Addis Ababa University

School of Graduate Studies

Department of Biology

Evaluating the efficiency of slow sand filtration in clay pot in removing coliforms and turbidity from drinking water at household level and assessment of the contamination level at the point-of-use at home in the central highlands of Ethiopia (Yubudo-Legebatu PAs)

Picture of Slow Sand Filtration in clay pot in a household in Yubudo-Legbatu PAs.

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ACRONYMS

APHA	American Public Health Association
AWWA	American Water Works Association
CFU	Colony Forming Unit
EC/E. coli	Escherichia coli
EC-broth	Escherichia coli broth
FC	Faecal coliform
ILRI	International Livestock Research Institute
IWMI	International Water Management Institute
IWSC	International Water and Sanitation Center
KAP	Knowledge Attitude and Practice
M-Endo Agar	Membrane Endo Agar
M-FC Agar	Membrane Faecal Coliform Agar
MF	Membrane Filtration
MOH	Ministry of Health
MoWR	Ministry of Water Resources
NTU	Niphlometric Turbidity Unit
PAs	Peasant Associations
SSF	Slow Sand Filtration
TC	Total coliform
TTC	Thermotolerant coliform
USEPA	United States Environmental Protection Authority
WHO	World Health Organization
YLPAs	Yubudo-Legebatu Peasant Associations

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Abstract

Approximately over one billion people world-wide lacks access to adequate amount of safe water and rely on unsafe drinking water sources from lakes, rivers and open well. Nearly all of these people live in developing countries, especially in rapidly expanding urban fringes, poor rural areas, and indigenous communities. This study is aimed at evaluating the efficiency of slow sand filtration (SSF) in clay pot in removing total and thermotolerant/faecal coliforms and reducing turbidity and assessing the contamination level at the point-of-use at home in the central highlands of Ethiopia (Yubudu-Legebatu PAs).

Eighty households were selected for this study where 40 households were intervention groups who used SSF in clay pot comprised of spring users (20) and river users (20). Assessment of drinking water quality from home storage containers were also conducted for the other 40 non-intervention groups from village 1 using spring water (20) and from village 2 using river water (20). Triplicate water samples in two-week interval were collected to determine the presence of total and thermotolerant/faecal coliform in the water samples. Membrane filtration and epifluorescence microscope methods were used for coliform bacteria (TC and TTC/FC) enumeration and turbidity was measured using

Turbidimeter. Interviews and observations were also used to assess overall satisfaction of SSF users.

Analyses of water samples for TC, TTC/FC and turbidity from influent and effluent of SSF in clay pot for spring users showed that average TC from influent (n=20) was 888.9 CFU/100ml where as from effluent (n=20) it was 5.5 CFU/100ml. Moreover, average TTC/FC from influent (n=20) was 289.4 CFU/100ml where as from effluent (n=20) it was 2.5 CFU/100ml. Similarly, average turbidity from influent (n=20) was 9.0 NTU and from effluent (n=20) it was 0.9 NTU. The study showed that an average removal efficiency of SSF in clay pot from spring users were 97.4 % (n=20) and 96.9 % (n=20) for total and thermotolerant/ faecal coliform bacteria, respectively, while the removal efficiency for turbidity was 92.9 % (n=20).

Similarly, analyses of water samples for TC, TTC/FC and turbidity from influent and effluent of SSF in clay pot for river users showed that average TC from influent (n=20) was 824.0 CFU/100ml where as from effluent (n=20) it was 4.8 CFU/100ml. In addition, average TTC/FC from influent (n=20) was 267 CFU/100ml, and from effluent (n=20) it was 2.0 CFU/100ml. Moreover, average turbidity from influent (n=20) was 8.4 NTU and from effluent (n=20) it was 0.9 NTU. Coliform removal efficiencies of SSF in clay pot from river users were 97.9 % (n=20) and 96.6 % (n=20) for total and thermotolerant/ feacal coliform, respectively, where as a turbidity reduction of 93.1 % (n=20) was obtained.

Moreover, percentage distribution of water samples for both spring and river users for TC and TTC/FC from influent and effluent of SSF in clay pot showed that 16(36 %) and 18(33 %) of water samples taken from the influent had 1 to 10(CFU/100ml) for TC and FC, respectively, which is ‘a reasonable quality’ according to WHO and MoWR standards. The remaining 31(64 %) for TC and 34(67 %) for FC were found to fall in the range of ‘polluted and dangerous’ according the standards. Where as 19(37.75%) and 22(43%) of water samples taken from the effluent had Zero (CFU/100ml) for TC and FC, respectively, which is ‘safe water’ and 31(62.25%) and 28(57%) had 1 to 10 (CFU/100ml) for TC and FC, respectively, which is ‘a reasonable quality’ according to the standards.

Mean TC and TTC/FC counts per100 ml water samples of village 1 and village 2 from home storage containers were also compared using t-test, and there was a significant difference ($P<0.05$) in village 1 at the 5 % level of significance.

All, 40(100%), of the households responded that they liked the filters, 39(99%) provides better quality water, 39(98%) health protection and 38(96%) it works well, as reasons. In 39(99%) of the households responded that they would recommend the filter to others.

It was concluded from these results that SSF in clay pot are efficient in removing bacterial contamination and turbidity, and the filtered water is safe for drinking from bacteriological point of view. Thus, a concurrent and equitable input on both safe water supply and sanitation sector is requisite for promoting the health of communities.

Key words: Slow sand filter, slow sand filter effectiveness, drinking water, Coliform, turbidity, household water treatment, rural water supply.

1. INTRODUCTION

1.1 Background

Water is the essence of life and access to safe drinking water is a fundamental human need and, therefore a basic human right essential to all. Supply of safe water of appropriate quality is important to the well-being of mankind and development of any country because it supports public health and therefore, ensures economic growth. The provision of water, sanitation and good hygiene services is vital for the protection and development of human resources (Devadas, 1984).

Approximately over one billion people world-wide lacks access to adequate amount of safe water and rely on unsafe drinking water sources from lakes, rivers and open well. Nearly all of these people live in developing countries, especially in rapidly expanding urban fringes, poor rural areas, and indigenous communities (Gundry *et al*., 2004; Bartram *et al*., 2005). Much of the global population now consumes untreated, non piped drinking water, usually consisting of small volumes <40 lpcd (liter per capita per day) collected and stored in the home by users. Typically, people collect water from any available source and store it in a vessel in the home for domestic and potable use, often without treatment and protection from further contamination. In many cases, such collected household water is heavily contaminated with faecal microbes and possess risks of exposure to water borne pathogens and thus to infectious diseases (Sobsey *et al*., 2003).

The greatest risk associated with the ingestion of water is the microbial risk due to water contamination by human and/or animal feces. The effects of drinking contaminated water results in thousands of deaths every day, mostly in children under five years of age in developing countries (WHO, 2004). In addition, diseases caused through consumption of contaminated water, and poor hygiene practices are the leading cause of death among children world wide, after respiratory diseases (WHO, 2003). Thus lack of safe drinking water supply, basic sanitation and hygienic practices is associated with high morbidity and mortality from excreta related diseases. Diarrhea illness remains a major killer in children and it is estimated that 80 % of all illness in developing countries is related to water and

sanitation; and that 15 % of all child deaths under the age of five years in developing countries result from diarrhea diseases (WHO, 2000; 2004; Thompson and Khan, 2003).

In Ethiopia, over 60 % of the communicable diseases are due to poor environmental health conditions arising from unsafe and inadequate water supply and poor hygienic and sanitation practices (Abebe, 1986). About 80 % of the rural and 20 % of urban population have with inadequate safe water supply of 3-4 liter per capita per day that is fetched from a distance of 3-8 km with human power (Abebe, 1986). Three-fourth of the health problems of children in the country are communicable diseases arising from the environment, especially water and sanitation (IWSC, 1989). Forty six percent of the mortality rate of less than five years of age is due to diarrhea in which water related diseases occupy a high proportion. The Ministry of Health of Ethiopia estimated that 6000 children die each day from diarrhea and dehydration (MOH, 1997).

Because of the magnitude of the health problems associated with water of inadequate quality and quantity, substantial efforts have focused on how to evaluate and maximize the health benefits derived from improved water supplies. In many developing countries, the high incidence of water borne diseases and wide-spread use of untreated and often highly polluted water sources necessitate the accurate assessment of faecal contamination of water particularly important.

Regular examination of water quality for the presence of pathogenic/indicator organisms, chemicals, and other physical contents provides information on the level of the safety of water. Frequent examinations of faecal indicator organisms remains the most sensitive way of assessing the hygienic conditions of water. Indicator organisms of faecal pollution include the coliform group as a whole and particularly *Escherichia coli*, *Streptococcus faecalis* and some thermotolerant organisms such as *Clostridium perferingens* (WHO, 1984). The overall concepts adopted for microbiological quality is that no water intended for human consumption shall contain *E.coli* in 100ml sample (WHO, 1984).

Bacteriological tastes for the detection of faecal pollution of water have developed using indicator bacteria (non-pathogenic groups of bacteria) selected on the basis of the following criteria; numerous in feces but not other materials, counted by means of simple reliable tests, more resistance than pathogens to physical and chemical inactivating agents and unable to grow in conditions outside intestine (WHO,1984). Organisms which have been found to fulfill most of these criteria are: The coliform group, the faecal coliform group, faecal streptococci and *Clostridium perferingens*.

The coliform are in the family Enterobacteriaceae which includes the genera *Escherchia, Citrobacter, Klebsiela and Enterobacter* (Clark and Pagel, 1977). Because several of these species are regularly found in unpolluted soils and water, the standard tastes for them can not be said to indicate specific faecal pollution. *Escherchia coli* are almost exclusively faecal microorganisms and constitute over 90 % of the coliform flora of the human intestine. It is easily distinguished from other coliforms on the basis of its growth at 44^0c on media normally used for coliform determination. The faecal coliform test must therefore been taken as the most sensitive, reliable and specific indicators of faecal pollution. One of the problems of this test is the incompatibility of enteric bacteria and viral infections. This is due to the ability of viruses to survive for long period in water, which makes the interpretation of the ratio of viruses to indicator bacteria very difficult (WHO, 1984; Abebe, 1986).

The mapping of water resources in the study area in the central Highlands of Ethiopia-Yubudo-Legebatu PAs in Dendi woreda-showed that the community had access to 28 water sources including rivers and springs distributed unevenly across three land types: upland, mid-slopes and bottomlands. Most of these sources were found unsuitable for human consumption as livestock has open access to all the sources at any point in time and all along their course with the exception of one-a force pump spring built by a church. Analyses of water for coliform count showed that, during the main rainy season most of the water sources were contaminated beyond acceptable level for human consumption while after the main rains the degree of contamination was less but still at unacceptable level. The situation is worse on bottomland and mid-slopes where no source of clean

(potable) water was available during the main rains. It is though that human feces washed down the slopes and animal dung and urine similarly washed down the slopes or deposited directly into the water sources during washing/watering serve to initiate and replenish organic contamination (Preliminary observation by ILRI). Community or municipal water treatment systems are frequently impractical and often unaffordable in these settings. At the present time, inexpensive household water treatment such as slow sand filtration (SSF) provides the only reasonable alternative for many of these people.

In order for a household water treatment technology such as SSF to achieve widespread sustainable use among the poor, it must meet the "criteria of the poor" (Duke and Baker, 2005).

- Effective in cleaning the water and improving its tests, smell and appearance.
- Easy to operate and maintain.
- Affordable and durable, with little or no recurring costs.
- Manufactured using local skills and materials.
- Does not use chemicals or energy.

Slow sand filtration is a proven, sustainable, and reliable drinking water treatment alternative for small communities. The process provides treatment through physical filtration of particles and biological removal of pathogens and organics in the upper biologically active layer of the sand bed known as biofilm. It has been recognized as an appropriate technology for drinking water treatment in rural areas, and is recognized as a suitable filtration technology for removing water borne pathogens and reducing turbidity. It is capable of improving the physical, chemical, and microbiological quality of water in a single treatment process without the addition of chemicals, and can produce an effluent low in turbidity and free of bacteria and viruses. In fact, Wegelin (1988) states, "no other single treatment process can improve the physical, chemical, and bacteriological water quality of surface water better than slow sand filtration". In addition, the USEPA (1997) states, "when used with a source water of appropriate quality, slow sand filtration may be

the most suitable filtration technology in small systems" These two statements elucidate the important role of slow sand filtration for treating surface water in small systems.

Slow sand filters can be constructed from local materials, mainly from properly graded sand/gravel, concrete/clay, and standard piping, can operate without the use of specialized equipment, and is much less labor intensive than rapid filters. Also slow sand filters operate under gravity flow conditions and energy intensive back washing is not required, its on-going energy demand is minimal. Thus, slow sand filtration is an attractive treatment alternative for local communities. Finally, there is very little water wastage during cleaning of the filters and the production of sludge is much less than rapid sand filters. The sludge can subsequently be handled in its dry state, preventing recontamination of surface water; and used as an amendment to agricultural fertility (Huisman and Wood, 1974).

Slow sand filtration is a sustainable technology for rural water treatment because it is low cost and simple to operate. In addition, it is able to produce excellent effluent quality without the use of treatment chemicals. In fact, under good source water conditions, Cleasby *et al.* (1984a) found that slow sand filtration achieved better treatment than coagulation followed by direct filtration. In addition to the potential health hazard of long-term chemical exposure, treatment chemical are also costly to manage in rural water systems. Due to lack of availability in rural areas, the transportation costs of importing chemicals can be a major concern for small systems. In addition, the use of chemicals requires more maintenance and monitoring from skill personal, as the chemical dosing-process is highly sensitive to fluctuations in raw water quality such as PH. Thus the on-going operational costs of a conventional treatment system that uses chemicals can be overwhelming for a small community.

