Volume: 5 | Issue: 10 | October 2019 || SJIF Impact Factor: 5.614||ISI I.F Value: 1.188 ISSN (Online): 2455-3662

EPRA International Journal of
Multidisciplinary Research (IJMR) *Peer Reviewed Journal*

HYBRID WATER FILTRATION AND DISINFECTION SYSTEM WITH COST ANALYSIS

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ABSTRACT

High construction cost of conventional water treatment plant and distribution system in most developing countries makes it challenging to provide safe and adequate water for all households, especially in rural areas. Unsafe drinking water supply, insufficient hygiene practice and inadequate sanitation are factors causing the significant share of all diarrhoea cases. It is not feasible to implement RO technology for filtration in rural areas where electricity might not be available continuously, and also the people find it expensive. The purpose of this paper is to combine the low-cost technologies of slow sand filtration and further solar disinfection while using a popular plant-based coagulant moringa oleifera to treat the local surface and groundwater in Kerala, a state in India, to be implemented on a household level. The cost analysis proves that it is an excellent alternative to conventional methods and can be implemented on a large scale by communities or individual households.

KEYWORDS: ***water treatment, coagulation, sand filtration, solar disinfection, moringa oleifera***

INTRODUCTION

Kerala is one of the most densely populated regions in India, and the population is increasing at a rate of 14% per decade. To satisfy the needs of this increasing population, the discharge of industrial pollutants along with fertilizers and pesticides used for agriculture has increased significantly. Industries discharge hazardous pollutants like phosphates, sulphides, ammonia, fluorides, heavy metals and insecticides into the downstream reaches of the river. The river Periyar and Chaliyar are excellent examples of the pollution due to industrial effluents. It is estimated that nearly 260 million litres of trade effluents reach the Periyar estuary daily from the Kochi industrial belt (Kerala State Pollution Control Board, 2011).

The assessment of rivers such as Chalakudy, Periyar, Muvattupuzha, Meenachil, Pamba and Achenkovil indicates that the significant quality problem is due to bacteriological pollution and falls under B or C category of CPCB classification. The main reasons for this are dumping of solid wastes, bathing and discharge of pollutants into the rivers. The water quality in the numerous wells across the state has also shown signs of chemical and biological contamination. The groundwater along the coastal areas has been found to have an excess chloride and fluoride concentration which poses a health risk for the countless people who have no option but to use this contaminated water for domestic purposes (Kerala State Pollution Control Board, 2017).

Primary Water Quality Criteria for Various Uses (CPCB)

Sl. No	Characteristics	A	B	C	D	E
1	Dissolved Oxygen(DO),mg/l, Min	6	5	4	4	_
2	Biochemical Oxygen Demand (BOD) ,mg/l, Max	2	3	3	_	_
3	Total Coli forms MPN/100ml, Max	50	500	5000	_	_
4	pH Value	6.5-8.5	6.5-8.5	6.5-8.5	6.5-8.5	6.5-8.5
5	Conductivity ,micromhos, Max	_	_	_	1	2.25
6	Total dissolved solids	500	_	1500	_	2500
7	Nitrates as NO_3, mg/l	20	_	50	_	_

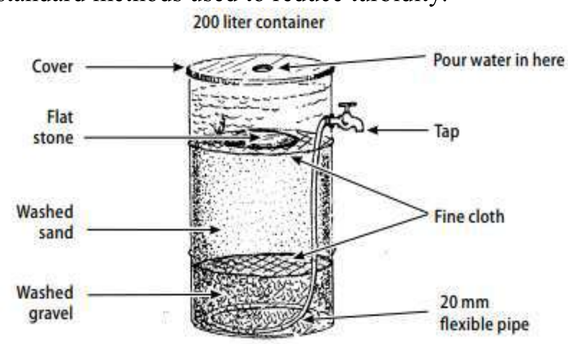
Potable water is one that should not contain microorganisms and chemical substances in an amount that can cause hazards to health (Alonge D.O., 1991). Water must be free of dissolved salts, plant, bacterial contamination and animal waste to be fit for human consumption. Poorly designed latrines and inadequately maintained septic systems could contaminate groundwater with nitrates, bacteria and toxic cleaning agents. This can serve as a means for spreading illnesses caused by microorganisms such as; Vibrio cholera, Yersinia enterocolitica, Escherichia coli, Cryptosporidium spp. and vector-borne diseases such as guinea worm, Schistosomiasis, lymphatic filariasis, Onchocerciasis, parasitic and viral infections (Swerdlow, D.S., 1992) (Mackenzie et al 1995). Fecal (Obi et al 2002) (Fenwick, 2006) and chemical contamination, combined with the failure to treat water adequately, have been incriminated in many waterborne epidemics (Bridgman et al 1995).

