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Research Article

Biosand Filter for Removal of Chemical Contaminants from Water

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Abstract: Numerous reports by the United Nations and the World Health Organization have indicated a significant worldwide problem with water pollution and inaccessibility to potable drinking water. Due to technological and economical barriers, the problem with water pollution is particularly more serious for under-developed and developing countries. The present study is aimed at designing, constructing and evaluating a cost-effective biosand filter was undertaken. Results indicated the removal of up to 80% total hardness, 86% chlorides, 96% turbidity and 90% colour. Moreover, the filter's performance was appraised by the absence of *E. coli* in the filtered sample. The filter describes the proven bioremediation technology and its ability to empower at-risk populations to use naturally occurring biology and readily available materials as a sustainable way to achieve the health benefits of safe drinking water.

Keywords: Biosand filter, Turbidity, Hardness, *E. coli*.

1. Introduction

Safe drinking water is a human birthright – as much a birthright as clean air. However, much of the world's population does not have access to safe drinking water. Of the 6 billion people on earth, more than one billion (one in six) lack accesses to safe drinking water. Moreover, about 2.5 billion (more than one in three) do not have access to adequate sanitation services. Together, these shortcomings spawn waterborne diseases that kill on average more than 6 million children each year (about 20,000 children a day) (1).

The rural population of India comprises more than 700 million people residing in about 1.42 million habitations spread over 15 diverse ecological regions. It is true that providing drinking water to such a large population is an enormous challenge. The health burden of poor water quality is enormous. It is estimated that around 37.7 million Indians are affected by waterborne diseases annually, 1.5 million children are estimated to die of diarrhoea alone and 73 million working days are lost due to waterborne disease each year. The resulting economic burden is estimated at $600 million a year (2). The problems of chemical contamination are also prevalent in India with 1, 95, 813 habitations in the country are affected by poor water quality. The major chemical parameters of concern are fluoride and arsenic (3, 4). Iron is also emerging as a major problem with many habitations showing excess iron in the water samples.

There is a growing need to address the twin problem of sustainability of water resource and water quality. Department of Drinking Water Supply (DDWS) has estimated a large gap in resources of about Rs. 6,800 crores to tackle problems of rural water sustainability & water quality (5). Water-related diseases put an economic burden on both the household and the nation's economy. At household level, the economic loss includes cost of treatment and wage loss during sickness. Loss of working days affects national productivity. On the other hand, the government spends a lot of money and time on treatment of the sick and providing other supportive services.

Despite the very real danger of future global water shortages, today's water crisis is not an issue of

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scarcity, but of access (6). Poor people living in the rural areas and slums often pay five to ten times more per liter of water than wealthy people (7). However, investment in safe drinking water and sanitation can contribute to economic growth. For each $1 invested, the World Health Organization (WHO) estimates returns of $3 – $34, depending on the region and technology (8).

There is conclusive evidence that biological sand (biosand) filters are capable of dramatically improving the quality of drinking water. Bios- and filters are based on a centuries-old bioremediation concept: water percolates slowly through a layer of filter medium (sand), and microorganisms form a bacteriological purification zone atop and within the sand to efficiently filter harmful pathogens from microbiologically contaminated water. Household-scaled biosand filters are a small adaptation of traditional large, slow sand filters such that they can uniquely be operated intermittently (9).

The purpose of the study is to facilitate knowledge transfer with the goal to empower vulnerable, poorest-of-poor populations in rural and peri-urban communities and to promote using naturally occurring biological agents and locally available materials as a cost-effective practical approach to combat poverty and inequality and achieve the health benefits of safe water by developing their own household water security solutions. The main goal of the project is to make these types of filters more effective for treating and purifying water inexpensively and more acceptable by populations in need of clean water. The conclusion is encouraging: appropriate, locally based, strategies can be devised to obtain safe drinking water in many different parts of the developing world.

The specific objectives of the study were to evaluate the following:

a) Design a sand filter using locally available material.
b) Testing its efficiency at laboratory scale.

The removal efficiency of the sand filter with reference to chemical contaminants from various samples collected from the villages where unsafe surface water is consumed.

