Development of A Sustainable Household Surface Water Treatment Filter

Mst. Nasrin Aktar

Department of Civil Engineering
Khulna University of Engineering and Technology (KUET),
Khulna, Bangladesh

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A Project report submitted to the Department of Civil Engineering of Khulna University of Engineering and Technology (KUET), Khulna, Bangladesh in partial fulfillment of the requirements for the degree of

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Supervised by:

Dr. Quazi Hamidul Bari
Professor
Dept. of Civil Engineering, KUET
Khulna-920300

Prepared by:

Mst. Nasrin Aktar
Roll No. - 0401551
Dept. of Civil Engineering, KUET
Khulna-920300

Department of Civil Engineering
Khulna University of Engineering and Technology (KUET),
Khulna, Bangladesh

August, 2008

Declaration

This is to certify that the project work entitled "Development of a Sustainable Household Surface Water Treatment Filter" has been carried out by Mst. Nasrin Aktar, in the Department of Civil Engineering, Khulna University of Engineering & Technology, Khulna, Bangladesh. The above project work has not been submitted anywhere for any award of degree or diploma.

Dr. Quazi Hamidul Bari	Mst. Nasrin Aktar
Professor	Roll no. - 0401551

Approval

This is to certify that the project work submitted by Mst. Nasrin Aktar entitled as **"Development of a Sustainable Household Surface Water Treatment Filter"** has been approved by the board of examiners for the partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering under Khulna University of Engineering & Technology, Khulna, Bangladesh in August, 2008.

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Dhaka, Bangladesh

Member
(External)

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Author
KUET, Khulna

Abstract

Potable drinking water is essential for the sustainable existence of the humanity. According to the Word Health Organization (WHO), one third of the world's populations are without access of clean drinking water. The urban and rural water supply system in the country is mainly dependent on groundwater. Widespread arsenic contamination and presence of elevated level of iron in groundwater are the major water quality problems for the country. Surface water can be used for domestic purposes in the areas where the ground water contains excess salinity, iron and arsenic. Water for drinking purposes must be free from pathogenic micro-organisms, excess concentration of unusable minerals and toxic substances which can produce adverse effects on health. The socio-economic conditions demands low-cost treatment systems that could be implemented in the rural areas at household levels. Although a few household level ground water treatment units have been developed and tested, little attempt has been made in the development of surface water treatment at household level.

Considering the above points, a sustainable bio-physicochemical treatment unit has been developed at laboratory scale for bacterial removal from surface water. The treatment unit using activated carbon and sand filtration has combined the bio-physicochemical removal processes in a single system. The combinations of rapid and slow sand flow have been found successful in reducing very high turbidities and coliform counts.

The developed household surface water treatment Unit has two columns with down flow –up flow process. The total length of flow path of the Unit is 143 cm. The first column acts as rapid flow filtration while synthesis raw water passes through it. Comparatively larger suspended particles precipitate and settle at the top of the sand column with a small detention time. The removal of bacteria and other fine particles are done in slow flow portion of the second column. This column was constructed on the basis of simple methodological technique of slow sand filtration under submerged condition i.e. stable bio-film slime layer. Partial treated water up-flowed at very slow rates through fine sands to retain suspended solids in the interstices between the sand grains. The pores in the sand grains bring the fine particles and bacteria in contact with sand surfaces, where they adhere because of physical attraction and presence of gelatinous coating. During the filtration process, the coating of micro-organisms formed around the sand grains was responsible for the removal of organic matters and bacteria.

The developed surface water treatment filter is a 'fixed point use' device because of its heavy weight. The water to be filtered can be collected from the closest water source, whether pond, river or stream, carried physically to the filter and used immediately thereafter. The water intake, water treatment and water use are therefore all within the control of the individual householder. The main mechanisms for microbial removal are mechanical trapping between sand pores, adsorption – onto each other and on to sand grains; micro-organisms consume pathogens and natural death of pathogens.

Following the above technique, detail laboratory analysis and tests were carried out to determine some selected water quality parameters. The main findings drawn from this test were that the unit is capable of treating both pond and river water with the same filter media. No sign of Total Coliform or Faecal Coliform were detected in the treated water produced by the unit. It appeared that the unit performed consistently well in complete elimination of bacteria. Some selected water quality parameters of treated water (pH, Turbidity, Color, TDS and TS) were determined at random basis and they were found within the acceptable limit of Bangladesh standard. The operation and maintenance of the developed treatment unit are simpler and more users friendly. It was observed that the clogging of the unit did not occur over eight months of its successful operation. The final finding was observed that the unit produced sparkling clear water with no bacteria for continuous duration of eight months without any maintenance.

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Chapter One

Introduction

1.1 General

The scarcity of drinking water in Bangladesh is increasing. The pipe water supply facilities are present only in few cities and towns in Bangladesh. The main drinking water sources of the country are ground water, surface water and rain water harvesting. Until 1970s most rural people obtained and consumed water from the hand-dug wells, ponds, rivers or canals. These waters were usually consumed directly without any treatment. So epidemics of diarrhea, cholera and other water-borne diseases were very common. Hundreds of people particularly the infants died only because of drinking these unsafe waters. Then the idea of tapping groundwater as the alternative water source came in front to save the community and finally it becomes the main source. This water seemed to be clean, plentiful and pathogen-free under anaerobic condition. That was accepted and hand tubewells were considered reliable means for extracting groundwater at an affordable cost. Extractions of ground water from shallow tubewells have been found to be the best option for rural and most of the urban water supply system. It is claimed that Bangladesh has achieved a remarkable success by providing 97 % of the rural population with tubewell water [Ref 17], which is the highest population coverage by tubewell water in the region. However, at this success in water supply, it is unfortunate that the presence of harmful heavy metals in drinking water has emerged as a serious threat to public health. In recent years there has been widespread coverage in the media about the problems of ground water in Bangladesh's drinking water. This has been an unforeseen consequence of a large-scale programme to replace contaminated surface water sources by 'safe' ground water.

Now it is suggested that rain water as an alternative source for drinking purposes. The collection, storage and use of rain water are not organized and need development through adoption of appropriate technologies. Again rain water is not available for round the year.

Since, the scarcity of potable drinking water is a national problem for the country. It is now established that the harmful heavy metals (As, Fe, Pb, Mn) are present in ground water in most of the areas. An attempt was taken to treat surface water by simple methodological technique of slow sand filtration. People should encourage using safe and pure water at-least for drinking and domestic purposes. The socio-economic conditions of Bangladesh demands low-cost as well as small-scale treatment systems that could be implemented in the rural areas at household or community levels. Water treatment options for developed countries are broad with capital, materials and technical expertise. The developing country like Bangladesh, however, requires technologies that are simple in operation and maintenance, economically sustainable and acceptable to the rural people.

So, to save millions of people from safe drinking water problem it is important to provide suitable, user friendly and cost effective household filter for the rural people of Bangladesh. Although a hundreds of community based surface water treatment units have been developed and tested in the field but these units are reported to fail [Ref 20]. The efforts proved as less efficient project due to lack of participation. The people do not like to work collectively to maintain their filter. In some cases, it was found that the product water contains larger number of micro organism than the source. A number of household filters developed for ground water treatment has sludge maintenance and iron bacteria problem. Thousands of pond sand filter (PSF) in the south-west part of the country are out of order due to the lack of maintenance. Most of the people in that region use pond and river waters without any treatment for drinking purpose. There are about 1,288,222 ponds in Bangladesh [Ref 17]. As much of 83% ponds keep alive throughout the year that would be a potential as well as reliable safe water source in the problematic areas of the country. So, it is clear that still we have the same opportunity to use surface water by treating individually.

A few number of household water treatment units are available in the country those have potential but not tested thoroughly for adoption. Most of the rural people are illiterate and they developed the habit of drinking hand tubewells water during the last 30 years. So any change in their behavior needs more friendly approach technology.

Therefore, the developed Treatment Unit should be chemical free, user friendly, simple in operation, reusable and cost effective to the users.

1.2 Objectives of the Project Work

Following are the major objectives of this project work:

- To develop a sustainable household surface water treatment filter unit by using locally available materials following simple methodological technique of sand filtration.
- To study the performance of the developed unit in the laboratory for some selected water quality parameters.
- To identify the problems of the developed unit associated with operation and maintenance.
- To determine the safe working period for the filter media without any maintenance.
- To monitor the product water quality using various surface water sources.

1.3 Scope of the Study

To achieve the above-mentioned objectives the following tasks were carried out:

- Laboratory batch study with different options of unit processes for bacteria, color and turbidity removal.
- Selection of the most appropriate unit processes for bacteria, color and turbidity removal.
- Detail laboratory analysis, model tests and evaluation of the removal efficiency of bacteria, color and turbidity with synthesis raw water.
- Identification of the problems associated of the developed unit through long-term monitoring.

1.4 Organization of the Project Paper

This project paper presents the detail analysis, results and findings of the study in five chapters and appendices as shown below. In addition a reference of related publications has also been presented.

Chapter 1: Represents brief introduction to the study along with its objectives and scope.

Chapter 2: Represents literature review concerning the available surface water sources in the country and their problem for use of domestic purposes. Criteria for Selection of Suitable Water Purification Technology, Water source and quality selection. The technologies and unit processes available for household arsenic and iron removal, requisite of different filter unit are also discussed in this chapter.

Chapter 3: Briefly reviews the methodologies of this project work concerning the associated unit processes with the Treatment Unit and the detail design of the Treatment Unit for laboratory model test. The laboratory set up and determination of variable parameters, construction and monitoring of the Unit under different conditions are also focused in this chapter.

Chapter 4: Represents the detail laboratory tests and analysis that had been carried out through Treatment Unit-Model for effective removal of bacteria and other selected parameters and the performance study of the Unit –model at the laboratory using pond and river waters.

Chapter 5: The chapter represents the details of engineering significance and economic aspect for developing the sustainable household surface water treatment filter

Chapter 6: Major conclusions of the project works and recommendations for future study for the sustainable approach of the developed Unit to go for mass scale construction have been cited in this chapter.