In Kodiyathur Village, there is a lack of protected water supply; hence, many homes have wells situated around the house near the latrine (Megha et al 2015). For most communities, the primary source of safe drinking water is piped water supplied from municipal water treatment plants. Often, most water treatment facilities fail to meet the water requirements of the community due to lack of infrastructure, maintenance or increased population. The scarcity of treated water has forced these people to find alternative sources of water that is groundwater sources being a ready source. Hence, the need to ensure the supply of potable water is a priority to the prevention of waterborne illnesses. The increasing dependence on groundwater as a source of clean water has led to an increase in efforts to protect the quality of this limited resource.

It has been estimated that the total volume of waste disposed via latrines is approximately 800 million gallons per year, all of which is discharged in the subsurface (USEPA, 2009). This makes latrines the leading contributor to the total volume of waste discharged directly to groundwater.

METHODOLOGY

A large percentage of domestic and organic waste in water bodies leads to high turbidity. Water with high turbidity levels can clog the fine sand in these filters. Water is added to slow sand filters without any pre-treatment when it has turbidity levels lower than 10 NTU (Collins, 1998). Hence, it is necessary to pre-treat the water to reduce the turbidity as far as possible before introducing the raw water to the bio-sand filter. Sedimentation is one of the standard methods used to reduce turbidity.



Roughing Filter:

The roughing filter is a simple, inexpensive, efficient and chemical-free alternative treatment process applied mainly for solid matter separation, and it also improves the microbiological water quality. Media types commonly used in roughing filtration are gravel, broken stones or rocks, broken burnt clay bricks, plastic material, burnt charcoal and coconut fibre, but can be replaced by any clean, insoluble and mechanically resistant material (Graham, 1988). The media size for roughing filter ranges from (4– 20 mm). The roughing filter classified according to the direction of flow to, vertical and horizontal flow roughing filter where the vertical flow roughing filter classified to downflow roughing filter and up-flow roughing filter. The roughing filter works at a filtration rate ranging between (0.3 – 1 m/h), (Wegelin, 1996). The acceptable performance of a slow sand filter is when the influent turbidity is between (10 – 30 NTU) or less (Wegelin, 1996).

Coagulation using moringa oleifera:

Moringa seeds consist of proteins (cationic and dimeric) which help in neutralizing and absorbing colloidal charges in water containing suspended solids. These suspended impurities combine and form heavy clumps which result in easy settling of suspended particles. Moringa seed cake or powder eradicates the suspended solids from wastewater. Being non-toxic and sustainable as compared to other synthetic materials, it is one of the promising techniques to remove the pollutants from wastewater (Okuda et al 2001).

The removal efficiency of *M. oleifera* increased when the raw water samples were highly turbid. For a water sample of relatively high initial turbidity of 45.6 NTU, *M. oleifera* produced the best results with an average turbidity reduction of 94% (Abatneh et al. 2014). The treatment of Moringa seeds removed copper (90%), cadmium (60%), lead (80%), chrome and zinc (50%). Moringa seeds can be used as coagulants primarily in a clarifier for the wastewater treatment, especially in underdeveloped and developing countries as other coagulants have high operating costs for metal removal and are expensive. The produced M. oleifera extracted by separation of various components from the seed as coagulant gave suspended solids removal of around 97% for the treatment of turbid water.

After the pre-treatment of raw water to reduce the turbidity, around 3 grams of this powder can be added for every 10 litres of water before proceeding with the filtration process.

Bio-Sand Filter:

The process of sand filtration percolates untreated water slowly through a bed of porous sand, with the influent water introduced over the surface of the filter, and then drained from the bottom. Construction of the filter consists of a tank or a drum, a bed of fine sand, a layer of gravel to support the sand, a system of drainage to collect the filtered water, and a flow regulator to control the filtration rate. No chemicals are added to aid the filtration process.

The bio-sand filter is the most effective and efficient when operated intermittently and used consistently (every day). There must be a rest period or pause period between uses. The pause period should be for a minimum of 1 hour after the water has stopped flowing, up to a maximum of 48 hours. The pause period is crucial because it allows time for the microorganisms in the biolayer to consume the pathogens in the water. This should be a minimum of 1 hour. If the pause period is extended for too long (over 48 hours), the microorganisms will eventually eat all of the nutrients and pathogens in the water and then die from starvation. If the microbes in the biolayer die, the filter will not work as well or remove as many pathogens when it is used again. A long pause period may also cause the standing water in the filter to evaporate, causing the biolayer to dry out and die. When water is poured into the filter, the high water level (also called the hydraulic head) pushes the water through the diffuser and filter. The water level in the reservoir goes down as the water flows evenly down through the sand. The flow rate will decrease as the reservoir empties because there is insufficient pressure to force the water through the filter. The inlet water contains dissolved oxygen, nutrients and contaminants. It provides some of the oxygen and nutrients required by the microorganisms in the biolayer.

