

Design and Evaluation of Household Horizontal Slow Sand Filter

1 **Abstract**

2 Slow sand filtration has been recognized as an appropriate technology for drinking water
3 treatment in rural areas, and is recognized as a suitable filtration technology in reducing
4 turbidity and coliform concentrations. It is capable of improving the physical, chemical, and
5 microbiological quality of water in a single treatment process without the addition of
6 chemicals, and can produce an effluent low in turbidity and free of bacteria. The objective of
7 this study was thus to develop a household-scale HSSF with a low-cost treatment process,
8 which can be operated and maintained by a member of the families. It therefore involves
9 obtaining different grain sizes of sand as a filter media and water quality data from laboratory
10 after filtering the water in different slopes of the HSSF tool. So, the primary product of this
11 project was the developed recommendations and design criterias for the use of HSSF
12 technology to improve water quality. Accordingly, the developed tool was found to produce
13 remarkable results in removing turbidity and coliform concentrations in water. The average
14 percent removal of coliforms was found to be 100% with effect from the 9th day; while,
15 turbidity had become within the permissible limit in the first day of filtration.

16 **Key Words**

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

18

19 **1. Introduction**

20 Water is not only a basic need but also human rights [1, 2]. According to different literatures
21 [3, 4], approximately one billion people worldwide lack access to adequate amounts, and
22 clean and safe water; while, 2.2 million people die of water born diseases, such as diarrhea
23 [5].

24 Whilst attempts have traditionally focused on providing centralized systems for water
25 treatment and distribution, there are millions of people who already have abundant access to

26 water but depend on rivers, streams and other unsafe water sources [3, 6]. The
27 implementation of municipal water treatment systems can be impractical and costly due to
28 dispersed populations and poor **transport** infrastructures in many rural areas. Therefore, low
29 cost community water treatment systems are reasonable alternatives [4].

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

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

49 However, the widely used type of slow sand filter is the vertical slow sand filter; while, it is
50 known that the flow in vertical slow sand filter is relatively faster than that of the horizontal
51 slow sand filter, for the head of water added at the top of the filter has its own pressure [10].
52 Moreover, the faster the flow within the filter results less quality of filtered water. Thus, a
53 tool that slows the flow of water within the filter and increases the filtration capacity is very
54 important in such a case. The objective of this study was therefore to develop a horizontal
55 slow sand filtration technology with a relatively better filtration capacity, and which is a low-
56 cost water treatment process that can be operated and maintained by a member of the
57 families. More specifically, the project was aimed to:

- 58 ❖ Develop affordable, socially acceptable and effective horizontal slow sand filter
59 (HSSF).
- 60 ❖ Evaluate the efficiency of HSSF in reducing turbidity and microbiological
61 concentrations of drinking water during lab analysis.
- 62 ❖ Evaluate the long term performance of the HSSF.
- 63 ❖ Determine what practices and water sources could be used during the filtration
64 process.
- 65 ❖ Recommend adequate maintenance procedures that could be used by communities.
- 66 ❖ Suggest any additional program components, which might aid the long term
67 sustainability of the filtration process.

