtered water and also to see if there were any patterns between the individual samples themselves.

3.4 Sample Testing

After collection the samples were transported to the testing site in Kunduchi, an area to the north of Dar es Salaam. A cool box, with 3-4 ice blocks, was used to maintain the temperature of the samples so that the E. coli did not reproduce in number as they do in higher temperature conditions.

All the membrane filtration took place at the Kunduchi site, in a closed off section of a converted shipping container, as there was no access to the local university laboratories. The Tanzanians would continue to use the container space for testing after completing the training this summer so it was important that a dedicated area was set aside in which to set up the equipment.

Membrane filtration is a simple method having few requirements other than a lighter (to sterilize forceps and filtration apparatus), disposable gloves, disposable pipettes and a car battery for the incubator, to guard against frequent power cuts which a regular feature of life in Dar es Salaam.

Here is a step by step guide of how the membrane filtration was carried out and the equipment needed is listed in the appendix C in table 3.1.

Membrane Filtration

1. Sterilize working area with disposable cover
2. Set incubator to a temperature of 35°c
3. Put on sterilized disposable gloves
4. Label Petri dish with appropriate information i.e. Filter No. (each filter has its own ID No.), Sample ID and source water type
5. Open Petri dish and fill with 2ml of Coliscan MF broth, then close Petri dish
6. Flame the surface of the Microfil support for 3-5seconds, paying particular attention to the outer edge.
7. Open the Millipore membrane envelope by peeling back one of the easy-to-open corners. Using pre-flamed forceps, place the membrane (gridded side up) onto the centre of the stainless steel support.

8. Open a pack of 100ml funnels at the bottom. Remove a funnel (base first) from the pack. Place the funnel onto the support, taking care not to touch the inside of the funnel. Apply even pressure to the upper rim to snap the funnel firmly into position.
9. Make sure vacuum valve is shut and attach vacuum piping and syringe.
10. Pour the Sample into the funnel. Filter the sample under vacuum until all the liquid has passed through the membrane. (Closing of the valve and emptying of the syringe is appropriate if syringe is fully extended. Re-attach the syringe to the tubing and open vacuum valve and continue).
11. Close valve to vacuum. Remove funnel and discard. Press the lever positioned on the support stem (this will automatically break the vacuum, and lift the membrane from the surface of the support) and with flamed forceps remove the membrane.
12. Place the membrane into the pre-filled Petri dish; avoid trapping air bubbles under the membrane as this can adversely affect the growth of the microorganisms.
13. Leave Petri dishes to sit for up to 1hr at room temperature. After which time place in incubator for 24-48 hours at 35°c.
14. After 24-48 hours if any microorganisms are present they will have had time to be colonized and be visible in the media.
15. Take out the samples and remove lid off Petri dish
16. Using the magnifying glass and the torch, count the E. coli bacterium, shown by a dark blue coloured dot/circle. (Use the grid to help count, easiest to count along the horizontal squares, down the grid. A click-counter is a great help when large numbers are present).
17. You will obtain a number for the count of E. coli bacterium in a 100ml sample.

This was repeated for each individual sample relating to each filter, that is, the source, filtered and stored water samples. Also a control test was carried out using the same procedure, with bottled water called DASANI, to make sure the Coliscan MF broth was working properly. Pictures were taken throughout and the results were recorded first into a field note book and then transferred into an Excel spreadsheet (see Appendix D, E & F, G).

Many water sources in Tanzania have extremely high values of E. coli and some are said to be too numerous to count (TNTC), with a reading of over 200/100ml (over 200 colonies of E. coli present in one Petri dish for a 100ml sample). When this was the case the samples were diluted to 10xs or 100x the original sample before the first test was done. Shallow surface water in previous testing had been shown to have values TNTC and so it was assumed that dilution was necessary for these waters. However it was hard to know simply by inspection, when dilution was needed. It was discovered after testing that even some of the piped and borehole water levels where higher than 200/100ml and so a TNTC value of 200 was recorded in these cases.

The next chapter will show and explain in short all the results that were collected.

4. Results

4.1 Overview

Samples were collected and then tested through the membrane filtration method where it was hoped the results would prove the hypotheses stated and that the filters would be shown to be working to the guidelines set by the WHO and NGO. These guidelines state that water is drinkable/clean with a bacterium presence of 0/100ml.

However it was recommended for this project to use a range of 0-10 E. coli/100ml as an adequate bacterium level due to the improbability of getting such small readings in an African environment. A number of the filters were installed in mud or simply built concrete block houses where, even though the inside was very clean, the surrounding areas were very dusty and far from sterile. Without access to dedicated laboratory space, sterile and temperature-controlled conditions for testing and analysis could not be guaranteed.

This range of 1-10 E. coli/100ml is also used by the NGO because however desirable the theoretical guideline is; in practice in the field it is not generally attainable. It has been stated in Duke (2006b) that 0-10 E. coli/100ml can be classed as a reasonable range of E. coli in water and although not perfect it does not constitute polluted or dangerous levels.

Each of the sections to follow summarizes the data collected graphically and seeks to establish how effective the filters were and provide evidence to support the other hypotheses stated.

4.2 How soon, after installation, is a filter able to produce clean drinking water to WHO and NGO guidelines?

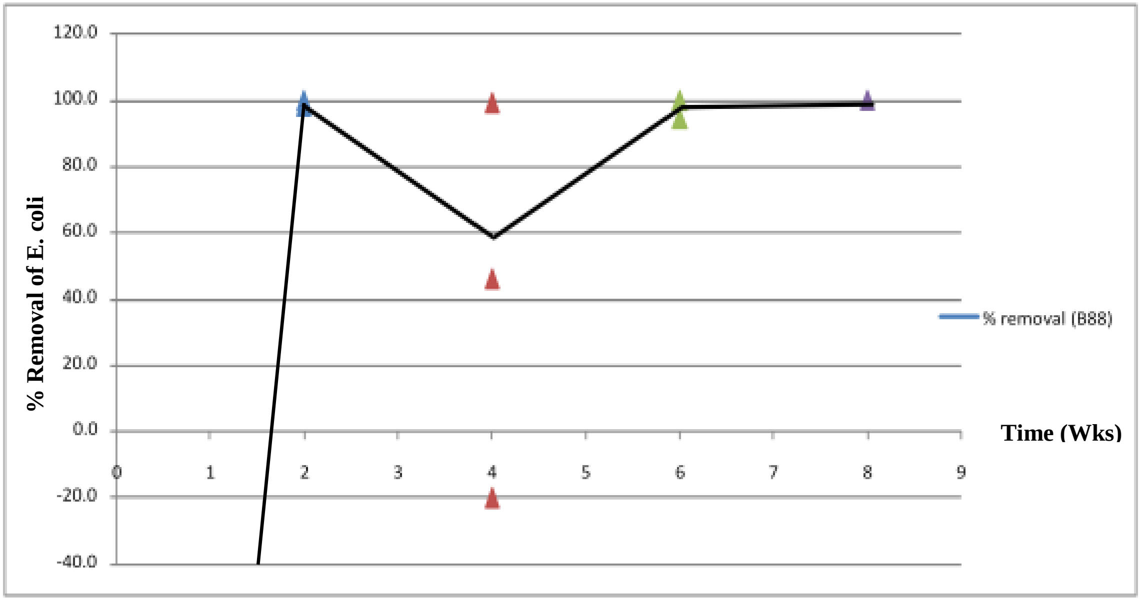

Figure 4: Percentage removal of E. coli over a period of 8 weeks for Filter B88, with the 3 different removal percentages for each week of sampling and an average removal line

In the second area of my research 3 filters were set up and tested over a period of two months from the time of installation. The aim was to see whether a statement made by the designers of the Bio-Sand filters, which stated that after 1 month the filters should be working within WHO and NGO guidelines, that is, producing water within 0-10bacterium/100ml. Each filter was used every day, by passing 20litres of water through it. It was not cleaned, unless circumstances (such as the arrival of a colony of thirsty ants) necessitated cleaning.

As shown in Figures 4 (above), 5 and 6 (overleaf) there was a degree of fluctuation in the results for each filter. However it clearly shows that a month is not a long enough time frame for the filter to be left to reduce bacteria levels to within the guidelines. However we can see that Filters O76 and B88 were at acceptable levels after two weeks, which shows that there is the possibility of filters producing clean water within a shorter time frame. For safety however it would be recommended that filters are used with precaution over the two month period. The results clearly show that after two months the bacterial cleaning layer in the filter has established itself and is capable of removing the bacteria to safe levels. In figure 4, on installation Filter B88 had a removal percentage of 3100%; it has been excluded out of the graph so that it could be show in a more presentable fashion.

