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Low Cost Advanced Water Treatment for Rural Areas

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ABSTRACT
Conventional water treatment including aeration, coagulation, clari-flroculation, rapid sand filtration and disinfection is generally used for treatment of raw surface water in urban areas. This treatment is not suitable for rural areas due to change in water properties, unavailability of the skilled staff & maintenance of plant. The population & cost constraint is also a major factor in determining the suitable treatment. Well water is the major source for rural areas. The well water contains more TDS, Hardness and other impurities. To remove these impurities, advanced treatment such as ion exchange, reverse osmosis, distillation, other membrane processes, etc are required which are not feasible in rural areas. A low cost water filter is developed to meet the requirement of rural area. About 45-60% hardness and TDS removal is observed with negligible cost.
Keywords–Hardness, TDS, advance treatment, adsorption

I. INTRODUCTION

Water is the elixir of life. Lack of access to safe water results into many health issues. Reasons for this include shortage of water, poverty, and lack of awareness about the effect of drinking unpurified water. Nearly, 2.2 million children die annually from water born diseases. All over the world, rural communities have adopted simple and rudimentary treatment techniques that mainly aim at filtering out the visible impurities from the water collected from local sources. In Urban areas, generally the source of water supply scheme is surface water like reservoir or dam. The surface water contains major impurities in the form of suspended matter which is measured turbidity. In this case, treatment flow sheet consisting of aeration, coagulation, flocculation, sedimentation, rapid sand filtration, and chlorination is provided. The treated water is supplied through pipe lines. But in rural areas there is no guarantee of purification with the traditional treatment method. In rural areas, well water is the main source of water. The well water contains more TDS, hardness and may be bacteria logically contaminated. Such water is not suitable for drinking [1]. Therefore there is need of suitable low cost water treatment technology. Studies were conducted for developing low cost treatment suitable for treatment of well water. Some of the low cost treatment method includes ceramic filters, bone char filtration, slow sand filtration, solar distillation; application of chlorine, activated carbon treatment for treatment of water has been in use since historical time [2]. These filters are effective for turbidity and bacteria removal. It is ineffective for TDS removal.

The rural area in Nashik district is is famous for grapes and sugarcane production. Canal irrigation and well water irrigation is the method of irrigation. Many problems are reported bythe farmers about blockage of drip irrigation pipes and salty water. Blockage of drip nozzle is major problem in areas where well water is source of irrigation.

Table 1: Ground water quality in Nashik District.

Sr No	Sample	Hardness mg/l as $CaCO_3$	TDS mg/l	Chlorides mg/l as Cl	Sulphates mg/l as SO_4
1	Takli	374.4	800	215.58	30
2	Niphad	538.2	920	265.22	15
3	Vihitgao	327.6	1360	184.56	50
4	Kalwan	257.4	840	155.1	20
5	Hirawadi Road	187.2	460	178.36	10
Permissible limit for drinking purpose (IS10500/2012)		200	500	250	200

To investigate the problem, water samples were collected from wells located in different villages and analyzed for TDS, Hardness, chlorides and sulfates. The water quality parameters for ground water in Nashik district are given in Table 1.The hardness and TDSin all the samples is found to be very high exceeding permissible values for drinking purpose [1].Excessive hardness and TDS in the well, water is the main cause of frequent blockage of nozzles in the drip pipes. Thus there is need of providing affordable water filters suitable for rural area and which can reduce TDS, hardness andreduce the risk of any waterborne diseases.

II. MATERIALS & METHODS

Study is conducted with pilot scale working model of a combination of conventional & advance filtration technique. Filter consists of different components drainage system, gravel, filter sand and additional layer of charcoal for removal .The following materials are used for construction of advances filter system.

