ORIGINAL ARTICLE

Efficiency of Declining Head Sand Filters for Household Level Water Purification

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ABSTRACT: Installation of conventional water treatment processes in the rural and suburban areas of developing countries is, at present, impractical due to economic reasons and the settlement characteristics of the population. Small-scale water treatment processes seem to be the most suitable methods to provide relatively clean water for those who draw their water supplies from unprotected streams, wells and ponds. In this study, a household sand filter has been designed that can be made from locally available materials, and that can be operated and maintained by the householder. The unit is designed to work at declining rate taking into account economic factors and the intermittent trend of collecting water in rural areas. The filter unit has a capacity sufficient to treat the quantity of water required for a typical household of 7 persons at 15 litres per person per day. The cost of materials and labor required for a single tank is Eth. Birr 215 but mass production results in a considerable cost offset. The filter produces effluent that satisfies the World Health Organization (WHO) recommendations for turbidity, color, odor, taste, pH and total dissolved solids (TDS). It is also capable of removing most of the bacterial load, thus reducing the probability of contracting water-borne diseases. It can treat raw water turbidity of 100 Nephelometric Turbidity Unit (NTU) for three weeks without losing its capacity and efficiency but for higher turbidities, simple pretreatment methods are recommended.

INTRODUCTION

Clean water is a necessity to have a healthy community. Mast surface water sources need treatment before use for domestic purposes. Conventional water treatment processes are not affordable at rural levels in developing countries, and people are forced to consume raw and polluted water in such areas. This has resulted in the fact that about 80% of all infections in the world are water-borne (1).

In Ethiopia more than 87% of the total population of the country live in rural areas. Because nearly 50% of the installed schemes become non-operational before the end of their design period, practically less than 10 % of the rural population get access to safe water (3). This has worsened the problem resulting in more than 80% of the diseases that affect the people of the country being water-borne (4). Out of these, only 19% have access to protected water sources, with the remaining 81% drawing their water supplies from

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unprotected springs, ponds, wells, and streams(2). Removal of fecal matter, suspended solids, algae and organic matter is absolutely necessary to reduce the incidence of water-borne diseases and make the water suitable for human consumption. Small-scale water treatment processes are one option to alleviate this problem. Several methods of household water treatment have been used in different parts of the world, some of them traditional and some supported scientifically. Boiling, straining (by cloth), storage to remove silt load, the use of natural coagulants such as chitosan, moringa and nirmali seeds (5, 6), upflow-downflow filters (7), ceramic candles and home-made sand filters (8) have all been tried. Each method has a varying degree of efficiency in removing impurities from water.

Straining and storage bring about partial removal of suspended matter in the water. Natural coagulants remove both bacteria and solids but the former regenerate if the water is kept unused for a prolonged time (usually for more than 24 hours) This is attributed to the organic material present in the coagulants (5, 6). Up flow-down flow filters produce an effluent that is hygienically safe but they need a minimum of three jars (7). The home-made sand filter is effective in reducing turbidity considerably but the filtered water is not safe from bacteriological point of view (8). The aim of this study was to modify the filtration system of home-made sand filter so that it could remove most of the impurities including pathogenic organisms by using a single filter tank, thus remedying the defects of the home-made sand filter and reducing the cost of jars required for upflow-downflow filtration. The filter tank used in the study was constructed from locally available materials with local labor. The tank was easily transportable and the system can be operated and maintained by the householder. In the study, the removal of microbiological organisms and aesthetic parameters such as turbidity, color, dour, taste, pH and TDS as per the WHO recommendations for rural water supplies, was given due consideration (9).

MATERIALS AND METHODS

Materials used in the study were a 1-m high filter tank fitted with outlet pipe, local sand, gravel, stone, and bamboo mat.

Construction of filter tank: The tank was constructed from a 1:2 cement mortar by plastering on a bamboo mat formwork. The mat was formed into a cylindrical section of 40-cm diameter and placed in the upright position. Mortar was then plastered from outside in layers of 1 cm until the thickness of the wall reached 3 cms. The base plate was constructed by fitting a wooden framework into the tank after it hardened. A two-week curing period was maintained for both the tank and the base plate. The tank was then fitted with a ½ inch outlet pipe, filtration rate regulator, drain valve and outlet tap.