68 **2. Materials and Methods**

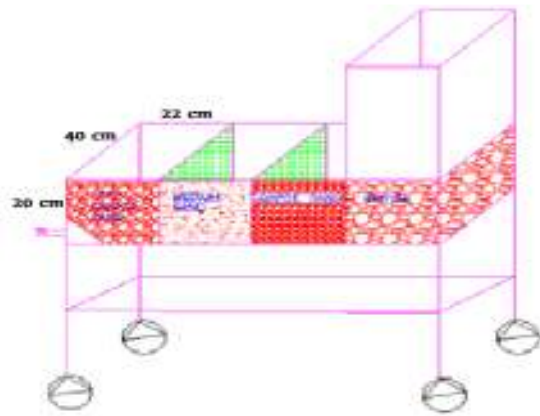
69 **2.1.Design of HSSF Tool**

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

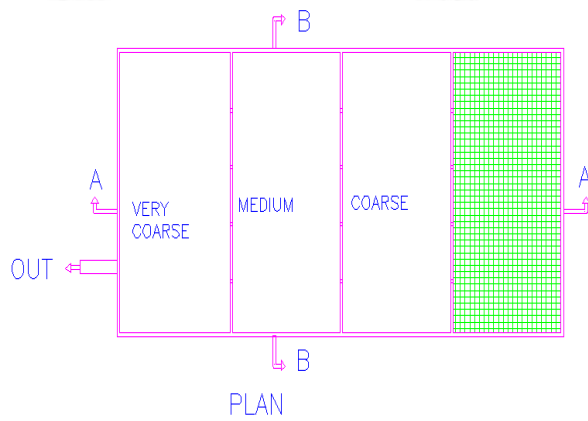
80 **2.1.1. Filter Components**

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

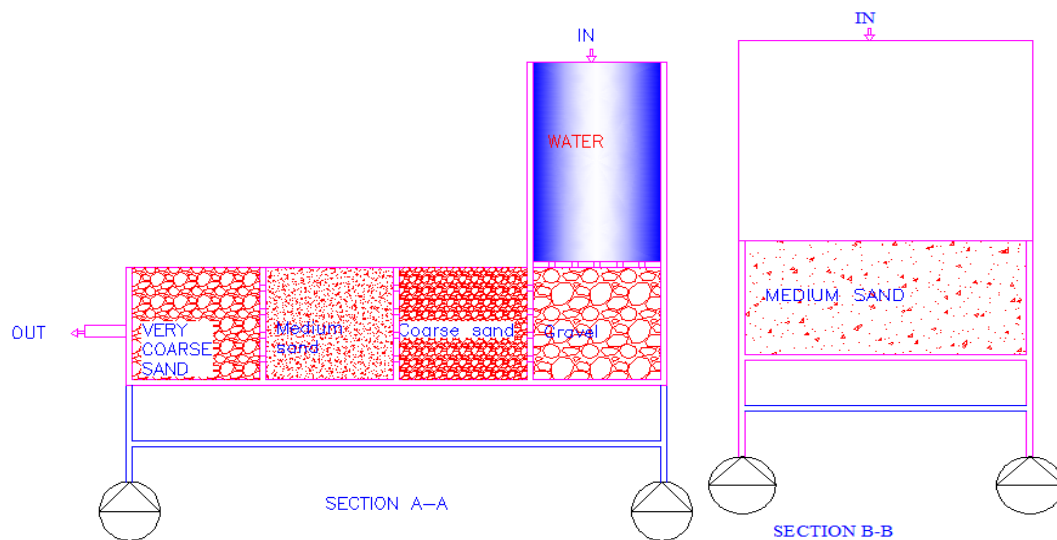
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94 **Figure 1: Horizontal slow sand filtration tool sections/views**

95 **2.1.2. Flow Rate**

96 Filter flow rates were measured in different grades/slopes of the HSSF. Flow rates were
 97 measured by filling the filter to a level approximately 10 centimeters into storage at the inlet

108 part. Discharged water was collected in a half-liter plastic bottle. The time required for 500
 109 ml of water to flow through the filter was thus recorded, and the rate was determined for each
 110 grades. The rates were therefore calculated using the following equation:

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

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

112 2.2.Sand and Gravel

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

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

127 **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

128 2.3.Characterizing Sand Samples

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

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

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

139 Thus, the standard sieve analysis procedures and apparatuses were used in this analysis (Fig.
140 2).



141



142

143 **Figure 2: Grain Size Analysis**

144 **2.4. Water Sampling Procedures and Analysis**

145 The water samples were analyzed for various parameters in the laboratory. Various physical
146 and chemical parameters like Temperature, pH, Turbidity, TDS and EC have been measured
147 from the filtered water of different grades/slopes of filtration instrument. Moreover, samples
148 were also analyzed microbiologically.