2.1 Pilot Scale Model

2.1.1 - Materials

Drainage system:

The under drainage system of the filter is designed on the basis of guidelines by CPHEO manual [3]. Under drainage system consists of a main drain of PVC pipe of 1inch dia. connected with 4 no of ½ inch dia. lateral drains.; The lateral drains are connected to main drain shown in Figure 2.The lateral drain consist of holes of about 4 mm diameter making an angle of 60º and it is placed at bottom of filter below the media. This arrangement is efficient in receiving filtered water during filtration and distributes the backwash water during cleaning.

Gravel: Gravel is small crushed stones. Primary role of gravel in filter is to give support to filter sand and prevent clogging. Highly spherical shape of uncrushed gravel promotes good flow and even distribution. The gravel layer of size 10-15 mm was used in this study.

Fine Sand : Fine sand are naturally occurring glacial deposits high in silica content and low in soluble calcium, magnesium and iron compounds are very useful in sedimentation removal. It is to be placed above the gravel layer. Top layer catches organic materials and microorganisms. It is also used for mechanical trapping, holds static charge and causes death of microorganisms. Sieve analysis was performed for deciding the size of filter sand. Here for the experimentation fine sand passing through 425 micron and retained on 600 micron IS sieve having uniformity coefficient 1.5 was used. Local sand was used for effective removal of turbidity; effective size is used in this project.

Wood Charcoal: Many different materials were used for filter media such as rice husk, drumstick seeds, dried banana leaf ash, stem and rind, dried leaves of neem, basil, coconut shell, activated charcoal, duckweeds[4] etc.Considering the problems in rural area, it was necessary to keep the operation cost to minimum and to develop simple technology. Investigations were carried out for checking suitability of locally available filter media. Wood charcoal is abundantly available locally and it has good absorption and adsorption propertie, usefull for removal of hardness and dissolved impurities. It was decided to use the charcoal as additional layer above the sand for the filter.

Wood charcoal's chemical composition and physical structure both contribute heavily to its strength as a water filter. It is 85-98% carbon the same substance used in most modern filtration methods[5]. Its structure is very porous, so it can absorb and retain impurities easily. When submersed in water, bamboo charcoal softens the water, absorbs harmful minerals including chlorine and releases its natural minerals (calcium, sodium, magnesium) into the water[6]. Charcoal is effective for removal of TDS. Suitability of charcoal is investigated in the present study and attempt is made to develop a low cost filter suitable for turbidity removal as well as removal of dissolved solids and hardness. Studies are conducted with pilot scale model ,on the basis of results obtained are used to develop a full scale model for greater scale application in rural areas.

2.1.2– Method of construction

Preliminary investigation was carried out to find suitability of charcoal for removal of TDS and hardness with small scale filter consisting of under drainage system, gravel layer, filter sand and charcoal layer. This filter was prepared in bucket as shown in Figure 3.The pilot scale model fabricated in a PVC bucket is having dimensions as 0.28 m diameter,0.27 m in height, and volume of 0.01662 m^3.Due to smaller dimensions of bucket, backwashing system is not provided. Sand layer of thickness 5-20cm is suitable for turbidity removal. Since the objectives of the investigation are to study the TDS and hardness removal using charcoal and not the turbidity. Therefore 5cm thick sandwas provided. Purpose of sand layer is to provide support to charcoal layer. Different layers were placed one by one. The gravel was first washed with water and then placed in the model to a thickness of 5cm layer. The fine sand was sieved through sieve 2.36 mm size and retained on 600 micron mm sieve having uniformity coefficient of 1.5 was used. The sand was also washed with water to remove the organic impurities. 5 cm thick sand layer was provided above the gravel layer.

Wood charcoal was first crushed and particles of size 10mm to 4.75 mm were used in the filter as additional layer. The charcoal was thoroughly washed with water to remove colour and loose organic impurities before placing in the filter.The charcoal layer of 10 cm thick was then placed above the sand layer.