Filter components: The dimensions of the filter components used in the study are purely experimental with the objective to modify the filtration system of home-made sand filters (8). The essential components of the filter unit are 10 cms stone underdrain, 9 cms filter gravel provided in three layers 3 cm deep each (bottom layer with grain size > 4.75 mm, middle layer with grain size between 4.75 and 1.18 mm and top layer with grain size between 1.18 and 0.60 mm), 30 to 40 cm deep filter sand (effective size (ES) = 0.15 - 0.35 mm and uniformity coefficient (UC) = 1.5 - 3), and 40 cm supernatant water. The tank has internal diameter of 40 cm and height of 1 m. The filter components are shown in figure 1. *Filter assembly*: To keep the number of tanks required to a minimum and hence the cost) and to avoid frequent attendance during filtration declining rate filtration was selected in the study. Raw water was being added to the tank from the top. Formation of negative pressure in the sand bed during initial assembly was avoided by placing the filter sand in the tank in layers of 10 cm each. Each layer was opened at the center and water was added slowly to displace any entrapped air before placing the next layer.

Addition of raw water: A cover of a plastic water container was placed on top of the sand bed and water was added onto this plastic, thus distributing the water slowly on to the sand bed. After the first day of filling, a minimum supernatant water layer of 5 cm was maintained on top of the sand that made the plastic to float. Water added onto the plastic cover (or any floating material) will lose its energy entirely when it reaches the sand bed. Therefore, it does not inflict any damage on the top filter skin (*schmuzdecke*), nor does it cause resuspension of settled mater.

Regulation of filtration rate: The filtration rate was controlled by fitting a gate valve on the outlet line as shown in figure 1. The maximum filtration rate at the beginning of the operation cycle was set at 0.2 meters/hour with the gate almost closed.

The rate was adjusted to this value raising it slowly over several hours. As resistance to the downward flow of water increased the rate dropped, coming down to less than 0.1 meters/hour after 2 weeks of operation at an average raw water turbidity less than 50 NTU. The head was recovered by opening the control valve by one round to raise the maximum filtration rate to 0.2 meters/hour again, the regulation being done slowly. This rate approximately yields 20 liters (one plastic bucket) in one hour.

Water quality analysis: Water from River Kulfo (Arba Minch), with average coliform concentration greater than 5000/100ml was passed through the filter bed, and the filtered and raw water were analyzed for selected water quality parameters of importance to the rural areas. For bacteriological analysis, multiple tube fermentation technique was used due to easy availability of chemicals and that membrane filtration technique is not suitable for turbid water. Standard laboratory procedures were used during the analysis (10).

RESULTS

The particle size of the local sand was tested by running grain size analysis (11). The sand was found to have effective size (ES) of 0.22 mm and uniformity coefficient (UC) of 3, thus satisfying the requirement for filter sand (12). A silt test (13) was conducted to check the silt content of the local sand. The result showed that the sand could be used for mortar without modification. But it had to be washed to remove the silt and organic matter to use it as a filter media. Results of water quality analysis during filtration of raw water for three weeks operation period with the filter are given in tables 1 and 2.

A test was also conducted to determine the filter operation period (filter run) before cleaning is required. At a constant raw water turbidity of 150 NTU, the filter clogged completely and the filtration rate became negligible after a week of operation although the filtration rate control valve was fully opened. On further addition of raw water, the filtered water turbidity and the flow rate started to fluctuate. At a constant raw water turbidity of 100 NTU during another cycle, the filter worked normally for the first 20 days without losing its capacity and efficiency with the flow rate varying between 0.33 l/min and 0.20 l/min. But for the next two days, the filtration rate was such that only drops of