The sand filter was evaluated for performance in removing chemical contaminants, maintenance practices and lifespan. The acceptance of the sand filter by people living in the rural areas is under investigation.

2. Methodology

2.1 Design and description

The sand filter has six distinct zones. The first zone is the inlet reservoir zone where water is poured in during filtration. This was constructed by removing the lid of a 25ℓ bucket. The second zone is the standing water zone. This zone is a separate container that is kept attached to the top container to collect water. The third zone is the bio-layer which develops a few cm (1-2cm) above the top sand layer. This layer comprises slime, sediments and microorganisms (10). The fourth layer is the biological zone that develops at the top 5 to 10cm of the sand surface and is useful for the removal of chemical and microbial contaminants (10).

The fifth layer is 15cm deep and forms the largest part of the filter media, this layer is composed of sand. The sixth zone is the gravel zone composed of coarse sand (0.95mm) and gravel (1-3mm). The gravel layer (2.5cm thick) is very useful in ensuring that there is an easy flow of water. The coarse sand layer (also 2.5cm deep) helps in retaining the sand and preventing it from being flushed down into the gravel layer.

In order to prevent poured water from disturbing the biological layer, a diffuser plate was made trimming a stainless steel mesh radically until it fitted into the plastic bucket. The diffuser plate distributes water at a steady rate, maintains the flow rate of the sand filter and also traps larger particles such as grass and leaves (11). The sand filter was produced with natural materials.

2.2 The source of the filter media

From the literature, it has been understood that the crushed rock is the best type of filtration sand since it has less chance of being contaminated with pathogens or organic material. This sand also has a less uniform size of the grains. A mixture of grain sizes is required for the proper functioning of the filter. Gravel pits or quarries are the best place to obtain crushed rock and are common in most parts of the world. In this work, it has been obtained from a local road work where granite is being crushed into various sizes. Sand with a lot of gravel, up to 10mm in diameter, was used. Care has been taken that it should not contain any organic material (e.g. Leaves, grass, sticks, loam and dirt).

2.3 Preparation of filter media

- ***Sieving***: The filtration sand and gravel were sieved to get various fractions/sizes of granite to fill in the filter as discussed above.
- ***Washing***: The different sizes of gravel, coarse sand and sand separately were washed with the addition of twice the amount of water in each container. The process is repeated until the water in the container was clear. Then all of the gravel is placed on a cover or concrete surface in the sun to dry.
- ***Constructing***: The large size gravels are placed at the bottom of the plastic container making a 2.5cm deep layer. Then 2.5cm deep layer of coarse gravel is placed above that. After that, the sand is added to a layer of about 25cm. The surface is smoothed out so that it’s as level as possible. Then the container

for collecting the water was attached and finally, the diffuser plate was fitted.

2.4 Performance of the Filter

An infiltration test was conducted by the falling-head method and the flow rate was observed and noted down (12, 13, 14 & 15). The filter was initially tested with synthetically prepared water of two different turbidities i.e. 70 NTU and 140 NTU, namely Sample 1 and Sample 2 respectively.

2.5 Collection of water samples

Surface water samples were collected from naturally formed small lakes and reservoirs of Visakhapatnam (Samples 1 – 3). Remaining samples were collected from the tribal rural zones where the filter is intended to be adopted (Samples 4 – 9). The surface water samples were collected in 24-litre plastic containers. The temperature, visual colour and odour of water were recorded on site. The turbidity and the pH were recorded immediately upon arrival at Environmental Monitoring Laboratory, GITAM University before the water was filtered through the sand filter. The pre and post analysis of the physical-chemical parameters like colour, turbidity, pH, chloride, hardness and *E. coli* presence (H_2S strip test) was tested.

2.6 Sampling Sites

Water samples are collected from the following places: - Mudasarlova, Kambalakonda, P.M. Palem, Adaravalasa, Kotragondi, Baliyaguda, Paddaguda, Kaguvalasa, Molligavalasa.

Table 1. Performance of the Filter with Synthetic Water Samples.

