Design and Evaluation of Household Horizontal Slow Sand Filter

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Abstract

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 in reducing turbidity and coliform concentrations. 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. The objective of this study was thus to develop a household-scalehorizontal slow sand filter (HSSF) with a low-cost treatment process, which can be operated and maintained by a member of the families. It therefore involvesobtaining different grain sizes of sand as a filter media and water quality data from laboratory after filtering the water in different slopes of the HSSF tool. So, the primary product of this project was the developed recommendations and design criterias for the use of HSSF technology to improve water quality.Accordingly, the developed tool was found capable to produce remarkable results in removing turbidity and coliform concentrations in water.The average percent removal of coliforms was found to be 100% with effect from the 9th day; while, turbidity had become within the permissible limit in the first day of filtration.

Key Words

Slow sand filter; Water Quality; Microbiological Analysis; Physico-Chemical Analysis

1. Introduction

Water is not only a basic need but also a human right[1,2]. According to different literatures [3, 4], approximately one billion people worldwide lack access to adequate amounts, and clean and safe water; while,2.2 million people die of waterborn diseases, such as diarrhea [5].

Whilst attempts have traditionally focused on providing centralized systems for water treatment and distribution, there are millions of people who already have abundant access to water but depend on rivers, streams and other unsafe water sources [3, 6]. The implementation of municipal water treatment systems can be impractical and costly due to dispersed populations and poor transport infrastructures in many rural areas. Therefore, low cost community water treatment systems are reasonable alternatives [4].

Interest in household water treatment technology has grown significantly over recent years as studies have concluded that these simple low-cost household interventions may be as effective at preventing diarrhea as other environmental approaches, such as improved sanitation, hygiene and improved water supply [7-9]. The increasing importance of such systems is also highlighted through the creation by the WHO of the International Network to Promote Household Water Treatment and Safe Water Storage, to support study and dissemination of both existing and developing technologies.

The slow sand filter (SSF), one of such technologies, developed by Dr. Eric Mantz at the University of Calgary, in 1976, Canada, has been successfully introduced to many countries of the world. The technology demands little maintenance, is primarily managed at the household level and has been demonstrated to significantly reduce the potential for diarrheal disease. For the first few years after introduction, most studies of the filter have been limited to the laboratory and very little research exists which explores their long-term performance and suitability. Years later, slow sand filtration was proved to be the first water treatment process introduced to improve the quality of surface water and soon also proved to provide protection against~~to~~ waterbornediseases. Thus, it has remained a suitable treatment technology throughout the world and is recognized as particularly appropriate for application in developing countries due to the simplicity of its design and construction and the ease of operation and maintenance.

However, the widely used type of slow sand filter is the vertical slow sand filter; while, it is known that the flow in verticalslow sand filter is relatively faster than that of the horizontal slow sand filter, for the head of water added at the top of the filter has its own pressure[10].

Moreover, the faster the flow within the filter results less quality of filtered water. Thus, a tool that slows the flow of water within the filter and increases the filtration capacity is very important in such a case.The objective of this study was therefore to develop a horizontal slow sand filtration technology with a relatively better filtration capacity, and which is a low-cost water treatment process that can be operated and maintained by a member of the families. More specifically, the project was aimed to:

- ❖ Developing affordable, socially acceptable and effective horizontal slow sand filter (HSSF).
- ❖ Evaluate the efficiency of HSSF in reducing turbidity and microbiological concentrationsof drinking water during lab analysis.
- ❖ Recommend adequate maintenance procedures that could be used by communities.
- ❖ Suggest any additional program components, which might aid the long term sustainability of the filtration process.

2. Materials and Methods

2.1.Design of HSSF Tool

Comment [MH1]: OK

The design of the HSSF sections was made using AutoCAD, version 2007. As shown in Fig. 1, the design of the sand filter has five sections, i.e., sections for the storage, gravel, coarse sand, medium sand and very coarse sand. The storage section is laid above the gravel container. Therefore, when the turbid water comes from the top to the gravel storage, the gravels help to disperse the water and to filter some of the large size dirt. Then, once water got dispersed by the gravel,pathogens are expected to be removed from the water through the filtration process and the coarse sand starts the serious filtration process. Finally, the turbid water passes through the medium sand section (filter media) and gets filtered well. At the end, very coarse sand section is used to prevent clogging of the outlet by the medium sand.