Therefore, the present study evaluates the efficiency of slow sand filtration with locally available modified clay pot applied to improve water quality for drinking at household level using total coliform and thermotolernt/faecal coliform indicator organisms. Similarly, my friend Birhanu Million also works on the assessment of contamination level of coliforms from the source water (spring and river) in the same study area.

1.2 OBJECTIVES OF THE STUDY

1.2.1 General objectives

- To evaluate the efficiency of slow sand filtration in clay pot in removing coliform bacteria colonies and turbidity in drinking water for household use and to assess the contamination level at the point-of-use at home in the Central Highlands of Ethiopia (Yubudo-Legebatu PAs).

1.2.2 Specific objectives

- To evaluate the efficiency of slow sand filtration in clay pot in removing total coliforms, thermotolerant/faecal coliforms and turbidity in drinking water at household level.
- To assess the contamination level of total and thermotolerant/faecal coliforms from home storage containers.
- To record the perceptions of household users with regard to water quality from the filter, ease of use and level of satisfaction with the filter to assess sustainability.
- To generate baseline information for further studies.

1.3 Hypothesis

- Slow sand filtration in clay pot is affordable, socially acceptable and effective technology in removing coliform bacterial colonies and turbidity in drinking water in poor households as source of water contaminates changes overtime, so will treated water improves the health and livelihoods of communities.

2. Literature Review

2.1 Slow Sand Filtration Process

2.1.1 Brief History of Slow Sand Filtration

Slow sand filtration dates back to 1829 in Paisley, Scotland, where John Gibb supplied water to the city from the slow sand filter (SSF) at his bleachery (Baker, 1948). However, the current model for slow sand filtration originated from a one-acre slow sand filter designed by Jams Simpson for the Chelsea water company in London in 1852, which treated surface water from the Thames River (Barrett *et al.,* 1991). After John Snow linked the outbreak of disease such as cholera and typhoid to waterborne contamination, slow sand filter become a legal requirement for all potable water extracted from the River Thames from 1892 (Huisman and Wood, 1974). Further convincing proof of the effectiveness of SSF at controlling waterborne disease was provided in 1894 by the experience of two neighboring cities, Hamburg and Altona, which both abstracted drinking water from the River Elbe. The former delivered drinking water from the river untreated, while the latter filtered the whole of its supply. When the river water becomes infected with cholera organisms, Hamburg suffered from a cholera epidemic while Altona did not. SSF was the sole method of water treatment until the advent of rapid sand filtration at the end of 19th century (Brink and Parks, 1996). Currently, the USEPA recognized slow sand filtration as an acceptable water treatment technology, which provides safe water for human consumption.

2.1.2. Characteristics of Slow Sand Filtration

The basic components of a slow sand filter are: supernatant water layer, sand bed (fine and course sand), gravel and outlet hose. The supernatant water layer provides a head of water that is sufficient to drive the water through the filter bed, whilst creating a retention period of several hours for the water. Sand is the usual filter medium because of its low cost, durability and availability. The sand has a relatively fine grain size (effective size 0.15-0.3mm). The gravel provides an unobstructed passage for treated water from the filter bed, which prevent sand from clogging the under-drain piping and supports the filter sand bed. Water percolates slowly through the porous sand medium, and inert particles, organic material, and microorganisms such as bacteria, viruses and cysts of *Giardia* and

Cryptosporidium enteroparasites are removed (Ellis, 1985; Fogel *et al*., 1993). Organic and inorganic particulate matter and pathogenic microorganisms are removed by physical filtration and biological degradation in the sand bed. Most of the treatment occurs at the top of sand bed where deposits of particulate and algal matter, combined with the dense growth of biomass, form a surface layer known as the biofilm. However, significant additional treatment also occurs throughout the rest of the sand bed. The literature reveals some variation in the recommended design parameters for slow sand filters (Table 1).

Table 1. Characteristics of Slow Sand Filters

Recommendations			
Design Criteria	Ten states standards USA (1987)	Huisman and wood (1974)	Visscher *et al.* (1987)
Bed depth (m)	0.8	1.2	0.9
Effective media size (mm)	0.3-0.45	0.15-0.35	0.15-0.3
Filtration rate (m/h)	0.08-0.24	0.1-0.4	0.1-0.2
Support bed (m)	0.4-0.6	Not reported	0.3-0.5
Supernatant waters (m)	0.9	1-1.5	1

Source: Galvis *et al.* (2002)

2.1.3. Mechanisms of Filtration

Filtration is used primarily for removal of suspended particulates, including pathogens, in the production of potable water. Table 2 lists the variety of particles found in raw waters. Particle removal efficiencies in the range of 99% to 99.9% are reported in the literature for biologically matured slow sand filters (Bellamy *et al*., 1985a), particularly from surface water of relatively low turbidity.

Table 2. Particles found in raw or ambient waters.

Category	**Group/name**	**Size (µm)**
Mineral	Clays (colloidal)	0.001-1
	Silicates	No data
	Non-Silicates	No data
Biological	Viruses	0.001-0-1

	Bacteria	0.3-10
	Algae, unicellular	30-50
	Giardia cysts	10
	Parasite eggs	10-50
	Nematode eggs	10
	Cryptosporidium oocysts	4-5
Other particles	Amorphous debris, small	1-5
	Organic colloids	No data

Source: Bellamy *et al.* (1985a)

Filtration rate is another important factor affecting removal in slow sand filters. In particular, sedimentation and biological mechanisms are dependent on filtration rate (Ellis, 1985). As expected, Poynter and Slade (1977) found that removal of viruses decreased with increased filtration rare. In addition, Muhammad *et al.* (1996) found that color removals, which depend mostly on sedimentation, were significantly decreased at higher filtration rates. This confirms that biological treatment and sedimentation are indeed influenced by filtration rate. Interestingly, Huisman (1977) reported that a higher filtration rate increases the organic loading rate, which results in higher substrate availability and forces microorganisms to live deeper than 300-400 mm in the sand bed, leading to potential breakthrough of bacteria. In some cases, however, filtration rate does not have an effect on bacteria removals. For example, Poynter and Slade (1977) found that increasing the filtration rate from 0.2 m/h to 0.4 m/h had no effect on removals of coliform bacteria and *E. coli*. Bed depth is also an important parameter for slow sand filter performance. The minimum depth for good turbidity and coliform bacteria removal is 300mm, but 600mm is necessary for removal of all viruses (Ellis, 1985). Bellamy *et al.* (1985c) found good removals of bacteria with reduced bed depth. Where coliform removals dropped from 97% to only 95% by reducing the bed depth from 0.97 m to 0.48m. This is because most of the biomass and biological treatment occurs in the upper portion of the sand bed. In fact, Williams (1987) found that all bacteria reduction occurs in the top 20cm of the filter bed. Where a 1 log removal of faecal coliforms was achieved after 5cm depth and another 1.3 log removal after 20cm depth, for a total of 2.3 log removal (99.5%). Overall, bed depth is

more important for removal of smaller particles, including viruses, colloidal matter, and color, and less significant for removal of bacteria.

In general, filtration occurs by physical (transport) and chemical mechanisms (attachment). Additionally, biological processes are important purification mechanisms operating in slow sand filtration (Huisman and Wood, 1974).

2.1.3.1. Physical-Chemical Mechanisms of Removal in Slow Sand Filtration.

Physical-chemical mechanisms of filtration are divided in to two categories: transport mechanism and attachment mechanism. Transport mechanism governs the transport of particulate matter to the filter media (otherwise referred to as collectors) and attachment mechanisms govern the attachment of particles to the media.

One of the major types of transport mechanisms in slow sand filtration is straining or screening, where particles larger than the pore size of media are physically removed. Huisman and Wood (1974) approximated the pore size of a given media to be about 15% of the media diameter. Thus, it is feasible that a 0.2mm diameter media could strain out particles larger than 30µm in size (Haarhoff and Cleasby, 1991). However, as the pore size of the media progressively decrease due to particle deposition and biofilm growth; straining will become more efficient in capturing particles that are even smaller in size (Weber-Shirk and Dick, 1997b).

There are particles in surface water that are much smaller than the pore size of the media, such as bacteria (0.01 to 10µm), viruses (0.01 to 0.1µm), and colloidal particles (0.001 to 1µm) (Montgomery, 1985). These particles penetrate deeper into the bed, where other mechanisms of transport (inertia, sedimentation, interception, hydrodynamic action and diffusion) become important. Impaction occurs when the inertia of the particle approaching the collector is greater than the hydrodynamic force that is carrying the water past the collector (Montgomery, 1985). The particle will deviate from the flow path and impact the collector. Hydrodynamic forces that result from changes in flow velocity and changes of pore size may also transport particles to the surface of the collector (Montgomery, 1985).

Sedimentation occurs when the mass density of a particle is much greater than that of water and its settling velocity causes the particle to deviate from the flow path and settle on to the media surface. Ellis (1985) reported that sedimentation is probably more important with suspended particulates between 4 and 20µm in size.

Interception occurs when deposited particles accumulate on the media surface, gradually reduce the pore size, and act as additional collectors for subsequently passing particles. It is generally known that as the ratio of the particle size to media size increase, interception also increases (Montgomery, 1985). Particles in the colloidal range (less than 1µm in diameter) are influenced by diffusion and will deviate from flow paths toward the filter media, depending on the electrostatic interaction between the particles and the media (Montgomery, 1985). As particles are transported to the filter media, attachment mechanisms will act to capture the particle resulting in a successful collision. Such attachment mechanisms include mass attraction (van der walls force) and electrostatic attraction between oppositely charged particles (Montgomery, 1985). The effects of van der walls forces, however, are only significant if the particle can overcome any electrostatic repulsion barrier and reach the surface of media (Haarhoff and Cleasby, 1991). Mc Connell (1984) suggests the possibility of multivalent cations acting as abridge between negatively charged surfaces and negatively charged particles. This theory was confirmed by the finding that "virus adsorption on sand is enhanced with increasing ionic strength and with higher concentration of higher valance cations in solution" (Galvis *et al*., 1998).

Adsorption of particles to the media is another important attachment mechanism. Microorganisms such as algae and bacteria will colonize the filter bed and form a sticky zoogleal biofilm on the sand grains to which particles can become attached to. Ellis (1985) suggests that adsorption is more important for smaller particles.

Detachment of particles is another important phenomenon of filters. As particle deposits and growth of biofilm reduce the pore size of the media, the interstial velocity in the pores

increases. This causes an increase in the hydrodynamic shear force on particle deposits and may cause particles to become detached. Shearing forces are expected to be highest in the biofilm (Weber-shirk and Dick, 1997b). Increased detachment may also occur with sudden increases in the influent solids concentrations. Detached particles can then penetrate deeper in to the filter bed and may ultimately breakthrough the filter. For example, Ellis and Aydin (1995) found that particulate deposits decreased rapidly with depth; however were still present at depth of 400mm.This highlights the importance of maintaining consistent operational conditions, and avoiding sudden fluctuation in influent or flow water quality.

2.1.3.2. Biological Mechanisms of Removal in Slow Sand Filtration

Pathogenic microorganisms including bacteria and viruses, and cysts of enteroparasites may be effectively removed by SSF (Burman, 1962; Poynter and Slade, 1977). This is partly explained by the slow filtration rate of water and fine sand used, but also attributed to biological mechanisms in the schmutzdecke and within the upper layers of the sand bed (Huisman and Wood, 1974). Among the several biological mechanisms operating in slow sand filters, predatory activities associated with the maturity of the filter bed are suggested as the main process responsible for removing and inactivating microbial pathogens during SSF.

Haarhoff and Cleasby (1991) concluded from a review of published literature that Predation of algae and bacteria, Scavenging of detritus by aquatic worms found mainly in the deeper region of the bed, natural death, inactivation, metabolic breakdown (i.e. reduction of organic carbon), and adsorption to the sticky Zoogleal surface of the sand are the principal biological mechanisms responsible for particle removal by SSF. For example, bacteria removal in SSF has been attributed to grazing by protozoa. Burman (1962) examined the bacterial condition of water before, during and after filtration at the Walton treatment works, in London. This showed that coliform and *E. coli* counts decreased in the supernatant water during the hydraulic retention time above the sand. This was attributed to bacterial grazing by protozoa or other predators migrating from the filter surface. Coliform counts increased at the sand surface, but lower *E. coli* counts were found, suggesting that growth of coliform bacteria may occur in the filter mat on the sand surface

but there was no evidence for the growth of *E. coli* in the filter. In another study at Walton on colonization of a resanded slow sand filter, the numbers of *E. coli* bacteria in the filtered water were inversely related to the size of numbers of flagellate and ciliate populations in the filter, suggesting that protozoa were important agents for bacteria removal (Weber-Shirk and Dick, 1999).

Weber-Shirk and Dick (1997a) suggest that bacteriveory or predation of bacteria is the most important of all these mechanisms, and adsorption is the least significant. However, at a lower water temperatures, it is suggested that adsorption to biomass is the dominating mechanism, due to reduced biological activity (Welte and Montiel, 1996).

Duncan (1988) provides a survey of the common organisms that can be found in the sand bed. These include aerobic bacteria, flagellates, ciliates, rotifers, flatworms (Microturbellaria), gastrotriches, nematode (round worms), anellida (segmented worms) and arthropods (harpacticids).

Of all these, the predominant organisms are gram-negative pigmented bacteria such as *Pseudomonas* and *Aeromonas* as well as algae, protozoa, and higher order eukaryotes (Eighmy *et al*., 1993). Bacteria that are typically present in biological process are generally classified as oligotrophs (Rittman and Huck, 1989). Oligotrophs are "characterized by their ability to simultaneously and efficiently utilize a wide array of substrates present at low concentrations." (Moll and Summers, 1996).