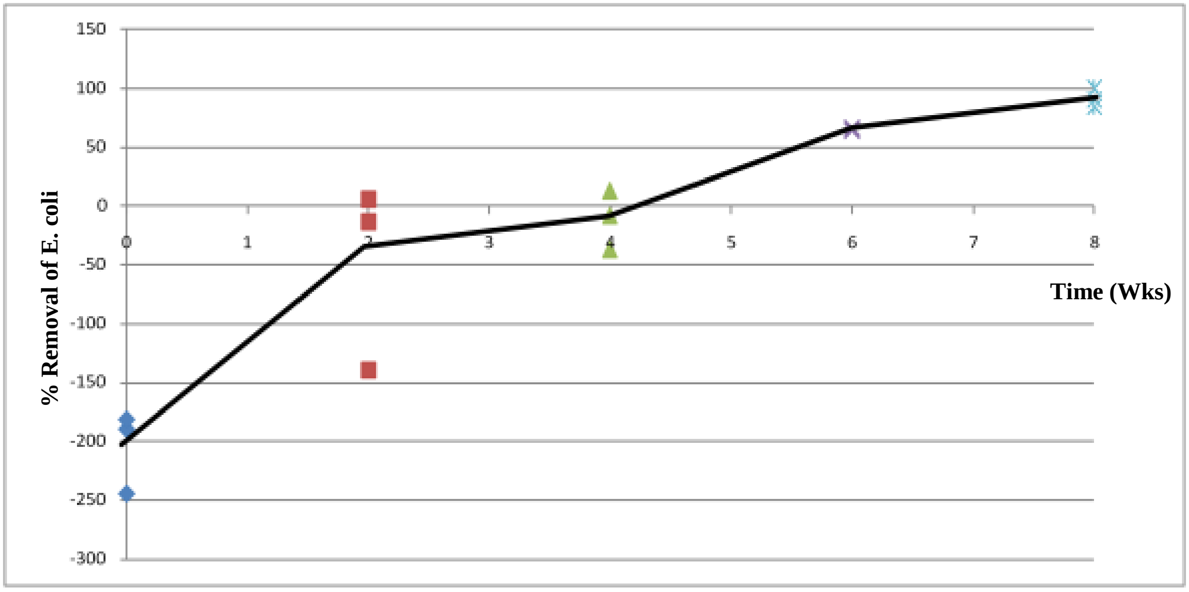

Figure 5: Percentage removal of E. coli over a period of 8 weeks for Filter B89, with the 3 different removal percentages for each week of sampling and an average removal line

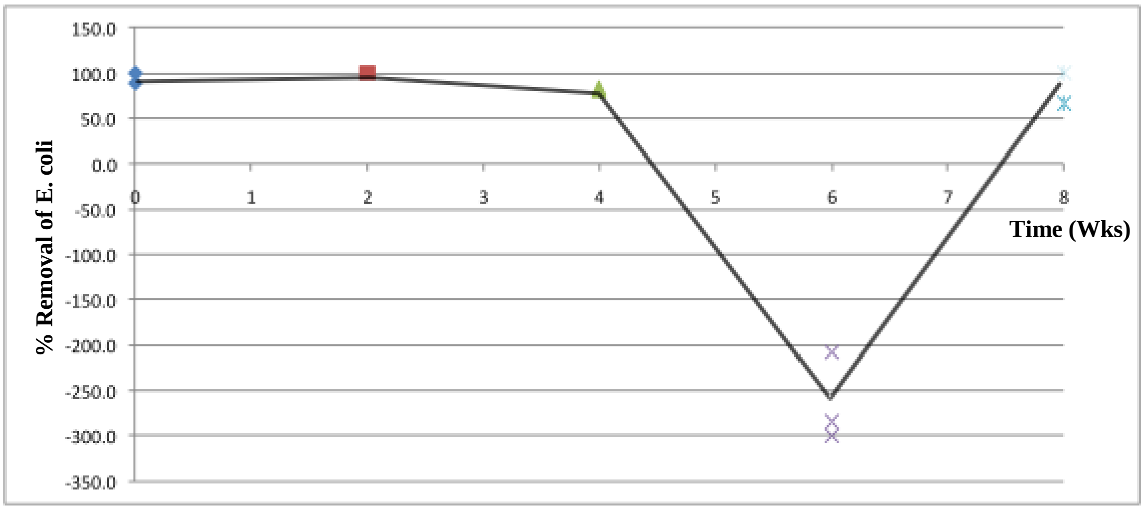

Figure 6: Percentage removal of E. coli over a period of 8 weeks for Filter O76, with the 3 different removal percentages for each week of sampling and an average removal line

4.3 Do Bio-Sand filters remove E. coli to safe recommended levels? How does a filter's age affect its ability to remove of E. coli?

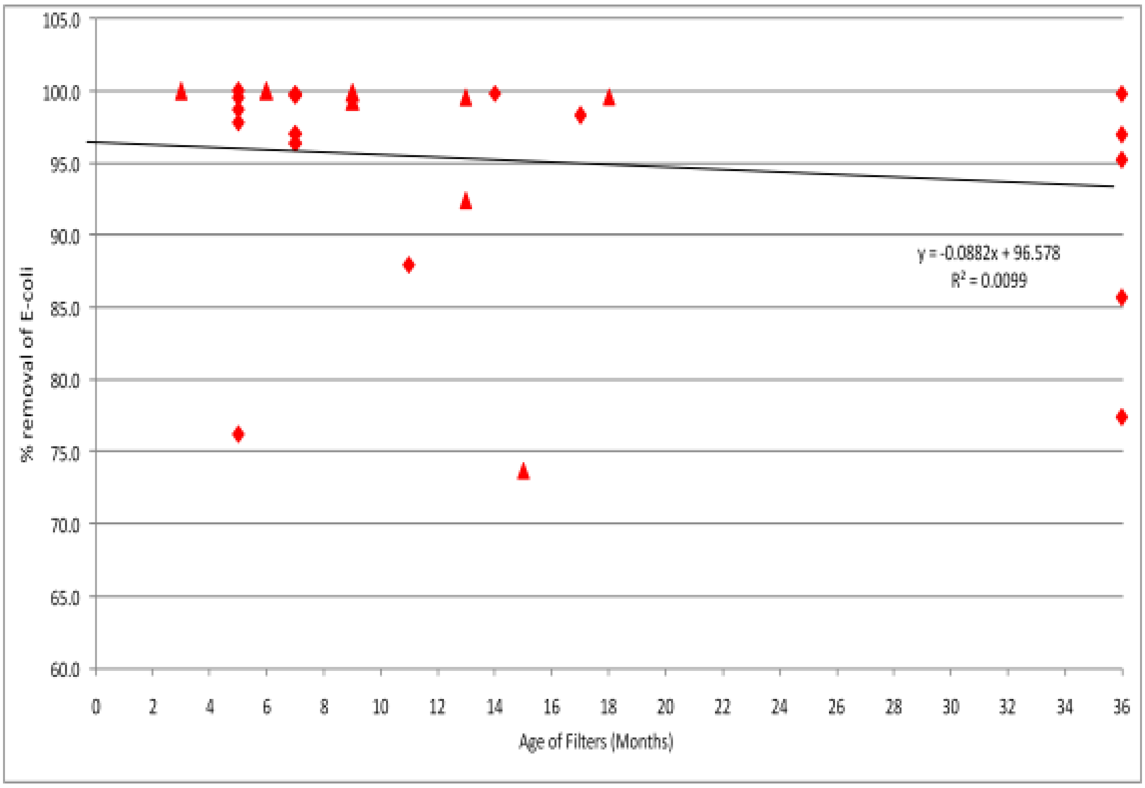

Figure 7: Percentage removal of E. coli for filters ranging in age from 3-36 months. All filters tested are shown and the average removal percentage line with the equation y = -0.0882x + 96.578

Many water treatment systems have a lifetime within which they function and produce water at acceptable standards. It was stated that the efficiency of the filters was dependent upon their age, i.e. the younger and older filters would be less efficient and that the middle-aged filters would be at their prime production. Figure 7 shows the percentage of bacteria that each filter removed by its filtration process. Looking at the data it shows a general decrease in the amount of bacteria removed through the filters as they age. The data collected showed by WHO guidelines that 19 of the 30 filters tested, were not producing drinking water to this exacting standard. However 28 filters of the 30 filters tested (93%) produced drinking water of a standard accepted, that is, within the NGO guidelines of 0-10 E. coli/100ml. This shows that the majority of the filters were within an acceptable range of E. coli (0-10/100ml). Secondly, Figure 7 shows a general decrease in the efficiency as the age of the filters increases but were still producing water with a removal percentage above 90%.

4.4 Do different types of source water affect the efficiency of the filter?

Different water types contain different levels of bacteria; therefore some sources of water are safer to drink. How do these different levels of contamination affect the efficiency of the filter?