Reference	Organism	Filtration rate (m/h)	Temperature (°C)	Removal percentage
Poynter and Slade (1977)	Poliovirus	0.2	16 to 18	99.997 average
Poynter and Slade (1977)	Poliovirus	0.4	16 to 18	99.865 average
Poynter and Slade (1977)	Poliovirus	0.2	5 to 8	99.68 average
Poynter and Slade (1977)	Poliovirus	0.5	5 to 8	98.25 average
Bellamy et al. (1985*b*)	Total coliform bacteria	0.12	17	97 average
Bellamy et al. (1985*b*)	Total coliform bacteria	0.12	5	87 average
Bellamy et al. (1985*a*)	*Giardia*	0.12	5 to 15	99.994 average
Bellamy et al. (1985*a*)	*Giardia*	0.4	5 to 15	99.981 average
Bellamy et al. (1985*b*)	*Giardia*	0.12	17	>99.93 to >99.99
Bellamy et al. (1985*b*)	*Giardia*	0.12	5	>99.92 to >99.99
Pyper (1985)	*Giardia*	0.08	0.5	93.7
Pyper (1985)	*Giardia*	0.08	0.5 to 0.75	99.36 to 99.91
Pyper (1985)	*Giardia*	0.08	7.5 to 21	99.98 to 99.99
Ghosh et al. (1989)	*Giardia*	0.3	4.5 to 16.5	>99.99
Ghosh et al. (1989)	*Giardia*	0.4	4.5 to 16.5	99.83 to 99.99
Ghosh et al. (1989)	*Cryptosporidium* oocysts	0.15 to 0.40	4.5 to 16.5	>99.99
Hall et al. (1994)	*Cryptosporidium* oocysts	0.2	Not stated	99.8 to 99.99
EES and TWU (1996[a])	*Cryptosporidium* oocysts	0.29	12 to 14	>99.99

For added benefits of heavy metal removal through adsorption, a layer of granular activated carbon can be incorporated into the filter media. The activated carbon could be of commercial grade or prepared locally from organic matter such as coconut shells which are abundant in tropical regions. Activated carbon made from coconut shells has shown an excellent removal efficiency for the heavy metals such as copper, lead, iron, zinc and cobalt which would be an added benefit to the filtration process (Bernard, Jimoh and Odigure, 2013).

Solar Disinfection (SODIS):

Source: Rural 21 – International Journal of rural development

Solar Disinfection (SODIS) is a cheap and easy to use, environmental friendly and effective drinking water disinfection technology (Sobsey et al. 2008). This method treats contaminated water in transparent plastic or glass bottles through exposure to sunlight for a minimum of 6 h (Byrne et al. 2011). Another technique which can be utilized is the aqua lens. After the exposure time, the water is safe to be consumed as the microbial quantity can be significantly reduced. SODIS technology enhances the bactericidal effect of UV electromagnetic region (wavelengths in the range of 320–400 nm) of solar radiation with a similar effect of heat (infrared wave) in the presence of dissolved oxygen species for inactivation of pathogens in the water. UV radiation showed an adverse effect on microbial ability to achieve cellular respiration and generation of adenosine triphosphate (Bosshard et al. 2010).

Key Pollutants to be removed:

1) Iron and Arsenic:

According to (Pramanik et al., 2016) coagulation with the help of moringa oleifera and further adsorption through biological activated carbon has high efficiency for the removal of arsenic and iron. Bio-sand filter is an optimum choice for filtration as a layer of granular activated carbon can be incorporated in the filter design for adsorption of these metals. A contact time of 60min was recommended for this process.

2) Fluoride:

The suitable methods for the removal of fluoride from the water would be coagulation or adsorption. According to (Koteswara & Mallikarjun 2012), the use of bone charcoal or bone char (carbonized animal bone) is reported to be an effective method for the removal of fluoride. Bone-char contains a carbon structure while supporting a porous hydroxyapatite matrix (a calcium phosphate hydroxide in crystalline form which is rich in surface ions which can be readily replaced by fluoride ion). Regeneration of this material can be achieved by a two per cent sodium hydroxide rinse and a backwashing cycle. However, the application of animal bone-char needs to be done, keeping the cultural preference of the people in mind.