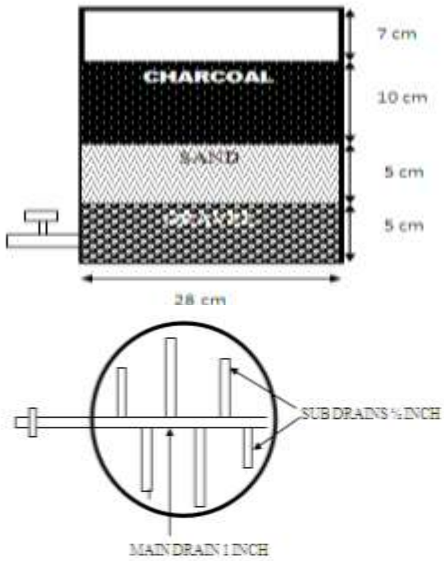

Fig 2: Plan & section of small scale model

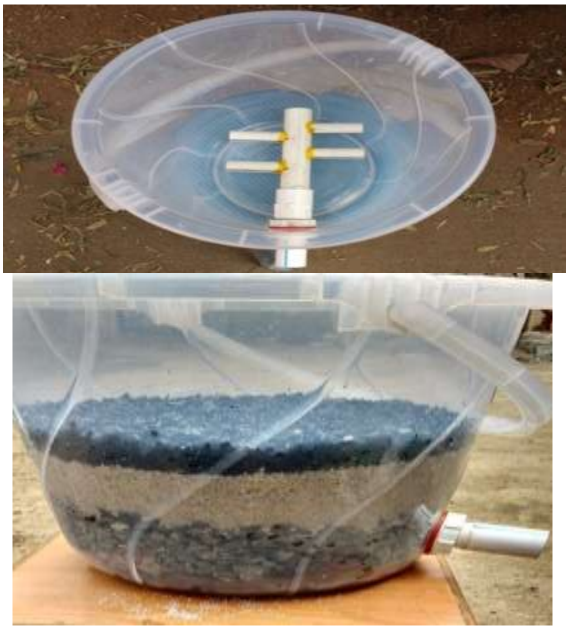

Fig 3.Small Scale pilot model.

Figure 2 shows the plan and section of filter showing under drainage system, different components as under drainage system, gravel layer, filter sand and charcoal layer. Figure 3 shows photographic view of the pilot scale model.

Study was conducted with clear water with zero turbidity but containing high TDS and hardness.Raw water was fed from top, keeping the outlet valve closed at the start. Water was fed till it reaches the total height of model. After getting fully saturated condition, the outlet valve is opened and the treated water is wasted. The raw water inlet valve and the treated watervalve at the outletwere adjusted to give static head of 5-7cm. The filter was operated at constant head. It was operated for about 2hrs a day. The flow rate observed was about 180 lit/hr. The treated water sample was collected after steady state condition is established and was then analyzed for pH, TDS, Total hardness, sulphates and chlorides.

It was observed that the filter was effective in removal of 15-20 %of TDS and about 20-30% of hardness. As the sand layer and gravel layer has no role in removal of hardness and TDS, it was clear that charcoal layer was responsible for hardness and TDS removal. Due to small capacity it was not possible to provide backwashing facility, therefore or turbidity removal was not studied. Considering the limitation of pilot scale model, a full scale model was developed for study of turbidity hardness, and TDS removal as single step treatment suitable for rural area.

2.2Full Scale Model

Materials

The materials used for full scale plant and pilot plant were same except additional facility for backwashing. In this case a tank (PVC) tough, durable and resistive plastic material was used for a full scale advanced water treatment method. A drainage system was made for the model which is to be placed at the bottom of model. It consists of a main pipe (PVC) of 1inch dia. Lateral drains of ½ inch dia; 6 in nos. connected to main drain holes were drilled on the bottom side of the ½ inch lateral drains at angle of 60˚ so that treated water will drain off safely prevent entry of sand in treated water. Tough, strong and durable PVC pipes were used for fabrication of under drainage system to resist the load of filter media placed above it. The full scale model is fabricated to including raw water inlet, filter media, charcoal layer, under drainage system, various valves required for smooth operation of filter and backwashing for cleaning of the filter. Figure 4 shows the section of the filter and Figure 5 shows the photographic view. The full scale model is constructed with good quality PVC tank of 0.46m diameter, 0.9m in height and having volume of 0.155m^3.