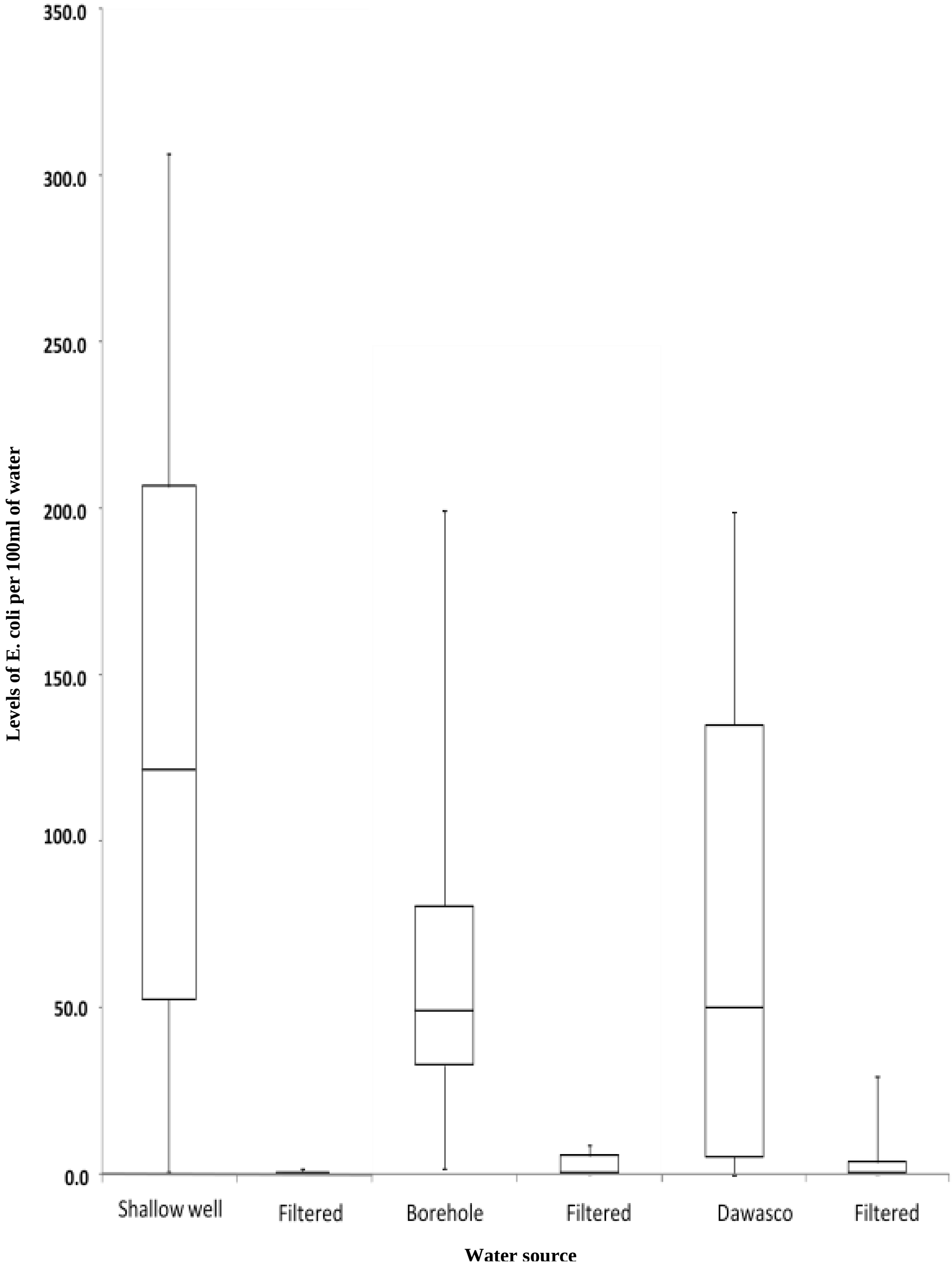

Figure 8: Box plots showing the quartiles for E. coli levels in 3 different water sources and their respective levels of E. coli after filtration through a Bio-Sand filter

In Figure 8 three different water types have been tested: these were borehole water, shallow well water, and Dawasco (**Da**r es Salaam **Wa**ter & **S**anitation **Co**mpany) water which is the piped water distributed in the Region in which samples were taken.

Figure 8 shows that there are high levels of contamination in all three of water sources with E. coli reaching levels over 200 E. coli/100ml being observed.

It was a surprise to see the level of contamination in the water sources from Dawasco. However considering the poor pipeline distribution infrastructure (pipes are cut and water stolen regularly) and that much of the water originating from Dawasco was brought to a central point in the village by ill-maintained lorries and often stored in large black plastic tanks, the opportunities for contamination are many. Indeed even collecting and carrying water from a Dawasco standpipe doesn't guarantee contamination-free water. What was even more surprising was that the filters appeared to be less efficient in removing E. coli than those using Shallow well and borehole water sources. This may be due to the fact that the Dawasco water is treated chemically and may well contain chemicals which change the bio-chemistry of the Bio-Sand filtration process. Of the Dawasco samples 26% of the filters produced water within WHO guidelines but 89% were within NGO guidelines

The filters using Borehole water as their source were able to bring E. coli levels down to acceptable standards with a few exceptions. 50% of the Borehole samples produced water within WHO guidelines and 100% within NGO guidelines.

Shallow well water is more contaminated than the other two due to the water coming into contact with soil in the upper layers, where bacteria are more prevalent and so are particulates and contaminants which the bacteria thrive on. `The spread of contamination levels is fairly even as is seen from the distribution of the quartiles, that is, the position and size of the outline box itself. However the change brought about by the filters was spectacular! The filters were able to cope with higher levels of contamination. Maybe there was more in this source of water for the bio-chemical process to engage with and maybe this intensified its ability to remove E. coli. Whatever the reasons, 75% of the filters which used Shallow well water as their source produced clean water within WHO regulations, and 100% within NGO guidelines.

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 but not to a significant extent. All types of source water were filtered to within NGO guidelines for safe drinking water and the majority to within WHO guidelines. The most efficient were filters using Shallow well water. Feedback from the NGO indicates that showing Tanzanians that a filter can turn muddy or even chalky water into pure drinking water really grabs their attention. Seeing is believing.

There were some exceptions of extremely high contamination levels such as filter B30 which will be discussed in the next main section of this report.

4.5 Is filtered water re-contaminated when stored?

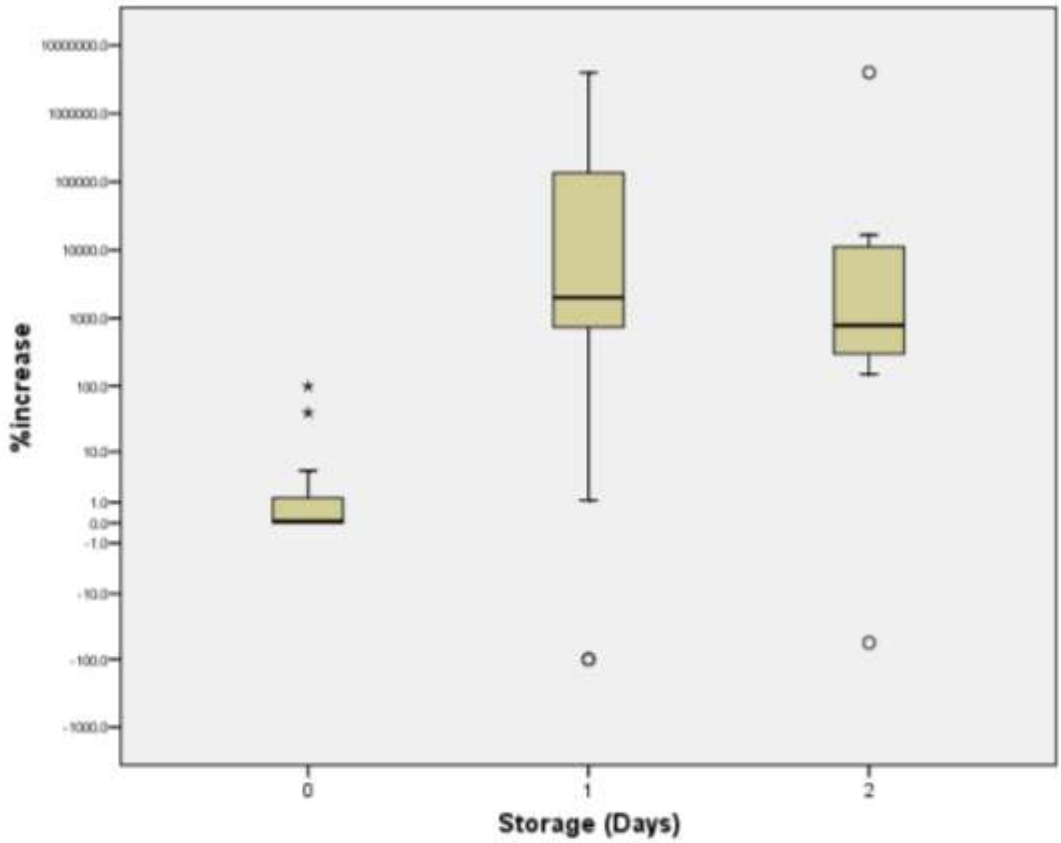

Figure 9: Showing the percentage increase in E. coli levels, on a log scale, from filtered water to stored water over different lengths of time.

The Tanzanians store their filtered water so that it could be used either later in the day or on a future day. It was suggested that many people were actually drinking re-contaminated water because the buckets they were using were dirty: Data collected (see Figure 9) shows the percentage increase of E. coli from filtered water (0days) to stored water after 24hrs (1day) and after 48hours (2days) of the water being filtered. This shows that when water is stored after filtration the percentage increase can be dramatic with levels increasing between 1000000% and 10000000% on the log scale. Highest levels of recontamination occur within the first 24 hours which means that unless the buckets are thoroughly cleaned any water stored will become infested with bacteria again. Surprisingly the water E. coli percentages did fall after 48 hours which may be due to further sedimentation whilst the water is stored. Stored water from all but two of the filters showed increased E. coli levels after being placed in buckets. This confirms that, as hypothesised, although the filters are producing water within adequate standards, there is a distinct lack of understanding about re-contamination on the part of the users.

This scenario basically renders the filtration process obsolete and needs to be dealt with so that the men, women and children using these filters are drinking water within WHO and NGO regulations even if they store it.