2.1.1. Filter Components

The dimensions of the filter components used in this study are purely experimental with the objective to design the filtration system of householdhorizontal slow sand filter. The essential components of the filter unit have 100cm tire leg from the ground, and also it has sieves dividing the grains from each other (Fig.1). The tank filter as a whole is divided into four places by 40cm width, 20cm height and 22cm length each (Fig.1). Moreover, the sizes of the sieves that are dividing the sections from each other are selected based on the grain sizes. For instance, the sieve size that is dividing the gravel and coarse sand is 1mm in diameter. Therefore, the sieve protects the coarse sand from coming back to the gravel section.

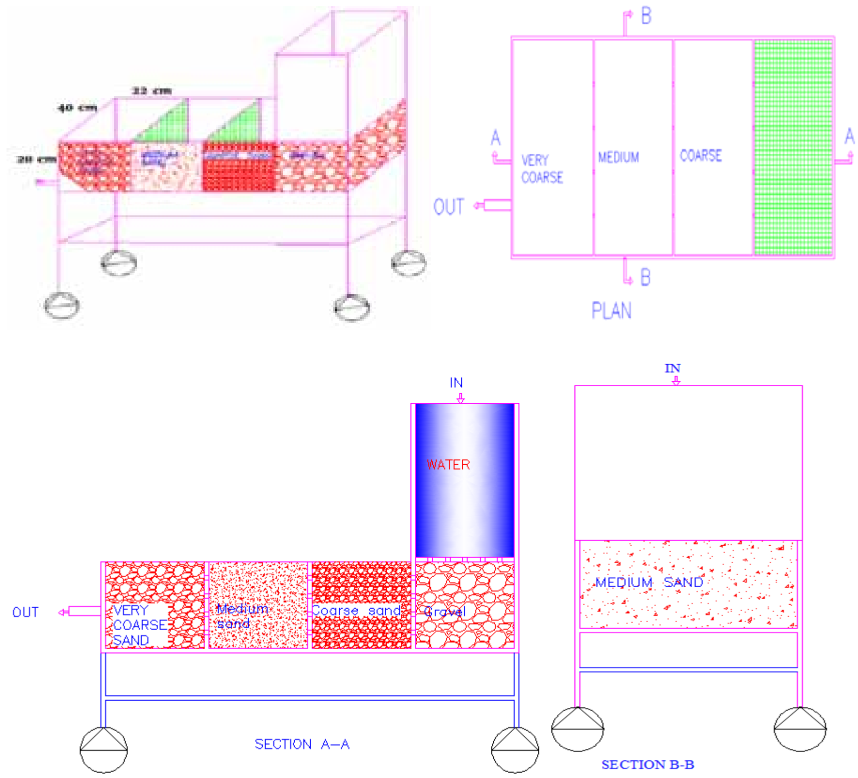

Figure 1: Horizontal slow sand filtration tool sections/views

2.1.2. Flow Rate

Comment [MH2]: OK

Filter flow rates were measured in different grades/slopes of the HSSF.Flow rates were measured by filling the filter to a level approximately 10 centimeters into storage at the inlet part. Discharged water was collected in a half-liter plastic bottle. The time required for 500 ml of water to flow through the filter was thus recorded, and the rate was determined for each grade. The rates were therefore calculated using the following equation:

$$Q = \frac{V}{t}$$

Where, Q is flow rate in L/s,V is volume in L and t is time in second

2.2. Sand and Gravel

Comment [MH3]: OK

A sample of sand taken from a source will not consist of uniformly sized grains but contains a range of grain sizes. Sand was taken from a source (gully sand bank),thenwashed by agitating it in running water to remove excessively fine grains and organic materials before shaking. The sand was dried thoroughly before testing.As RedR recommended"sand used in slow sand filters should have an effective size of 0.15 – 0.35 mm and a uniformity coefficient of 1.5 – 3; however,< 2 is desirable. Preferably, the sand should have rounded, rather than jagged grains and be free from clay. Hence, sand from streams and rivers is normally better suited to slow sand filters than sand from pits.

The sand was then sieved to obtain sand grains that could be used as filter media. A mesh with very small openings was used to prevent the sand clogging, the opening through which the water passes from one media to another sand media and the gate valve. Gravel, in two different sizes, was obtained by sieving the sample. Particle size of sand was known after sieving, and the range of particle size distribution was classified based on USDA sand classification system (Table 1).