Method of construction

Different layers were then placed one by one. The gravel was first washed with water and then placed in the model to a thickness of 20cm layer. The fine sand was sieved through sieve 2.36mm size and retained on 600 micron sieve. The sand was washed with clean water to remove dirt, silt and clay and other impurities. After washing, sand was dried and then placed to thickness of20cmin the model above the gravel layer. Wood charcoal was crushed and washed with water till the black colour of filtered water disappears. It was then placed above the sand layer up to thickness of 25cm.

Water was fed from the inlet at top, keeping the outlet valve closed till the tank is completely filled with water. The inlet and outlet valves were adjusted to give static depth of 20 cm above the filter media.After development of steady statecondition, treated water samples were collected and analyzed for pH.Hardness.TDS, sulphates and chlorides.

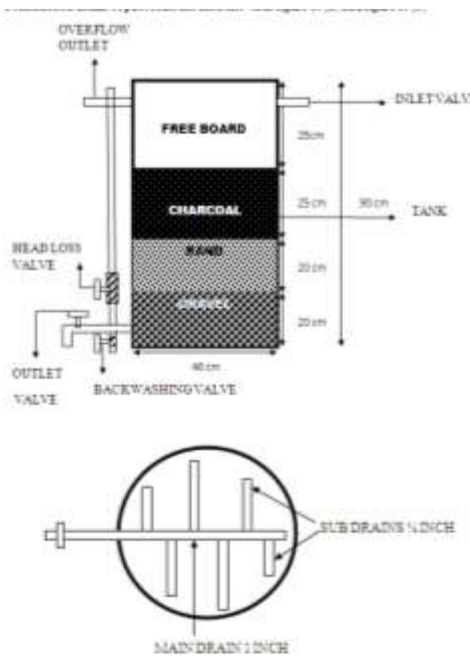

Fig 4: Plan & section of full scale model

With this set up thickness of charcoal layer was varied from 5cm to 25 cm. Performance in removal of TDS and hardness improved with increase in thickness of charcoal layer. Maximum removal was observed for 25 cm thickness. Further increasing thickness of charcoal layer was not possible with this set up. As satisfactory removal is observed for 25 cm thick charcoal layer, it is considered adequate for further work. The filter was operated for 2 hours a day for 1 month at constant water depth of 20 cm above the media. The filtration rate initially observed was 180 L/hr. Backwashing of filter was carried out on the last day of the week that is at the frequency of once in week. Backwashing of filter was necessary due to increase in head loss and reductions in filtration rate.Treated water sample were collected on the last day of every week before backwashing. The water samples were analyzed for TDS (mg/L), total hardness (mg/L as $CaCO_3$), chlorides (mg/L as Cl^-) and sulphates(mg/L as SO_4).

Fig 5: Snaps of full scale pilot model

Such numbers of cycles were conducted. Results of analysis treated water samples for each cycle are given in Table no.2.

Table 2: Treated water quality analysis

Parameter	Raw Water	Value for treated water collected at			
		7th day	14th day	21st day	28th day
1.Total Hardness(mg/L as $CaCO_3$)	412	208	220	270	336
2.TDS,(mg/L)	520	360	370	386	410
3.Chlorides (mg/L as Cl^-)	128	56	68	80	108
4.Sulphates (mg/L as SO4)	18	11	12	13	16
5.Turbidity (NTU)	20	0.3	0.3	0.5	0.5