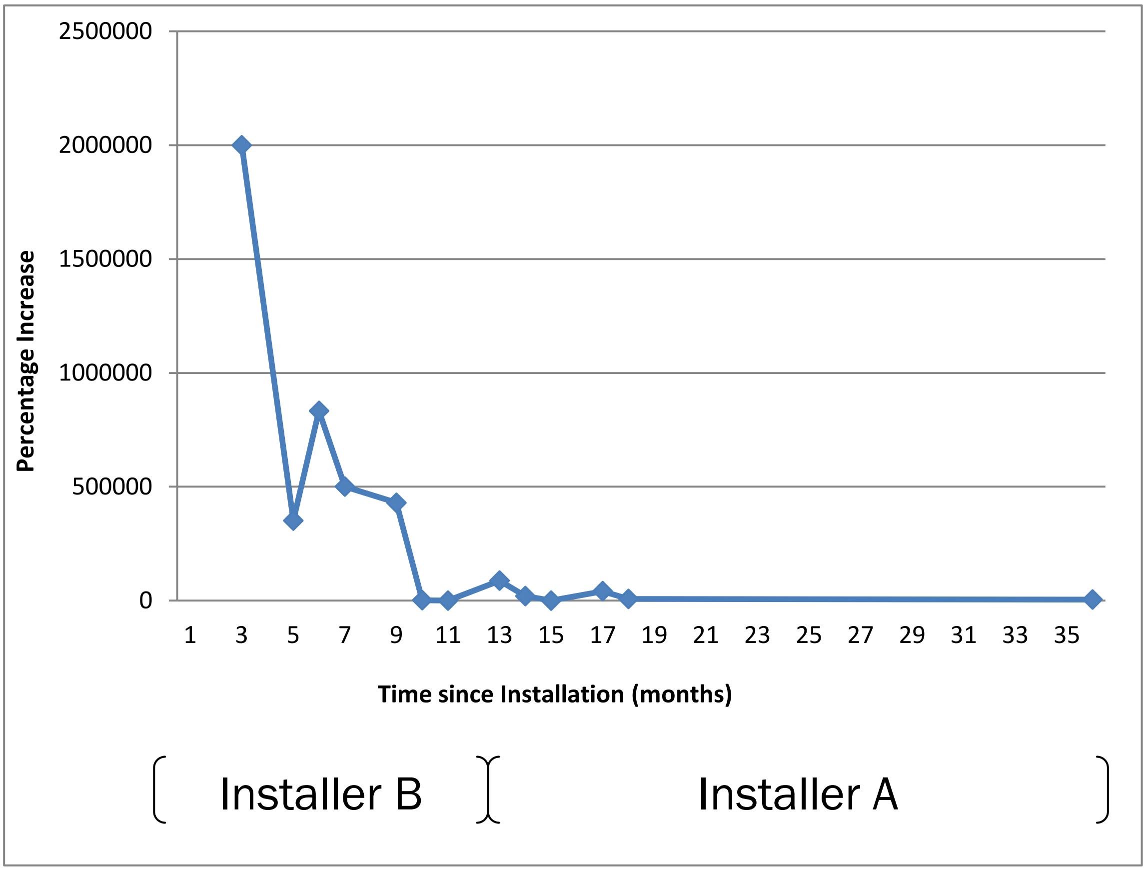

Figure 10: Percentage increase of E. coli levels in stored water and the correlation between who installed them and how much the stored water increased.

As seen in Figure 10, recontamination levels increased dramatically in stored water from filters installed within the last 10 months. Although some of stored water from the filters installed earlier have high levels of recontamination, there is clear evidence to indicate that at present the explanation and emphasis on causes of recontamination is not being stressed with the customer when the filter is installed. This lack of awareness and training is leading Tanzanians to use dirty buckets to store clean water in which undermines the value of the filter.

5. Discussion

5.1 General observations

This study found that on average 93% of the filters tested had an E. coli removal percentage of >90%. These values are well within expected data and agree with other studies. Laboratory and field studies by Stauber (2006b) examined E. coli reductions achieved by the Bio-Sand filter. During two laboratory studies, mean E. coli reductions were 94% and they improved over the period of filter use, reaching a maximum of 99%. Further field analysis conducted on 55 household filters near Bonao, Dominican Republic averaged E. coli reductions of 93% as seen in Stauber et al. (2009a). Furthermore in Stauber et al. (2008b) recent laboratory studies suggest that the Bio-Sand filter can achieve high (>99.9%) removals of parasites, moderate removals of bacteria (99–99.9%) and modest removals of viruses (80–95%). Also in Duke (2006c), a field study of 107 households was conducted to evaluate the use and performance of the Manz Bio-Sand filter in the Artibonite Valley of Haiti. The filters were found to have an average E. coli removal efficiency of 98.5%, and the filters were found to produce water in the safe or reasonable range in 97% of the cases. However, 20% of the samples from the filter spout were above the WHO limit of zero E. coli/100ml for 'safe' water.

The results obtained in this project, when placed in comparison with those conducted in the past, clearly show that the Bio-Sand filters in Tanzania achieve a performance that is well within the world averages. However, it should be noted, just as 20% of the samples in Haiti were above the WHO limit, >50% of the filters examined in this project were also above the WHO limits. Despite this, of the 93% which had a percentage removal of >90%, 100% of them produced water within safe and reasonable range.

5.2 Specific 'out-of-line' filters

Two filters that did not have a removal efficiency of >90% were filter O12 and A26 (each filter is given a letter followed by a number which helps the NGO match the filter to its corresponding background data). One of the main reasons why O12 was not producing at an efficient level was that it had never been cleaned since it had been installed – which was 15months. The filter having not been cleaned the filter for this period of time resulted in suspended particles being trapped which decreased the pore size within the filter media, and thus decreased flow rate. This reduction in pore size reduces the available surface area for the bio-chemical processes during filtration (described in Section 2.2) to take place. This reduces the efficiency of the filter to below the WHO and NGO guidelines.

In the case of filter A26, it was located in Dar es Salaam situated on the Indian Ocean coastline in an area where the water table is very high. A26 provided water for a household which had its own well which was only used when their regional piped water (Dawasco) supply was limited or cut off – this can be a regular occurrence. Having completed the questionnaire it was established that the shallow well was in fact saltwater fed and this had been used in the filter. It is not clear how the salt water affects the removal efficiency of the filter. However it may be assumed that the salt particles in the water act as a unit on which the bacteria can bind. This means that the bacteria on the salt particles are not removed through the sand filtration processes and so may need a different type of treatment.

5.3 Filter age versus efficiency

One of the variables looked at in this project was whether the age of the filters increased or decreased their removal efficiency. The results clearly show that although there is a slight decrease in the filters removal percentages, they are still producing water which is within the NGO guidelines and reasonable safe range. This slight reduction in filter efficiency may be due to the filters not being cleaned as often as they should, which as will be discussed later, which reduces the flow rate which can affect the removal of E. coli. The two filters which had decreased removal percentages were not due to its age as discussed above. Therefore it is concluded that the age of the filters does not affect the efficiency of the filter.

Having looked at how efficient the Bio-Sand filters are in Tanzania and how their age does not affect their removal percentage of E. coli, it is clear that they are working efficiently and attention must turn to a more serious problem.

5.4 Re-contamination

At every house, where a filter was tested, the water that was produced could never be drunk or used at the speed at which it was being filtered. This led to every single house storing the filtered water in buckets – which is the source of a new problem, namely, water re-contamination.

- Out of the 30 filters tested 28 (93%) households had stored water with E. coli levels which were higher than the filtered water produced
- Of these 28 filters, a staggering 25 had stored water which was outside the reasonable range (0-10 E. coli/100ml)
- Some filters increased from zero E. coli in the filtered water to over 200 E. coli/100ml

Due to a lack of basic education Tanzanians held the misconception that if water is clear it is clean and safe. After all many have been collecting water from shallow wells all their lives, leaving it to settle and then drinking it with apparently no real ill-effects apart from the recurrent tummy bugs. What they did not realise was that harmful bacteria cannot always be seen. Hence they did not recognise the need of cleaning the buckets they were storing the water in. This led my colleague and I to spend more time at every sampling site explaining again the importance of cleaning storage buckets, and the effects and dangers of recontamination.

Examples of this are shown below (see Table 5.4.1) and the extent to which recontamination can occur. Both filters were producing water that was within the WHO and NGO guidelines but due to the water being placed in contaminated buckets the E. coli levels increased to up to 217 E. coli/100ml of water which is extremely dangerous.

	Before filtration	After filtration	Stored water
Filter C69	88.0	0.0	217.3
Filter G18	5.0	0.0	200.0

Table 5.4.1: Showing no. of E. coli bacteria per 100ml of sampled

This creates a real and present problem with the filters. If the water is not placed into clean/disinfected bottles or buckets the process of filtration is of no use because in the majority of the samples taken, the E. coli levels in the stored water were much higher: 1000000% and 10000000% on the log scale (Figure 9 – pg 27). These extraordinary results show that the majority of Tanzanians using the filters are not actually drinking clean water. This could be for many reasons such as their lack of understanding in relation to contamination in buckets. Also the importance of making sure containers being used for storing water are clean may not have been made clear at the time of filter installation. A large majority of the samples taken were from poverty stricken areas where typically the houses did not have sealed windows, only mosquito mesh over the window frames. These physical conditions together with the fact that buckets of water are often left uncovered could lead to the water being contaminated again. Also the cost of buying a bucket is significant relative to their income, so a bucket is used for many tasks such as washing clothes, household cleaning, transporting and storing food and carrying food waste. Having a bucket dedicated to storing clean water is often not a priority for Tanzanians. Education is the key to the solution, both in the awareness-raising seminar that introduces the household to the filter and its benefits, and additionally at installation. A clear understanding of the dangers and causes of re-contamination together with maintaining high standards

5.5 Types of Source Water

The major factor which affects the potential of a filter to remove E. coli is the extent to which the source water is contaminated. This being the case, all the different sources of water which were used in the filters, were taken and compared to see whether a specific type of water was more difficult to clean. Three main categories of water were tested: Dawasco (regional piped water), Borehole water and Shallow well water. The results from this study showed that all the filters were able to cope with the higher levels of contamination. Of the three categories Dawasco water had the lowest percentage of filters which fell within the WHO and NGO guidelines and this is due to the filter O12 and A26 as discussed before having Dawasco water as their source. However when the average of percentage removal are taken into consideration (see Table 5.4.1 below) the extremes are removed and it shows that all the filters have a percentage removal of E. coli of over 95% which means that no specific water source affects the removal of E. coli in filtration.

Dawasco		**Borehole**		**Shallow Well**	
Av in	% removal	Av In	% removal	Av in	% removal
78.6		70.1		136.9	
Av out	**95.6**	Av out	**95.7**	Av out	**99.7**
3.5		3.0		0.4	

Table 5.5.1: Showing the overall removal efficiencies of the filters for different

There was however a fourth category of source water. The main supply for filter B30 was rainfall. The water was collected from roofs via guttering and downpipes, from surface run off or run off from grass roofs and collected via concrete channels and stored in a large 100,000 litre tank underground. This source water had E. coli levels of 1306/100ml. At this level of contamination the filter was only able to reduce the E. coli level to 100/100ml. This would suggest that there is a limit to the levels of E. coli contamination in source water which a filter removes in order to bring it to within safe or even reasonable levels. This could be due to the low residency time of the water in the filter: with such a high original levels of contamination the water does not filter through slow enough, that is, it is not within the biological media for a long enough time for the bacterial layer in the filter to work to its full potential.