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



153

154 **Figure 3: (A) sampling site (B) water samples filtered with different slopes of the sand**
 155 **filter**

156 **2.4.1. Drinking Water Quality Standards**

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

160 **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

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

162 **2.4.2. Methodology for the Measurement of Temperature**

163 **2.4.2.1.Procedure**

- 164 a) Temperature was measured with the thermometer immersed directly in the water
165 sample, after a period of time sufficient to permit constant readings.
166 b) Reading was therefore taken from the sample bottles after sufficient time has elapsed
167 to allow the thermometer to come to the exact temperature of the water.

168 **2.4.3. Methodology for the Measurement of Turbidity**

169 **2.4.3.1.Principle**

170 It is based on comparison of the intensity of light scattered by the sample under defined
171 conditions with the intensity of light scattered by a standard reference suspension under the
172 same conditions.

173 **2.4.3.2.Procedure**

174 Turbidimeter Calibration follows the manufacturer's operating instructions. Measure the
175 standards on turbidimeter covering the range of interest. If the instrument is already
176 calibrated in standard turbidity units, this procedure will check the accuracy of calibration.

177 For turbidity values less than 40 units, shake the sample to disperse the solids. Wait until air
178 bubbles disappear. Pour sample into turbidimeter tube and read turbidity directly from the
179 instrument scale or from calibration curve.



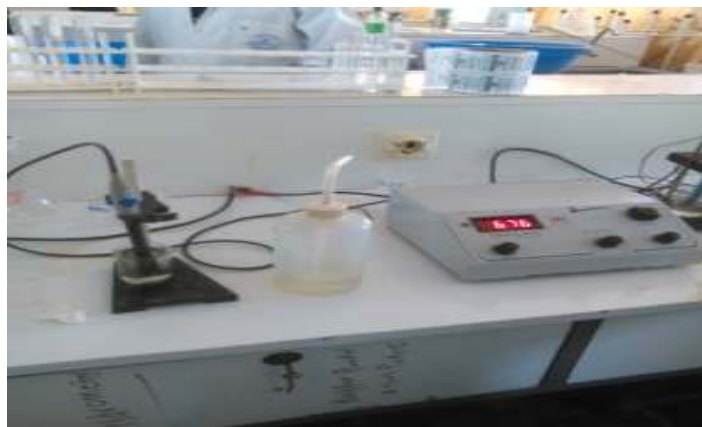
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181 **Figure 4: Measurement of turbidity meter**

182 **2.4.4. Methodology for the Measurement of pH Value (Electrometric Methods)**

183 **2.4.4.1.Procedure**

184 After required warm-tip period, the instrument was standardized with a buffer solution of pH
185 near that of the sample and electrodes were checked against at least one additional buffer of
186 different pH value. The temperature of the water was measured. Electrodes were rinsed and
187 gently wiped with solution. The sample pH and temperature were thus noted and recorded.



188

189 **Figure 5: Measurement of pH**

190 **2.4.5. Methodology for the Measurement of Electrical Conductivity**

191 **2.4.5.1.Procedure**

192 For testing the given water sample, first the reagents were prepared. Then the conductivity
193 meter was calibrated. Then:

- 194 1. The electrode was thoroughly rinsed with deionised water and carefully wiped with a
195 tissue paper.
- 196 2. 200 ml of water sample was measured and transferred to a beaker and placed it on the
197 magnetic tube stirrer.

198 The electrode was dipped into the sample solution taken in a beaker and a steady reading was
199 taken. Make sure that the instrument is giving stable reading. And the reading was recorded
200 in micro Siemens per centimeter. Finally, the electrical conductivity was calculated as
201 follows: $EC_{\text{calcu}} = (EC_{\text{read}} \times K) / (1+0.0191(T -25))$, where, K = cell constant with the value of
202 0.97, T = Temperature & EC = electrical conductivity.