Parameter	Before Filtration	After Filtration	% Reduction
Synthetic Water sample – 1			
Turbidity	70	35	50
Total solids	10800	4200	61.11
Total Dissolved solids	9200	3600	60.86
Suspended solids	1600	600	62.5
Chlorides	799.9	424.9	46.88
Synthetic Water sample – 2			
Turbidity	140	56	60
Total solids	13800	4600	66.66
Total Dissolved solids	7400	3800	48.64
Suspended solids	6400	800	87.5
Chlorides	598.9	269.9	54.93

***Except for Turbidity all the other values are given in mg/l;**
*** Turbidity is given in NTU**

3. Results

In the first stage, two synthetic samples were prepared with turbidity 70 NTU and 140 NTU which were named as Sample 1 and Sample 2 respectively. The physicochemical parameters of these water samples pre and post filtration in the sand filter were analyzed. After, the filtration considerable results were achieved. The water obtained after filtering Sample 1 showed a turbidity and chlorides reduction of 50% and 46.88% respectively. There was nearly 61.11% reduction in the total solids followed by 60.86% in total dissolved solids and 62.5% in suspended solids. The water attained after filtration of Sample 2 was observed to be purged out of impurities having a reduction of around 66.66% in total solids, 48.64% in total dissolved solids, 87.5% in suspended solids, 54.93% in chlorides and 50% in turbidity (Table – 1).

The sand filter was evaluated for its efficiency to reduce chemical contaminants from environmental water sources (surface water) with low and high turbidity. Filtration was carried out in the Environmental Monitoring laboratory (GITAM University) to mimic filtration in rural homes. The collected water samples were filtered through the sand filter upon arrival in the laboratory. Filtration was carried out for 3h with the assumption that enough purified water would have been produced over this period of time for drinking and cooking. Different volumes of filtrates were collected at 1h intervals over the 3h period of filtration. This was done to establish whether there was a difference in the reduction of chemical contaminants at different times and to make the necessary adjustments and recommendations. The collected samples were analyzed in triplicate to determine the water quality after filtration.

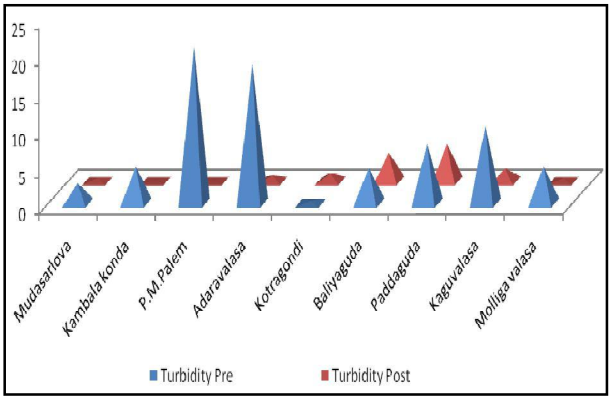
The results pertaining to the efficiency of the sand filter with various surface water sources is presented in Table – 2.

The turbidity of samples was quite varied based on their source. There was a notable positive reduction in the turbidity of the water samples after filtration, even when they were highly turbid. The major turbidity reduction mechanism is believed to be through surface straining as predicted by Haarhoff and Cleasby (6). Excessive turbidity or cloudiness, in drinking water, is aesthetically unappealing and may also represent a health concern. Turbidity can provide food and shelter for pathogens. If not removed, turbidity can promote regrowth of pathogens in the distribution system, leading to waterborne disease outbreaks, which have caused significant cases of gastroenteritis throughout the world (17). Although turbidity is not a direct indicator of health risk, numerous studies show a strong relationship between the removal of turbidity and removal of protozoa (18).

Table 2. Pre-Post Analysis results of various parameters.