In such cases it is recommended that source water with levels over 1000 E. coli/100ml should either;

- be filtered twice if the water is intended for drinking, or
- be used for washing up and cleaning purposes if passed through the filter only once – it should not be drunk

In both cases care must be taken to ensure that the storage container is clean and as free from contamination as possible.

5.6 Time needed to reach maximum removal efficiency

A Bio-Sand filter is a method of water filtration which takes time to become established and to be producing water of optimal quality. What this means is, that once a filter is installed, although it can be used immediately, it will not be filtering at its maximum potential as the ‘schmutzdecke layer’ will not have fully developed and established itself within the filter. It has been stated that Bio-Sand filters can take up to 2-4 weeks for this potential to be reached and this is shown in Tiwari (2009): “They were also instructed not to use Bio-Sand Filter treated water for drinking during the 2-week biological maturation period.” This was an interesting fact which was worth investigating.

Three new filters were set up and monitored over an 8-week period to see whether this 2-4 week maturation period was long enough for the filters too reach their removal potential and be producing clean safe water. As shown in Figure 8 there are three very different patterns which were observed over the 8 weeks.

- Filter B88 showed a fluctuating 4 week maturation period after which it continued to have a removal efficiency of over 90% and E. coli levels well within the NGO ‘reasonable range’ guidelines.

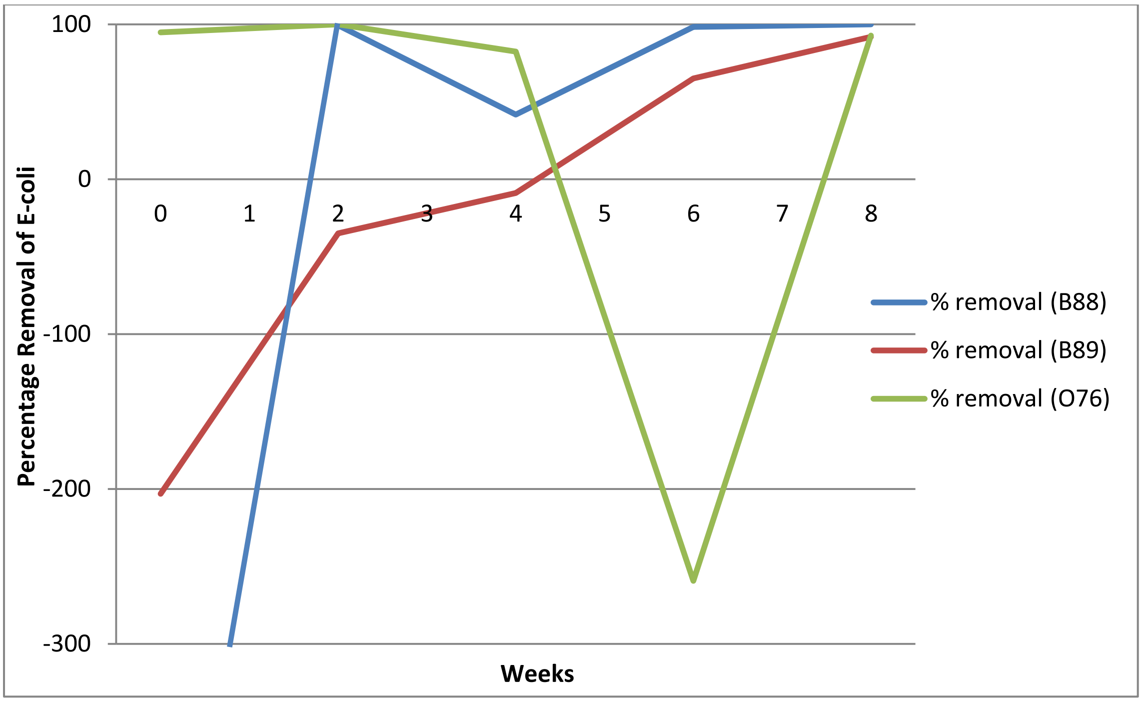

Figure 10: Percentage Removal of E. coli over a period of 8weeks in 3 newly installed filters.

- Filter B89 however, established a more progressive method of removal of E. coli and it took 6 weeks for the filter to be producing water with less E. coli present than it's respective source water. This could have been due to the actual presence of bacteria in the filter sand at installation and therefore as the dirty source water was passed through the filter sand it was actually washed out leaving more bacteria in the filtered water. However by week eight, Filter B 89 was operating at a removal efficiency of 91% and had E. coli levels of 1.7/100ml showing it was working efficiently.
- After two weeks Filter O76 had a removal percentage of 95% with water E. coli levels of 0.3/100ml. However by week four and six, the removal efficiency had fallen drastically - with removal percentages of -259%. This fall in removal efficiency was not caused by a reduction in the filters capabilities; it was caused by circumstances around where the filter was being used. The house in which this filter was kept had only recently been built and therefore the finishing touches were still being applied. This created a huge influx of dust which caused the spike in the removal efficiency. Once the filter had been cleaned and the dust in the area was cleaned the filter responded with clean water once again at the exact same level of E. coli it had established at the first testing, 0.3 E. coli/100ml.

5.7 Difficulties Encountered

Bio-Sand filters are an efficient method of providing clean drinking water from many different types of water sources and they were designed as a modification of the large-scale, continuously operated slow sand filter and allows intermittent water dosing for household use (Sobsey, 2008c) The Bio-Sand filter is a promising household water treatment technology in use by over 500,000 people globally (Stauber et al. 2009b).

In this study it has been recognized that there are a number of factors relating to the use and characteristics of the filters which have not been taken into consideration. These factors will now be discussed to show how they may have affected the results and how the testing could be improved. This project was undertaken in a developing country where practical issues had to be addressed which may not have arisen in a developed country, such as lack of laboratory facilities, accessibility to filters, communication with filter owners to ensure their presence when testing, language barrier (but this was largely overcome by using a translator) and reliability of usage information given by user. Consequently this led to the design of this project controlling these variables to give results that were accurate and specific to what was tested.

The aim of this project was to show that the filters were working efficiently, but it may be difficult to establish which of the factors ignored may have had a significant effect on the results.

One of the main problems in conducting a spot check on a Bio-Sand filter is how to establish whether the filter has been properly maintained or used at all. For this reason a questionnaire (as seen in appendix five) was carried out at the beginning of the sampling to establish how the owner was using the filter.

It was important that a Tanzanian carried out this questionnaire directly with the user. This is because if a visitor were to ask them, for example, about their filter usage history, a Tanzanian would want to give a good impression and so the information they would provide would usually be what they thought the visitor would want to hear rather than the actual facts. A Tanzanian interviewer was used to prevent the data from being culturally skewed.

A number of targeted questions were asked (see Appendix H), for example:

- how many times is water was passed through the filter in a week – *it was found on several occasions that the filters were not being used well and in some cases were not being used at all. These filters were then not sampled because it was realized that they would distort the results. The filter needs to have water poured through it every day so that the biological bacteria layer remains active so that the removal of E. coli in the water is at its maximum levels.*
- has the owner carried out a 'swirl and dump' procedure – *this cleaning procedure is required when the flow rate has slowed to over 3 minutes per litre. This is achieved by reducing the water level in the filter to just over a centimetre from the top of the sand media. Then the water is stirred (by hand/utensil of some kind) to unsettle the bacteria layer on top and loosen/free up any fine sediment particles which may reduce the flow rate by clogging up the pores on top of the sand. The water above the sand layer is then removed*

The flow rate of a filter will depend upon how well it is kept, i.e. swirl and dump. If it is kept well the filter will have a flow rate of about 36 litres per hour, but if it has been damaged or the sand has been altered, through excess stirring of the water, the flow rate can increase leading to reduced efficiency. A slower flow rate, over 3 minutes per litre, generally means that the filter needs to be cleaned. However if the sample water is in the filter for a longer period the removal of microorganisms will be increased. This is because the water is in contact with the sand and bacterial layer for a longer period of time therefore the mechanisms of the bacterial removal have a greater period in which to work.

Filters are made to a specification which provides a balance between not only meeting standards of water purity but providing it in within a time-frame which is practical. For this reason a filter is set up so that when the flow rate is measured it should be between 1-3 minutes per litre. This means that a 20 litre bucket will be available within an hour which offers a family enough water for drinking and cooking in a reasonably amount of time.

5.8 Further Study

There are many different criteria which could be studied further to gain a greater understanding of what affects the Bio-Sand filters.

- When a filter is installed it is generally placed inside someone's house and they are trained how to use and care for it. But how does the positioning of the water filter for example i.e. indoors (in the shade) or outdoors (in the sun) effect how the filter works?
- As has been said the flow rate affects the time allowed for filtration to take place. Residence time affects the performance of the Bio-Sand Filters and it has been stated that 8 hours should be left between each 20 litre bucket (Baumgartner et al. 2007). What is the optimum residency time for water in the filter?
- The first randomized controlled trial of the Bio-Sand filters, undertaken in an urban setting in the Dominican Republic, was recently completed. Stauber et al. (2009c) report a significant improvement in drinking water quality and all-age reduction in incidence of diarrhoea. A similar project could be carried out in Tanzania to test whether the filters affects the levels of diarrhoeal disease in the Tanzanians using the filter.
- Adoption of filtration techniques can be increased by further improving their production and distribution systems. For Bio-Sand filters lightweight, stackable plastic filter casings and centralized facilities for bulk production of the different types of sand for the filters are being developed (Sobsey, 2008d). Another area to investigate would be to see whether these different distribution systems have a higher removal efficiency than the Bio-Sand filter and are as affordable and simplistic to use.