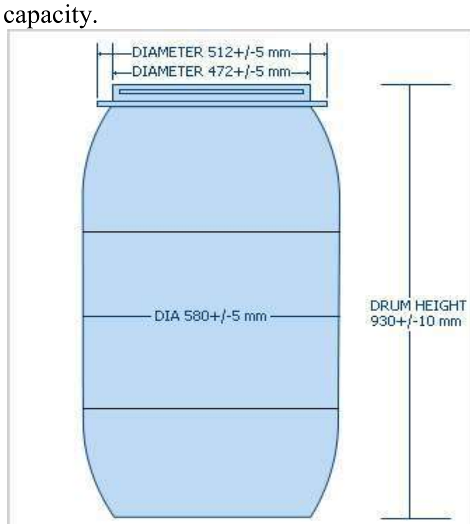
Fluoride removal by coagulation is of chemical nature due to the formation of chemical complexes, between the fluoride ions and the long-chained polymers present in Moringa oleifera. Removal of fluoride by molinga increased from 75% to 89% as the pH was increased from 3 to 6. From pH 6 to 12 the fluoride removal decreased from 89% to 77%. (Koteswara & Mallikarjun 2012)

COST ANALYSIS

The following cost estimation was done taking into account the availability of materials locally with focus on reducing the capital cost as far as possible. In the case of varying price of a product the higher value was considered for final calculation which would give us an upper limit for the construction cost.

The sources for the products include local vendors and e-commerce websites such as IndiaMart to obtain an initial estimate.

The drum to be used as the sand filter has a capacity of 200 litres and its dimensions are mentioned in the figure below. The cost calculation for the gravel and sand to be used is done according to the specifications for this drum. However, the calculations can be adjusted for a drum of lesser capacity.



Cross Sectional Area (centre) = 0.264m2

1) *Bio-Sand Filter:*

Sr.No.	Materials	Quantity Required	Cost (INR)	Total (INR)
1	Gravel 0.5-0.75 inch	1 cubic foot	18/cu. ft	18
2	Gravel 0.25 inch	1 cubic foot	20/cu. Ft	20
3	Coarse Sand	2 cubic feet (80kg)	3/kg	240
4	Fine Sand	4 cubic feet (160kg)	3/kg	480
5	HDPE Drum	150 - 200 litres	800	800
6	Vessel (Storage + Sedimentation)	100 litres X 2	300/vessel	600
7	20mm PVC Electrical conduit (pipe)	5 metre (0.75kg)	90/kg	90
8	20mm PVC T-junction	6	10 per piece	60
9	20mm PVC 90 degree bends	10	70/ dozen	70
10	Tap (20mm)	1	50	20
11	Ball Valve	1	100	100
12	PVC weld/glue	1	50/piece	50
13	Granular Activated Carbon	1 Pack (1kg)	50- 100/kg	100
14	moringa oleifera	10 gm per batch	150-200/kg	200
15	Thread tape roll	2	20/piece	40
16	Plexiglass sheet for diffuser	1	50	50
17	Mosquito mesh (plastic)	3 sq ft	20/sq ft	60
18	Calcium Hypochlorite soln for disinfection	1	95/kg	95

Total Cost: 3093

The coarse sand layer should have a minimum height of 50cm for effective filtration and the amount of sand required is calculated accordingly (CAWST manual). The cost for sand and gravel could be reduced if the materials are locally available from the river bed or nearby areas. The gravel can be washed, dried and sieved based on size and thenthe river bed or nearby areas. The gravel can be washed, dried and sieved based on size and thenused for the filter, however the quality of the coarse sand is important for the filter and should not contain impurities or clay content.

2) SODIS:

SODIS Materials

Sr.No.	Materials	Quantity Required	Cost (INR)	Total
1	PET plastic bottles	1 litre X 15	20/bottle	300
2	Reflective Aluminium Foil	1 Pack	200	200
3	Rectangular Tray for placing bottles	1 large or 2 small	300	300
			TOTAL	800

The total cost for the construction is **INR 3893** or approximately **INR 4000**.

3) *Miscellaneous Costs:*

There may be some added costs incurred beside the ones mentioned such as those for transportation of materials. While building the output piping system for the filter there would be a need for purchasing a drill machine with drill bits of various sizes. This would add another INR 1500 to the total cost. However, renting a machine from a workshop or buying it second hand would lower the costs for the same.

CONCLUSION

The proposed hybrid filtration system offers a good solution to the people who lack the availability of potable water. The construction is simple and the materials are easily obtained. Since no chemicals are used except for initial cleaning of the components, it provides safe water to the people for drinking and other domestic purposes. It has the potential to be deployed across multiple households and can be commercialized with the help of local civic organizations.

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