203

204 **Figure 6: Measurement of electrical conductivity**205 **2.4.6. Methodology for the Measurement of Total Dissolved Solids**

206 Electrical conductivity of water is directly related to the concentration of dissolved ionized
 207 solids in the water. Ions from the dissolved solids in water create the ability for that water to
 208 conduct an electric current, which can be measured using a conventional conductivity meter
 209 or TDS meter. When correlated with laboratory TDS measurements, conductivity provides an
 210 approximate value for the TDS concentration, usually to within ten-percent accuracy. The
 211 relationship of TDS and specific conductance of water can be approximated by the following
 212 equation:

$$213 \quad \text{TDS} = K_e \times \text{EC}$$

214 Where: TDS is expressed in mg/L

215 EC is the electrical conductivity in microsiemens per centimeter at 25 °C and

216 The correlation factor K_e varies between 0.55 and 0.8. An average of $K_e=0.67$ was
 217 taken in this calculation. Therefore, the TDS values of the samples were calculated based on
 218 the above equation.

219 **2.4.7. Microbiological Test**

220 **A filtered sample from the filter** with a 5% slope and the pre-filtered sample were taken to the
 221 microbial test. The 70188 Violet Red Bile Agar (VRB-Agar) and Peptone Bacteriological
 222 reagents were used in the laboratory tests. In our case, 9.625 mg of VRB-Agar and 3.75 mg
 223 of Peptone were weighed first in an electrical balance. Then, they were added to separate
 224 glasses and mixed with 250 ml of distilled water each. The VRB-Agar was thus boiled at a
 225 100 °C; while, the Peptone mixture was autoclaved at a 121 °C in an autoclave machine. So, 1
 226 ml of sample from each of the 3 samples were taken and placed to separate tubes and diluted
 227 to a 10^{-1} and 10^{-2} dilution with a 9 ml each of the Peptone mixture. The analysis was in a
 228 duplicate analysis type. Finally, 1 ml of each of the diluted and original samples was taken to

229 a plate where the microbes can grow and 10-15 ml of the VRB-Agar was added to each of the
 230 plates. The plates were then placed to an incubator with a 32 °C temperature. Counting was
 231 finally conducted after 48 hours of period.