Chapter Two

Literature Review

2.1 Available sources of water in Bangladesh

2.1.1 General

Water exists in solid, liquid and gaseous forms. Oceans and seas are the main sources of water on earth which is salty. The fresh liquid water sources on land surfaces and in the ground constitute only about 1 % of the total water on earth. These fresh water sources have been formed by condensation of water evaporated mainly from the oceans and seas. The main sources of water in Bangladesh are surface waters in rivers, canals, reservoirs, lakes and ponds, and ground water in shallow and deep aquifers. The rain water is an alternative source of water that has good potential for water supply in the country.

2.1.2 Surface water

Surface water is abundant in wet season in Bangladesh. An estimated 795,000 Million cubic meter of surface water is discharge through Gannga-Brahmaputra system, in the downstream of the confluence of the Ganges and Brahmaputra. This is equivalent to 5.52m deep water over a land area of 144,000 km^2. An average annual rainfall of 2.30m within the country replenishes surface water sources. Each year about one-third of Bangladesh is submerged in a normal flood, and the area submerged may increase to about two-thirds during severe floods which recharge the aquifer.

In Bangladesh, ground and surface water sources are dependent on each other. Elsewhere, water from surface streams is the main source of recharge for ground water. In general, ground water flows into the surface water sources in the dry season and surface water enters into ground during monsoon. The two sources of water are interrelated and the use of one usually affects the water available from the other source. In recent years, large-scale use of ground water for irrigation purposes has caused a lowering of the ground water level and drying up of surface water sources. So, water scarcity persists in many areas in dry season.

There are about 1,288,222 ponds in Bangladesh. As much of 83% ponds keep alive throughout the year that would be a potential as well as reliable safe water source in the problematic areas of the country. About 17% of these ponds are derelict and probably dry up in dry season [Ref 17]. Many of these ponds are contaminated due to fish culture, agricultural, industrial, domestic and municipal sources. These ponds are not to be considered for domestic uses.

Problems in surface water

- Presence of highly diseases producing micro-organisms;
- Highly colored and turbid;
- Presence of dissolved and suspended solids;
- Drying up of water sources in many areas in dry season;
- High silt concentration in the monsoon;
- Chemically and bio-chemically contaminated due to industrial, domestic and municipal wastes.

2.1.3 Ground water

Ground water is the most important source of water supply in Bangladesh. Except for hilly regions Bangladesh is entirely under laid by water bearing formation at depth varying from zero to 20m below ground surface. The solid mostly stratified and formed by alluvial deposits of sand and silt, having occasional lenses of clay. The main constituent of the aquifer material is the medium grained sand deposited at the lower reach by the mighty rivers the Gangs, the Brahmaputra and the Meghna with their tributaries. Ground water can be easily abstracted by installation of wells for development of water supply systems. The water abstracted for various purposes is replenished in the monsoon.

Physically ground water is generally clear, colorless with little or no suspended solids and has a relatively constant temperature. Groundwater is also free from disease producing micro-organisms which are normally present in large numbers in surface waters. The slow filtering action of fine grained soil through which the surface water percolates to join the ground water removes almost all suspended impurities. Moreover, the lack of oxygen and nutrients in groundwater makes it an unfavorable environment for disease producing micro organism to survive, grow and multiply. On the other hand, being a universal solvent, water dissolves many of minerals present in earth's crust during its slow travel through the ground. Anaerobic conditions in soils in some flood plains and the presence of organic acids and carbon dioxide increase the solubility of groundwater. As a result, groundwater may contain minerals in varying concentrations depending on soil conditions.

Problems in groundwater

Ground water is available abundantly and it is the main sources of water supply in rural and urban areas of Bangladesh. The availability of ground water for drinking purposes has become a problem for the following reasons:

- Arsenic in groundwater;
- Excessive dissolve iron;
- Salinity in the coastal areas;
- Lowering of ground water level;
- Rock-stony layers in hilly areas.

2.1.4 Rain water

Bangladesh is a tropical country and receives heavy rainfall due to north-easterly winds during the rainy season. Rain water harvesting can be a potential source of water supply. The average yearly rainfall varies from 2,200 to2800mm, 75% of which occurs between May and September. The high rainfall occurs in the eastern part, including the eastern part of the coastal area, and highest rainfall occurs in the north-eastern region of the country. The low rainfall, less than 1500mm, occurs in the western part. In the coastal districts, particularly in the offshore islands, rain water has been used for drinking purposes since time immemorial. The protected ponds annually replenished by rain water are a main source of water supply in that area. Since various uses and unhygienic practices pollute these ponds. In some areas having a high salinity problem, as many as 36% of house hold has been found to harvest rain water in the rainy season for drinking purposes. But the collection, storage and use of rainwater are not organized and need development through adoption of appropriate technologies.

The coastal and hilly areas with high source problem intensity lie in the high rainfall opportunity for rain water harvesting. The unequal monthly rainfall distribution over the year means that a water supply system completely based on rain water requires large rainwater storage reservoirs.

Problems in rain water

Rain water harvesting can be a potential source of water supply but it has the following problems:

- Unequal yearly rainfall distribution;
- Unavailability of protected ponds or reservoirs;
- Still the collection, storage and use are not organized;
- Lack of minerals.

2.2 Criteria for Selection of Suitable Water Purification Technology

There are several factors which determine the suitable approach for water purification in developing countries like Bangladesh. The most significant among these are:

- **Cost:** Most of the people of our country live in villages and are not economically solvent. They use pond and river water directly without considering any health implications. It should be kept in mind that these poor villagers cannot afford expensive techniques.
- **Power:** The idea of any local technology will not be dependent on external power or sunlight to function.
- **Location:** Extensive field experience has determined that locating the water purification in the household produces the most effective results rather than community based.
- **Simplicity:** Training of the consumer and follow-up monitoring by trained personnel are essential to success for any local technology. So, the simpler the system, the better will be the outcome.
- **Availability***:* The technology must be constructed from the available materials in the country.

Satisfying the above requirements, slow sand filter is the best option for surface water treatment at household level. This also supports the following purposes to encourage for using surface water:

- Reducing the number of micro-organism present in water.
- Retain fine organic and inorganic solids matters present in water.
- Oxidize organic compounds dissolved in water.

2.3 Criteria for Water source selection

The selection of the source determines the adequacy reliability and quality of the water supply. The raw water quality dictates the treatment requirements. For examples, most ground waters that are free from objectionable mineralization are both safe and potable, and may be used without treatment, provide the wells or springs are properly located and protected. On the other hand, surface waters are exposed to direct pollution, and treatment is usually a prerequisite for their development as a drinking water supply.

Whenever possible, the raw water source of highest quality economically available should be selected, provided that its capacity is adequate to furnish the water supply needs of the community. The careful selection of the source, and its protection, are the most important measures for preventing the spread of waterborne enteric diseases in affected areas. Dependence upon treatment alone to assure safe drinking water in affected areas is in appropriate, because of inadequate resources, as illustrated by their poor record in operating and maintaining water treatment plants, particularity with respect to adequate disinfection before the treated water enters the distribution system [Ref 14].

Groundwater is the preferred choice both for the community and household level. This water does not require extensive treatment and operation is limited to pumping and possibly chlorination. In the case of surface water, relatively clear waters from ponds, lakes or streams are preferred, because these can be treated by slow sand filtration. If surface waters are heavily silted, pre-treatment may be provided by plain sedimentation or roughing filters prior to slow sand filtration. So, it is necessary to examine the physical, bacteriological and chemical analysis of water which could be helpful in providing useful information about the sources.

Finally, it is important to start off with a fairly clean source of water that needs to get a water sample tested at a laboratory. Sand filters cannot cope with heavy metals or other excessive pollutants. Their prime purpose is to remove bacteria and particles. It is not appropriate to use the technology to clean up water contaminated by chemicals. If the chosen water source does have a high level of contamination, ideally it should locate a new one. If this isn't possible other methods of filtration may be used, depending on the level of contamination. For example, even spring water or very clean river water should be checked for undesirable contaminants. If the water contains sediment, it should be passed through an initial settling tank (roughing filter) before it gets to the sand filter.

2.4 Water quality selection

Water quality varies from place to place and from season to season. So the treatment selected must be based on some factors:

- Treated water specifications.
- Raw water quality.
- Local constraints.

Pure water is not available in nature nor is it desirable for any water supply. Some impurities may present in natural water in the forms of suspension, solution or pseudo-solution. The effects of some of the impurities on water and human health are not ignorable. Some of the water quality parameters respond to human senses of sight (turbidity, color), taste (salty, offensive) and smell (odor). The presence of pathogens and poisons in drinking water cannot be identified by human senses. These are of greater importance in water supply.

The basic requirements of drinking water are that the water should:

- Be completely free of pathogenic micro organisms that can cause disease;
- Contain no elements or compound in concentrations that can cause acute or long-term adverse effect on human health;
- Be fairly clear and aesthetically attractive, i.e. low turbidity and color;
- Not be saline to cause salty taste;
- Contains no compounds that can cause an offensive taste and odor;
- Not cause corrosion, scale formation discoloration or staining [Ref 01].

The most important parameter of drinking water quality is the bacteriological quality, i.e. presence of pathogenic organisms. The water-borne diseases are caused by the ingestion of pathogens with drinking water. Improvement of drinking water quality is an effective preventive measure against transmission of water born diseases. Control of most water born diseases is hinged upon availability of enough water for domestic and personal cleanliness. The water born diseases can therefore also be described as water washed diseases.

In water supply, it is not practical to test the presence of all pathogens in water, instead, the water examined for specific type of bacteria which originate in large numbers from human and animal excreta and whose presence in water is indicative of faecal contamination.

2.5 Available Water Treatment Filter

2.5.1 Iron Removal Units:

To remove soluble iron it is generally accepted that an oxidation process followed by a suspended solids removal process is most effective. Usually oxidation of soluble iron is accomplished by simple aeration or chlorination/potassium permanganate application. Coagulation – flocculation with sedimentation and filtration are employed as solid removal processes.

Ahmed (1987) developed a low-cost iron removal plant based on four major units, e.g. aeration channel, sedimentation and two brick chips adsorption chambers. Several plants were constructed and it was found to be effective in removing iron from No. 6 tube well with yielding capacity of 9 to 13 L/min. The plants have been found to be very effective in removing soluble iron from tubewell water in excess of 90 percent.