The larger microorganisms such as protozoa either feed on suspended particles or bacteria, or are predators of other inhabitants of the sand bed. This is confirmed by Weber-Shirk and Dick (1999) who state, "predators that graze on attached bacteria potentially free up sites for future bacteria attachment while suspension feeding predators directly remove particles from the mobile phase". A proven species to be implicated as a bacterial predator is Chrysophyte (Weber- Shirk, 2002). Other predacious fauna include meiofaunal species (0.1 to 1mm in size), which feed on individual bacterial or algal cells, suspended particles, or other species (Duncan, 1988). Some eukaryotes are known to be predators to bacteria,

while some microorganisms simply produce substances that are toxic to enteric bacteria (Lloyd, 1973; Huisman and Wood, 1974).

Aerobic oligotrophic bacteria grow on the sand media to form a dense biofilm. This sticky biofilm, sometimes referred to as zoogloea, is known to adsorb colloidal material. Some researchers are postulated that filtration efficiency is partially a function of particle adsorption to the sticky biofilm (Huisman and Wood, 1974). Bacteria such as *Pseudomonas aeruginosa* are known to produce extra-cellular polymeric substances (EPS), polysaccharides and proteins, which serve to anchor bacteria to surfaces (Dai *et al*., 2002). Bellamy *et al.* (1985b) suggest that the polymers act to flocculate organisms and destabilize clay and bacteria to facilitate attachment. Wheeler *et al.* (1988) suggests that these extra- cellular polymers can also provide binding sites for viruses. Removal of viruses is achieved through microbial predation and adsorption to biomass (Wheeler *et al*., 1988). Due to the relatively small size of viruses; physical mechanisms of removal are of less importance. Wheeler *et al*., (1988) found that biomass concentration is just as important for the removal of viruses (e.g. rotavirus) as it is for the removal of pathogenic bacteria. In fact, they found similar patterns of removal between viruses and bacteria with respect to depth in the filter.

The term 'bioantagonism' has been used by a few authors to explain a mechanism of removal where by incoming pathogenic bacteria are either 'out competed' or 'inactivated' by autochthonous (naturally occurring) bacteria in the sand bed. For example, in the natural environment, Sattar *et al.* (1999) found that survival of *Cryptosporidium* declined in the presence of autochthonous microorganism, and this phenomenon was referred to as bioantagonism. Although no specific microorganism was determined responsible for oocyst decay and the actual mechanisms of bioantagonism were unclear, autochthonous bacteria could similarly be responsible for oocyst decay in slow sand filters. This assumption is supported by the research of Uhl (2000), which indicates that the member of pathogens in biofilters decrease, rapidly in the presence of autochthonous bacteria. The reasoning is that pathogenic bacteria, or autochthonous bacteria, are accustomed to high concentrations of organic matter where they thrive and experience a high growth rate.

However, at low concentrations of organic matter, their growth rate is low. In contrast, the growth rate of autochthonous bacteria is still high even at low concentrations of organic matter (less than 1mg/L) of carbon, thus out competing pathogens (Uhl,2000).

The term,' inactivation', is used to describe the removal of enteric microorganisms due to predation or bioantagonism (Datta and Chaudhuri, 1991). Each layer of the sand bed has its own inactivation potential depending on the vertical distribution of biomass. For example, Prokaryotes and Eukaryotes were active through out the filter bed in inactivating enteric microorganisms (*E. coli);* however inactivation potential was highest near the surface of filter bed (Datta and Chaudhuri, 1991).

2.2. Performance of Slow Sand Filtration

Slow Sand filtration produces an effluent low in turbidity, free of impurities and more importantly, virtually free of bacteria, entero-viruses and protozoa (Galvis *et al*. 1998). Galvis *et al*. (1998; 2002) found that typical removal efficiencies for slow sand filter as shown in Table 3. Most of the results are from slow sand filters operating at temperatures above 5^0c, filtration rates between 0.04 and 0.2 m/h, bed depths above 0.5 m, and effective media diameters between 0.15 and 0.3mm.

Table3. Typical Removal Efficiencies for Slow Sand Filtration

Parameter	Effluent or Removal Efficiencies	Comments.
Turbidity	<1NTU	Treatment efficiency depends on quantity, nature and distribution of particles.
Coliform bacteria	>99%	Treatment efficiency mostly depends on the biological maturity of the filter.
Entero bacteria	90-99.9%	Treatment efficiency affected by temperature, filtration rate, media size, bed depth and cleaning.

Entero viruses and *Giardia*	99-99.9%	Effect of cleaning practices on removal efficiency in a biologically mature bed is minimal.
True color	25 to 40%	Color is associated with organic material and humic acids. Average 30% removal.
Total organic Carbon (TOC)	<15-25%	Mean 16%
Dissolved organic carbon (DOC).	5-40%	Mean 37%
Biodegradable dissolved Organic carbon (BDOC)	46-75%	Mean 60%
Assimilable organic carbon (AOC)	14.40%	Mean 26%
UVabsorbance (254nm)	5-35%	Mean 16-18%
Trihalomethane (THM)	<25%	
Iron and Manganese	30to 90%	Fe levels> 1mg/L reduce filter run length due to precipitation and filter clogging.

Source: Galvis *et al.* (1998; 2002)

2.2.1. Removal of Bacteria

It is suggested that slow sand filtration can achieve between 99 and 99.9% of pathogenic bacterial removal (Van Dijk and Ooman, 1978). However, removal efficiencies may be somewhat site specific as there is some variation in the findings from several authors. The variation in bacteria removals can be attributed to differences in source water quality conditions and filter operational conditions. This highlights the importance of onsite pilot

testing to determine treatment performance under the prevailing water quality and operational conditions.

2.2.2. Removal of Viruses

Slow Sand filtration can achieve very good removals of viruses. Typically virus removals in slow sand filtration range from 2 to 6logs (Troyan and Hansen, 1989), and generally increase with increasing bed depth and decreasing filtration rate and increasing water temperature. Poynter and Slade (1977) found 99.9% removal of poliovirus I with a bed depth of 600 mm and filtration rate of 0.2 m/h. Removal efficiencies decreased with lower bed depth and higher filtration rates, and were only slightly affected by temperature. For example, 99.9% removal was achieved at a temperature of 11 to 12^0 C but decreased only slightly to 99% at 6^0C. Yahya *et al*. (1993) studied the removal of bacteriophages MS-2 and PED-I which represent human enteric viruses because they are similar in shape and size (25nm and 62 nm, respectively) and they absorb poorly to sand. Removal of MS-2 and PRD-1 was 99% and 99.9%, respectively.

2.2.3. Removal of Parasites.

Slow sand filtration is very efficient in removing *Giardia* and *Cryptosporidium*. A summary of removals reported by several authors is presented in Table 4. In general *Cryptosporidium* is more difficult to remove than *Giardia* because; due to its smaller size and it has lower collector efficiency than *Giardia* (Hsu *et al*., 2001).

Table 4. Removals of *Giardia* and *Cryptosporidium* in Slow Sand Filters.

Author	*Giardia*	*Cryptosporidium*	Comments.
Bellamy *et al*. (1985a)	>98%	-	-
Schuler *et al*. (1988)	99.83 to 100%	100%	-
Schuler *et al*. (1991)	-	3.9 to 7.11og	-
Fogel *et al.* (1993)	Average of 93%	-	-
Logsdon *et al.* (1993)	93.7 to 99.99%	-	-
USEPA (2001)	-	99.9 to 99.99%	-
Timms *et al.* (1995)	-	99.997%	Influent spike of 4,000oocyst/L,Filtratio

			n rate of 0.3 to 0.4 m/h
Logan*etal*.(2001)	-	>3 to 41og	Influentspikeof65,000oocyst/L, Less removal with larger media

Overall, slow sand filtration can achieve excellent removals of bacteria, viruses, *Giardia* and *Cryptosporidium*, suspended particulates or turbidity, so it provides drinking water that is consistently safe for human consumption.

2.3. Operational Factors Affecting Removal in Slow Sand Filtration

2.3.1 Removal Efficiency of Slow Sand Filtration

Slow sand filtration is proven to achieve excellent removals of pathogenic bacteria, protozoa, viruses, suspended solids, and turbidity. However, removal efficiency is highly dependent on physical and operational characteristics of the filter including the media size, bed depth, filtration rate, biological maturity of the filter, and cleaning practices.

Generally, there are similarities in the findings of many authors, who report a decrease in filter efficiency with increased media size, increased filtration rate, decreased bed depth, and decreased biological maturity of the sand bed. A smaller media is favored due to its increased filtration efficiency. Ellis (1985) reports improved bacteria removals with smaller media. Although, the impact of media size on filter performance largely depends on the size distribution and surface chemistry of the particulate matter in the source water. For example, if there are a high proportion of solids in the water with a relatively large particle diameter, they are more likely to be removed, even in large media. On the other hand, a high proportion of smaller size particles possessing a negative surface charge are more difficult to remove, especially in larger media. Vander Hoek *et al.* (1996) documents a varied response from several authors regarding the effect of media size on slow sand filter performance. Interestingly, Bellamy *et al.* (1985c) reported that an increase in effective sand size did not necessarily result in poor filter performance. An increase in effective media diameter from 0.128 mm to 0.615mm resulted in only a small decrease in bacteria removals from 99.4% to 96%.

2.3.2. Cleaning of Slow Sand Filtration

Cleaning must be performed at the end of a filter run. Typically, filter run times range from 30 to 60 days, but could reach more than 100 days (Ellis, 1985). The traditional method of cleaning slow sand filters involves draining the water level down to just below the sand surface and scarping off the top 1 or 2 cm of biofilm. The biofilm is where the highest concentration of biomass exists, hence the region where most biological treatment is achieved. Thus, pathogen removal may be compromised for a couple of days after cleaning until biofilm maturity is reestablished. In some cases, however, cleaning my have no effect on treatment efficiency. For example, Fox *et al.* (1984) found that bacteria removal was unaffected by scraping, and Poynter and Slade (1977) found that scraping had little effect on the removal efficiency of viruses.

Eighmy and Collins (1988) reported using an alternative method of cleaning known as "harrowing" where the sand is raked by a comb harrow, which penetrates 30cm in to the sand bed and detaches particulate debris. The debris is then washed away by a continuous flow of water across the top of the sand bed.

Generally, cleaning times are significantly lower with the harrowing method than the scraping method, and filters could be put back on line within days instead of weeks. Also this method results in minimal or no sand loss, thus re-sanding of the filter after many years of operation is not an issue. But most importantly, Eighmy and Collins (1988) found that very little biomass was lost during cleaning and biomass populations penetrated deeper in to the sand bed, providing more biological contact time and improving removals of non- purgeable dissolved organic carbon.

An additional advantage of harrowing is that it is an *in-situ* cleaning method, and it is not necessary to drain the water level down to expose the sand. Lloyd (1996) fond that some protozoa such as spiratichs, which graze on incoming bacteria, are particularly susceptible to desiccation when the sand is exposed. Thus, *in-situ* methods of cleaning are preferred to maintain the viability of the biomass ecosystem in the sand bed.

Burman (1962) found that cleaning of the slow sand filter lead to a reduction in the removal of *E.coli* from 99 to 94%, although removal of coliform bacteria was unaffected. Burman (1962) also found that removal of chlorine resistant spore-forming bacilli ranged from 81 to 88%, and after cleaning these removals dropped from 81 to 73%, Bellamy *et al.* (1985a) found that cleaning or replacing the sand resulted in a 1 log decrease in bacteria removal efficiency.

The biological maturity of the filter also has an important influence on removal efficiency. Basically, if the length of filter run is short and cleaning is frequent, the biologically layer will never have enough time to reestablish equilibrium and maturity. Cleasby (1984b) found that the removal of coliform bacteria increased from 95% to greater than 99% as the filter matured. Likewise Bellamy *et al*. (1985a) found that *Giardia* removal was 98% in new sand, where as in biologically mature sand, removal was 3 to 4 log. Thus, the importance of lengthy filter runs, which allow plenty of time for maturation, can not be over stated.

2.4. Contamination of water in home storage containers

Most water sources in developing countries are polluted by chemical and biological agents. Feachem (1980) noted that in developing countries, water sources sometimes show indicator bacteria concentration, which is equivalent to that of weak untreated sewage. These contaminated water sources can be vehicles for the transmission of pathogens (Esrey *et al*., 1985). According to Ngoma (1992) more than one-third of deaths in developing countries are caused by drinking water from these highly contaminated sources.

In their study on water borne transmission of cholera in Trujillo, Peru, Swerdlow *et al.*(1992) tested the variation of water quality at the source (i.e. well water), and later in the household (i.e. stored water). In this study, progressive deterioration of water quality was observed during distribution and storage at home. Consequently, the mean coliform counts were higher (20 faecal coliforms and 794 total coliforms per 100ml) in water sample from household storage container and lower (1 faecal coliform and 1 total coliform per 100ml) in city well water (Swerdlow *et al*., 1992).

The risk of diarrhoeal disease due to contamination of drinking water during household storage was noted in surveys conducted by different researchers. Pinfold and Horan (1991) stated that there is higher risk of ingesting faecal micro-organisms with water that is contaminated during collection and storage than with water from the source.

Swerdlow *et al.* (1992) in a case-control study indicated that stored water contamination during hand washing and scooping was strongly associated with cholera illness. The stored water has become contaminated with *Vibro cholera* and coliform bacteria (Swerdlow *et al*., 1992). Mintz *et al.* (1995) summarized some investigations in which recognized enteropathogens were identified from stored water. *Escherchia coli*, *Vibro cholera* 01, *Strongyloides*, and *Ascaris* were repeatedly isolated from the home storage water samples (Mintz *et al*., 1995).