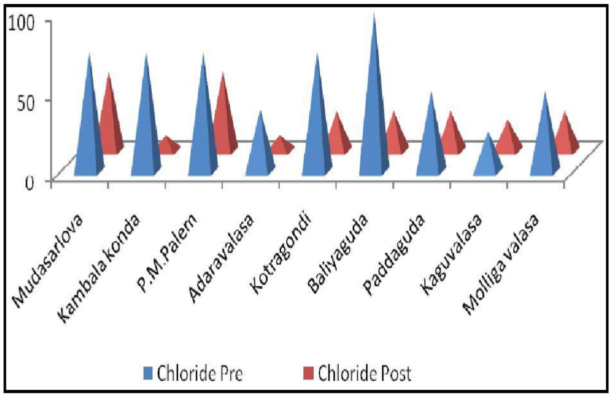
S. No.	Sample	Turbidity		Chloride		Total Hardness		pH		*E. Coli*		Colour	
		Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
1	**Mudasarlova**	2.7	0.4	75	50	390	270	7	8	+	-	13	7
2	**Kambalakonda**	5	0.1	75	10	380	190	7	7	+	-	14	1
3	**P.M. Palem**	21.2	0.1	75	50	400	240	9	9	+	-	28	7
4	**Adaravalasa**	18.8	0.8	39	10	40	20	7	6	+	-	10	1
5	**Kotragondi**	0.3	1.1	75	25	40	20	6	7	+	-	19	27
6	**Baliyaguda**	4.8	3.8	100	25	60	10	6	8	+	-	62	60
7	**Paddaguda**	8	5	50	25	60	40	6	7	+	-	68	50
8	**Kaguvalasa**	10.4	1.7	25	20	20	10	6	7	+	-	72	12
9	**Molligavalasa**	5	0.4	50	25	80	50	5	7	+	-	48	10

Units: · Turbibidty – NTU · *E-coli* - + Present - Absent · Colour – Pt-Co Scale · Remaining mg/l



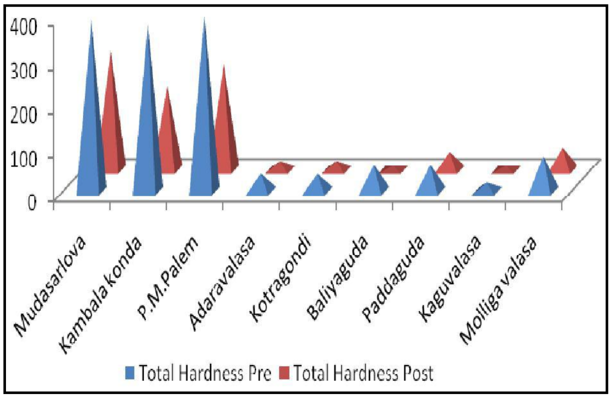
Low filtered water turbidity can be correlated with low bacterial counts and low incidences of viral disease. Positive correlations between removal (the difference between raw and filtered water samples) of pathogens and turbidity have also been observed in several studies. In fact, in every study to date where pathogens and turbidity occur in the source water, pathogen removal coincides with turbidity/particle removal as in this work it has been seen that the removal of *E. coli* was good (19).

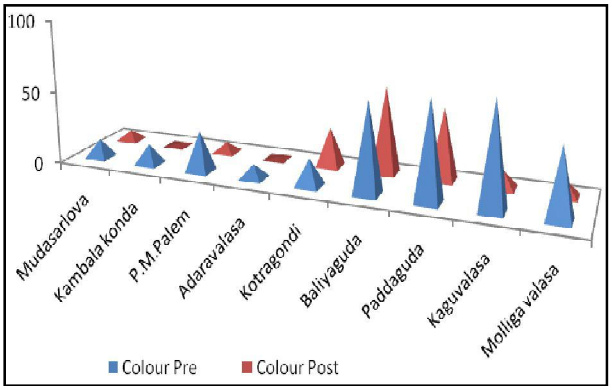
Chlorides are widely distributed in nature as salts of sodium (NaCl), potassium (KCl), and calcium ($CaCl_2$). The taste threshold of the chloride anion in water is dependent on the associated cation. Taste thresholds for sodium chloride and calcium chloride in water are in the range 200–300mg/litre (20). Chlorides are leached from various rocks into soil and water by weathering. The chloride ion is highly mobile and is transported to closed basins or oceans. Chloride in surface and groundwater from both natural and anthropogenic sources, such as runoff containing road de-icing salts, the use of inorganic fertilizers, landfill leachates, septic tank effluents, animal feeds, industrial effluents, irrigation drainage and seawater intrusion in coastal areas (21). The efficiency of the filter in removing chloride was observed from 20 to 50%. Chloride toxicity has not been observed in humans except in the special case of impaired sodium chloride metabolism, e.g. in congestive heart failure (22). Healthy individuals can tolerate the intake of large quantities of chloride provided that there is a concomitant intake of fresh water. Little is known about the effect of prolonged intake of large amounts of chloride in the diet. As in experimental animals, hypertension associated with sodium chloride intake appears to be related to the sodium rather than the chloride ion (20). Chloride increases the electrical conductivity of water and thus increases its corrosivity. In metal pipes, chloride reacts with metal ions to form soluble salts (23), thus increasing levels of metals in drinking water. In lead pipes, a protective oxide layer is built up, but chloride enhances galvanic corrosion (24). It can also increase the rate of pitting corrosion of metal pipes (23).