Ahmed (1987) conducted some studies on horizontal flow roughing filter for the removal of iron from water. It was observed that in a roughing filter of 0.4 m long with 4 to 10 mm filter grain size and a filtration rate of 0.4 m/hr, an average of over 92% iron removal could be achieved during a total run of 100 hours. It was also observed that the most important factor that affects the performance of a roughing filter is the increasing depth of penetration of iron sludge with time.

In 1986-87 UNICEF developed an improved iron removal plant consists of three units e.g. perforated Ferro cement channel, sedimentation chamber and brick chip filter. The plant was found to be effective in iron removal and the filter run was also satisfactory. A study by WHO, UNICEF and DPHE (1990) on these iron removal plants showed that iron removal was satisfactory. The iron concentration was reduced to around 1.5 ppm from 15 ppm with average cleaning period of 12 days (with minimum of 5 days). With the same interval of cleaning it has been observed that the higher the concentration in raw water the higher the concentration in treated water but it was not exceeded 2.5 ppm.

For the elimination of iron from hand pump tubewell water, Aowal (1981) proposed to introduce a spray aeration, a settling tank and a plain sand filter, all housed in a single chamber. Although an effective removal was achieved the length of run between cleaning was very short, less than 24 hours. The top layer of fine sand was needed to be removed, washed and dried for the next use, which is not easy.

Kibret (1986) has shown that dry filter is one of the alternatives that can be applied for iron removal and the process uses the self-purification capacities of iron bacteria. Investigation made on the pilot plants showed that iron removal process by dry filtration depends on the hydraulic load, filter depth, size of filter material, the development of the microorganisms and iron concentration in the raw water. Dry filter does not only remove iron but it also removes manganese, ammonia, and carbon dioxide and provides sufficient oxygen supply to the treated water. The results obtained from the test plants were not bellowing the standard limits except from the full-scale production plant. However, complete removal of iron by dry filter is feasible provided the best possible favorable combinations of the factors on which iron removal depends are found.

In 1985-86 over hundred iron removal units, which were originally designed by BUET under a research programme, were built at Sirajgonj and Comilla. These units are reported to fail due to following reasons [Ref 20]:

- Lack of community participation in all activities of the project.
- Lack of continued support and technical advice from DPHE/UNICEF.
- Difficulty in cleaning the filter due to short filter runs.
- Complicated design of the unit.

In 1988, DPHE with the help of UNICEF, Dhaka Bangladesh, designed and constructed iron removal plant for hand pump tubewells in different parts of Bangladesh. Those plants were also failed due to faulty design of sedimentation chamber, where flocs were gradually settled and mixed with treated water.

Wong (1984) has shown that processes in which oxidation is followed by removal of suspended solids can effectively remove soluble iron and manganese from water. He has developed three common processes for removing iron and manganese, e.g. (i) aeration-filtration (ii) chlorination-filtration and (iii) potassium permanganate-manganese greensand filtration.

Other processes such as ion exchange, chlorine dioxide filtration, stabilization with polyphosphates etc. have also been applied but with less frequency, owing to cost and operational considerations. Removal processes are selected on the basis of iron concentration and other conditions.

2.5.2 Arsenic Removal Units:

The following articles are summarized from Ahmed (2003) [Ref 05]

(a) Bucket Treatment Unit:

The Bucket Treatment Unit (BTU), developed by DPHE-Danida Project is based on the principles of coagulation, co-precipitation and adsorption processes. It consists of two buckets, each 20 liter capacity, placed one above the other. Chemicals are mixed manually with arsenic contaminated water in the upper bucket by vigorous stirring with a wooden stick for 30 to 60 seconds and then flocculated by gentle stirring for about 90 seconds. The mixed water is then allowed to settle for 1-2 hours. The water from the top bucket is then allowed to flow into the lower bucket via plastic pipe and a sand filter installed in the lower bucket. The flow is initiated by opening a valve fitted slightly above the bottom of the upper bucket to avoid inflow of settled sludge in the lower bucket. The lower bucket is practically a treated water container.

The DPHE-Danida Project in Bangladesh distributed several thousands BTU units in rural areas. These units are based on chemical dosages of 200 mg/L aluminum sulfate and 2 mg/L of potassium permanganate supplied in crushed powder form. The units were reported to have very good performance in arsenic removal in both field and laboratory conditions (Sarkar et al., 2000). Extensive study of DPHE-Danida BTU under BAMWSP, DFID, and Water Aid (2001) rapid assessment program showed mixed results. In many cases, the units under rural operating conditions fail to remove arsenic to the desired level of 0.05 mg/L in Bangladesh (Ahmed, 2001). Poor mixing and variable water quality particularly pH, phosphate, nitrate, sulfate and chloride of groundwater in different locations of Bangladesh appeared to be the cause of poor performance in rapid assessment.

Bangladesh University of Engineering and Technology (BUET) modified the BTU and obtained better results by using 100 mg/L of ferric chloride and 1.4 mg/L of potassium permanganate in modified BTU units. The arsenic contents of treated water were mostly below 20 ppb and never exceeded 37 ppb while arsenic concentrations of tubewell water varied between 375 to 640 ppb (Ahmed, 2001). The BTU is a promising technology for arsenic removal at household level at low cost. It can be built by locally available materials and is effective in removing arsenic if operated properly.

(b) Stevens Institute Technology:

This technology also uses two buckets, one to mix chemicals (reported to be iron sulfate and calcium hypochloride) supplied in packets and the other to separate floc by the processes of sedimentation and filtration. The second bucket has a second inner bucket with slits on the sides to help sedimentation and keeping the filter sand bed in place. The chemicals form visible large flocs on mixing by stirring with stick. Rapid assessment showed that the technology was effective in reducing arsenic levels to less than 0.05 mg/L in case of 80 to 95% of the samples tested (BAMWSP, DFID, Water Aid, 2001). The sand bed used for filtration is quickly clogged by flocs and requires washing at least twice a week.

(c) BCSIR Filter Unit:

Bangladesh Council of Scientific and Industrial Research (BCSIR) have developed an arsenic removal system, which uses the process of coagulation, co-precipitation with an iron based chemical followed by sand filtration. The unit did not take part in a comprehensive evaluation process (Ahmed, 2001).

(d) Fill and Draw Units:

It is a community type treatment unit designed and installed under DPHE-Danida Arsenic Mitigation Pilot Project. It is 600 L capacity (effective) tank with slightly tapered bottom for collection and withdraws of settled sludge. The tank is fitted with a manually operated mixer with flat-blade impellers. The tank is filled with arsenic contaminated water and required quantity of oxidant and coagulants are added to the water. The water is then mixed for 30 seconds by rotating the mixing device at the rate of 60 rpm and left overnight for sedimentation. The water takes some times to become completely still which helps flocculation. The floc formation is caused by the hydraulic gradient of the rotating water in the tank. The settled water is then drawn through a pipe fitted at a level, few inches above the bottom of the tank and passed through a sand bed and finally collected through a tap for drinking purpose. The mixing and flocculation processes in this unit are better controlled to effectively higher removal of arsenic (Ahmed, 2001). The experimental units installed by DPHE-Danida Project are serving the clusters of families and educational institutions.

(e) Arsenic Removal Unit Attached to Tubewell:

The principles of arsenic removal by alum coagulation, sedimentation and filtration have been employed in a compact unit for water treatment in the village level in West Bengal, India. The arsenic removal plant attached to hand tubewell has been found effective in removing 90% arsenic from tubewell water having initial arsenic concentration of 300 μg/L (Ahmed, 2001). The treatment process involves addition of sodium hypochloride (Cl_2), and aluminum alum in diluted form, mixing, flocculation, sedimentation and up flow filtration in a compact unit. This process was found effective in removing arsenic but associated with high operation costs of chemicals as well as frequent maintenance due to clogging of filter bed.

(f) Chemical Packages:

In Bangladesh different types of chemical packages have been distributed in the forms of tea bags, small packets and powder of tablet form for the removal of arsenic from drinking water. The principals involved in arsenic removal by these chemicals involve oxidation, sorption and co-precipitation. Application methodology and efficiency of any of these chemicals have not been fully optimized by long experimentation. Quality assurance and dosage control in rural condition are extremely difficult. The residuals of added chemicals in water after treatment can do equal harm. The use of unknown chemicals and patented process without adequate information should be totally discouraged (Ahmed, 2001).

(g) Activated Alumina Based Units:

- BUET Activated Alumina
- Alcan Enhanced Activated Alumina
- ARU of Project Earth Industries Inc., USA
- Apyron Arsenic Treatment Unit

The BUET and Alcan activated alumina have been extensively tested in field condition in different areas of Bangladesh under rapid assessment and found very effective in arsenic removal (BAMWSP, DFID, Water Aid, 2001). The arsenic removal units (ARU) of Project Earth Industries Inc., USA used hybrid aluminas and composite metal oxides as adsorption media and were able to treat 200-500 Bed Volume (BV) of water containing 550 μg/L of arsenic and 14 mg/L of iron (Ahmed et al., 2000). The Apyron Technologies Inc. (ATI) also uses inorganic granular metal oxide based media that can selectively remove As(III) and As(V) from water. The Aqua-Bind ™ arsenic media used by ATI consists of non-hazardous aluminium oxide and manganese oxide for cost-effective removal of arsenic. The proponents claimed that the units installed in India and Bangladesh consistently reduced arsenic to less than 10μg/L (Ahmed, 2001).

(h) Iron Coated Sand:

BUET has constructed and tested iron coated sand based small-scale unit for the removal of arsenic from ground water. Iron coated sand has been prepared following a procedure similar to that adopted by Joshi and Choudhury (1996). The iron content of the iron coated sand was found to be 25 mg/g of sand. For raw water having both As(III) and As(V) of concentration 300μg/L when filtered through iron coated sand, it was found that 350 bed volume (BV) could be treated satisfying the Bangladesh drinking water standard of 50 ppb (Ali, 2001). The saturated medium is regenerated by passing 0.2N sodium hydroxide followed by washing with distilled water. No significant change in bed volume (BV) in arsenic removal was found after 5 regeneration cycles. It was interesting to note that iron coated sand is equally effective in removing both As(III) and As(V). Iron coated brick dust has also been developed in Bangladesh for arsenic removal from drinking water.