The majority of faecal bacteria found in stored water are, most likely transferred from environment through water related activities by way of water handling practices (Pinfold and Horan, 1991). The practices include method of collection from the sources, transport to the house, drawing of water from storage container, keeping the water container clean, and washing hands before collecting (Pinfold and Horan, 1991).

Several researchers, Pinfold and Horan (1991), Swerdlow *et al.* (1992), Bartram and Johns (1988) and Kelly (1990) stressed the need for hygiene education to the community on the contamination of water during collection and storage in home. In communities where household storage of water is common, hygiene education is considered the most effective means to quality improvement. Guidelines for hygiene education (Boot, 1987) and for cholera control (WHO, 1993) also emphasized on the prevention of contamination of water borne diseases.

3. Materials and Methods

3.1 Description of the study area

The study was conducted in West Shoa, Dendi district, Ginch town, Yubudo-Legebatu Peasant Association (YLPA). YLPAs are located at about 80km west of Addis Ababa in the Dendi district of Oromiya region. The PA is located at about 20km from the district town Ginchi. The study area has uneven topography with upland, mid-slopes and bottom lands. It receives mean annual rainfall ranging from 800-1172.2 mm and has an average temperature of between 9.3^0C and 23.8^0 C. The altitude of the area ranges between 1600 and 3268 meter above sea level. Total populations in YLPAs are 5614 and number of households in upland and bottom land of YLPAs is 746 (Source: Ginchi Bureaus of Agriculture). The mapping of water resources in YLPAs in Dendi woreda- showed that the community had access to 28 water sources including rivers and springs distributed unevenly across different land types; upland, mid-slopes and bottom lands.

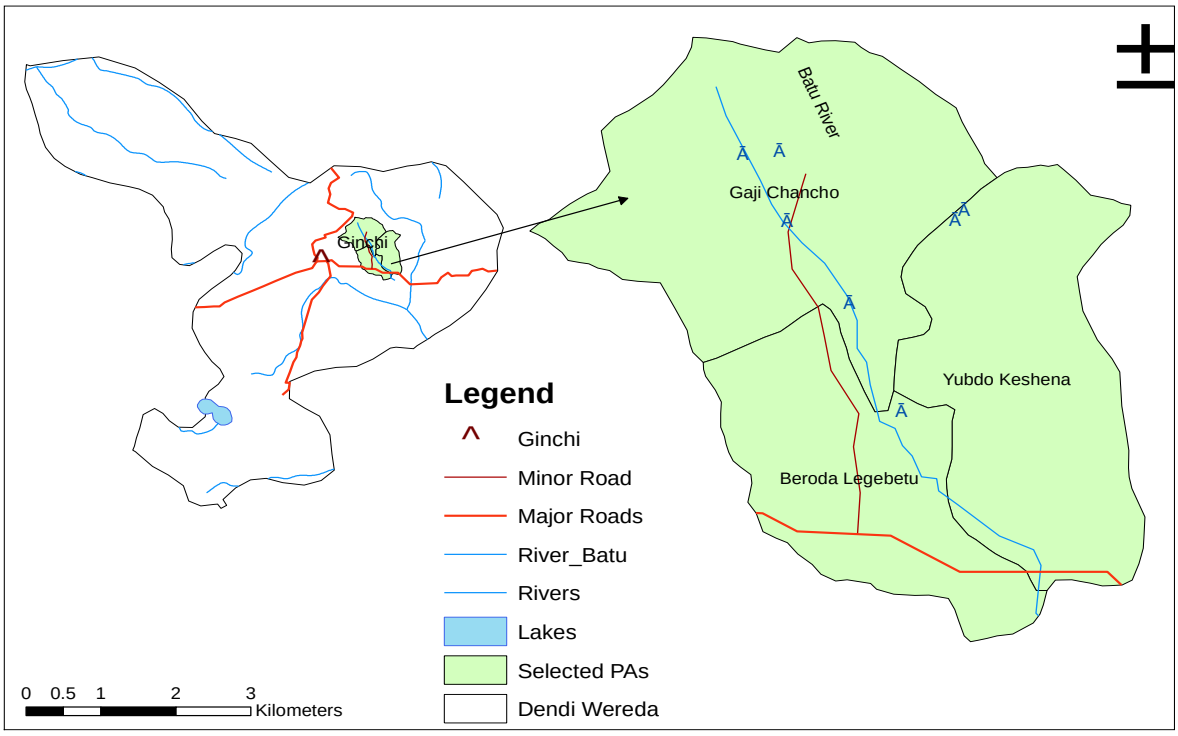


Figure1. Map showing the study area, Ginchi, Yubudo-Legebatu PAs.

3.2 Design of the study

The study was made up of literature review and field works. The field works were consisted of analyses of drinking water quality for indicator bacteria, such as total coliforms, thermotolerant/faecal coliforms and for turbidity from the influent and effluent of slow sand filtration in clay pots (Figure 1.) from intervention groups, and from home storage containers of village 1 and 2 of non-intervention groups. Moreover, the field work comprises of interviewing 40 intervention groups who used a slow sand filtration in clay pots to record the perceptions of household users with regard to water quality from the filter, ease of use, and level of satisfaction with the filter to assess sustainability using questionnaires and observations (**Annex. 2**).

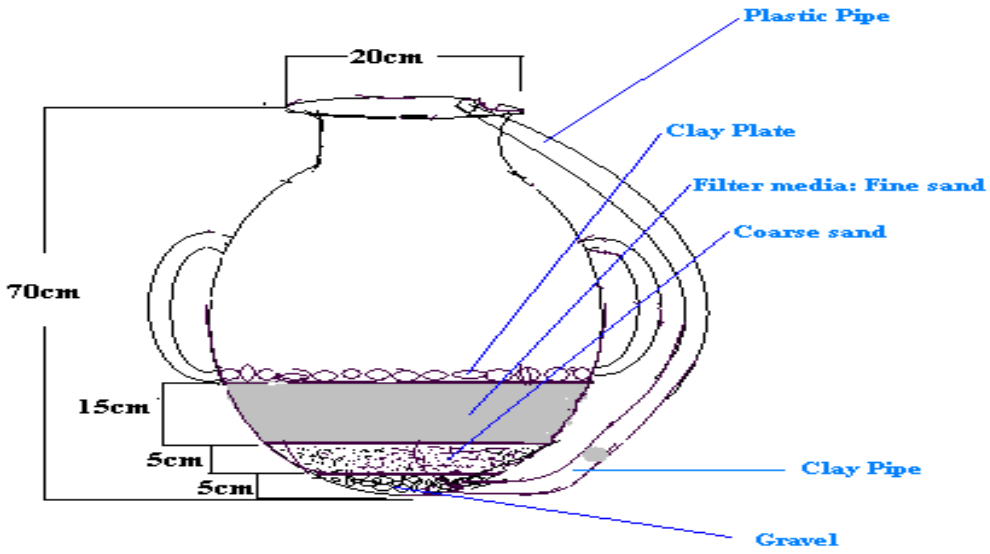


Figure 1: Schematic drawing of slow sand filtration in clay pot.

Picture 1. Slow Sand Filtrations in clay pot in two households in Yubudo-Legebatu PAs.

3.3 Water Samples and Sampling Points

Eighty households were selected for this study where 40 households were intervention groups who used slow sand filtration in clay pot comprised of spring users (20) and river users (20). Assessment of drinking water quality from home storage containers were also conducted for the other 40 non-intervention groups from village 1 using spring water (20) and from village 2 using river water (20). Water sample were collected from the influent and effluent of slow sand filtration in clay pots. Likewise, water samples were taken from home storage containers of village 1 and village 2 of non-intervention households (**Annex 1**). Samples were taken at two-week interval using a sterile 200ml glass bottle, labeled and kept in cool ice box during transportation to Applied Microbiology Laboratory, Department of Biology, Addis Ababa University. The appropriate tests were undertaken with in 8 hours of collection to avoid the growth or death of organisms in the sample.

(a) (b)

Picture 2. Water collection sources spring (a) and river (b) in the study area.

3.4 Sample Analyses

All samples were analyzed for total coliform bacteria, thermotoleratn/ faecal coliforms and turbidity in Applied Microbiology Laboratory, Department of Biology, Addis Ababa University. To determine the presence of total coliform and thermotolerant/faecal colifrom in the water samples, standard membrane filtration methods were used as described in membrane filtration techniques (APHA, 1998). Turbidity also measured using Turbidimeter (HACH- *2100P model Turbidimeter*).

Picture 3. Sample water quality analyses in the laboratory.

3.5 Membrane Filtration Techniques

The membrane filter technique, which involves direct plating for detection and estimation of coliform densities, is as effective as the multiple-tube fermentation test for detecting bacteria of the coliform group and it is the best techniques currently available (APHA, 1998).

The samples were analyzed for total coliforms (TC) and thermotolerant/faecal coliforms (TTC/FC) using the membrane filter technique as outlined by the APHA (1998). This technique involved filtering water through a membrane that retained total coliforms, thermotolerant/fecal coliforms, incubating this membrane on a growth promoting medium and then counting the resultant TC and TTC/FC units.

An ideal sample volume of water which yields 20 to 80 coliform colonies and not more than 200 colonies of all types on a surface of membrane were used and drinking water were analyzed by filtering 100ml, or by filtering replicate smaller sample volumes. Using sterile forceps, a sterile membrane filter paper (0.45µm pore sizes, 47mm in diameter, sterile and gridded were from WAGTECH) was placed on the membrane filter support assembly (from WAGTECH). Funnel unit were placed carefully over the filter support assembly and were locked in place. The sample were mixed thoroughly by shaking for about 30 minutes and poured in to the funnel assembly then the entire volume of sample were filtered through the membrane-filter by applying vacuum pump. Funnel and membrane-filter assembly were rinsed by sterile dilution water.

Up on completion of the filtration process, vacuum were disengaged, unlocked and using a sterile forceps funnel were removed and membrane were removed immediately and placed on Dehydrated Difco M-Endo Agar (LES) (No.0736) with a rolling motion to avoid entrapment of air in glass Petri dishes. Finally the prepared culture dish were inverted and incubated for 22 to 24h at 35 $\pm$0.5 ^{0}C. Up on completion of incubation period, typical coliform colonies (Pink to dark red color with sheen) were seen on the surface of membrane filter paper. Colony counts on the filter paper were determined using a low-power (10 to 15 magnifications) binocular wide-field-dissecting microscope, with a cool

white fluorescent light source for optimal viewing of sheen. Then total coliforms per 100ml, of sample were calculated. This meets the objectives on determination of total coliforms from influent and effluent of slow sand filtration and from home storage containers.

Following the same procedure of filtration process, membrane filter papers were placed on Dehydrated M-FC Agar with rosolic acid (to increase specificity of medium). Finally the prepared culture dish were inverted and incubated for 24 $\pm$2h at 44.5 $\pm$0.2^0 C. Up on completion of the incubation period, blue colored colonies on the surface of the filter paper were counted. Then thromtolerant/faecal coliform colonies per 100ml of sample were calculated. This meets the objectives on determination of thermotolerant/faecal coliforms from the influent and effluent of slow sand filtration and from home storage containers (APHA, 1998).

Verification tests were done by transferring growth from each colony and placed in lauryl tryptose broth; incubating the lauryl tryptose broth at 35±0.5^{o}c for 48 h. Gas formed in lauryl tryptose broth within 48h verifies the colony as a coliform. Inclusion of EC broth inoculations for 44.5±0.2^{o}c incubation were verifies the colony as faecal coliforms (APHA, 1998).

Further identification of TC and TTC/FC were made by examining the colonies under an epifluorescence microscope (Olympus BX51, Japan) attached to a CCD camera. Analyses Docu soft-ware (cc12 Docu, Germany) was used for image acquisition of the respective colonies.

3.6 Statistical Analyses of Data

The 40 households with SSF in clay pots were selected by ILRI in collaboration with the peasant association. All 40 households with a clay pot filter were included in the study, representing 5 % of the 746 households in the area. Half of these, 20 households were located in the highland part of the area, using a spring as their major water source. The other 20 were located in the low land part and used a river. A comparable group of 2 times

20 households, with small children but without filters, was selected as a control. Results of water analyses were compared against standards set by World Health Organization (WHO, 2004) and Federal Democratic Republic of Ethiopia, Ministry of Water Resources (MoWR, 2002) for drinking water qualities. T-taste at 5 % level of significance was used to compare the quality of water between village 1 and 2 from home storage containers. The data were analyzed using the statistical soft-ware SPSS version 13.0 for windows.

3.7. Ethical Consideration

Informed consent was obtained from the concerned offices and community leaders before implementing the actual study. Sampling of water was carried out with full consent of the head of the households. Before each sampling, the study objectives were clearly explained to the households, that the aim of the study was neither to evaluate the performance of the individual nor to blame any one for weakness, but to gather information that might lead to eventual improvement in the situation. Each household was assured that the information provided would be confidential and used only for the purpose of research.

4. RESULTS

In the present study, the efficiency of slow sand filtration (SSF) in clay pot in removing total coliforms (TC), thermotolerant/faecal coliforms (TTC/FC) and turbidity, and assessment of the contamination level of total coliforms and thermotolerant/faecal coliforms in village 1 and 2 from home storage containers were considered. A total of 360 (40 x 2 (inf. & effl.) x 3 + 40 (home storage) x 3) water samples were collected from the influent and effluent of slow sand filtration in clay pot and from home storage containers taking triplicate water samples from each point for each households. All samples were analyzed for bacteriological qualities and turbidity.