Both calcium and magnesium are essential minerals and beneficial to human health in several respects. Inadequate intake of either nutrient can result in adverse health consequences. Concern for excess calcium intake is directed primarily to those who are prone to milk-alkali syndrome (the simultaneous presence of hypercalcaemia, metabolic alkalosis and renal insufficiency) and hypercalcaemia. The major cause of hypermagnesemia is renal insufficiency associated with a significantly decreased ability to excrete magnesium. Increased intake of magnesium salts may cause a temporary adaptable change in bowel habits (diarrhoea), but seldom causes hypermagnesemia in persons with normal kidney function. Drinking-water in which both magnesium and sulfate are present at high concentrations (above approximately 250mg/l each) can have a laxative effect, although data suggest that consumers adapt to these levels as exposures continue (25).

Exposure to hard water has been suggested to be a risk factor that could exacerbate eczema. The environment plays an important part in the etiology of atopic eczema, but specific causes are unknown. Numerous factors have been associated with eczema flare-up, including dust, nylon, shampoo, sweating, swimming and wool (26). A suggested explanation relative to hard water is that increased soap usage in hard water results in metal or soap salt residues on the skin (or on clothes) that are not easily rinsed off and that lead to contact irritation (27). There are reports of a relationship between both 1-year and lifetime prevalence of atopic eczema and water hardness among primary-school children. Eczema prevalence trends in the secondary-school population were not significant (28).





Highly colored water has significant effects on aquatic plants and algal growth. Light is very critical for the growth of aquatic plants and colored water can limit the penetration of light. Thus highly a colored body of water could not sustain aquatic life which could lead to the long-term impairment of the ecosystem. The presence of colour in drinking water may be indirectly linked to health, although its primary importance in drinking water is aesthetic. Colour may be due to natural geology or may indicate possible drinking water contamination. The hue of the water may provide information regarding the source.

4. Conclusion

Poor water quality spreads disease, causes death and hampers socioeconomic progress. Around five million people die due to waterborne diseases. In addition, these diseases affect education and result in loss of workdays, estimated at 180 million person-days annually. The annual economic loss is estimated at Rs.112 crores (29).

In conclusion, the biosand filter designed, constructed and evaluated for chemical contaminant removal efficiency. The sand filter is easy to construct, maintain and operate. The sand filter is cost effective and could be afforded by most rural people. There is no additional maintenance. The filter was observed to have higher flow rates which make it suitable for use by a larger family for the production of clean water for both drinking and cooking purposes. The size of the filter makes it convenient for the users to position it in an area where food is prepared and hence encourages the use and maintenance of the filter. The sand filter had a higher removal efficiency of chemical contaminants and hence can be used for production of high-quality water at lower costs. If lower turbidity reductions during the first day of filter run are observed, it implies that the sand was not thoroughly washed. Removals of ~90% are expected with time as the filter is continuously used. Cleaning the top layer of sand improves turbidity reduction by the sand filter. Highly turbid raw water needs to be left standing for a while to allow total suspended solids to settle before filtration. The sand filter could be used for the removal of calcium, magnesium, chlorides and colour. Cultural factors and social wisdom, therefore, have been considered strongly in re-designing filters and the development of effective and innovative educational programs for their applications (30).

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