(i) Indigenous Filters:

There are several filters available in Bangladesh that use indigenous material as arsenic adsorbent. Red soil rich in oxidized iron, clay minerals, iron ore, iron scrap or fillings and processed cellulose materials are known to have capacity for arsenic adsorption. Some of the filters manufactured using these materials include:

- Sono 3-Kolshi Filter
- Garnet Home-made Filter
- Chari Filter
- Adarsha Filter
- Shafi Filter
- Bijoypur Clay/Processed Cellulose Filter

The Sono 3-Kolshi Filter uses zero valent iron fillings and coarse sand in the top Kolshi, wood coke and fine sand in the middle Kolshi while the bottom Kolshi is the collector of the filtered water (Khan et al., 2000). This unit has been found to be very effective in removing arsenic but the media was found contaminated with the growth of microorganism (BAMWSP, DFID and Water Aid, 2000). The one-time use unit becomes quickly clogged, if groundwater contains excessive iron.

The Garnet homemade filter contains relatively inert materials like brick chips and sand as filtering media. No chemical is added to the system. Air oxidation and adsorption on iron-rich brick chips and flocs of naturally present iron in groundwater could be the reason for arsenic removal from groundwater. The unit produced inadequate quantity of water and did not show reliable results in different areas of Bangladesh and under different operating conditions. The Chari filter also uses brick chips and inert aggregates in different Charis as filter media. The effectiveness of this media in arsenic removal is not known (Ahmed, 2001).

The Shafi and Adarsha filters use clay material as filter media in the form of candle. The Shafi filter was reported to have good arsenic removal capacity but suffered from clogging of filter media (Ahmed, 2001). The Adarsha filter participated in the rapid assessment program but failed to meet the technical criterion of reducing arsenic to acceptable level (BAMWSP, DFID and Water Aid, 2000). Bijoypur clay and treated cellulose were found to absorb arsenic from water (Khair, 2000).

2.6 Requisite of Different Filter

2.6.1 Slow Sand Filter

It consists of a layer of ungraded fine sand through which water is filtered at a low rate. In general, slow sand filters have filtration rates of up to 0.4 m/hour. The low filtration rate causes long detention times of the water above the sand and within the sand bed. This allows substantial biological activity. Slow sand filtration removes particles mainly at the surface of the sand bed. Because of the low hydraulic loading and smaller sand size found in slow sand filters, most of the solid particles are removed within the top 0.5 - 2 cm of sand [Ref 12]. Filter sand should have an effective size between 0.15 and 0.35mm and uniformity co-efficient between 1.5 and 3.0 [Ref 07].

To ensure removal of cysts, bacteria and other particles slow sand are preferred from the very beginning of water treatment. Slow sand filters are more practical in the treatment of water with turbidity below 50 NTU, although higher turbidities can be tolerated for a few days. The best purification occurs when the turbidity is below 10 NTU [Ref 18].

Slow sand filters work through the formation of a gelatinous layer (or biofilm) called the hypogeal layer or *Schmutzdecke* in the top few millimetres of the fine sand layer. This layer consists of bacteria, fungi, protozoa, rotifera and a range of aquatic insect larvae. The

Schmutzdecke is the layer that provides the effective purification in potable water treatment, the underlying sand providing the support medium for this biological treatment layer. As water passes through the *Schmutzdecke*, particles of foreign matter are trapped in the mucilaginous matrix and dissolved organic material is absorbed and metabolised by the bacteria, fungi and protozoa. The water produced from a well-managed slow sand filter can be of exceptionally good quality with no detectable bacterial content. Slow sand filters can remove up to 99.99 percent of turbidity, bacteria, viruses, and Giardia lamblia cysts without the need for chemical flocculants or the use of electrical power.

Slow sand filters slowly lose their performance as the *Schmutzdecke* grows and thereby reduces the rate of flow through the filter. Eventually it is necessary to refurbish the filter. Two methods are commonly used to do this. In the first, the top few millimetres of fine sand is very carefully scraped off using mechanical plant and this exposes a new layer of clean sand. Water is then decanted back into the filter and re-circulated for a few hours to allow a new *Schmutzedecke* to develop. The filter is then filled to full depth and brought back into service. The second method, sometimes called wet harrowing, involves lowering the water level to just above the *Schmutzdecke*, stirring the sand and thereby suspending any solids held in that layer and then running the water to waste. The filter is then filled to full depth and brought back into service. Wet harrowing can allow the filter to be brought back into service more quickly.

In order to be effective, most literature insists that a constant flow of water passing through a slow sand filter is essential. This flow provides oxygen and food to the organisms that make up the '*schmutzdecke*' and biological zone living within the top part of the sand, which are responsible for much of the removal of disease-causing organisms [Ref 12].

From the above discussion it could be summarized that the people who rely on private surface water sources for household use, slow sand filtration - or more accurately biologically active filtration - may be an effective choice for water treatment.

Finally, slow sand filtration is a preferred technology for the people who:

- forced to use surface water (ponds, streams, rivers) in absence of other suitable sources;

- have no access to electrical power;

- cannot or do not wish to use chemical treatment.

2.6.2 Rapid Sand Filter

It consists of a layer of graded sand or in some instances a layer of coarser filter media (e.g., anthracite) placed on top of a layer of sand, through which water is filtered. Rapid sand filtration is the flow of water through a bed of granular media, normally following settling basins in conventional water treatment trains. As its name suggests water in rapid sand filters passes quickly through the filter beds. The purpose of this filtration is to remove any particulate matter left over after flocculation and settling. The filter process operates based on two principles, mechanical straining and physical adsorption.

Sand filtration is a "physical-chemical process for separating suspended and colloidal impurities from water by passage through a bed of granular material. Water fills the pores of the filter medium, and the impurities are adsorbed on the surface of the grains or trapped in the openings." (Culp, page 91). The key to this process is the relative grain size of the filter medium. Effective size of filter sand is 0.55 mm and higher and uniformity coefficient 1.5 and lower.

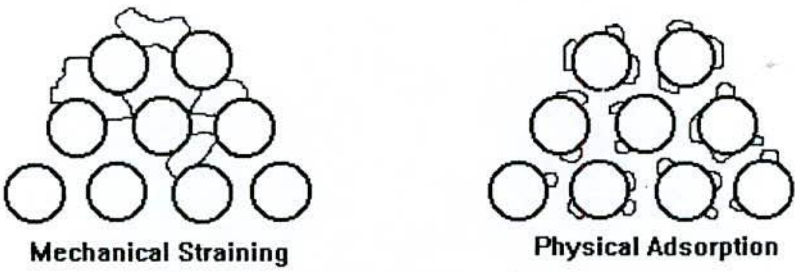

Figure – 2.6: Schematic of basic filtration principles by D. Schmitt

The main distinction from slow sand filtration is the fact that biological filtration is not part of the purification process in rapid filtration. Rapid filtration is used widely to remove impurities and remnants of flocculants in most water treatment plants. As a single process, it is not as effective as slow sand filtration in production of drinking water. Rapid sand filtration is contrasted to slow sand filtration by increased flow rate. In general, rapid sand filters have filtration rates of up to 21 m/hour. Physical straining is the most important mechanism present in rapid filters. Particles that are larger than the pore spaces between the sand grains are trapped - smaller solids however can pass through the filter. Rapid sand filtration removes particles over a substantial depth within the sand bed.

Methodology

A brief description of the methodology that was followed in conducting the laboratory study is given below:

3.1 Selected processes for the treatment Unit

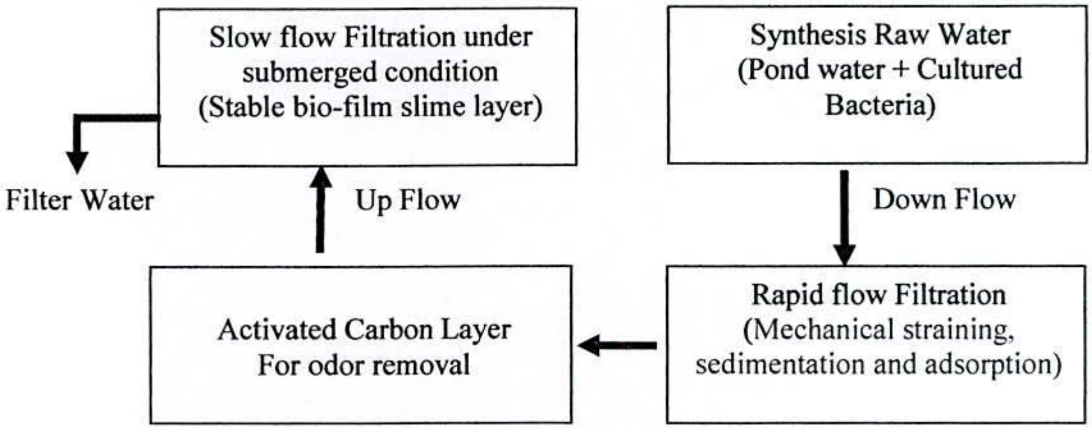

Figure-3.1: Flow diagram of the developed Surface water treatment Unit

The Treatment Unit has two columns with down flow –up flow process. The first column acts as rapid flow filtration while synthesis raw water passing through it. Comparatively larger suspended particles precipitate and settle at the top of the sand column with a small detention time. It reduces various impurities through mechanical straining, sedimentation and adsorption. Other fine and coarse particles precipitates at the beginning of the activated carbon layer through lateral movement. The final removal of bacteria and other fine particles are done in slow flow portion of the second column. This column was constructed on the basis of simple methodological technique of slow sand filtration under submerged condition i.e. stable bio-film slime layer. Partial treated water up-flowed at very slow rates through fine sands to retain suspended solids in the interstices between the sand grains. The pores in the sand grains bring the fine particles and bacteria in contact with sand surfaces, where they adhere because of physical attraction and presence of gelatinous coating. During the filtration process, the coating of micro-organisms formed around the sand grains was responsible for the removal of organic matters and bacteria [Ref 01].