Table 1: USDA sand classification system

Types of sand sample	Particle size range (mm)
Gravel	2 – 4
Very coarse sand	1 – 2
Coarse sand	0.5 – 1
Medium sand	0.25 – 0.5
Fine sand	0.1 – 0.25
Very fine sand	0.05 – 0.1

2.3. Characterizing Sand Samples

Comment [MH4]: OK

Sieve analysis was used to characterize the sand samples. Advantages of the sieve analysis include: easy handling, low investment costs, precise and reproducible results in a comparably short time and the possibility to separate the particle size fractions. Therefore, this method is an accepted alternative than analysis methods using laser light or image processing.

To guarantee a high degree of reproducibility and reliability, sieve shakers and accessories have to fulfill the requirements of national and international standards. This means that test sieves, sieve shakers and all other measurement instruments which are used for the characterization of particle distributions have to be calibrated and subjected to test agent monitoring as part of the quality management system. Apart from that, it is necessary to carry out the sample preparation with great care. Only then is it possible to achieve sieving results which allow a reliable characterization of a product.Two quantities are needed to characterize the sand sample:

- Effective particle size – this is the particle diameter such that 10% (by weight) of the grains in the sample are smaller than it and 90% of grains are larger than it. The effective particle size is therefore referred to as D_{10}.
- Uniformity coefficient – this is a method of expressing the size differences between the largest and smallest grains in the sample (also known as the particle size distribution). The uniformity coefficient is defined as the ratio of D_{60}/D_{10}. Like D_{10}, $D_{60}$is the particle size whereby 60% of the samples grains are smaller and 40% are larger.

Thus, the standard sieve analysis proceduresandapparatus were used in this analysis (Fig. 2).

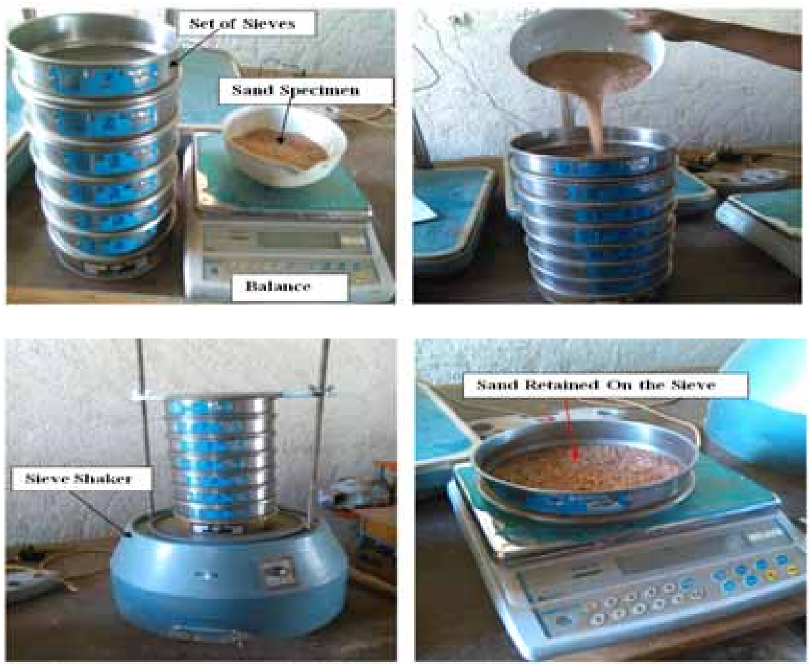

Figure 2: Grain Size Analysis

2.4.Water Sampling Procedures and Analysis

Sieve Shaker

The water samples were analyzed for various parameters in the laboratory. Various physical and chemical parameters like Temperature, pH, Turbidity, TDS and EC have been measured both from the original water and filtered water samples of different grades/slopes of filtration instrument (Fig. 3). Moreover, samples were also analyzedmicrobiologically.

Plastic bottles of 2.0 liter capacity were used for collecting samples.Each bottle was washed with distilled water. The bottles were then preserved in a clean place. The bottles were filled leaving no air space, and then sealed to prevent any leakage. Each container was clearly marked with the name and date of sampling.

Figure 3: Water samples filtered with different slopes of the sand filter

2.4.1. Drinking Water Quality Standards

Comment [MH5]: OK

The results of the analyzed parameters of filtered water of the different grades of HSSF were compared with the related standards for drinking water [11, 12]. The drinking water standards are given in the table 2.