III. RESULTS & DISCUSSION

Role of sand layer is primarily in turbidity removal, to some extent to test, odor and bacterial removal. It has no effect on removal of dissolved solids and hardness. When the filter was modified by providing additional 25 cm thick layer of charcoal, satisfactory removal of TDS, hardness, chlorides and sulphates is observed as shown in table no.2. Charcoal layer was found to be very effective in removal of almost all dissolved impurities. In first week, total hardness removal of 49.5 %, TDS removal of 31%, chlorides removal of 56% and sulphates removal of 38.8% was observed. Removal of these impurities was found decreasing with each subsequent operation cycle of filter. The values of these impurities are almost closure to the raw water quality after 5th week of operation. Removal of various dissolved solids and hardness by charcoal may be due to its adsorption and absorption capacity. This capacity goes reducing with operation of filter as the area available for adsorption and absorption in charcoal gores on decreasing. This indicates that there is need for regeneration of the charcoal. However, the filter was found to very effective in turbidity removal if backwashing is done regularly. In the present study backwashing of filter was carried out in every week after operating the filter daily for two hours.

IV. REGENERATION

Regeneration is required for adsorption process. It was observed that outlet water quality was equal to inlet water quality after duration of one month.

The adsorbent consist of porous structure which is helpful for removal of different impurities. Charcoal, activated carbon, coal fly ash, coal fly ash derived-zeolite, dematerialized coals, sulphonated coals, calcium-loaded coals, and many other compounds[7] are used for absorption process for treatment of water and wastewater. The adsorbent consist of microspores (up to 3nm), mesopores (3-60nm) and mesopores (60-1000nm).During filtration of water, many organic and inorganic impurities accumulate within the porous structure of adsorbent. Microspore constitutes the primary adsorption sites, and therefore gets saturated earlier compared to mesopores (3 to 60nm) and macro pores (60 to l0000nm).Mesopores and macropores contribute for removal of adsorbates of relatively high molecular mass. Due to these factors, adsorption efficiency goes on reducing and affects performance of the filter. At this stage regeneration is required for removing the impurities adsorbed and to increase adsorption capacity. The objectives during regeneration are the selective removal of the adsorbates that have accumulated on the charcoal during adsorption operations and the restoration of the original porous structure. Various methods like steam regeneration, thermal regeneration, chemical regeneration and biological regeneration are available for regeneration. These methods are costly; require skilled persons therefore not suitable for rural area. Therefore using fresh charcoal was preferred instead of regeneration; also it is available at cheaper rates about Rs. 20 per Kg. The regeneration cycle was found to be for about five weeks. The cycle is considered for one month to study cost economics.

So it costs about Rs. 240 annually for small model. It is found to be economical. Whereas it costs about Rs.800 annually for large model. The filter was operated for about 8 hrs a day under constant flow. The regeneration point was observed after 1 month with filtration rate 3200 lit/day.

V. COST ECONOMICS OF FILTER

Main objective of developing the filter suitable for rural areas .Well water is the main source, removal of TDS and hardness is necessary at low cost. The cost economics of the filter is shown in table no.3

Table 3: Cost economics of filter

Sr no.	Parameter	Capital cost (Rs)
A	Capital Investment	
1	PVC Tank of 93 cm height and 46cm diameter	1140
2	Crushed charcoal (10 kg)	200
3	Plumbing cost	600
	Total cost involved	1880
B	Recurring expenses	
1	Cost for replacing the charcoal per year(10 cycles of 5 week)	2000
2	Quantity of filter water output 360 L/d for 1 year	131400 L
3	Cost per litre	0.03 Rs

Therefore cost of treated water is very low almost negligible.

VI. CONCLUSION

Well water is the major source of water in rural areas. Most of the time, well water is not suitable for drinking purpose due to high TDS and hardness. Due to lack of funds, power supply use of sophisticated methods like water softening, RO is not feasible. An attempt is made to develop a low cost filter suitable for rural areas. The conventional rapid sand filter fabricated using locally available materials, local sand. This filter was modified using washed charcoal. It is found that the filter is very effective in removal of turbidity, hardness, sulphates and chlorides. After disinfection, the filtered water is suitable for drinking purpose. The cost of treatment is very low almost negligible. This filter can be used for rural areas where well water is main source for drinking.

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