4.1 Total coliform (TC), Thermotolerant/Faecal coliform (TTC/FC) and Turbidity removal by SSF in clay Pot.

Table 5 below shows analyses of water samples for TC, TTC/FC and turbidity from influent and effluent of SSF in clay pot for spring users. The result revealed that average TC from influent (n=20) was 888.9 CFU/100ml where as from effluent (n=20) it was 5.5 CFU/100ml. Moreover, average TTC/FC from influent (n=20) was 289.4 CFU/100ml where as from effluent (n=20) it was 2.5 CFU/100ml. Similarly, average turbidity from influent (n=20) was 9.0 NTU and from effluent (n=20) it was 0.9 NTU. The result of TC, TTC/FC and turbidity from effluent of SSF in clay pot are at acceptable level which meets the standards set by World Health Organization (WHO, 2004) and Federal Democratic Republic of Ethiopia, Ministry of Water Resources (MoWR, 2002) (Table 9).

Table 5. Analyses of water samples for TC, TTC/FC and Turbidity (TR) from influent and effluent of SSF in clay pot for those households leaving in the highland using spring water (n = 20). (The average was calculated from each water sample taken in each rounds from each household from Nov., 2006 to Jan., 2007)

H H. No	Influent TC	Effluent TC	Influent FC	Effluent FC	Influent TR	Effluent TR
1	780.7	11.3	256	4.7	6	0.8
2	1016.3	12.3	260	4.3	6.3	0.7
3	1030.3	13.3	340	5.7	4.7	1
4	926	7.3	176	6.7	4.7	0.8
5	803	5.3	340	3	11	1
6	706.7	11.7	283	7	6.3	1.3
7	1036	13.7	360	4.7	4.3	1
8	773.7	11	256	5.7	6.7	0.7
9	810	4	290	7.3	6.3	0.8
10	1013	5.6	210	6	6.3	0.7
11	780.7	7.7	280	1.7	5.3	1
12	956	12.7	240	4.7	8	0.5
13	970.3	2.3	376	3	6.3	1
14	933	10.7	300	7.3	4	0.8
15	770.7	2.3	273	7.3	6.7	0.8
16	863	2	360	5	6	0.8
17	1020	2.3	176	8.3	6	1
18	763.3	11.7	296	2.7	7	0.8
19	893.3	7.3	456	1	5.7	0.8
20	933.7	7	260	5.7	6.7	1
Mean	**888.9**	**5.5**	**289.4**	**2.5**	**9.0**	**0.9**
S.D	**339.190**	**0.938**	**49.358**	**0.426**	**1.535**	**0.153**

The effectiveness of SSF in clay pot in removing microbial pathogens from water was based on total coliforms (TC) and thermotolerant/faecal coliforms (TTC/FC) colony counts from the influent water samples versus samples taken from the effluent. Table 6 below shows removal efficiencies for each SSF in clay pot for spring users. The result showed that an average removal efficiency of SSF in clay pot were 97.4 % (n=20) and 96.9 % (n=20) for total and thermotolerant/ faecal coliform bacteria, respectively, while the removal efficiency for turbidity was 92.9 % (n=20) were found.

Table 6. Removal efficiencies of each SSF in clay pot for total coliform (TC), Thermotolerant/faecal coliform (TTC/FC) and Turbidity, per 100 ml of water samples, for those households leaving in the highlands for spring users (n =20).

Household No.	Removal Efficiencies (%)		
	TC	TTC/FC	Turbidity
1	99.0	97.5	84.6
2	98.7	98.3	84.5
3	97.9	98.4	98.3
4	94.3	93.2	81.9
5	99.3	99.3	85.0
6	98.5	95.5	97.1
7	93.0	98.4	95
8	93.5	96.4	82.6
9	99.3	97.4	86.2
10	96.3	94.7	89.0
11	99.1	99.2	96.9
12	95.7	97.8	93.7
13	99.7	99.3	82.9
14	98.8	97.5	99.4
15	96.3	95.0	87.7
16	97.2	98.2	96.1
17	99.7	95.1	82.5
18	98.5	93.1	87.3
19	99.2	97.8	94.2
20	94.1	97.7	84.1
Mean	**97.4**	**96.9**	**92.9**

Table 7 below shows analyses of water samples for TC, TTC/FC and turbidity from influent and effluent of SSF in clay pot for river users. The result revealed that average TC from influent (n=20) was 824.0 CFU/100ml where as from effluent (n=20) it was 4.8 CFU/100ml. In addition, average TTC/FC from influent (n=20) was 267 CFU/100ml, and from effluent (n=20) it was 2.0 CFU/100ml. Similarly, average turbidity from influent (n=20) was 8.4 NTU and from effluent (n=20) it was 0.9 NTU. The result of TC, TTC/FC and turbidity from effluent of SSF in clay pot are at acceptable level which meets the standards set by World Health Organization (WHO, 2004) and Federal Democratic Republic of Ethiopia, Ministry of Water Resources (MoWR, 2002) (Table 9).

Table 7. Analyses of water samples for TC, TTC/FC and Turbidity (TR) from influent and effluent of SSF in clay pot for those households leaving in the Lowland using river (n =20). (The average was calculated from each water sample taken in each rounds from each household from Nov., 2006 to Jan, 2007)

H H. No	Influent TC	Effluent TC	Influent FC	Effluent FC	Influent TR	Effluent TR
1	850	7	156.7	2.3	7.3	0.8
2	756.7	11.7	200	5.3	6	0.8
3	876.7	3	153.3	3.7	4.3	0.5
4	1126.7	16.3	160	7.3	8.3	0.5
5	716.7	5.7	276.7	7.7	7.3	1
6	796.7	5.3	333.3	3	9.3	1.7
7	613.3	8.7	396.7	5.3	6.7	1.2
8	730	8.7	353.3	8.7	7	1.3
9	980	11.3	276.7	3	6.3	1.3
10	800	10.7	360	8.7	6.7	0.7
11	1020	7	296.7	8.3	5.7	1.3
12	756.7	5.7	236.7	4.3	6.7	1
13	833.3	7	163.3	1.7	7	1.2
14	480	4	286.7	5.3	6	1.3
15	766.7	10	313.3	9	5.3	0.8
16	876.7	14	243.3	10.7	6.7	0.7
17	870	6..3	330	3	5	0.8
18	876.7	10.7	313.3	9	4	0.7
19	906.7	9	256.7	1	6.7	1.2
20	846.7	11.7	233.3	3	6	0.8
Mean	**824.0**	**4.8**	**267**	**2.0**	**8.4**	**0..9**
S.D	**140.537**	**0.819**	**45.538**	**0.341**	**1.432**	**0.153**

Table 8 below shows removal efficiencies for each SSF in clay pot for river users. The result showed that an average removal efficiency of SSF in clay pot were 97.9 % (n=20) and 96.5 % (n=20) for total and thermotolerant/ faecal coliform bacteria, respectively, while the removal efficiency for turbidity was 93.1 % (n=20) were found.

Table 8. Removal efficiencies of each SSF in clay pot for total coliform (TC), Thermotolerant/faecal coliform (TTC/FC) and Turbidity, per 100 ml of water samples, for those households leaving in lowlands for river users (n =20).

Household No.	Removal efficiencies (%)		
	TC	TTC/FC	Turbidity
1	99.1	98.6	88.2
2	96.4	96.9	95.4
3	99.6	97.4	87.8
4	99.1	95.4	93.9
5	99.2	93.5	86.3
6	95.4	98.9	81.9
7	98.5	98.3	81.9
8	98.3	97.5	99.7
9	98.8	94.9	97.9
10	98.7	97.2	90.3
11	97.2	97.1	95.2
12	98.9	93.5	84.7
13	99.1	98.5	80.3
14	93.2	96.6	97.5
15	98.6	95.7	80.2
16	98.4	95.6	99.8
17	99.3	98.5	83.3
18	94.7	94.5	90.6
19	98.9	95.8	82.5
20	98.3	97.4	84.6
Mean	**97.9**	**96.5**	**93.1**

Figure 3 below shows percentage distribution of water sample in each range of TC and TTC/FC from influent and effluent of SSF in clay pot for both spring and river users. The result in Figure 3, revealed that 16(36 %) of water sample taken from the influent had 1 to 10 TC (CFU/100ml) which is 'a reasonable quality', 14(30 %) had 11 to 100 TC (CFU/100ml) found in the 'polluted' range, 12(26 %) tested 101 to 1000 TC (CFU/100ml) which is 'dangerous' range, while 5(8 %) were over 1000 TC (CFU/100ml) which is found in 'a very dangerous' range according to the standards set by World Health Organization (WHO, 2004) and Federal Democratic Republic of Ethiopia, Ministry of Water Resources (MoWR, 2002) (Table 9). Similarly, 18(33 %) of water sample taken from the influent had 1 to 10 TTC/FC (CFU/100ml) which is 'a reasonable quality', 21(44 %) tested between 11 to 100 TTC/FC (CFU/100ml) found in 'polluted' range, 11(20 %) tested 101 to 1000 TTC/FC (CFU/100ml) 'dangerous' range, while 2(3 %) were over 1000 TTC/FC (CFU/100ml) which is found in 'a very dangerous' range. Where as 19(37.75%) of water sample taken from the effluent had Zero TC (CFU/100ml) which is 'safe water' and 31(62.25%) tested 1 to 10 TC (CFU/100ml) 'a reasonable quality'. In addition, 22(43%) of water sample taken from the effluent had Zero TTC/FC (CFU/100ml) 'safe water' and 28(57%) tested 1 to 10 TTC/FC (CFU/100ml) which is 'a reasonable quality' range according to the standards set by World Health Organization (WHO, 2004) and Federal Democratic Republic of Ethiopia, Ministry of Water Resources (MoWR, 2002) (Table 9).

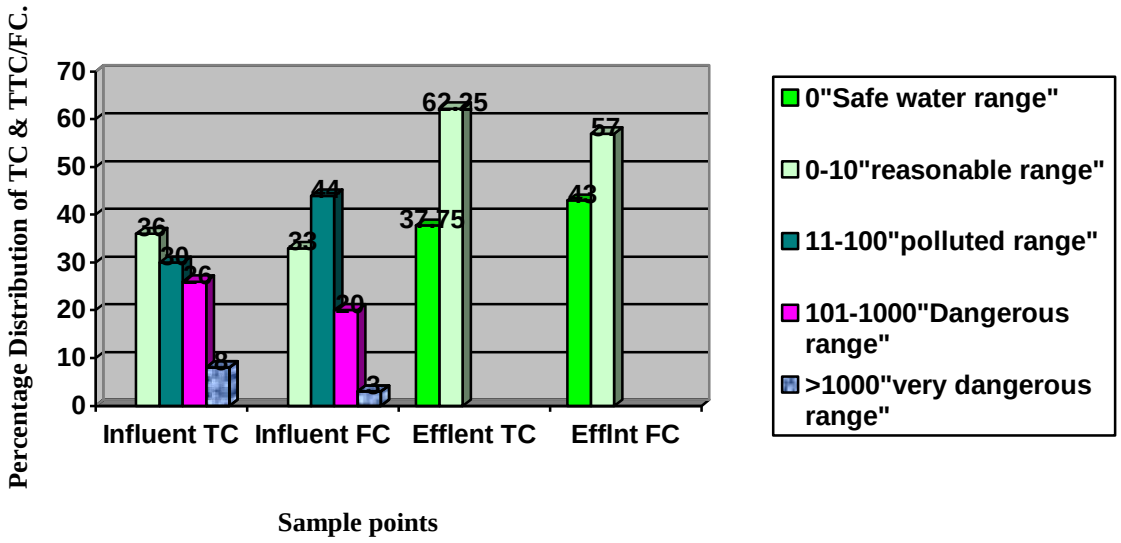


Figure 3. Ranges of TC and TTC/FC from influent and effluent of SSF in clay pot for both spring and river users (n = 40).

Table 9. Standards set by World Health Organization (WHO, 2004) and Ethiopian, Ministry of Water Resources (MoWR, 2002).

Ranges of coliform (TC and TTC/FC)	Standards
0 CFU/100 ml	‘ Safe water’ range
1-10 CFU/100 ml	‘a reasonable water quality’ range
11-100 CFU/100 ml	‘polluted’ range
101-1000 CFU/100 ml	‘dangerous’ range
> 1000 CFU/100 ml	‘very dangerous’ range

4.2 Results from Home storage Containers

The mean values of observations of total coliform (TC) and thermotolerant/ faecal coliform (TTC/FC) counts from water samples of village 1 and village 2 from home storage containers were compared using t-taste for significant differences between the means (Table 10 and Table 11). The result showed that the difference in total coliform and thermotolerant/faecal coliform counts were significant in Village 1 ($P<0.05$) at the 5 % level of significance. That is, water sample taken from home storage containers of village 1(spring users) had high concentration of total and thermotolerant/ faecal coliforms than village 2 (river users).

Table 10. Mean Total coliform (TC) counts per 100 ml water sample taken on Jan., 2007 from village 1 and village 2 (n = 20).

Sample sources	N	Mean of No. of TC/100ml	Std. Deviation	P*
Village 1 spring user	20	979.55± 83.598	373.864	P<0.05
Village 2 river user	20	812.70± 30.994	138.610	

P* = t-taste for significance differences between the means of the two groups.

Table 11. Mean Thermotolerant/ Faecal coliform (TTC/FC) counts per 100 ml water sample taken on Jan., 2007 from village 1 and village 2 (n = 20).

Sample source	N	Mean of No. of TTC/FC /100 ml	Std. Deviation	P*
Village 1 spring user	20	282.15±14.10	63.057	P<0.05
Village 2 river user	20	227.10±7.974	35.661	

P* = t-taste for significance differences between the means of the two groups.