Table 2: Drinking Water Standards (WHO 2006)

S/No.	Parameters	Permissible value
1	Color	Unobjectionable
2	Taste	Agreeable
3	Ph	6.5-7.5
4	Turbidity(Max NTU)	5
5	TDS	500
6	TSS	5
7	BOD	Nil to 5

8	DO	4.0-6.0
9	Total hardness	300
10	Chloride	250
11	Alkalinity	120
12	Residual chlorine	0.2

NB: Except pH and turbidity other parameters are in mg/l.

2.4.2. Methodology for the Measurement of TemperatureTurbidity, pH, EC and TDS

The parameters considered in this study, Temperature, Turbidity, pH, EC and TDS, were measured following the standard procedures [13].

2.4.3. **Microbiological Test**

Comment [MH6]: OK

A filtered sample from the filter with a 5% slope and the pre-filtered sample were taken to the microbial test. The 70188 Violet Red Bile Agar (VRB-Agar) and Peptone Bacteriological reagents were used in the laboratory tests. In our case, 9.625 mg of VRB-Agar and 3.75 mg of Peptone were weighed first in an electrical balance. Then, they were addedto separate glasses and mixed with 250 ml of distilled water each. The VRB-Agar was thus boiled at a 100 ^{o}C; while, the Peptone mixture was autoclaved at a 121 ^{o}C in an autoclave machine. So, 1 ml of sample from each of the 3 samples were taken and placed to separate tubes and diluted to a 10^{-1} and 10^{-2} dilution with a 9 ml each of the Peptone mixture. The analysis was in a duplicate analysis type. Finally, 1 ml of each of thediluted and original samples was taken to a plate where the microbes can grow and 10-15 ml of the VRB-Agar was added to each of the plates. The plates were then placed to an incubator with a 32 ^{o}C temperature. Counting was finally conducted after 48 hours of period.

3. Result and Discussion

3.1.Grain Size Analysis

Sieve Analysis:

Comment [MH7]: I feel table 3 line 176 to 186

(1) The mass of sand retained on each sieve was obtained by subtracting the weight of the empty sieve from the mass of the sieve + retained sand, and this mass was recorded as the weight retained on the data sheet. The sum of these retained masses should approximately be equals the initial mass of the sand sample. A loss of more than two percent was considered as unsatisfactory.

(2) The percent retained on each sieve, by dividing the weight retained on each sieve by the original sample mass, was therefore calculated.

(3) The percent passing (or percent finer) was finally calculated by starting with 100 percent and subtracting the percent retained on each sieve as a cumulative procedure. The overall calculation results are shown in table 3.A semi logarithmic plot of grain size vs. percent finer was finally prepared as shown in Fig. 4.

Table 3: Grain size analysis

Sieve Number	Diameter (mm)	Mass of Empty Sieve (g)	Mass of Sieve+ Sand Retained (g)	Sand Retained (g)	Percent Retained	Percent Passing
5	4	604.36	619.74	15.38	2.25	97.75
10	2	560.46	714.85	154.39	22.61	75.14
20	0.85	503.63	787.63	284	41.62	33.52
30	0.6	496.51	548.03	76.52	11.21	22.31
60	0.25	448.97	486.22	62.25	9.12	13.19
140	0.106	429.80	441.83	37.03	5.43	7.76
230	0.063	347.23	360.27	38.04	5.58	2.18
Pan	-	578.13	592.9	14.77	2.18	0.00

*Percent passing=100-cumulative percent retained.