3.2 Design Criteria of the Treatment Unit

The design of the filter unit is important before its manufacturing. For designing the amount of water that can be filtered by the filter unit is to be mentioned. For family size filter unit should have the maximum capacity of filtration.

Beside that the following criteria were considered in the design of the Unit:

- Filter material should be locally available.
- The size of filters bed selected with due regard to the character of the raw water and rate of filtration.
- Lower rate and fine sand being used when bacterial pollution is serious.
- Filter materials should so graded that can prevented penetration and provide the flow of water towards the under drain.
- Regeneration or changing of the filter media should be limited.
- The life period of the treatment unit should so designed that the users could get maximum service from the unit with low or no maintenance.
- The construction cost of the filter unit should with in the affordable limits of the users.

3.3 Materials used for developing the Treatment Unit

The materials and equipments required for the development of the household surface water treatment unit were-

1. Special type of Vertical Column (Gazi Sliver Can)
2. PVC pipe
3. GI / Plastic tape
4. Wooden filter lid
5. PVC elbow
6. Plastic net
7. Local sand
8. Sylhet sand
9. Activated carbon
10. Wooden diffuser plate
11. Synthesis raw water

3.4 Functions of the Materials

The function of the above materials and equipments are given below-

- Synthetic Raw Water (Pond water + Cultured bacteria):

Cultured bacteria were mix with pond water to prepare synthesis raw water for the laboratory study. Fresh rectangular shape coconut husk of size-25 ~38 mm (about 500 gm) was submerged by pond water in a bucket (35 liters capacity) about two to four weeks to produce bacteria. In that period the husk was washed thoroughly after every three to four days to reduce its color and odor [Ref 11].

- Wooden diffuser plate:

A wooden diffuser plate was used over the rapid flow sand layer to protect the biological layer from damage when raw water is poured into the first column.

- Sylhet Sand:

Sylhet sands were used for making rapid sand filter bed with required depth to remove large and suspended particles present in the raw water in the first column.

- Local Sand:

Local sands acted as a filter bed while water passed through it, used for making slow sand bed with required depth and final removal of bacteria and other small colloidal particles present in the raw water in the second column.

- Plastic Net:

Plastic net of small opening (100 nos. per square inch) were used at the beginning of activated carbon layer to protect unwanted entering of sand from the first column.

- Activated Carbon:

Used for the removal of color, odor and taste from the raw water.

- GI / Plastic Tape:

Suitable GI or plastic tap was used for collecting the filter water from the sliver can.

- Filter Lid:

Used for prevention of unusual contaminants from entering the filter water.

- First Column:

It is long vertical PVC pipe having diameter of 4.0" containing rapid sand where the raw water flows in down ward direction through the filter media.

- Second Column :

It is a special type of vertical Column. It contains the slow sand filter media and the activated carbon layer where water flows in upward direction through the filter media. It also acts as water tub for filtered water.

- Standing Water Level:

Keeps the biological layer alive during pause periods.

3.5 Dimension of the Filter Unit for Laboratory Study

The following dimensions were maintained in the developed unit for laboratory study and are shown in Figure-3.5

- Capacity of the total Second Column = 42 liters.
- Capacity of the total Second Column after installing the filter media = 25 liters.
- Height of the Second Column = 103 cm.
- Diameter of the Second Column =30.5 cm.
- First Column length (Vertical column) = 100 cm.
- First Column length (Horizontal part) = 15 cm.
- First Column diameter =10 cm.
- Rapid sand column height inside First Column = 62.5 cm
  (Sand size -#08 passing & #50 retain)
- Slow sand column height inside Second Column = 42.5 cm.
  (Sand size -#50 passing & #200 retain)
- Height of the activated carbon layer inside Second Column =17.5 cm
  (Size - #08 passing & #30 retain)
- Height of standing water layer = 5 cm
- Thickness of diffuser plate = 1.5 cm
- Total length of water flow inside the Unit = 143 cm.

Filter Description

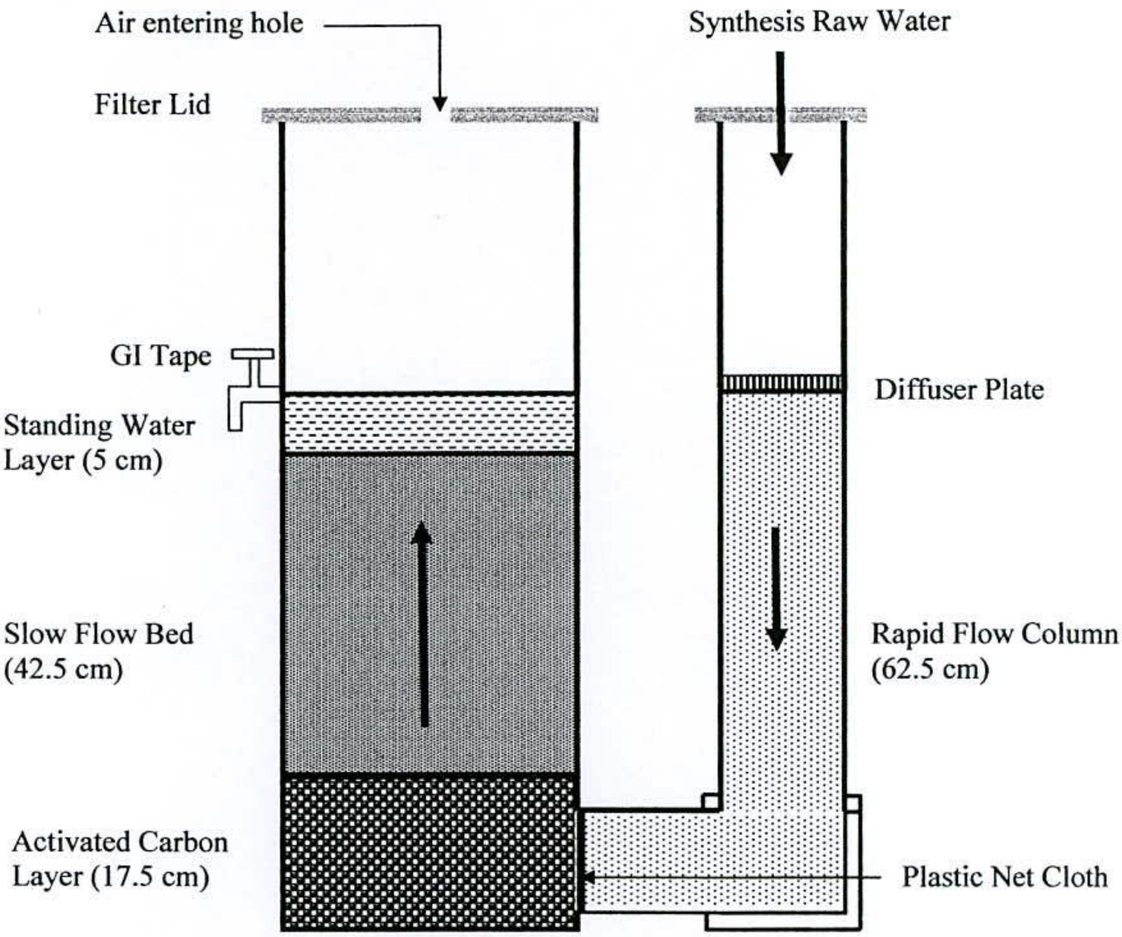

Figure-3.5: Schematic diagram of the developed surface water treatment unit

3.6 Specifications for the treatment unit

The developed surface water treatment filter is a 'fixed point use' device because of its heavy weight. The water to be filtered can be obtained from the closest water supply point, whether pond, river or stream, carried physically to the filter and used immediately thereafter. The water intake, water treatment and water use are therefore all within the control of the individual householder.

Design Parameters

- Household (6-10 users)
  - All plastic filter body
  - Raw Water loading capacity-2.5 liters at a time
  - Filtration Rate 15 liters/hour (average)
  - Specific Loading Rate- 30 liters/min/m2
  - Adaptation of slow sand filter technology
  - Biological layer forms on surface of sand media
  - Pathogens consumed, absorbed and strained out of the water

Figure-3.6 (a): Developed household surface water treatment filter

- Intermittent Operation
  - Shallow and constant water layer
  - Run and pause periods (water level maintained during pause periods)
- Flow rate controlled by sand size (Sieving and washing)

- Pause period (Micro-organisms consume pathogens)
- Water – Sand levels
  - Too shallow – bio-film slim layer dries out
  - Too deep – insufficient oxygen for bio-film slim layer
- Start up time required to establish bio-film slim layer [Ref 12].

Sand Specifications

Sand is characterized by the diameter of the individual sand grains and the effective size of the composite sand, the ES or d10. Sand needs to be of a fine grade, uniform and be washed free of loam, clay and organic matter. Fine particles will quickly clog the filters and frequent cleaning will be required. Sand that is not uniform will also settle in volume, reducing the porosity and slowing the passage of water. The filter has been designed for developing rapid sand filter layer of sand size passing from # 08 sieve and retained on sieve # 50 (F.M -2.9 ~ 3.0). For slow sand filter layer, sand size passing from #50 sieve and retained on sieve # 200 has used (F.M -1.1 ~1.2).

Sand Filter Media

- Should obtained from clean, crushed rock
- Screened through metal mosquito mesh screen
- Washed to ensure an effective size ES of 0.075 to 0.15 mm for slow sand bed and 0.30 to 1.20 mm for rapid sand bed
- Non uniform sizing
- Used uncontaminated sand (usually means limited use of some beach and river sand; cleaning and disinfection would be recommended)
- No substrate should present (clay, loam, organic material free)

Grain Size Distribution

Sand was washed thoroughly and sieved to obtain specified size for rapid and slow sand filtering bed preparation. The grain size distributions of rapid and slow sand are shown in Figure 3.6 (b) and Figure 3.6 (c) respectively.