4.3 Comparing water qualities between the source (influent as an indicator) and home storage containers.

Mean values of observations of total coliform counts from water samples of influent and home storage containers of village 1 for spring users were compared using t-taste for significance differences between the means (Table, 12). The result showed that the difference in total coliform counts were significant in village 1 (P<0.05) at the 5% level of significance. That is, water sample taken from home storage containers of village 1 had high concentration of total coliforms than the source (influent as an indicator).

Table 12. Mean Total coliform (TC) counts per 100 ml water sample from influent and home storage containers of village 1 for spring users (n = 20).

Sample sources	N	Mean of No. of TC/100ml	Std. Deviation	P*
Influent	20	888.9± 75.859	339.190	P<0.05
Village 1	20	979.55± 83.598	373.864	

P* = t-taste for significance differences between the means of the two groups

Table 13 below shows mean total coliform counts from influent and home storage containers of village 2 for river users were compared using t-taste for significance differences between the means. The result showed that the difference in total coliform counts were significant in village 2 (P<0.05) at the 5% level of significance. The reason in both cases was that water could be contaminated during collection, transportation, storage in open vessels, and/or in vessels that are not washed regularly. And using communal cups and immersing dirt hands when drawing water also contaminate the water.

Table 13. Mean Total coliform (TC) counts per 100 ml water sample from influent and home storage containers of village 2 for river users (n = 20).

Sample sources	N	Mean of No. of TC/100ml	Std. Deviation	P*
Influent	20	812.70± 30.994	138.610	P<0.05
Village 2	20	824± 31.425	140.537	

P* = t-taste for significance differences between the means of the two groups

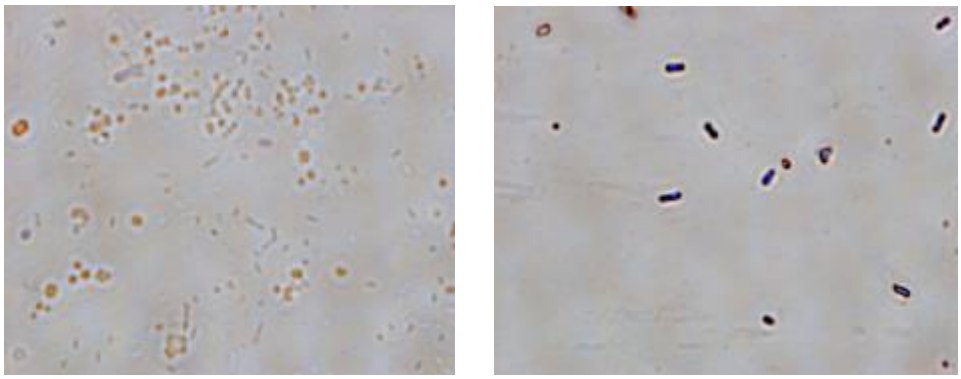
4.4 Total and Thermotolerant/Faecal coliform colonies Identification

Bacterial colonies were identified using membrane filtration techniques. Colors of total coliform bacterial colonies were pink to dark red with sheen, using a low-power (10 to 15 Magnifications) binocular wide-field-dissecting microscope, with a cool white fluorescent light source for optimal viewing of sheen as shown below in picture 4(a).Where as colors of thermotolerant/ faecal coliform bacterial colonies were blue as shown below in picture 4(b).

(a) (b)

Picture 4.Total coliform colonies in membrane filtration (a) and Faecal coliform colonies in membrane filtration (b).

Further identification of total and thermotolerant/ faecal coliform was made by examining the colonies under an epifluorescence microscope (Olympus BX51, Japan) attached to a CCD camera. Analyses Docu soft-ware (cc12 Docu, Germany) was used for image acquisition of the respective colonies. Colors of total coliform colonies are pink to dark red with sheen and they are rod-shaped as shown below in picture 5(a), where as colors of thermotolerant/ faecal coliform colonies are blue and they are rod-shaped as shown below in picture 5(b).



(a) (b)

Picture 5. Epiflorescence microscopic examination of Total coliform colonies (a) and thermotolerant/ faecal coliform colonies (b).

4.5 Results of Questionnaires and Observations

In addition to water quality analysis, the field work consisted of interviews and observations to record overall satisfaction of filter users (**Annex 2**). The following results were obtained**:**

In 37(94%) of the households, the filtered water was used only for drinking. None of the households treated the water with chlorine and boiling after filtering. In 38(95%) of the households, they poured the source water directly in to slow sand filter, not allowing time for sedimentation or settling. All, 40(100%) of the households reported that the filter was easy to use, and that the children who were old enough to lift the bucket could use the filter. In 39(98%) of the households said that the filter produced enough water for the entire household. All, 40(100%) of the households reported that they liked their filters, 39(98%) responded for better quality water, 39(98%) health protection and 38(96%) 'because it works well' as reasons. In 39(98%) of the interviews, the participants answered that the filter water appeared cleaner, tested better, and smelled better than the source water. In 39(98%) of the respondent of households felt that their family's health had improved since they begun using the filter, while 1(2%) had not noticed any change. From all households, 39(98%) of them responded that they would recommend the filter to others.

In 3(7.5%) of the 40(100%) households reported that they had had problems with slow flow rates and two said that they had to obtain assistance from Community Development to correct the problem. In all of these cases, the problem was blocking of the filter due to impurities and suspended solids in the water. All were easily corrected by cleaning procedure. The average flow rate for the filters was 35 L per hour, ranging from 21 to 47 L per hour.

Results of observation indicated that in 39(98%) of the cases, the filters were appeared to be clean and well-maintained and it was functioning at the time of the unannounced first visit. The filters were found to be durable with a few having minor problems such as cracked lids or diffuser plates were observed. One of the filters was found to have a crack near the lip of the filter above the spout, but it was still being used and seemed to function well and other seven filters was found to have a broken near the lip of the filter, a place where an outlet hose become attached, during transportation to the home. For all of these it was replaced by a new one. At the time of the second visit, in 40(100%) of the cases, the filters were found to be well-maintained, functioning properly and sustainable, implying regular use.

5. Discussion

Health is determined by many factors, including income, environmental conditions like access to adequate sanitation and safe drinking water supplies, behavioral change and availability of health services. More than half of the world's population lives in villages in rural areas and most of those without access to safe drinking water supply or basic sanitation are rural dwellers (Howard *et al*., 2003). Thermotolerant/ faecal indicator bacteria have been used to measure water quality and personal hygiene standards in a variety of settings (Kaltenthaler *et al*., 1996).

In this study, the bacterial total coliforms and thermotolerant/ faecal indicator organisms were used to provide an insight in to the water quality from influent and effluent of slow sand filtration in clay pot and from home storage containers of village 1 and village 2. Coliform bacteria may not cause disease but can be used as indicators of pathogenic organisms that cause intestinal infections, such as dysentery, hepatitis, typhoid fever, cholera, and other illness.

Several qualitative studies on the evaluation of the effectiveness of slow sand filtration in removing coliform bacteria and reduction of turbidity have been carried out in various countries; however, this is the first report on the evaluation of the effectiveness of slow sand filtration in clay pot in removing total coliforms and thermotolerant/ faecal coliforms and of turbidity from drinking water in rural areas of Ethiopia.

In the present study, results of analyses of water samples for TC, TTC/FC and turbidity from influent and effluent of SSF in clay pot for spring users, revealed that average TC from influent (n=20) was 888.9 CFU/100ml where as from effluent (n=20) it was 5.5 CFU/100ml. Moreover, average TTC/FC from influent (n=20) was 289.4 CFU/100ml where as from effluent (n=20) it was 2.5 CFU/100ml. Similarly, average turbidity from influent (n=20) was 9.0 NTU and from effluent (n=20) it was 0.9 NTU (Table 5). The result of TC, TTC/FC and turbidity from effluent of SSF in clay pot is in 'a reasonable water quality' range according to the standards set by World Health Organization (WHO,

2004) and Federal Democratic Republic of Ethiopia, Ministry of Water Resources (MoWR, 2002) (Table 9). The analyses of water samples from influent and effluent of SSF for total and faecal coliforms and turbidity conducted in rural district of Chikwana in southern Malawi (George, 2005). The result showed that analyses from effluent of SSF for all parameters 6.5 CFU/100 ml, 3.0 CFU/100 ml and 0.8 NTU, respectively were found, which meets the standards of World Health Organization while from influent of SSF were not meet, which is found to be similar with the present study. Study on analyses of water quality from influent and effluent of SSF for faecal coliforms and turbidity conducted by (Huisman and Wood, 1974). The result showed that analyses from effluent of SSF were 2.5 CFU/100 ml and 0.8 NTU respectively, which meets the standards of World Health Organization, which is found to be similar with this study.

In the present study, slow sand filtration in clay pot was found to have an average removal efficiency of 97.4 % (n=20) and 96.9 % (n=20) for total and thermotolerant/ faecal coliform bacteria, respectively, while the removal efficiency for turbidity was 92.9 % (n=20) were found, this is for those households in which their main water collection sources were spring (Table 6). In a study of the performance of a low cost household slow sand filtration system carried out in Haiti. It was reported that the system achieved 98.5% removal of coliform bacteria and a reduction on turbidity from 11.2 to 0.9 NTU (Duke and Baker, 2005), which is found to be similar with the present findings. As opposed to the present study, a study conducted in The Hague, Netherlands, suggested that slow sand filtration can achieve between 99 and 99.9 % reduction of coliform bacteria (Van Dijk and Ooman, 1978). However, removal efficiencies may be somewhat site specific as there is some variation in the findings from several authors. The variation in bacteria removals can be attributed to differences in source water quality conditions and filter operational conditions. In the present study efficiency of SSF in clay pot were excellent this is due to increased biological maturity of the filters as well as increased biological treatment resulting from warmer water temperature, resulted in a stable effluent quality. In addition, the increase is because of Physical and biological layers in slow sand filtrations which are responsible for removal of microorganisms. Biological layer, known as biofilm, is mainly responsible for the removal of microorganisms from raw water. The growth of the biofilm,

increase the ‘stickiness’ of the filter medium and the specific bed surface, and thus raised the filtration efficiency value. Among the several biological processes occurring within slow sand filter beds, predatory action, maturity of sand bed, and biofilm development are very important for water purification. Pathogenic microorganisms including bacteria and viruses, and cysts of enteroparasites may be effectively removed by SSF (Burman, 1962; Poynter and Slade, 1977). This is partly explained by the slow filtration rate of water and fine sand used, but also attributed to biological mechanisms in the biofilm and within the upper layers of the sand bed (Huisman and Wood, 1974). Among the several biological mechanisms operating in slow sand filters, predatory activities associated with the maturity of the filter bed are suggested as the main process responsible for removing and inactivating microbial pathogens during SSF.

Furthermore, results of analyses of water samples for TC, TTC/FC and turbidity from influent and effluent of SSF in clay pot for river users showed that average TC from influent (n=20) was 824.0 CFU/100ml where as from effluent (n=20) it was 4.8 CFU/100ml. In addition, average TTC/FC from influent (n=20) was 267 CFU/100ml, and from effluent (n=20) it was 2.0 CFU/100ml. Similarly, average turbidity from influent (n=20) was 8.4 NTU and from effluent (n=20) it was 0.9 NTU (Table 7). The result of TC, TTC/FC and turbidity from effluent of SSF in clay pot is in ‘a reasonable water quality’ range which meets the standards set by World Health Organization (WHO, 2004) and Federal Democratic Republic of Ethiopia, Ministry of Water Resources (MoWR, 2002).

Similarly, slow sand filtration in clay pot was found to have an average removal efficiency of 97.9 % (n=20) and 96.5 % (n=20) for total and thermotolerant/ faecal coliform bacteria, respectively, while the removal efficiency for turbidity was 93.1 % (n=20) were found, this is for those households in which their main water collection sources were river (Table 8). A study conducted by Clarke *et al.* (1996b) in South Africa, indicated that faecal coliform removals were in the range of 90 to 97 %, and suggested that slow sand filters play a significant role to pathogen removal, this results are in agreement with the present findings. In another study, Wegelin *et al.* (1998) reported that removals of faecal coliforms in the range of 91 to 97 %. The higher removals are achieved with higher levels of

bacterial contamination, which is found to be similar with the present study. For example, Barrett *et al.* (1991) found peak coliform bacteria removals of 96 % by slow sand filtration, and found that higher reductions were associated with higher influent turbidity loadings. Wegelin and Schertenleib (1993) found even higher coliform bacteria removals of 90 to 99 % by slow sand filtration; both results are similar with the present findings. In the present study efficiency of SSF in clay pot were excellent this is due to increased biological maturity of the filters as well as increased biological treatment resulting from warmer water temperature, resulted in a stable effluent quality. In addition, the increase is because of Physical and biological layers in slow sand filtrations which are responsible for removal of microorganisms. Haarhoff and Cleasby (1991) concluded from a review of published literature that Predation of algae and bacteria, Scavenging of detritus by aquatic worms found mainly in the deeper region of the bed, natural death, inactivation, metabolic breakdown (i.e. reduction of organic carbon), and adsorption to the sticky Zoogleal surface of the sand are the principal biological mechanisms responsible for particle removal by SSF. For example, bacteria removal in SSF has been attributed to grazing by protozoa. Some larger species of organisms likes eggs of worm, cyst etc are removed by physical straining in sand layer. Other small species are removed by biological activities in the biofilm layer. The biological maturity of the filter also has an important influence on removal efficiency. Basically, if the length of filter run is short and cleaning is frequent, the biologically layer will never have enough time to reestablish equilibrium and maturity. Cleasby (1984b) found that the removal of coliform bacteria increased from 95% to greater than 99% as the filter matured, which is similar with the present study. About 2 to 3 weeks of time is required to form full fledge biofilm layer on the surface of fine sand.