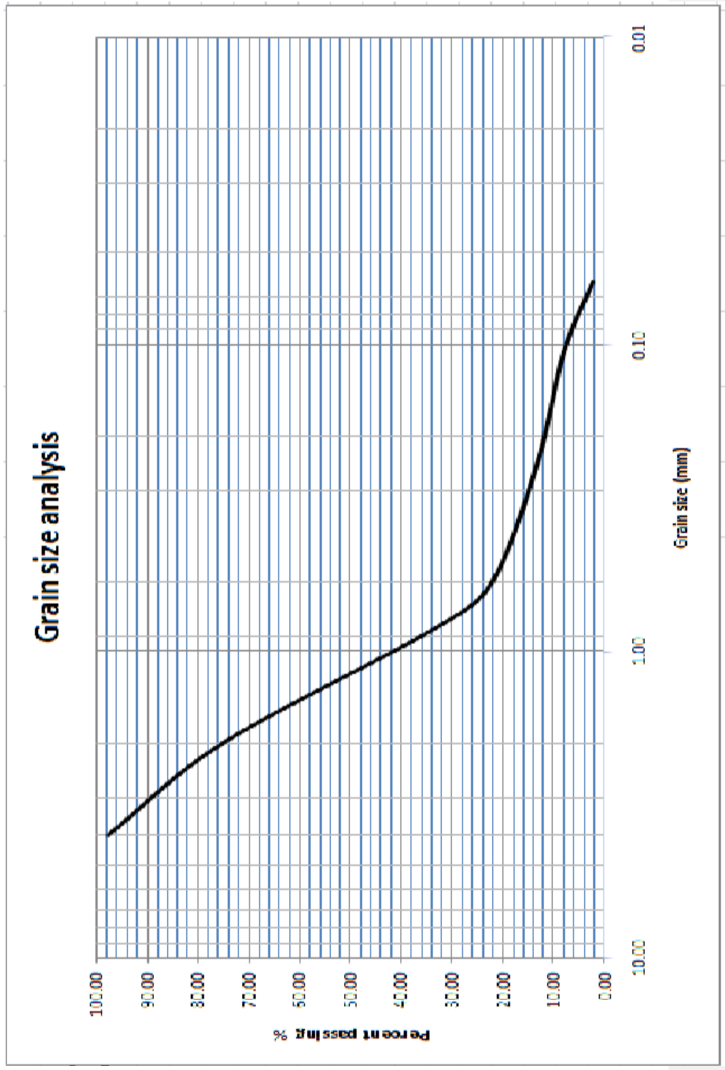

Figure 4: The semi-logarithmic graph of grain size vs. percent finer

(4) Cc and Cu for the sand were also computed as:

$C_U = D_{60}/D_{10} = 1.5/ 0.17 = \underline{8.82}$

$C_C = D_{30}^2/ D_{60}*D_{10} = 0.8^2/ 0.17*1.5= \underline{2.51}$

- The sand we used as a filter media in this HSSF has an effective size of 0.17 mm and a uniformity coefficient of 8.82.

3.2.Flow Rates Analysis

Flow rates were found to increase with the increase in grade/slope. The highest flow rate was found at 30% grade with an average rate of 0.022 L/s. In contrary, the lowest flow rate was found at a 5% grade, averagely 0.011 L/s. The average flow rates of the filter tested using all gradesare shown in Table 4.

Table 4: flow rates with different grades of HSSF

S/No	Grades/slope (%)	Flow rates (L/s)
1	5	0.011
2	10	0.013
3	20	0.015
4	30	0.022

3.3.Water Quality Analysis

3.3.1. Temperature

The temperature values of the filtered water samples werefound to be within the permissible limits (Table 5).

3.3.2. Turbidity

Comment [MH8]: OK

Measurement of Turbidity reflects the transparency in water. It is caused by the substances present in suspension in water. In natural water, it is caused by clay, silt, organic matter and other microscopic organisms. In our case, turbidity was found to range from 3.93 to 75 NTU. However, the prescribed limit of turbidity for drinking water is 5 NTU [11, 14]. Turbidity was not found within the permissible limit in the filtered water samples with the grade/slope value greaterthan 10% (Table 5). It is also obvious that the filtration capacity of a sand filter increases with the increase in filtration days, for the filtered dirt will increase the filtration capacity of tool. However, in our case, the turbidity value of the sample had become within the permissible limits in the first day of experiment. So, we didn't continue testing for turbidity up to the 10^{th} day of experimentation.

3.3.3. The pH Value

The pH is a measure of the intensity of acidity or alkalinity and measures the concentration ofhydrogen ions in water. It has no direct adverse effect on health; however, a low value, below 4.0will produce sour taste and higher value above 8.5 shows alkaline taste. A pH range of 6.5 – 8.5is normally acceptable as per the guidelines suggested by different organizations

[11]. In thisstudy, the fluctuation ofpH in the samples was found to range from 6.80 to 7.06, which is within the standard.

Comment [MH9]: ARE THESE F UNFILTERED SAMPLES?

3.3.4. Total Dissolved Solids (TDS)

Comment [MH10]: OK

TDS may be considered as a salinity indicator for the classification of water samples.The TDS in water is due to the presence of Calcium, Magnesium, Sodium, Potassium,Bicarbonate, Chloride and Sulphate ions. The TDS of the filtered water, in our case, was found tovary from 190 to 464 mg/l and that of unfiltered water was 500. While, the prescribed limit of TDS for drinking water is 500 mg/l, all the water samples had TDSconcentrations below the prescribed limit.