232 Result and Discussion

233 2.5. Grain Size Analysis

234 **Sieve Analysis:**

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

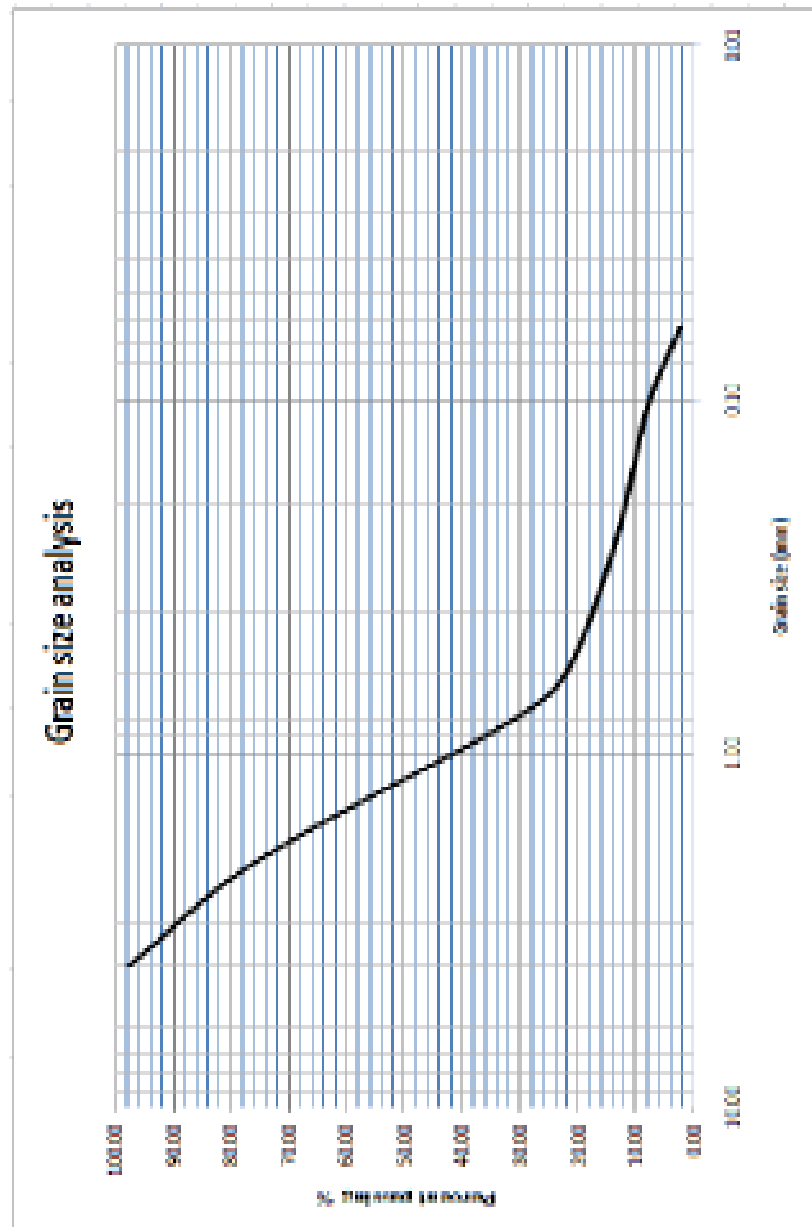
240 (2) The percent retained on each sieve, by dividing the weight retained on each sieve by
 241 the original sample mass, was therefore calculated.

242 (3) The percent passing (or percent finer) was finally calculated by starting with 100
 243 percent and subtracting the percent retained on each sieve as a cumulative procedure.
 244 The overall calculation results are shown in table 3. A semi logarithmic plot of grain
 245 size vs. percent finer was finally prepared as shown in figure 7.

246 **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

247 *Percent passing=100-cumulative percent retained.



248

249 **Figure 7: The semi-logarithmic graph of grain size vs. percent finer**

250 (4) C_c and C_u for the sand were also computed as:

251 $C_U = D_{60}/D_{10} = 1.5/ 0.17 = \underline{8.82}$

252 $C_C = D_{30}^2/ D_{60} * D_{10} = 0.8^2/ 0.17 * 1.5 = \underline{2.51}$

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

255 2.6.Flow Rates Analysis

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

260 **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

261 2.7.Water Quality Analysis

262 2.7.1. Temperature

263 The temperature values of the filtered water samples were found to be within the permissible
 264 limits (Table 5).

265 2.7.2. Turbidity

266 Measurement of Turbidity reflects the transparency in water. It is caused by the substances
 267 present in suspension in water. In natural water, it is caused by clay, silt, organic matter and
 268 other microscopic organisms. In our case, turbidity was found to range from 3.93 to 75 NTU.
 269 However, the prescribed limit of turbidity for drinking water is 5 NTU [11, 13]. Turbidity
 270 was not found within the permissible limit in the filtered water samples with the grade/slope
 271 value greater than 10% (Table 5). It is also obvious that the filtration capacity of a sand filter
 272 increases with the increase in filtration days, for the filtered dirt will increase the filtration
 273 capacity of tool. However, in our case, the turbidity value of the sample had become within
 274 the permissible limits in the first day of experiment. So, we didn't continue testing for
 275 turbidity up to the 10th day of experimentation.