Turbidity is one of the very important quality parameter. Turbidity may not have direct health impact, but it is more associated with the social acceptance of water. In the present study, water sources which are found in the study area especially produced water with high turbidity levels due to suspended particles. The filters, under study were found very excellent in terms of turbidity removal (Table 5 and Table 7). The water quality standards of World Health Organization emphasize to have the turbidity of drinking water below 5 NTU; thus, results of the clay pot filters meet the standards. Turbidity was expected to

have a positive and strong correlation with chlorophyll-a and bacteria counts and it is caused by the presence of suspended solids including inorganic matter such as clay, silt, calcium carbonate, silica, and organic matter such as phytoplankton and other microorganisms (Sadar, 1998).

Also in the present study, percentage distribution of water sample in each range of TC and TTC/FC from influent and effluent of SSF in clay pot for both spring and river users (Figure 3) showed that 18(36 %) of water sample taken from the influent had 1 to 10 TC (CFU/100ml) which is 'a reasonable quality', 14(30 %) tested between 11 to 100 TC (CFU/100ml) in the 'polluted' range, 12(26 %) tested 101 to 1000 TC (CFU/100ml) 'dangerous' range, while 5(8 %) were over 1000 TC (CFU/100ml) which is found in 'a very dangerous' range according to the standards set by World Health Organization (WHO, 2004) and Federal Democratic Republic of Ethiopia, Ministry of Water Resources (MoWR, 2002) (Table 9). Similarly, 16(33 %) of water sample taken from the influent had 1 to 10 TTC/FC (CFU/100ml) which is 'a reasonable quality', 21(44 %) tested between 11 to 100 TTC/FC (CFU/100ml) found in 'polluted' range, 11(20 %) tested 101 to 1000 TTC/FC (CFU/100ml) 'dangerous' range, while 2(3 %) were over 1000 TTC/FC (CFU/100ml) which is found in 'a very dangerous' range according to the standards set by World Health Organization (WHO, 2004) and Federal Democratic Republic of Ethiopia, Ministry of Water Resources (MoWR, 2002). Where as 19(37.75%) of water sample taken from the effluent had Zero TC (CFU/100ml) which is 'safe water' and 31(62.25%) tested 1 to 10 TC (CFU/100ml) 'a reasonable quality'. In addition, 22(43%) of water sample taken from the effluent had Zero TTC/FC (CFU/100ml) 'safe water' and 28(57%) tested 1 to 10 TTC/FC (CFU/100ml) which is 'a reasonable quality' range. Both ranges, which are found from the effluent of slow sand filtration, are at an acceptable level, which would not present a risk to human health according to the standards set by World Health Organization (WHO, 2004) and Federal Democratic Republic of Ethiopia, Ministry of Water Resources (MoWR, 2002). The presence of faecal coliforms in drinking water shows that the water has been fecaly contaminated and therefore, presents a potential risk of excreta related diseases.

When the mean values of total coliform and thermotolerant/faecal coliforms were compared between village 1 and village 2 from home storage containers using t-taste (Table 10 and Table 11), the result showed that the difference in total coliform and thermotolerant/faecal coliform counts were significant in Village 1 ($P<0.05$) at the 5 % level of significance. That is, water sample taken from home storage containers of village 1(spring users) had high concentration of total and thermotolerant/ faecal coliforms than village 2 (river users). Contamination of water for total and thermotolerant/ faecal coliforms in village 1 (spring users) may have arisen because, soiled hands and water drawing cups placed on the ground prior to being dipped in to the storage container might be the possible reasons for the significant difference in total coliforms. People in the study communities give serious attention to keep their water from faecal contamination rather than keeping from any foreign things. This is because; more emphasis was given on the issue of management of faecal matter during educating about safe water supply, sanitation and hygiene in the study communities. Similar study conducted in rural Thailand (Pinfold and Horan, 1991) indicated that there was a significant difference in stored water samples contaminated with total and faecal coliforms, which is in agreement with the present findings. The presence of faecal coliforms in drinking water shows that the water has been fecally contaminated and therefore presents a potential risk of excreta related diseases. Contamination after collection and during transportation and storage is increasingly being recognized world wide as an issue of public health importance (Lindskog, 1988; Genthe and Strauss, 1997). Water quality was shown to deteriorate significantly after handling and storage with increasing levels of indicator organisms. Studies conducted in other developing countries have found similar results, with varying total and faecal coliform concentration between source and point-of-use water samples (Lindskog, 1988). The authors reported the type of water container to have an effect on stored water quality. Other factors in addition to water quality play an important role for improvements in health to occur, i.e., improved hygiene and health-related knowledge and practices. Different researchers have documented water quality variation between the source and storage in household. The deterioration of water quality between the source and its use is the result of poor water handling practice (Jim *et al*., 2004), which is similar with the present study. The World Health Organization survey team observed that drinking water drawn from

relatively safe supply was stored in earthen jars for subsequent use but was later found totally contaminated with faecal matter indicating the rate of unhygienic containers contribute to increase the number of diarrhea cases (Boot *et al.*, 1988), which is in agreement with the present findings.

Studies on household water quality also showed that mean coliform counts were substantially higher in household water containers than in water sources. Pinfold and Horan (1991) carried out a study on water use and pattern of contamination in rural Thailand. The result of the study reveled that the level of contamination of stored water in homes was higher than that of water at the source. The study showed also that the quality deterioration was mostly occurred after the water has been collected. The author stated that the indicator bacteria found in the stored water was transferred from the environment by practices related to water handling (Pinfold and Horan, 1991), which is similar with the present study (Table, 12 and Table, 13).

The majority of faecal bacteria found in stored water are, most likely transferred from environment through water related activities by way of water handling practices (Pinfold and Horan, 1991). The practices include method of collection from the sources, transport to the house, drawing of water from storage container, keeping the water container clean, and washing hands before collecting (Pinfold and Horan, 1991).

In their study on water borne transmission of cholera in Trujillo, Peru, Swerdlow *et al.*(1992) tasted the variation of water quality at the source (i.e. well water), and later in the household (i.e. stored water). In this study, progressive deterioration of water quality was observed during distribution and storage at home. Consequently, the mean coliform counts were higher (289 faecal coliforms and 794 total coliforms per 100ml) in water sample from household storage container, which is found to be similar with the present findings, and lower (1 faecal coliform and 1 total coliform per 100ml) in city well water (Swerdlow *et al.*, 1992).

Simango and Rukure (1991) also isolated *Campylobacter* species, which are important causative agents of diarrhoeal disease in humans, from household stored drinking water. Quick *et al.* (1996) in a pre-intervention study in Bolivia, found faecal coliform in 37 (79%) of 42 water samples collected from home water vessels, which is similar with the present study.

In the present study, from interviews and observations, in 37(94%) of the households, the filtered water was used only for drinking and in 2(6%) of the households the filtered water was used for both drinking and food preparation. In 39(98%) of the households said that the filter produced enough water for the entire household. All, 40(100%) of the households reported that they liked their filters, 39(98%) responded for better quality water, 39(98%) health protection and 38 (96%) 'because it works well'as reasons.

In 39(98%) of the interviews, the participants answered that the filter water appeared cleaner, tested better, and smelled better than the source water. In 39(98%) of the respondent of households felt that their family's health had improved since they begun using the filter, while 1(2%) had not noticed any change. In 39(98%) of the households responded that they would recommend the filter to others.

The respondents indicated that a high degree of user satisfaction were supported by the observation that 39(98%) of the cases, the filters were appeared to be clean and well-maintained and it were functioning at the time of the unannounced first visit. The filters were found to be durable with a few having minor problems such as cracked lids or diffuser plates were observed. One of the filters was found to have a crack near the lip of the filter above the spout, but it was still being used and seemed to function well and other seven filters was found to have a broken near the lip of the filter, a place where an outlet become attached, during transportation to the home. For all of these it was replaced by a new one. At the time of the second visit, in 40(100%) of the cases, the filters were found to be clean, well-maintained, functioning properly and sustainable, implying regular use.

6. Conclusions and Recommendations

6.1 Conclusions

The improvement of water quality is closely associated with man-environment relationships. There should be a dialogue between all actors and the community when undertaking water and sanitation activities. For positive results and better sustainability, the community should be involved and participate at all stages of water development and environmental sanitation schemes.

A combination of safe drinking water, adequate sanitation and hygiene practices like hand washing is a pre-requisite for morbidity and mortality rates reduction, especially among under five years old children in developing countries. To reduce the incidence and prevalence of diarrhoeal diseases, improvements in the availability, quantity, and quality of water, improved sanitation, and general personal and environmental hygiene is required. Majority of people in developing countries do not have access to piped drinking water and must carry; transport and store water within their homes and in the process the quality of water may deteriorate.

Therefore, slow sand filtration has been recognized as an appropriate technology for drinking water treatment in rural areas, and is recognized as a suitable filtration technology for removing water borne pathogens and reducing turbidity. It is capable of improving the physical, chemical, and microbiological quality of water in a single treatment process without the addition of chemicals, and can produce an effluent low in turbidity and free of bacteria, parasites and viruses.

In this study, the efficiencies of slow sand filtration in clay pot at household level in removing total coliforms, thermotolerant/ faecal coliforms and turbidity were studied. Water analyses from the effluent of slow sand filtration in clay pot showed that it is safe for drinking purpose from bacteriological point of view. In light of results obtained so far, following conclusions are drawn**:**

- The study findings indicated that slow sand filtration in clay pot was found to be excellent to have a significant average removal efficiency of 97.4 % and 96.9 % for total and thermotolerant/ faecal coliform bacteria, respectively, while the removal efficiency for turbidity was 92.9 % for spring users.
- Moreover, slow sand filtration in clay pot was found to have a significant average removal efficiency of 97.9 % and 96.6 % for total and thermotolerant/ faecal coliform bacteria, respectively, while the removal efficiency for turbidity was 93.1 % for river users.
- The study findings suggest that percentage distribution of water samples for both spring and river users from influent and effluent of SSF in clay pot for total and thermotolerant/ faecal coliform showed that only 18(36 %) and 16(33 %) of water samples taken from the influent, respectively, were 'a reasonable quality' ranges which meets the standards. The remaining 31(64%) and 34(67 %) of water samples, respectively, would not meet the standards set by World Health Organization (WHO, 2004) and Federal Democratic Republic of Ethiopia, Ministry of Water Resources (MoWR, 2002).
- Also the study findings indicated that in 19(37.75 %) and 22(43 %) of water sample taken from the effluent of SSF for total and thermotolerant/ faecal coliform counts, respectively, were Zero (CFU/100ml) which was in the 'safe water' range and 31(62.25 %) and 28(57 %), respectively, found in 'a reasonable quality' range, both ranges are at an acceptable level which would not present a risk to human health according to the standards.
- Water analyses from home storage container showed that there was a significance difference in mean concentration of total and thermotolerant/ faecal coliforms in village 1(spring users) than village 2 (river users).
- Even though, the overall increases in the contamination of water at village 2 (river users) at home after collection were not sufficient to cause human illness, in some households contamination was found to increase sufficiently to potentially cause sickness. This indicates those households consumed poor water quality/ unsafe water.

- Perceptions of the householders regarding: (**a**) the taste, smell and appearance of the filtered water, (**b**) ease of use of the filter, (**c**) health protection, and (**d**) sufficient quantity of water produced by the filter for the entire family, indicate high levels of overall satisfaction.
- Observations revealed that the filters were durable, and that most were well-maintained, and functioning properly.
- Major problems of slow sand filter users were plugging of the filter due to suspended solids in the influent. In addition, they lack knowledge regarding maintaining the filter to remove plugging material and to restore flow rate.
- The study findings suggest that when considering the development and protection of any water source, improvement of environmental sanitation and hygiene promotion program should be one of the issues to be considered as top priority.
- Thus, a concurrent and equitable input on both safe water supply and sanitation sector is requisite for promoting the health of communities.
- Finally, the baseline information generated from this study may contribute to develop similar programs and also pave the way for further studies.

6.2 Recommendations

Based on the research findings, the following recommendations can be formulated:

- On the basis of this research, slow sand filtration in clay pot is an attractive option for supplying water treatment to family units in rural areas of poorly developing countries.
- Since the filter is efficient in removing total coliforms, thermotolerant/ faecal coliforms and turbidity, it may be adopted as one of the best household technology in treating drinking water.
- The efficiency of water improvement through reduction of bacterial numbers, coupled with the low cost and low technology of these units was seen to be a significant attribute to reducing the risk of water borne disease and improving general medical health.
- Education about water-borne diseases, sanitation and hygiene should accompany during the installation of the filter.

- Any shortcomings of the slow sand filters are likely best addressed by user education about the operation and maintenance and proper monitoring of the filter media (fine sand) preparation and installation and of fundamental hygiene practices but that the basic principles of the technology are sound.
- Disinfection and supervision of the stored filter water is recommended to ensure that it remains in a safe or reasonable range with respect to bacterial contamination.
- There was a statistically significant difference in concentration of total and faecal coliforms from home storage containers. For such cases, safer household water storage may be an appropriate additional intervention to prevent contamination of domestic water.
- An information-gathering tool, called the KAP (Knowledge, Attitude and Practice) for hygiene should be developed and implemented in the rural areas in supporting water supply and sanitation development programs.
- Regular bacteriological assessment of all sample points should be conducted to check for contamination.
- We would recommend that up-scaling of SSF technology to other poor rural areas of Ethiopia are required.
- We would recommend that study on the elements which may interfere the removal efficiency of filter should be carried out.
- Further, more detail and in depth study on slow sand filtration on the removal of microbial contamination (bacteria, parasites, and viruses) and turbidity is required.