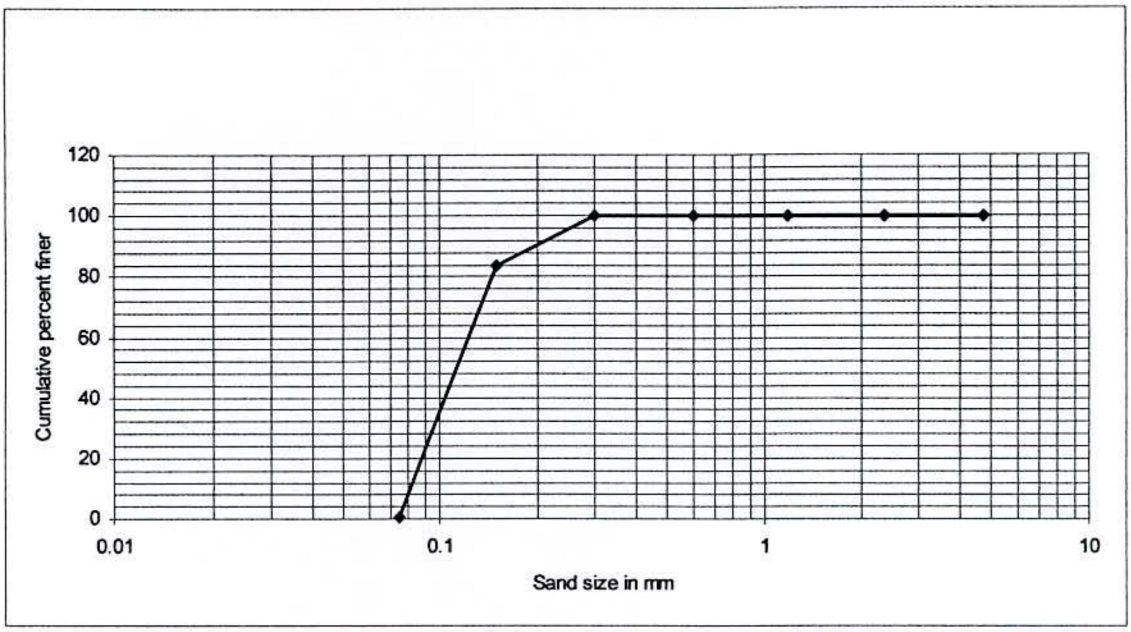

Figure – 3.6 (b): Grain size distribution curve for Fine sand.

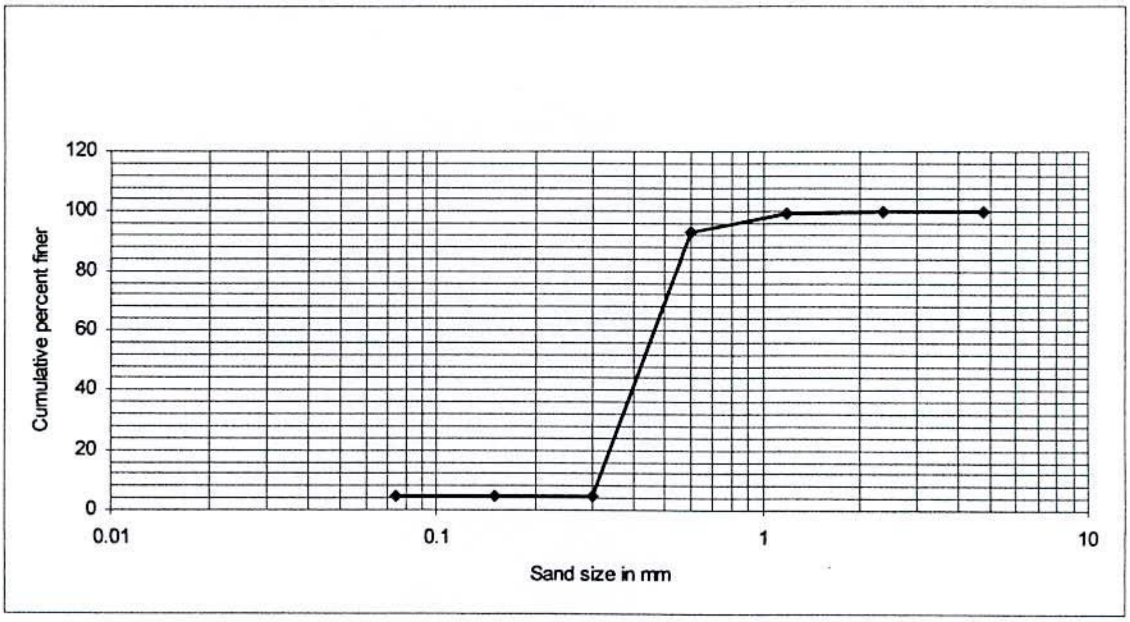

Figure – 3.6 (c): Grain size distribution curve for coarse sand.

Removal Mechanisms

- Combination of biological action and mechanical straining
- Fine sand traps organic material at surface of sand and forms a layer where micro organisms grow
- Four main mechanisms for microbial removal
    - Mechanical trapping between sand pores
    - Adsorption – onto each other and on to sand grains
    - Predation- Micro-organisms consume pathogens
    - Natural death of pathogens [Ref 12].

Start-up Time

It normally takes a period of one to three weeks for the biological layer to develop to maturity in a new filter. During that time, the removal efficiency of the filter increase as the biological layer grows [Ref 15].

Water Source

The developed household filter can be used for water from ponds or rivers. It should be consistently taken from the same source.

The turbidity or amount of suspended particles in the water is also a key factor in the operation of the filter. It should be relatively free of suspended particles to prevent premature fouling of the filter. If the turbidity is greater than 50-100 NTU, the water should be pre filtered by roughing filter before it goes though the filter.

Flow Rate

The second column of the filter has been designed to allow for a filtering rate of 0.25 liter/minute which has proven to be effective in laboratory tests. The amount of water that flows through the filter is controlled by the size of sand media contained within the filter. If the rate is too fast, the efficiency of bacterial removal may be reduced. If the flow rate is too slow, there will be an insufficient amount of treated water available from the filter to meet the needs of the users.

Standing Water Depths

Proper construction and correct operation of the filter will result in a constant water level over the pause periods. Changes in the water depth above the sand surface will cause a change in the biological zone disrupting the efficiency of the filter. A water depth of greater than 5-8 cm results in lower oxygen diffusion and consequently a thinner biological zone. A high water level can be caused by a blocked outlet spout or by an insufficient amount of sand media. As the water depth increases, the oxidation and metabolism of the micro organisms within the biological zone decrease. Eventually the layer dies off and the filter becomes ineffective. Correct operation of the filter requires a constant water level of approximately 5 cm (2") above the slow sand level during the pause periods.

Pause Periods

If the pause period is extended for too long, the micro-organisms will eventually consume all the substrate and then die. This results in a marked reduction in micro-organism removal efficiency of the filter. The pause periods are also very important because they allow time for the micro-organisms in the biologic layer to consume the pathogens contained in the water, thereby increasing the hydraulic conductivity of the filter. Consequently, the developed filter is most effective and efficient when operated intermittently [Ref 07].

Diffuser Plate

- Required to prevent the disturbance of the sand surface when raw water is poured into the filter.
- Can be made of various materials that are suitable to be submerged in water such as porous mortar, wood, heavy plastic or galvanized metal.
- 50~100 holes, no larger than 1/8" diameter, are drilled or punched in case of wooden or heavy plastic plate.

Tightly fitting lid

- Prevents contamination of source water and treated water.
- Inside or outside lip.
- Can be made from various material usually wood or galvanized metals.

3.7 Operation and Maintenance

The maintenance of the unit is vital for its smooth running. The operation and maintenance of the filter are simple. There are no moving parts that require skill to operate. However, the whole maintenance system was divided into the following parts:

- **Placement of diffuser plate:**

  Wooden diffuser plate was used in the First column to protect scouring of the sand surface. Wood has floating tendency over water. To protect this floating tendency the diffuser should be placed tightly through the First column over the sand surface.

- **Ensuring air entering system:**

  For proper oxidation one or more small hole was kept in the filter lid.

- **Placement of different filter media:**
  - Height of different filter beds was maintained as per specification.
  - The First column of the unit should be kept moistened.
  - Plastic net with small opening was provided at the end of the horizontal portion of the unit to protect the unusual entering of sand to the activated carbon layer in the Second column

- **Ensuring standing water depth:**

  Standing water level over slow sand filter bed in the Second column should be maintained as per design.

- **Observing the clogging:**

  Over time, continuous use of the filter causes the pore opening between the sand grains to become clogged with debris. As a result, the flow rate of water through the filter decreases. In case of filter bed clogging it was essential to refurbish the filter bed. The top few millimetres of sand was very carefully scraped off and this exposed a new layer of clean sand. Water was then decanted back into the filter and re-circulated for a few hours to allow a new *Schmutzedecke* to develop. The filter was then filled to full depth and brought back into service. The process can be repeated as many times as necessary to regain the desired flow rate.

Chapter Four

Laboratory Tests and Analysis

4.1 Laboratory Tests and Analysis using Pond Water

4.1.1 General

Detail laboratory tests and analysis were carried out through the treatment unit-model to determine important parameters for synthesis raw water. The raw and treated water were then tested for various selected water quality parameters according to the standard methods. The selected parameters were Color, Turbidity, TDS, TS, pH, TC and FC. The flow rate was kept almost constant through the treatment unit to understand the removal efficiency. The treatment unit was based on bacteria removal by mechanical straining, adsorption, predation and natural death of pathogens (Ch-3, Art-3.6).

The bacteria in the raw water were produced biologically from coconut husk and mixed with pond water to prepare synthesis raw water. These were completely eliminated in Second column by the slow sand filtering system under submerged condition.

Pond water naturally contains greenish color, high turbidity, dissolved and suspended particles and also bacteria. The organic or inorganic particles in pond water settle at the bottom of the pond due to the stagnant tendency. These reduce the color, turbidity and dissolved solids from the top surface water. Again the top surface of pond water always stays under direct sunlight. Due to high temperature the natural microbial growth of pond water is too low. Raw water was collected from the nearest pond for laboratory study. Considering the presence of bacteria in pond water, cultured bacteria (Ch-3, Art-3.4) were mixed into the pond water to bring high concentration of coliform for preparation of synthesis raw water to understand the highest removal efficiency of the developed treatment unit.