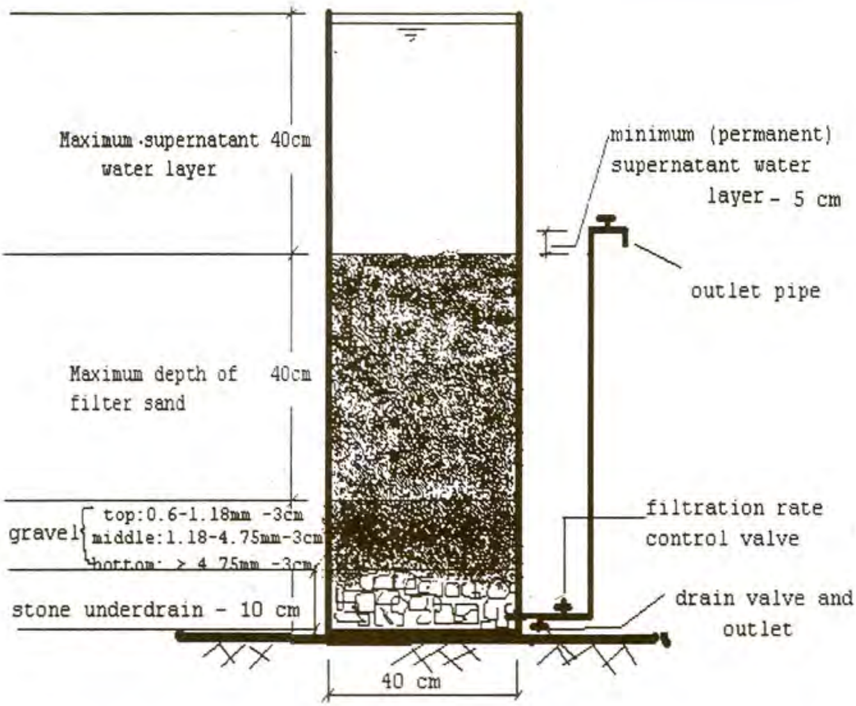

Fig 1 Components of household filter (not to scale)

Table 1. Test results for selected physical constituents(Filter sand ES = 0.22 mm; UC = 3)

Day	pH[a]	Temp °C[a]	Turbidity, NTU		Color, ACU		TDS(mg/l)[a]
			Raw	Filtered	Raw	Filtered	Filtered
1	7.0	29.1	18	1.8	35	< 5	640
3	7.0	28.5	25	2.5	40	< 5	310
5	7.0	26.2	6.3	2.5	20	< 5	190
6	7.0	25.5	75	2.5	> 250	< 5	115
7	7.0	26.9	32	2.0	40	< 5	115
8	7.0	29.5	20	0.9	30	< 5	112
10	8.0	22.4	23	0.6	30	< 5	104
12	7.0	25.7	25	0.6	30	< 5	105
14	7.0	27.2	2.3	0.4	20	< 5	246
15	7.0	27.2	5	0.4	20	< 5	240
22	7.0	26.7	30	0.3	40	< 5	225
28	7.5	29.3	23	0.26	30	< 5	252

[a] Temperature, pH and TDS results are similar for both raw and filtered water.

Table 2: Bacteriological removal test results (Filter sand E.S – 0.22 mm; U.C = 3)

Day	Parameter	Results: MPN/ 100 ml	
		Raw	Filtered
1	Total Coliform	5000	2800
	Fecal Coliform	240	0
8	Total Coliform	16000[b]	180
	Fecal Coliform	320	4
15	Total Coliform	5000	40
	Fecal Coliform	320	4
22	Total Coliform	5000	17
	Fecal Coliform	270	2

[b] *Sample collected from river course after storm flood.*

water were coming out of the tap. On the 23rd day the rate increased to 0.40 l/min but it dropped back to drops of water for the next 10 days. It then increased to 0.50 l/min on the 33rd and 34th days but eventually went on dropping until almost no flow was coming on the 43rd day.

DISCUSSION

Dimensions of the filter components in this study were based on daily rural water consumption per household. Typical water demand assessments for rural and suburban communities collecting water from surface sources show that the average per capita consumption is usually below 15 liters per day (1, 14). In rural areas water for domestic use is usually collected early in the morning (before going out to work in the field) and late in the afternoon (after work). Therefore, this trend of collecting water twice a day was used in the study. Each time the tank accommodates about 50 liters, totaling to 100 liters of water per day, which is sufficient for an average family of 7 persons at the demand indicated. Each 50 liters of filtered water is ready for use after 3 to 4 hours of operation. If water is added continuously, the unit can treat up to 300 liters of raw water per day.

The study showed that by passing water through a 30 to 40 cm builder's grade sand (ES = 0.22 mm, UC = 3), it is possible to remove most of the impurities in the water, including pathogenic organisms. Filtered water with turbidity < 5 NTU and color < 5 ACU was obtained using this filter. The filtered water was also free of taste and odor and had pH and TDS within permissible limits of the WHO recommended guideline values. The bacteriological quality of the effluent did not satisfy the WHO recommended level (15) but most of the bacteria were removed. The filter reduced the coliform content of the raw water by 98.9% (by a factor of 90) after a week, by 99.2% (by a factor of 125) after two weeks and by 99.7% (by a factor of 300) after three weeks of operation. This is a great improvement for those who have no alternative to consuming the raw water.

When coarser sand is used as filter media, it may take some time before WHO guideline values are met for aesthetic parameters but bacteriological removal efficiency of the filter is similar for the range of filter sand size as shown in the study (16).