276 2.7.3. The pH Value

277 The pH is a measure of the intensity of acidity or alkalinity and measures the concentration of
 278 hydrogen ions in water. It has no direct adverse effect on health; however, a low value, below
 279 4.0 will produce sour taste and higher value above 8.5 shows alkaline taste. A pH range of
 280 6.5 – 8.5 is normally acceptable as per the guidelines suggested by different organizations

281 [11]. In this study, the fluctuation of pH in the samples was found to range from 6.80 to 7.06,
 282 which is within the standard.

283 **2.7.4. Total Dissolved Solids (TDS)**

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

290 **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

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

294 **2.7.5. Microbiological Analysis**

295 HSSF is a highly biologically active unit; therefore, the filter has to be operated for several
 296 days to develop a biological film (schmutzdecke) on the grain of the filter until the purifying
 297 bacteria become well established and plays an important role in the treatment process [14-
 298 16]. According to Bellamy et al. [17], the biological conditions governing the effectiveness of
 299 the slow sand filter are:

- 300 (i) The degree of scum formation and
- 301 (ii) The microbiological maturity of the sand bed

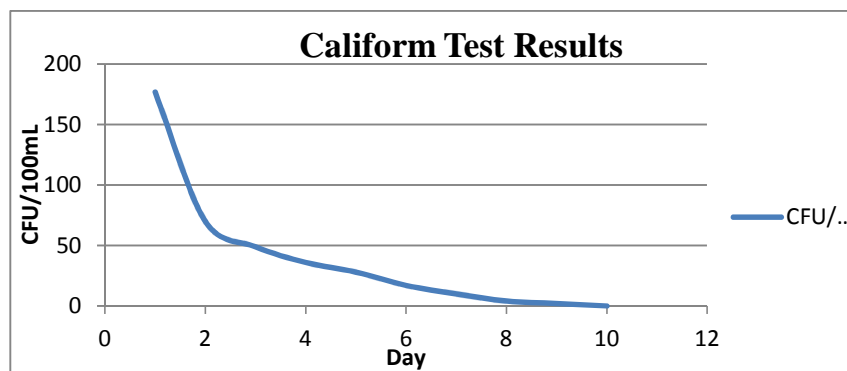
302 In this study, the microbial quality was monitored for 10 consecutive days, and samples had
 303 been collected both from the influent and effluent. It was observed that the qualities were
 304 improved and potable water was achieved after the 9th day of experimentation. The HSSF, in
 305 this experiment, was provided with a 5% slope. This was made purposely to increase the flow
 306 rate from the filter. The microbial analysis results are therefore presented in the table below

307 and fig. 8. According to the results shown in table 6 and figure 8, HSSF was found to be
 308 effective in removing coliform bacteria as well.

309 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

310



311

312 Figure 8: Coliform Test Results

313 In general, HSSF was found to be very effective in removing turbidity and coliforms. The
 314 average percent removal of coliforms was found to be 100% with effect from the 9th day.
 315 This is therefore in agreement with the findings of Ellis and Bellamy et al. [14, 17].
 316 Therefore, developing a household HSSF would help in protecting the people from
 317 waterborne diseases.

318 **3. Conclusions and Recommendations**

319 In conclusion, slow sand filtration has been recognized as an appropriate technology for
320 drinking water treatment in rural areas, and is recognized as a suitable filtration technology in
321 reducing turbidity and coliform concentrations. It is capable of improving the physical,
322 chemical, and microbiological quality of water in a single treatment process without the
323 addition of chemicals, and can produce an effluent low in turbidity and free of bacteria.

324 In this study, the efficiencies of the HSSF at laboratory level in removing total turbidity and
325 coliform bacteria were evaluated. Water analyses from the influent using HSSF with 5% and
326 10% grades showed that it is safe for drinking purpose, from turbidity and flow rate required
327 to satisfy family need points of views. Moreover, the filter was able to remove coliforms
328 100% at the 9th day of analysis and monitoring. Thus, the baseline information generated
329 from this study may contribute to develop a household-scale HSSF with a low cost water
330 treatment process which can be operated and maintained by a member of the families.

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

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

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