5.9 Improvements to the testing procedure

To improve this project there are different ideas or procedures which could be adopted.

- Sampling more and a greater range of filters, outside of Dar es Salaam/Coastal region. More data to analyse would give more accurate and more meaningful results. The number of filters tested in this project was limited by the funds available and the equipment which was able to be purchased. Portability of the testing equipment and the need for the samples to be tested within 6 hours of sampling also brought its own limitations.

- Secondly a new monitoring/testing “Colilert Quanti tray” system is available, but was too expensive for to be used. This may provide more accurate readings for the bacteria testing.

- A more adequate laboratory which provides sterile, temperature-controlled conditions in which testing and analysis could take place – such as a university or private laboratory.

6. Conclusion

Overall this project provides a good initial base line record of how Bio-Sand filtration is performing in the coastal region of Tanzania. It has lead to a greater understanding, on the part of the researcher, of the processes that affect E. coli bacteria removal efficiency and how physical parameters affect this. The experience in the field together with testing and analysis procedures being shared with a local Tanzanian, has equipped him to continue monitoring filters installed by the NGO. He in turn has already started to train his colleagues in aspects of this work. This understanding will then lead to the Tanzanians being able to test the filters themselves and be able to state whether filters are working to within International guidelines. The study will clarify other areas that can be investigated at a later time.

It is also encouraging to know that small things can make a big difference and because of these low-tech, low-maintenance Bio-Sand filters many Tanzanians are now enjoying clean drinking water, meeting WHO guidelines and the quality of their health has been improved.

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Appendix A

Table 1.1.1: WHO's 2009 World Health Statistics for Tanzania's urban and rural community and their access to improved drinking water sources in comparison with the U.K and U.S.A

5. Risk factors

Member State	MDG 7 Access to improved drinking-water sources [a] (%)									MDG 7 Access to improved sanitation [a] (%)								
	Urban			Rural			Total			Urban			Rural			Total		
	1990	2000	2006	1990	2000	2006	1990	2000	2006	1990	2000	2006	1990	2000	2006	1990	2000	2006
United Kingdom	100	100	100	100	100	100	100	100	100	...	...	...	...	...	...	...	...	...
United Republic of Tanzania	90	84	81	39	44	46	49	53	55	29	31	31	36	35	34	35	34	33
United States of America	100	100	100	94	94	94	99	99	99	100	100	100	99	99	99	100	100	100

Appendix B

Table 1.2 Guideline values for verification of microbial quality (WHO, 2006b)

Organisms Guideline value
1. All water directly intended for drinking
E- coli or thermotolerant coliform bacteria, Must not be detectable in any 100-ml sample
2. Treated water entering the distribution system
E-coli or thermotolerant coliform bacteria, Must not be detectable in any 100-ml sample
3. Treated water in the distribution system
E-coli or thermotolerant coliform bacteria, Must not be detectable in any 100-ml sample

Appendix C

Table 3.1: Equipment list for a complete Membrane Filtration test

Equipment needed:
47mm Petri Dish
Microfil 100ml funnels (width 47mm)
45mmMCE white gridded Millipore filter membrane
Coliscan MF liquid
tweezers/ forceps
lighter
vacuum apparatus (vacuum tubing, vacuum syringe and Microfil support)
incubator (35°c) and car battery
whirl pak sample bags with 100ml of sample water
mini torch
recording sheet
5ml pipette
Counter and magnifying glass

Appendix D

E-coli Levels in 3 maturing filters over time. (2month period)

Units per 100ml

		Filter B 88	Filter B 89	Filter O 76
Week 0	Pre-filtered A	0	69	3
	Pre-filtered B	1	58	8
	Pre-filtered C	1	71	9
	Post-filtered A	20	200	0
	Post-filtered B	28	200	0
	Post-filtered C	16	200	1
Week 2	Pre-filtered A	57	15	200
	Pre-filtered B	63	10	200
	Pre-filtered C	200	18	200
	Post-filtered A	1	17	0
	Post-filtered B	1	24	0
	Post-filtered C	0	17	0
Week 4	Pre-filtered A	13	30	460
	Pre-filtered B	5	24	360
	Pre-filtered C	200	37	460
	Post-filtered A	7	26	88
	Post-filtered B	6	33	59
	Post-filtered C	1	40	76
Week 6	Pre-filtered A	33	200	50
	Pre-filtered B	18	200	65
	Pre-filtered C	16	200	52
	Post-filtered A	0	70	200
	Post-filtered B	1	72	200
	Post-filtered C	0	67	200
Week 8	Pre-filtered A	2	19	5
	Pre-filtered B	1	20	6
	Pre-filtered C	0	23	3
	Post-filtered A	0	3	0
	Post-filtered B	0	2	0
	Post-filtered C	0	0	1

Where and when the filters were placed and tested respectively.

B 88	African rented compound - piped water
B 89	My house compound - piped water
O 76	Local Village house - piped and stored tank water

Dates of Install Samples	03/07/2009	03/07/2009	06/07/2009
Dates of 2 week Samples	21/07/2009	16/07/2009	16/07/2009
Dates of 4 week Samples	06/08/2009	06/08/2009	06/08/2009
Dates of 6 week Samples	24/08/2009	24/08/2009	24/08/2009
Dates of 8 week Samples	03/09/2009	03/09/2009	03/09/2009

Average E-coli Levels in the 3 filters over time.

	B88 Averages	B89 Averages	O76 Averages
Wk 0 - pre	0.7	66.0	6.7
Wk 0 - post	21.3	200.0	0.3
Wk 2 - pre	106.7	14.3	200.0
Wk 2 - post	0.7	19.3	0.0
Wk 4 - pre	72.7	30.3	426.67
Wk 4 - post	4.7	33.0	74.3
Wk 6 - pre	22.33	200.0	55.7
Wk 6 - post	0.3	69.7	200.0
Wk 8 - pre	1	20.7	4.7
Wk 8 - post	0.0	1.7	0.3

Percentage Removal of E-coli for filter B88

				%removal	Age (wks)
pre 1	**0.0**	post 1	**20.0**	-199900.0	0
pre 2	**1.0**	post 2	**28.0**	-2700.0	0
pre 3	**1.0**	post 3	**16.0**	-1500.0	0
pre 1	**57**	post 1	**1**	98.2	2
pre 2	**63**	post 2	**1**	98.4	2
pre 3	**200**	post 3	**0**	100	2
pre 1	**13**	post 1	**7**	46.2	4
pre 2	**5**	post 2	**6**	-20.0	4
pre 3	**200**	post 3	**1**	99.5	4
pre 1	**33**	post 1	**0**	100	6
pre 2	**18**	post 2	**1**	94.4	6
pre 3	**16**	post 3	**0**	100	6
pre 1	**2**	post 1	**0**	100	8
pre 2	**1**	post 2	**0**	100	8
pre 3	**0.01**	post 3	**0**	100	8

Percentage Removal of E-coli for filter B89

				% removal	Age (wks)

pre 1	**69**	post 1	**200**	-189.9	0
pre 2	**58**	post 2	**200**	-244.8	0
pre 3	**71**	post 3	**200**	-181.7	0
pre 1	**15**	post 1	**17**	-13.3	2
pre 2	**10**	post 2	**24**	-140.0	2
pre 3	**18**	post 3	**17**	5.6	2
pre 1	**30**	post 1	**26**	13.3	4
pre 2	**24**	post 2	**33**	-37.5	4
pre 3	**37**	post 3	**40**	-8.1	4
pre 1	**200**	post 1	**70**	65.0	6
pre 2	**200**	post 2	**72**	64.0	6
pre 3	**200**	post 3	**67**	66.5	6
pre 1	**19**	post 1	**3**	84.2	8
pre 2	**20**	post 2	**2**	90.0	8
pre 3	**23**	post 3	**0**	100.0	8

Percentage Removal of E-coli for filter O76

				% Removal	Age (wks)
pre 1	**3**	post 1	**0**	100.0	0
pre 2	**8**	post 2	**0**	100.0	0
pre 3	**9**	post 3	**1**	88.9	0
pre 1	**200**	post 1	**0**	100.0	2
pre 2	**200**	post 2	**0**	100.0	2
pre 3	**200**	post 3	**0**	100.0	2
pre 1	**460**	post 1	**88**	80.9	4
pre 2	**360**	post 2	**59**	83.6	4
pre 3	**460**	post 3	**76**	83.5	4
pre 1	**50**	post 1	**200**	-300.0	6
pre 2	**65**	post 2	**200**	-207.7	6
pre 3	**52**	post 3	**200**	-284.6	6
pre 1	**5**	post 1	**0**	100.0	8
pre 2	**6**	post 2	**0**	100.0	8
pre 3	**3**	post 3	**1**	66.7	8

Appendix E: Excel record sheet of spot checks on 30 filters ranging in age and located in different areas and using a variety of water sources.