The WHO guideline values for bacteriological quality may particularly be difficult to attain under rural conditions in developing countries. They may rather be looked at as long term targets, and for the short term, interim national standards should be set which promote improved water quality and which are realistic. Otherwise, too high targets may be counterproductive because they may lead to ignorance if they are not obtainable (17).

Ockwell (1986), cited in Waterlines (17), gives a more relaxed guideline values arguing that the WHO recommendations are not attainable in rural areas of developing countries. This guideline groups the quality of water with F. Coliforms/100ml concentration of 0-10 as reasonable, 10–100 as polluted, 100-1000 as dangerous and above 1000 as very dangerous for rural areas and emergency water supplies. Thus, the household filter can produce water of reasonable quality.

Slow sand filters clog after a certain operation period. The length of the operation time, also called the filter run, depends on the turbidity of the raw water. It is proved that conventional slow sand filters need raw water turbidity of 10 NTU for good performance, and can accommodate raw water turbidity of 50 NTU only for a few days (5). But the household filter works on intermittent basis and the filter run for different turbidity ranges differs from that of conventional filters. The filter operated normally for one week at a raw water turbidity of 150 NTU. The irregularity in filtration rate after one week may be due to possible formation of cracks in the filter bed due to the effect of air-binding (18). The same phenomenon was observed after three weeks of operation at raw water turbidity of 100 NTU. For average raw water turbidity of less than 50 NTU, the filter run period may be several weeks or months. For instance, for raw water turbidity of 25 NTU, the filtration rate control valve was one-quarter open after a month in operation; for average raw water turbidity of 35 to 50 NTU the control valve is one-quarter open after three weeks of operation.

The microbial film in the *schmuzdecke* of the filter plays the major role in removal of bacteria in the water. Full ripening process of this film takes some time and usually more than a week (5). To make efficient use of this film, the filter run should be more than a week. Thus, the household filter should better not be used to treat raw water with turbidity greater than 100 NTU.

The household sand filter is a relatively low cost, simple technology for household water treatment. Above all, the rural people, who do not have access to protected water sources, are the beneficiaries of the findings of this study. The filter can be used to treat raw water from surface sources with moderate turbidity, unprotected wells, springs or ponds. The major areas of application include emergency water supplies, temporary lodgings, concentration camps, and isolated households where it is economically not possible to provide clean water for domestic use by other means.

To appreciate the outcomes of this study, the users must know the dangers associated with the use of untreated water from contaminated sources. This awareness can be brought through planned health and hygiene education. Once this is understood, an unskilled person can construct the filter tank after two days of training, and the same can operate and maintain the filter after a day of training. The material and labor cost required for construction of a single filter tank is Birr 215 but mass production may result in an offset of more than Birr 35 per tank.

Uncontrolled addition of raw water and exposure of the filter surface to heavy rain should be avoided, as this will cause scouring of sand bed and resuspension of settled solids. If it happens, it impairs the efficiency of the filter. The drain valve must not be opened at all unless the filter run is over. If it is opened by mistake during operation of the filter, uncontrolled high flow rates will destabilize the filter, and may wash the finer portion of sand out of the tank. This will form a 'pipe' that will bring about short-circuiting of untreated water as observed in the study (16). Therefore, if such a mistake happens, the filter components must be reassembled. The filtration rate control valve should be regulated properly in response to increase in resistance to flow (head loss).

The household filter clogs after a certain period of operation. The end of the filter run is marked by full opening of the filtration rate control valve followed by a drop in the filtration rate to a negligible level. At this point, some maintenance is required to recover the filtration rate. This is done by first, opening the drain valve slightly and draining the supernatant water up to a level 2 cm below the top of the sand bed, closing the valve, and then scraping away the top 2 cm of sand filled with settled and adsorbed particles. In order not to lose the sand depth, 2-cm clean sand is replaced on the top. Then, raw water can be added carefully. When, after a certain period of operation, the filtration rate can no longer be recovered in this manner, all the components have to be removed, and new ones replaced. The head loss in the clean filter sand, gravel and stone under drain is negligible.

The modification of the filtration system of homemade sand filters is necessary to increase impurity removal efficiency of the filter. The household filter can not handle raw water with turbidity greater than 100 NTU for more than three weeks. When such water is to be treated, some form of pretreatment such as plain jar settlement, straining or coagulation using natural coagulants should precede the filtration unit.

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