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Annex-1

A. Procedure for collecting a sample from effluent of SSF in clay pot

1. Remove from the outlet hose any attachments that may cause splashing.
2. Wipe the faucet using a clean cotton pad.
3. Allow the water to run for one minutes.
4. Fill the sterilized bottle by opening the stopper carefully (NB: A small air space was left to make shaking before analysis easier).
5. Place the stopper in the bottle.

B. Procedure for collecting a sample from home storage containers.

1. Wipe the drawing cup using a clean cotton pad.
2. Sterilize the drawing cup with a flame from ignited alcohol-soaked cotton.
3. Open the storage container, draw the water and fill the sterilized bottle by opening the stopper carefully.
4. Place the stopper in the bottle.

NB: - The above procedure was used during sampling from clay pot and bucket containers.

In the case of Jerry can container, sample was taken by pouring to fill the sterilized bottle.

** Source: Cheesbrough Monica. Medical Laboratory Manual for Tropical Countries Vol.II Microbiology Cambridge University press, 1984.

Annex-2

Questionnaires used in the study of the effectiveness of SSF in clay pot in Ginchi, YLPAs

Respondent Name ----------

Village----------

Code No. ----------

Date of visit----------

A. Slow Sand Filtration in clay pot questions.

1. **W**hat are all the purposes you use filtered water for?
   Drinking (Yes/No), Food preparation (Yes/No), for both (Yes/No)
2. Do you treat the water after filtering it? (Yes/No)
3. If yes in question 2 above what do you use?
   Chlorine (Yes/No), Boiling (Yes/No), other----------
4. Do you do anything with the water before you put in to the filter?
   Let it settle (Yes/No), Pour it through cloth (Yes/No), we don't--------
5. Is it easy to use the filter? (Yes/No)
6. Do the children know how to use the filter? (Yes/No)
7. Does the filter produce enough clean water for the entire household? (Yes/No)
8. Do you like the filter? Yes, because----------, No, because----------
9. Since you started using the filter, do you think your family's health improved, stayed the same, or become worse?
   Is better (Yes/No), is worse (Yes/No), is the same (Yes/No)
10. Tell us about the taste of filtered water-is better, worse or the same as before filtering it? IS better (Yes/No), is worse (Yes/No), is the same (Yes/No)
11. What about its smell?
    Is better (Yes/No), is worse (Yes/No), is the same (Yes/No)
12. What about its appearance?
    Is better (Yes/No), is worse (Yes/No), is the same (Yes/No)
13. Would you recommend the filter to others? (Yes/No)
14. Have you had any problems with the filter?

Yes, specify---------, No----------

15. Do you ever require help to fix the filter? (Yes/No)

B. Slow Sand Filtration in clay pot Observations.

1. Is the filter located inside or outside of the house?

Inside (Yes/No), Outside (Yes/No)

2. Does the filter appear to be level (not tilted)

Level (Yes/No), Tilted (Yes/No)

3. Does the filter appear clean (outside, inside and outlet hose)? (Yes/No)

4. Is the lid in place? (Yes/No)

5. Is the diffuser plate in place? (Yes/No)

Annex-3

Table showing the effectiveness of SSF in clay pot in removing total coliforms (TC), thermotolerant/ faecal coliforms (TTC/FC) and turbidity (TR) per 100 ml of water sample, and this table is for those households where their main water collection sources were spring.

	1st Round Analyses									2nd Round Analyses								
HH. No.	Inf. TC	Effl. TC	Removal%	Inf. FC	Effl FC	Removal %	Inf. TR	Effl TR.	Removal %	Inf. TC	Effl. TC	Removal%	Inf. FC	Effl FC	Removal %	Inf. TR	Eff TR.	Removal %
1	960	21	97.8	460	5	98.9	5	1	80	540	7	98.7	120	5	95.8	8	0.5	93.8
2	930	12	98.7	240	0	99.9	6	0..5	91.7	1160	10	99.1	320	6	98.1	6	1	83.3
3	870	13	96.5	420	9	97.9	5	1	80	1060	19	98.2	290	0	99.9	5	1	80
4	940	0	99.9	180	7	96.1	4	1	75	940	12	98.7	180	8	95.5	4	0.5	87.5
5	920	10	98.9	500	9	98.2	8	1..5	81.3	730	0	99.9	210	0	99.9	5	1	80
6	980	25	97.4	210	0	99.9	7	1	85.7	520	10	98.1	370	9	97.5	7	1	85.7
7	970	7	97.3	270	9	96.6	6	1	83.3	1120	17	98.5	450	0	99.9	3	1	66.7
8	1040	19	98.2	130	9	93.1	9	0.5	94.4	630	5	99.2	220	8	96.3	5	1.5	70
9	1080	0	99.9	270	7	97.4	5	1	80	660	0	99.9	270	9	96.6	7	1	85.7
10	1200	0	99.9	150	9	94.8	8	0.5	93.8	910	16	98.2	290	0	99.9	6	1	83.3
11	930	23	97.5	230	0	99.9	9	1	88.9	830	0	99.9	240	5	97.9	3	1	66.7
12	970	16	98.4	280	6	97.9	7	0.5	92.9	990	15	98.5	260	0	99.9	8	0.5	93.8
13	1090	0	99.9	210	0	99.9	7	0.5	92.9	920	7	99.2	500	9	98.2	5	1.5	70
14	950	15	98.4	320	9	97.1	5	1	80	940	9	99	320	6	98.1	3	0.5	83.3
15	750	0	99.9	310	8	97.4	8	1	87.5	730	0	99.9	170	7	95.8	7	1	85.7
16	910	5	94.5	430	0	99.9	6	0.5	91.7	890	18	97.9	360	0	99.9	6	1	83.3
17	920	7	99.2	210	7	96.7	5	1	80	1030	0	99.9	160	9	94.3	5	1	80
18	890	11	98.8	320	8	97.5	5	1	80	750	16	97.8	260	0	99.9	7	0.5	92.9
19	980	16	98.4	410	9	97.8	5	0.5	90	900	0	99.9	430	9	97.9	8	1	87.5
20	990	0	99.9	220	5	97.7	9	1	88.9	890	21	97.6	310	5	98.3	5	1	80

Where, HH. No. ------Household number.

Inf. TC ----Influent Total coliform, Inf. FC---Influent Faecal coliform

Effl.TC ----Effluent Total coliform, Effl. FC-EffluentFaecalcoliform

Inf.TR. ----Influent Turbidity, Effl. TR----Effluent Turbidity

Continued…..

3rd Round Analyses								
Inf. TC	Effl. TC	Removal %	Inf. FC	Effl. FC	Removal %	Inf. TR.	Effl. TR.	Removal %
840	6	99.3	190	4	97.75	5	1	80
960	15	98.4	220	7	96.8	7	1..5	78.6
1160	8	99.25	310	8	97.4	4	1	75
900	10	98.8	170	5	97.1	6	1	83.3
760	6	99.2	310	0	99.9	8	0.5	93.8
620	0	99.9	270	13	95.2	5	2	60
1020	17	98.3	360	5	98.6	4	1	75
650	9	98.6	420	0	99.9	6	1	83.3
690	12	98.2	330	6	98.2	7	0.5	92.9
930	0	99.9	190	9	95.3	5	0.5	90
850	0	99.9	370	0	99.9	4	1	75
910	7	99.2	180	8	95.6	9	0.5	94.4
900	0	99.9	420	0	99.9	7	1	85.7
910	8	99.1	260	7	97.3	4	1	75
830	7	89	340	7	97.9	5	0.5	90
790	7	99.2	290	15	94.8	6	1	83.3
1110	0	99.9	160	9	94.4	8	1	87.5
650	8	98.8	310	0	99.9	9	1	88.9
800	6	99.3	530	12	97.7	4	1	75
920	0	99.9	250	7	97.2	6	1	83.3

Annex-4

Table showing the effectiveness of SSF in clay pot in removing total coliforms (TC), thermotolerant/ faecal coliforms (TTC/FC) and turbidity (TR) per 100 ml of water sample, and this table is for those households where their main water collection sources were river.

	1st Round Analyses									2nd Round Analyses								
HH. No.	Inf. TC	Effl. TC	Removal%	Inf. FC	Effl FC	Removal %	Inf. TR	Effl. TR.	Removal %	Inf. TC	Effl. TC	Removal%	Inf. FC	Effl. FC	Removal %	Inf. TR	Effl. TR.	Removal %
1	910	11	98.8	170	0	99.9	6	1	83.3	770	10	98.7	130	0	99.9	8	1	87.5
2	920	10	98.9	100	5	95	6	1	83.3	580	12	97.9	190	0	99.9	5	1	80
3	1030	9	99.1	150	4	97.3	3	0.5	83.3	670	0	99.9	140	7	95	5	0.5	90
4	1160	12	98.9	130	6	95.4	7	0.5	92.9	1120	18	98.4	200	8	96	9	0.5	94.4
5	640	0	99.9	190	0	99.9	7	1	85.7	780	9	98.8	350	9	97.4	7	1	85.7
6	870	7	99.2	290	0	99.9	9	2	77.8	610	0	99.9	410	0	99.9	9	2	77.8
7	650	9	98.6	210	7	96.7	6	1.5	75	450	7	98.4	570	9	98.4	8	1	87.5
8	970	0	99.9	270	5	98.1	7	1	85.7	330	11	96.7	430	5	98.8	5	1.5	70
9	920	15	98.4	310	9	97.1	4	1	75	1030	19	98.2	270	0	99.9	8	1	87.5
10	690	0	99.9	460	0	99.9	8	1	87.5	1030	21	97.9	220	9	95.9	6	0.5	91.7
11	1040	0	99.9	250	8	96.8	5	2	60	1080	0	99.9	330	8	97.6	7	1	85.7
12	560	17	96.9	330	0	99.9	7	0.5	92.9	950	0	99.9	150	7	95.3	5	1	80
13	790	11	98.6	120	5	95.8	5	0.5	90	830	10	98.7	190	0	99.9	5	2	60
14	640	0	99.9	190	0	99.9	5	1	80	250	0	99.9	160	16	90	7	1	85.7
15	900	21	97.7	430	9	97.9	3	1	66.7	530	9	98.3	130	0	99.9	8	0.5	93.8
16	1110	16	98.6	220	9	95.9	4	0.5	87.5	710	10	98.6	200	9	95.5	7	0.5	92.9
17	910	0	99.9	340	9	95.6	3	0.5	83.3	690	0	99.9	310	0	99.9	6	1	83.3
18	980	0	99.9	430	0	99.9	3	1	66.7	790	19	97.6	270	18	93.3	6	0.5	91.7
19	870	19	97.8	220	8	96.4	6	1	83.3	850	8	99.1	240	9	96.3	7	1	85.7
20	900	12	98.7	350	0	99.9	5	1	80	880	17	98.1	230	0	99.9	5	1	80

Where, HH. No. ------Household number.

Inf. TC ----Influent Total coliform, Inf. FC---Influent Faecal coliform

Effl.TC ----Effluent Total coliform, Effl. FC---EffluentFaecacoliform

Inf.TR. ----Influent Turbidity, Effl. TR----Effluent Turbidity

Continued…..

3rd Round Analyses								
Inf. TC	Effl. TC	Removal%	Inf. FC	Effl FC	Removal %	Inf. TR.	Effl. TR.	Removal %
870	0	99.9	170	7	95.9	8	0.5	93.75
770	13	98.3	310	11	95.8	7	0.5	92.9
930	0	99.9	170	0	99.9	5	0.5	90
1100	19	99.9	150	8	94.7	9	0.5	94.4
730	8	98.9	290	14	95.2	8	1	87.5
910	9	99	300	9	97	10	1	90
740	10	98.6	410	0	99.9	6	1	83.3
890	15	98.3	360	16	95.6	9	1.5	83.3
990	0	99.9	250	0	99.9	7	2	71.4
680	11	98.4	400	17	95.8	6	0.5	91.7
940	21	97.8	310	9	97.1	5	1	80
760	0	99.9	230	6	97.4	8	1.5	81.3
880	0	99.9	180	0	99.9	11	1	90.9
550	12	97.8	510	0	99.9	6	2	66.7
870	0	99.9	380	18	95.3	5	1	80
810	16	98.02	310	14	95.5	9	1	88.9
1010	19	98.1	340	0	99.9	6	1	83.3
860	13	98.5	240	9	96.3	3	0.5	83.3
1000	0	99.9	310	16	94.8	7	1.5	78.6
760	15	98.03	120	9	92.5	8	0.5	93.8

Annex-5. Table showing t-taste analyses for mean difference in total coliform (TC) **(**A) and thermotolerant/ faecal coliforms (TTC/FC) (B) in village 1 and village 2 from home storage containers per 100 ml water sample.

(A)

	N	Mean	Std. Deviation	95% Confidence Interval of the Difference		P*
				Lower	Upper	
Village1TC	20	979.55±83.598	373.864	373.864	804.58	P<0.05
Village2TC	20	812.70± 30.994	138.610	138.610	747.83	

	Taste Value = 0					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
Village1TC	11.717	19	.000	979.550	804.58	1154.52
Village2TC	26.221	19	.000	812.700	747.83	877.57

(**B)**

	N	Mean	Std. Deviation	95% Confidence Interval of the Difference		P*
				Lower	Upper	
Village1FC	20	282.15± 14.100	63.057	63.057	252.64	P<0.05
Village2FC	20	227.10± 7.974	35.661	35.661	210.41	

	Taste Value = 0					
	t	Df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
Village 1 FC	20.011	19	.000	282.150	252.64	311.66
Village 2 FC	28.480	19	.000	227.100	210.41	243.79

Declaration

I, the undersigned, declared that this is my original work, has not been presented for a degree in this or any other University, and that all sources of materials used for the thesis have been duly acknowledged.

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Date of Submission: 19-07-2007

This thesis has been submitted for examination with my approval as University Advisor.

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