Table 5: Laboratory results of filtered water parameters with different grades of HSSF

S/No.	**Grades**			**Parameters**		
		T° (°c)	Turbidity (NTU)	pH	EC (µs)	TDS (mg/l)
1	5%	22.1	3.93	7.06	283.00	190.00
2	10%	21.7	4.90	6.92	314.00	210.00
3	20%	21.6	49.00	6.85	382.00	256.00
4	30%	21.5	55.50	6.82	692.00	464.00
5	Pre-filtration	21.0	75.00	6.80	745.00	500.00

Finally,HSSF was found to be very effective in removing total turbidity, and able to decrease EC and TDS of water. Filtration usingHSSF with 5% and 10% grades showed safe values for drinking purposes; while, filtering at 5% slope is very effective.

3.3.5. Microbiological Analysis

Comment [MH11]: WELL PRES

HSSF is a highly biologically active unit; therefore, the filter has to be operated for several days to develop a biological film (schmutzdecke) on the grain of the filter until the purifying bacteria become well established and plays an important role in the treatment process [15-17]. According to Bellamy et al. [18], the biological conditions governing the effectiveness of the slow sand filter are the degree of scum formation and the microbiological maturity of the sand bed.

In this study, the microbial quality was monitored for 10 consecutive days, and samples had been collected both from the influent and effluent. It was observed that the qualities were improved and potable water was achieved after the 9th day of experimentation. The HSSF, in this experiment, was provided with a 5% slope. This was made purposely to increase the flow rate from the filter. The microbial analysis results are therefore presented in the table below and Fig. 5. According tothe results shown in Table 6 and Fig. 5, HSSF was found to be effective in removing coliform bacteria as well.

Table 6: Coliform test results

Day	Influent Conc.(Average) - cfu/100mL	Effluent Conc.(Average) - cfu/100mL
1	Unable to count (more than 300)	177
2	Unable to count (more than 300)	70
3	Unable to count (more than 300)	49
4	Unable to count (more than 300)	36
5	Unable to count (more than 300)	28
6	Unable to count (more than 300)	15
7	Unable to count (more than 300)	08
8	Unable to count (more than 300)	02
9	Unable to count (more than 300)	0.0
10	Unable to count (more than 300)	0.0

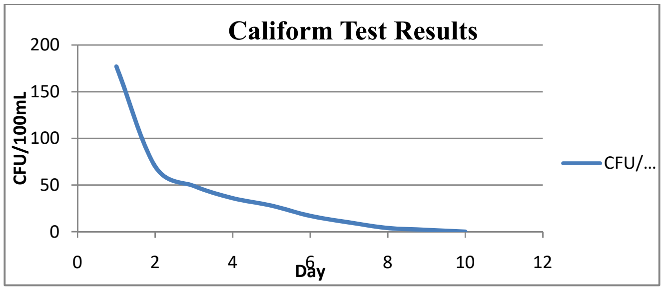

Figure 5: Coliform Test Results

In general, HSSF was found to be very effective in removing turbidity and coliforms. The average percent removal of coliforms was found to be 100% with effect from the 9th day. This is therefore in agreement with the findings of Ellis and Bellamy et al. [15,18]. Therefore, developing a household HSSF would help in protecting the people from waterborne diseases.

4. Conclusions and Recommendations

Comment [MH12]: OK

In conclusion, 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 in reducing turbidity and coliform concentrations. 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.

In this study, the efficiencies of the HSSF at laboratory level in removing total turbidity and coliform bacteria were evaluated. Water analyses from the influentusing HSSF with 5% and 10%grades showed that it is safe for drinking purpose, from turbidity and flow rate required to satisfy family need points of views. Moreover, the filter was able to remove coliforms 100% at the 9th day of analysis and monitoring.Thus, the baseline information generated from this study may contribute to develop a household-scale HSSF with a low cost water treatment process which can be operated and maintained by a member of the families.

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

- On the basis of this research, HSSF is an attractive option for supplying water treatment to family units in rural areas of developing countries.
- Decreasing the size of filter media from medium sand to fine sand and increasing the length of the filter are suggested to improve the filtration capacity.
- Education about waterborne diseases, sanitation and hygiene should accompany during the installation of the filter.
- Any shortcomings of the HSSF are likely best addressed by user education about the operation, maintenance and proper monitoring of the filter media preparation and installation, and of fundamental hygiene practices, but the basic principles of the technology are sound.

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