Source Type	SW	RW	D	D	D	D	D	D	D	BH	BH	BH	D	D	D
Filter	**B 28**	**B 30**	**Z 1**	**Z 2**	**C 88**	**A 26**	**E 6***	**O 12**	**Z 3**	**P 35***	**A 41**	**I 69**	**C 8**	**Z 4**	**Z 5**
Source A	0	1140	11	3	0	92	30	72	1	1	200	28	115	200	41
Source B	0	1400	8	6	1	144	16	122	6	3	200	25	172	200	180
Source C	3	1380	12	9	0	102	13	121	0	2	200	40	190	200	116
averages	**1.0**	**1306.7**	**10.3**	**6.0**	**0.3**	**112.7**	**19.7**	**105.0**	**2.3**	**2.0**	**200**	**31.0**	**159.0**	**200.0**	**112.3**
FIlter A	1	200	4	0	0	26	1	7	0	0	7	0	0	6	5
FIlter B	2	60	0	0	0	27	0	19	0	0	10	0	0	8	5
FIlter C	2	40	3	0	0	36	0	12	1	0	5	0	2	4	6
averages	**1.7**	**100.0**	**2.3**	**0.0**	**0.0**	**29.7**	**0.3**	**12.7**	**0.3**	**0.0**	**7.3**	**0.0**	**0.7**	**6.0**	**5.3**
Store A	18	30	13	3	200	22	200	50	0	20	40	9	31	65	122
Store B	11	60	16	1	200	28	17	28	5	3	68	18	50	46	123
Store C	15	40	3	1	200	40	0	17	2	17	56	14	71	57	68
averages	**14.7**	**43.3**	**10.7**	**1.7**	**200.0**	**30.0**	**139.0**	**31.7**	**2.3**	**13.3**	**54.7**	**13.7**	**50.7**	**56.0**	**104.3**
Control	0		0				0			0			0		
Notes		(Dilution of 1-10%)					*there were general coliforms present. = 13			*NOTE: power went off on incubator for a number of hours					

SW – Shallow well, RW – Rainwater, D – Dawasco, BH – Borehole.

Source Type	**D**	**D**	**D**	**D**	**D**	**D**	**BH**	**BH**	**BH**	**D**	**D**	**SW**	**SW**	**SW**
Filter #	**E32**	**K37**	**E36**	**G15**	**G18**	**E48**	**N37**	**C69**	**D65**	**I 18**	**I 38**	**M 37**	**P24**	**N23**
Source A	200	60	4	97	6	200	42	149	43	2	0	180	-	600
Source B	200	102	14	130	3	200	67	64	39	2	0	240	80	260
Source C	200	115	5	>200	6	200	71	51	36	2	0	100	60	60
averages	**200.0**	**92.3**	**7.7**	**113.5**	**5.0**	**200.0**	**60.0**	**88.0**	**39.3**	**2.0**	**0.0**	**173.3**	**70.0**	**306.7**
FIlter A	0	2	0	0	0	12	0	0	13	0	0	0	0	0
FIlter B	1	0	0	1	0	2	3	0	5	0	1	0	0	0
FIlter C	0	0	0	1	0	4	1	0	10	0	0	0	0	0
averages	**0.3**	**0.7**	**0.0**	**0.7**	**0.0**	**6.0**	**1.3**	**0.0**	**9.3**	**0.0**	**0.3**	**0.0**	**0.0**	**0.0**
Store A	78	29	107	34	200	63	200	132	30	15	14	0	0	220
Store B	96	49	59	3	200	132	200	120	21	13	2	0	0	180
Store C	28	45	90	4	200	92	200	200	30	51	5	0	0	100
averages	**67.3**	**41.0**	**85.3**	**13.7**	**200.0**	**95.7**	**200.0**	**150.7**	**27.0**	**26.3**	**7.0**	**0.0**	**0.0**	**166.7**
Control	0			0			0			0		0		
Source Type														

SW – Shallow well, RW – Rainwater, D – Dawasco, BH – Borehole.

Excel Record Sheets of data used in production of Box plots for the different water sources

	Borehole	Filtered	Stored
Mean	70.1	3.0	87.7
St Dev	69.9	4.2	95.1
Max Value	200.0	9.3	200.0
Upper Q	81.0	5.8	163.7
Median	49.7	0.7	40.8
Lower Q	33.1	0.0	17.0
Min Value	2.0	0.0	13.3

	Dawasco	Filtered	Stored
Mean	78.6	3.5	61.9
St Dev	81.5	7.1	61.9
Max Value	200.0	29.7	200.0
Upper Q	135.8	3.8	90.5
Median	50.3	0.7	41.0
Lower Q	5.5	0.2	13.5
Min Value	0.0	0.0	1.7

	Shallow well	Filtered	Stored
Mean	137.8	0.4	45.3
St Dev	133.0	0.8	81.2
Max Value	306.7	1.7	166.7
Upper Q	206.7	0.4	52.7
Median	121.7	0.0	7.3
Lower Q	52.8	0.0	0.0
Min Value	1.0	0.0	0.0

Appendix F

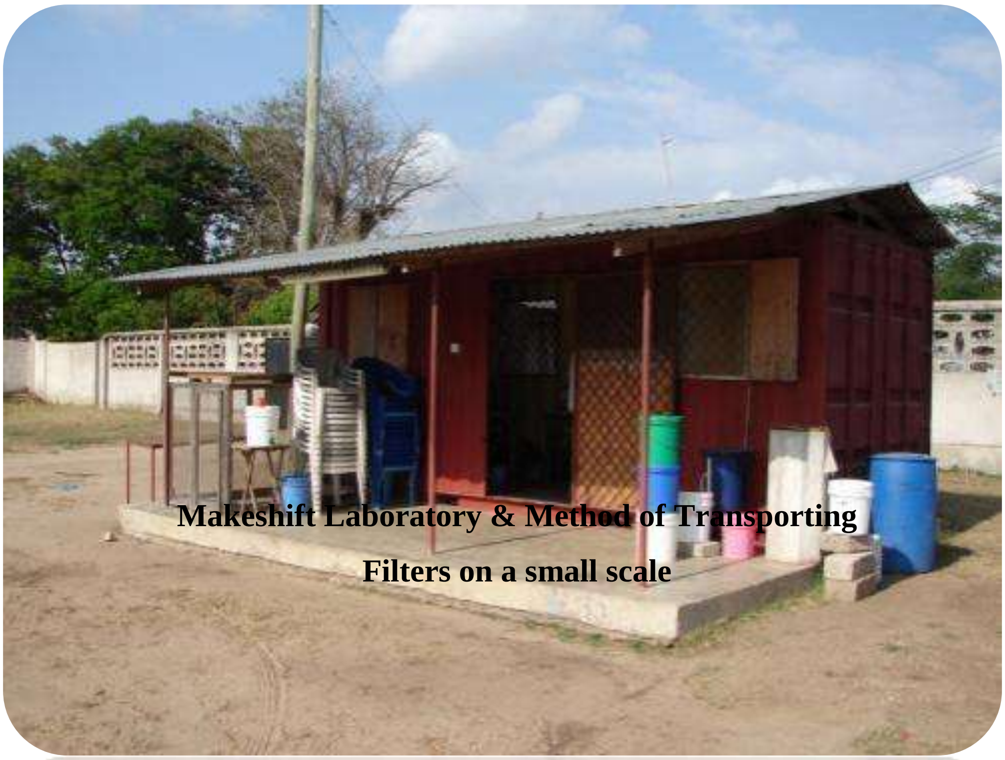
Excel record sheet of spot checks on 30 filters, showing their percentage removal from source water to filtered water.

	Source	Filtered	Age		
Filter C 88	0.3	0.0	3		**100**
Filter P 35	2.0	0.0	5		
Filter I 69	31.0	0.0	5	**Av in**	
Filter D65	39.3	9.3	5	63.42857143	**97.43844**
Filter N37	60.0	1.3	5	**Av out**	
Filter C69	88.0	0.0	5	1.6	
Filter M 37	173.3	0.0	5		
Filter M45	50.3	0.7	5		
Filter P24	66.7	0.0	6	186.7	**100**
Filter N23	306.7	0.0	6	0	
Filter A 41	200.0	7.3	7	**Av in**	
Filter G18	5.0	0.0	7	153.5	
Filter G15	209.0	0.7	7	**Av out**	**97.71824**
Filter E48	200.0	6.0	7	3.5025	
Filter E36	7.7	0.0	9	50	**99.3**
Filter K37	92.3	0.7	9	0.35	
Filter I 38	0.0	0.3	10		**-3233.333**
Filter O 12	105.0	12.7	11		**87.93651**
Filter I 18	2.0	0.0	13	**Av in**	
Filter B 30	1306.7	100.0	13	436.5555556	
Filter B 28	1.0	1.7	13	**Av out**	**92.23645**
				33.89222222	
Filter E32	200.0	0.3	14		**99.83333**
Filter A 26	112.7	29.7	15		**73.66864**
Filter E 6	19.7	0.3	17		**98.30508**
Filter C 8	159.0	0.7	18		**99.58071**
Filter Z 3	2.3	0.3	36	**Av in**	
Filter Z 2	6.0	0.0	36	66.2	
Filter Z 1	10.3	2.3	36	**Av out**	**95.76737**
Filter Z 5	112.3	5.3	36	2.802	
Filter Z 4	200.0	6.0	36		

Appendix G

Various Pictures of every stage in this projects methodology, equipment used and the Bio-Sand filters

Bio-Sand filters – sponsored by Thirst Relief



Makeshift Laboratory & Method of Transporting Filters on a small scale

Dawasco Water (top left), Shallow well water (top right) & Bore Hole water (below)

Pictured is Emmanuel Abel, Supporting Technician and Trainee

The MCD team removing and re-waxing the filter moulds (above).

Preparing the coral stone (kokoto) before being used for building the filters (middle) & then pouring the filters (bottom)

Sampling Dawasco Water using Whirlpak 100ml bags

Membrane Filtration and Laboratory equipment

Completed Petri Dishes with E. coli present and the control sample – DASANI water

Appendix H

Questionnaire Answer Database – 10 questions, general feedback and example questionnaire.