4.1.2 Micro-organism (TC & FC) Removal Efficiency

Figure 4.1 (a) and 4.1 (b) illustrates the total coliform (TC) and faecal coliform (FC) removal efficiency of the developed treatment unit. As stated in the previous article (art-4.1.1) that the bacteria in the raw water were produced biologically from coconut husk and mixed with pond water to prepare synthesis raw water. That's why the synthesis raw water exhibited high total coliform of about 75 nos. per 100 ml of raw water. These were completely eliminated in the Second column. This column acted as simple methodological technique of slow sand filtration system under submerged condition. During the bacteriological test a small number of faecal coliform was noticed in the synthesis raw water of about 5 nos. per 100 ml of raw water. These were also completely removed. So, the micro-organism removal efficiency of the laboratory unit was 100 percent.

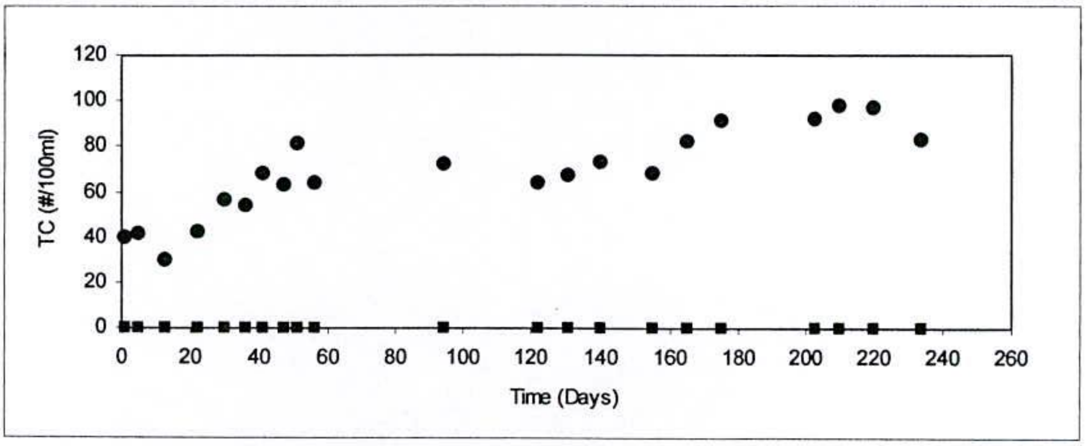

Figure-4.1 (a): Removal efficiency of Total Coliform

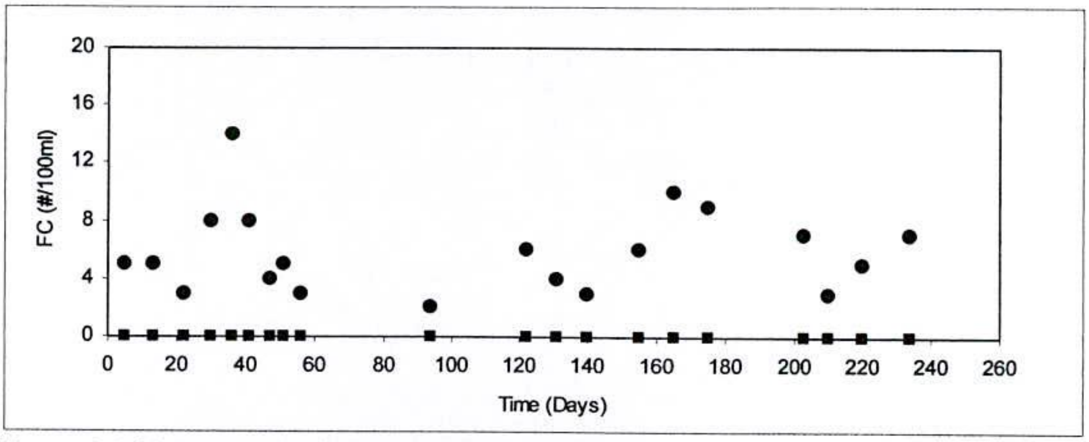

Figure-4.1 (b): Removal efficiency of Faecal Coliform

** **Note:** —●— = Synthesis raw water, —■— = Filtered water for all graph presented in this paper.

4.1.3 Variation of pH of the Treatment Unit

The pH value of synthesis raw water was gradually increasing in nature after passing through the filtering media of the treatment unit. This may due to the presence of some calcium substances in the sand grain of the rapid and slow sand filter bed inside the First and Second column respectively. Also the activated carbon in the unit was responsible for exhibiting high pH value. The minor variation of pH of synthesis raw and treated water of the laboratory unit in Figure 4.1 (c) states about 3 % increase of pH value after filtration.

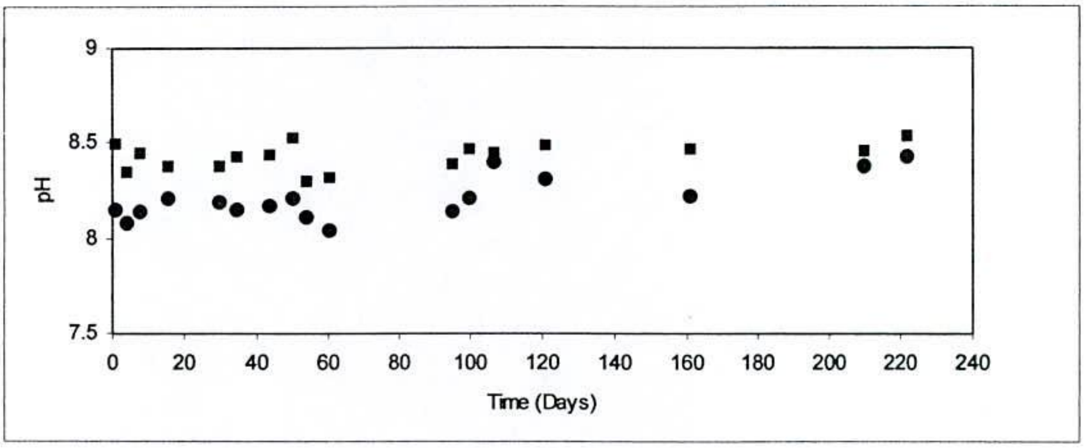

Figure-4.1 (c): Variation of pH for raw and filtered water

4.1.4 Removal Efficiency of Turbidity and Color

Translucent and sparkling treated water was found in the developed treatment unit although the synthesis raw water exhibited high color and turbidity value. After treating the results showed that the average color and turbidity value of the treated water was within 7 pt-co units and 1.5 NTU respectively. So, the color and turbidity removal efficiency of the laboratory unit was found sufficient and that was over 90 %. The color and turbidity removal efficiency of the treatment unit is shown in Figure 4.1 (d) and Figure 4.1 (e) respectively.

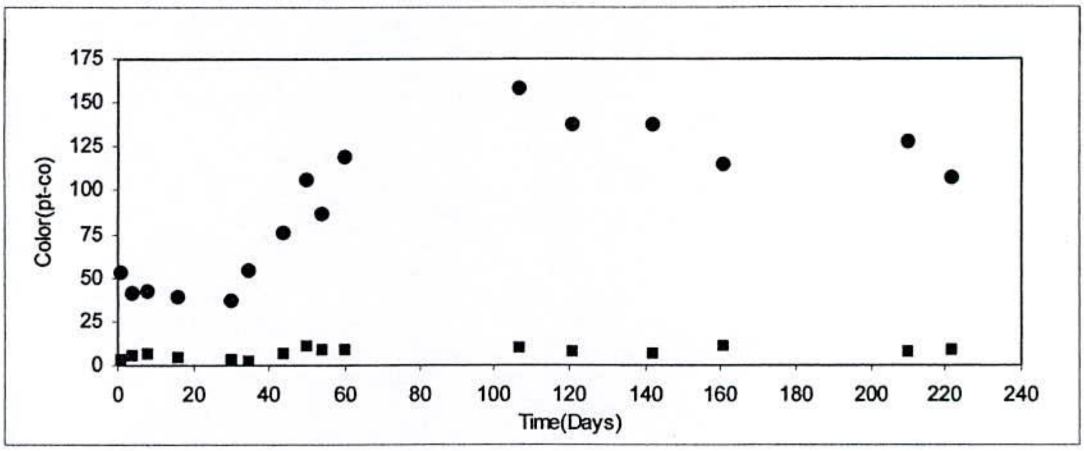

Figure-4.1 (d): Color removal efficiency

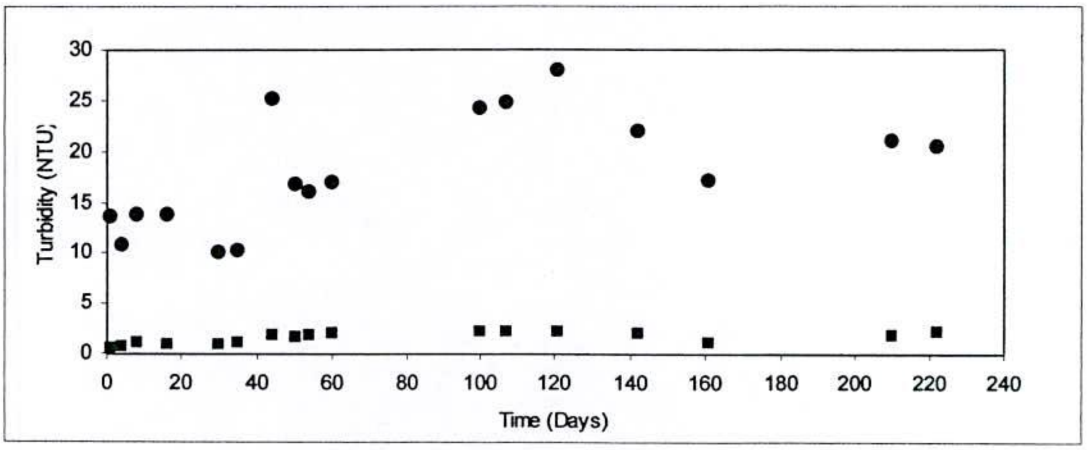

Figure-4.1 (e): Turbidity removal efficiency

4.1.5 Total Dissolved Solids and Total Solids Removal Efficiency

The amount of dissolved solids present in water is an important consideration in its suitability for domestic use. In general, waters with a total solids content of less than 500 mg/l are most desirable for such purposes. It can be seen from Figure 4.1 (f) and Figure 4.1 (g) below that the amount of total dissolved solids and total solids in the synthesis raw water was within the acceptable limit. After filtering that reduces about 40% which indicates the suitability for drinking purposes.