Filter No	Location	**Qu 1** **Where do you get your water from?**	**Qu2** **Where was last bucket from?**
F# B30	Kinzudi, Goba	SW, GW	SW, GW
F# B28	Kinzudi, Goba	RW, SFW	RW, SFW
F# Z1	Ubungo, Kibangu.	D	D – ST (simtank)
F# Z2	Tabata	D	D
F# C88	Kigogo	D	D
F# A26	Kigogo	D	D
F# Z3	Kunduchi, Maputo	D	D
F# E6	Tegeta, Wazo Hill	D	D
F# O12	Tegeta, Wazo Hill	D	D
F# P35	Kigamboni, Vijibweni	B	B
F# A41	Mbagala, Goroka	B	B
F# I69	Kigamboni, Vijibweni	B	B
F# C8	Bagamoyo, Dunda, Bongwa	D	D
F# Z4	Kerege	D	D
F# Z5	Kerege	D	D
F# E32	Kawe	D	D
F# E36	Kawe	D	D
F# K37	Kawe	D	D
F# G18	Magomeni	D	D
F# G15	Manzese	D	D
F# E48	Tandale	D	D
F# N37	Yombo	B, SW	B, SW
F# D65	Yombo	B – PS	B
F# C69	Yombo	B – PS	B
F# I38	Kinondoni Shamba	D	D
F# I18	Kindondoni Victoria	D – ST	D – ST
F# M45	Mwenge	D	D
F# P24	Mzenga	SW	SW
F# N23	Mzenga	SW	SW
F# M37	Mzenga	SW	SW

Key

D - Dawasco
SW - shallow well
B - borehole
RW - rain water
GW - ground water
SFW - surface water   ST - storage tank

Filter No	Qu 3 Other water sources used	Qu4 What do you use to collect your water?	Qu5 How many times is water passed through filter?
F# B30	RW, D	B, PC	EO
F# B28	N	B	EWD – not over the weekend
F# Z1	N	B	E
F# Z2	D - ST	B	EO
F# C88	SW	B, HP to drum	EO
F# A26	D, salt water (deep well)	B	E
F# Z3	N	B	E
F# E6	D	B	EO
F# O12	D	B	EO
F# P35	N	B	E
F# A41	N	B	E.
F# I69	N	B	E.
F# C8	SW	B	EO
F# Z4	N	B, PC	E.
F# Z5	SW	B	E.
F# E32	N	B	E.
F# E36	N	B	E.
F# K37	N	B	E.
F# G18	N	B	E.
F# G15	N	B	E
F# E48	N	B	E
F# N37	N	B	E.
F# D65	N	B	E.
F# C69	N	B	E.
F# I38	N	B	E.
F# I18	N	B	E.
F# M45	N	B	E.
F# P24	RW	B, PC	E.
F# N23	GW , SFW	B	E.
F# M37	N	B	
Key:	N - none	PC - Plastic container	E- everyday
		B - bucket	EO - every other day
		HP - hosepipe	EWD - every week day

Filter No	Q 6: How many buckets put through filter on each occasion?	Q 7: When was the filter last cleaned?
F# B30	3	MW
F# B28	1	MW
F# Z1	2	MW
F# Z2	1	MM
F# C88	1	N
F# A26	3	W
F# Z3	1 or 2	MW
F# E6	1	MM
F# O12	1	N
F# P35	2	LW
F# A41	1	MW
F# I69	1	N
F# C8	1	LW
F# Z4	1	MM
F# Z5	2	LW
F# E32	2	MM
F# E36	1 (10 or 20l)	MM
F# K37	1 (20l)	MM
F# G18	1 (20l)	MM
F# G15	1 or 2	N
F# E48	1 or 2	LW
F# N37	1	N
F# D65	1	MM
F# C69	1	MM
F# I38	1 (10lt or 20lt)	LW
F# I18	1 (20l)	MM
F# M45	2 or 3	LW
F# P24	1 (20l)	N
F# N23	1 (20l)	LW
F# M37	2 or 3 (20l)	MM

Key:

1 - 1 bucket
2 - 2 buckets
3 - 3 buckets

LW - less than a week
W - a week
MW - more than a week
MM - more than a month
N - never

Filter No	Q 8: How do you look after your filter?	Q 9: Has anyone been ill since using the filter?
F# B30	Didn't Clean filter - GT	N
F# B28	CD, PWE, S&D	N
F# Z1	PWE, S&D, CW	N
F# Z2	CLD, S&D	N
F# C88	CF	N
F# A26	CS, CO, S&D	N
F# Z3	PWE & CF	N
F# E6	CLD often, S&D	N
F# O12	CLD often, CO of filter	N
F# P35	CLD, S&D	N
F# A41	CLD	N
F# I69	PWE, DM	N
F# C8	PWE, S&D	N
F# Z4	CF, PWE	N
F# Z5	PWE	N
F# E32	UGC, CO of the filter, CLD	N
F# E36	PWE, S&D	N
F# K37	CLD, NGF	N
F# G18	CS, CLD, CO	N
F# G15	PWE, GCU	N
F# E48	CLD, CS, S&D and CO	N
F# N37	PWE	N
F# D65	PWE, MT	N
F# C69	PWE, MT	N
F# I38	PWE, CLD	N
F# I18	CO,MT	N
F# M45	CS, CD, PWE, S&D	N
F# P24	CS, CO. GCU. CLD	N
F# N23	PWE, GCU, S&D	N
F# M37	GCU, S&D, NGF, DM	N

Key:	CLD - clean lid and diffuser	N - none
	CS - clean spout	
	PWE - pour water everyday	
	CO - clean outside	
	CD - clean diffuser	
	S&D - swirl and dump	
	CW - clean well	
	CF - cleans filter	
	DM - don't move	
	GCU - good containers used	

Q 10:

Filter No	**What advantages do you think the filter gives you?**
F# B30	FW and CW
F# B28	CW
F# Z1	CW, NS
F# Z2	EA, CW, NB, CW for washing baby
F# C88	FW, NE, EU, NS, EA
F# A26	NBT, NS
F# Z3	Keep healthy, EU, SM
F# E6	RC, NB, MFT
F# O12	NB, QS
F# P35	EA to CW
F# A41	ST, CW, NS
F# I69	SM
F# C8	NB of water – SM, clear clean and safe water
F# Z4	NS, access of clean and safe water
F# Z5	CW, NS, RC due to NB
F# E32	SM, NS
F# E36	SM and ST, NB, availability of CW
F# K37	NB, RC
F# G18	NB, RC
F# G15	SM
F# E48	CW – safe to drink, NS
F# N37	SM – NB with charcoal, EA
F# D65	NB, EA, CW, RC
F# C69	NB, EA, CW, RC
F# I38	NS, ST and SM, EU
F# I18	CW and safe to drink
F# M45	CW free of smell, NB, RC
F# P24	NB , ST and SM, RC
F# N23	NS, SM
F# M37	NB – ST and SM, CW access for drinking

Key:

FW – free water
ST – saves time
NS – no sickness,
CW – clean water
NB – no boiling
EU – easy to use
EA – easy access
NE – no energy used
MFT – more free time
NBT - no bacteria
RC - reduced cost

QS – quick system

Filter No	Feedback from installers/inspectors
F# B30	NC, SLF. 5
F# B28	NC, SLL. Need to add more sand. 3
F# Z1	NC, SNL, GC, LDF, 1, flow rate of 111secs
F# Z2	NC, SNL (more sand needed to be added), GC, LDF, 1, flow rate of 151secs
F# C88	NC, SLF, GC, LDF, 1, flow rate of 47.5secs
F# A26	NC, SLF, GC, LDF, 1, flow rate of 77secs
F# Z3	NC, SLF, GC, LDF, 1, flow rate of ? secs
F# E6	NC, SLF, GC, LDF, 1, flow rate of over 300 secs = after swirl and dump = 104 and 110 sec
F# O12	NC, SLF, GC, LDF, 1, flow rate of 193 secs = after swirl and dump = 143sec
F# P35	NC, SLF, GC, LDF, 1, flow rate of 78 secs
F# A41	NC, SLF, GC, LDF, 1, flow rate of 71 secs / 500ml = 142secs
F# I69	NC, SLF, GC, LDF, 1, flow rate of 53 secs/ 500ml = 106 sec/ 1l
F# C8	NC, SLL = added more sand then swirled and dumped, GC, LDF, 1, flow rate of 128secs, 144 secs after dump.
F# Z4	NC, SLF, GC, LDF, 1, flow rate of 88 secs
F# Z5	NC, SNL – deep one side: steep the other, GC, LDF, 1, flow rate of 113 secs before swirl and dump, 103sec after
F# E32	NC, SLF, GC, LDF, 1, flow rate of 99 secs
F# E36	NC, SNL – deep on one side (levelled after testing), GC, LDF, 1, flow rate of 96 secs
F# K37	NC, SLL (more than 2inches of water on top), GC, LDF, 1, flow rate of 147 secs
F# G18	NC, SLF, GC, LDF, 1, flow rate of ? secs
F# G15	NC, SLF, GC, LDF, 1, flow rate of 163 secs
F# E48	NC, SLF, GC, LDF, 1, flow rate of 75 secs
F# N37	NC, sand level was too high, GC, LDF, 1, flow rate of 81 secs, flow rate was 71 after sand removed
F# D65	NC, SLF, GC, LDF, 1, flow rate of 67 secs
F# C69	NC, SLF, GC, LDF, 1, flow rate of 143 secs
F# I38	NC, SLF, GC, LDF, 1, flow rate of 85 secs
F# I18	NC, SLL, GC, LDF, 1, flow rate of 88 secs
F# M45	NC, SLL, GC, LDF, 1, flow rate of 152 secs
F# P24	NC, SNL, GC, LDF, 4, flow rate = 214 secs/l after swirl and dump = 105sec/l
F# N23	NC, SLF, GC, LDF, 2, flow rate = 159sec/l
F# M37	NC, SLF, GC, LDF, 4, flow rate = 116sec/l

Key:		
	NC - no cracks	1 - clear and no colour
	SLF - Sand level fine	2 - clear grey
	SLL - Sand level low	3 - clear brown
	SNL - Sand not level	4 - cloudy white
	GC - Good container	5 - cloudy grey

LDF - lid and diffuser fine 6 - cloudly brown