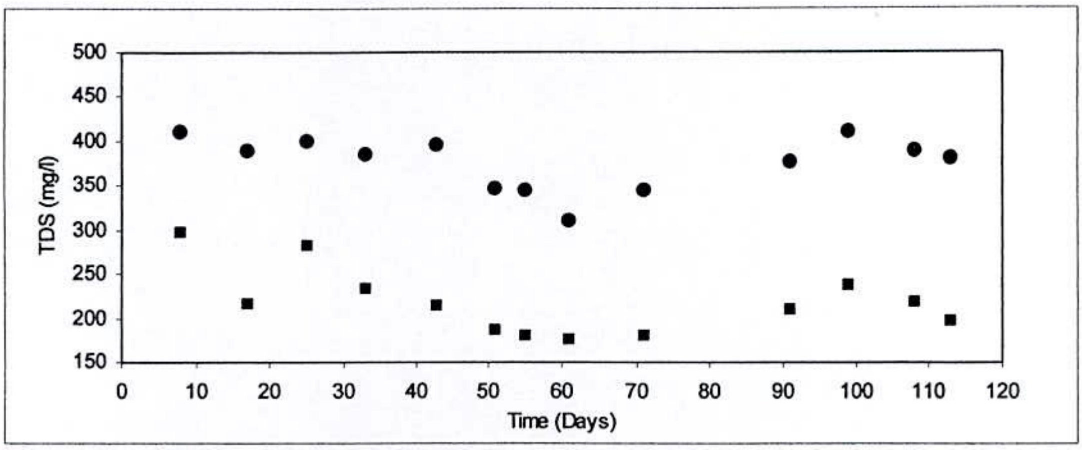

Figure-4.1 (f): TDS removal efficiency

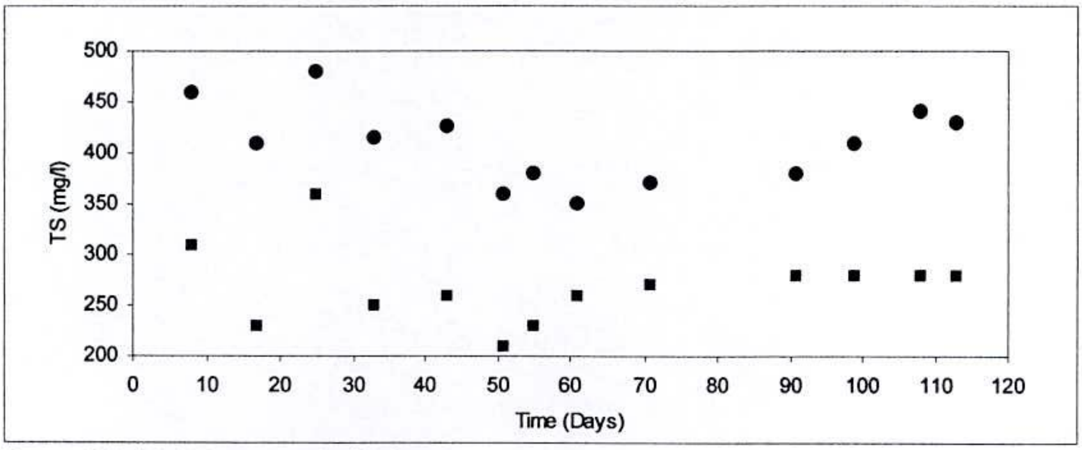

Figure-4.1 (g): TS removal efficiency

4.1.6 Performance Study of the Developed Treatment Unit

The developed surface water treatment unit was studied intensively for synthesis raw water. The performance study results of the laboratory model unit are represented in the following Table- 4.1 (a):

Table – 4.1 (a): Performance Study of the Developed Treatment Unit

Parameter		TC	FC	pH	Turbidity	Color	TDS	TS
Unit		# / 100ml	# / 100ml	-	NTU	pt-co	mg/l	mg/l
BD. Standards		0	0	6.5~8.5	10	15	1000	-
22.7.07	Synthesis Raw Water	-	-	8.15	13.57	53	-	-
	Filtered Water	-	-	8.49	0.59	3	-	-
25.7.07	Synthesis Raw Water	40	-	8.08	10.84	41	-	-
	Filtered Water	0	-	8.34	0.72	5	-	-
29.7.07	Synthesis Raw Water	41	5	8.14	13.78	42	411	460
	Filtered Water	0	0	8.44	1.13	6	298	310
06.8.07	Synthesis Raw Water	30	5	8.21	13.76	39	390	410
	Filtered Water	0	0	8.37	0.86	4	216	230
15.8.07	Synthesis Raw Water	42	3	-	-	-	399	480
	Filtered Water	0	0	-	-	-	282	360
20.8.07	Synthesis Raw Water	-	-	8.19	10.06	37	-	-
	Filtered Water	-	-	8.37	0.91	3	-	-
23.8.07	Synthesis Raw Water	56	8	-	-	-	385	415
	Filtered Water	0	0	-	-	-	233	250
25.08.07	Synthesis Raw Water	-	-	8.15	10.21	54	-	-
	Filtered Water	-	-	8.42	1.04	2	-	-
29.08.07	Synthesis Raw Water	54	14	-	-	-	-	-
	Filtered Water	0	0	-	-	-	-	-
03.09.07	Synthesis Raw Water	68	8	8.17	25.08	76	395	425
	Filtered Water	0	0	8.43	1.88	7	215	260
09.09.07	Synthesis Raw Water	63	4	8.21	16.68	106	346	360
	Filtered Water	0	0	8.52	1.70	11	186	210
13.09.07	Synthesis Raw Water	81	5	8.11	16.10	86	344	380
	Filtered Water	0	0	8.29	1.93	9	179	230

Parameter		TC	FC	pH	Turbidity	Color	TDS	TS
Unit		# / 100ml	# / 100ml	-	NTU	pt-co	mg/l	mg/l
BD. Standards		0	0	6.5~8.5	10	15	1000	-
18.09.07	Synthesis Raw Water	64	3	8.04	17.00	119	310	350
	Filtered Water	0	0	8.31	1.99	9	176	260
23.10.07	Synthesis Raw Water	-	-	8.14	-	-	-	-
	Filtered Water	-	-	8.38	-	-	-	-
28.10.07	Synthesis Raw Water	72	2	8.21	24.30	-	345	370
	Filtered Water	0	0	8.46	2.25	-	180	270
05.11.07	Synthesis Raw Water	-	-	8.39	24.70	158	-	-
	Filtered Water	-	-	8.44	2.23	10	-	-
19.11.07	Synthesis Raw Water	-	-	8.30	27.90	137	377	380
	Filtered Water	-	-	8.48	2.16	8	210	280
26.11.07	Synthesis Raw Water	64	6	-	-	-	410	410
	Filtered Water	0	0	-	-	-	237	280
04.12.07	Synthesis Raw Water	67	4	-	-	-	390	440
	Filtered Water	0	0	-	-	-	219	280
09.12.07	Synthesis Raw Water	-	-	-	21.93	137	380	430
	Filtered Water	-	-	-	2.10	6	198	280
13.12.07	Synthesis Raw Water	73	3	-	-	-	-	-
	Filtered Water	0	0	-	-	-	-	-
28.12.07	Synthesis Raw Water	68	6	8.22	17.20	115	-	-
	Filtered Water	0	0	8.46	1.08	11	-	-
07.01.08	Synthesis Raw Water	82	10	-	-	-	-	-
	Filtered Water	0	0	-	-	-	-	-

Parameter		TC	FC	pH	Turbidity	Color	TDS	TS
Unit		# / 100ml	# / 100ml	-	NTU	pt-co	mg/l	mg/l
BD. Standards		0	0	6.5~8.5	10	15	1000	-
17.01.08	Synthesis Raw Water	91	9	-	-	-	-	-
	Filtered Water	0	0	-	-	-	-	-
14.02.08	Synthesis Raw Water	92	7	8.37	21.11	128	-	-
	Filtered Water	0	0	8.45	1.94	8	-	-
21.02.08	Synthesis Raw Water	98	3	-	-	-	-	-
	Filtered Water	0	0	-	-	-	-	-
26.02.08	Synthesis Raw Water	-	-	8.42	20.59	107	-	-
	Filtered Water	-	-	8.53	2.27	9	-	-
02.03.08	Synthesis Raw Water	97	5	-	-	-	-	-
	Filtered Water	0	0	-	-	-	-	-
16.03.08	Synthesis Raw Water	83	7	-	-	-	-	-
	Filtered Water	0	0	-	-	-	-	-

4.1.7 Reserve Filtered Water Quality Test

As stated in the previous chapter (Ch-4, art-3.6) that the developed surface water treatment filter is most effective and efficient for intermittent operation. The pause periods are very important to ensure better filter water quality. These allow time for the micro-organisms in the biological layer to consume the pathogens contained in the water, thereby increasing the hydraulic conductivity of the filter. If the pause period is extended for too long this results in a marked reduction in removal efficiency of the filter. Again it is very important to find out how long the filtered water is bacteriologically saved. Because the major issues relating to the prospects for the technologies and for sustainable use are the risk of bacteriological contamination and the acceptability of the technologies to prospective users [Ref 19]. In this regard, the filtered water was reserved for three weeks inside the filter. After first and second week the filter water was diluted in different ratios and tested for bacteriological growth. The following table 4.1 (b) illustrates that reserve filtered water after one week has not changed significantly. Only three samples out of ten have noticed the presence of total coliform (max. # 2 per 100ml). The reserve filtered water after two weeks has changed significantly and noticed the presence of bacteriological contamination. So, it could be concluded that the filtered water should not be stored after one week for better operation of the unit and also for ensuring safe potable water quality.

Table-4.1 (b): Performance study of Reserve Filtered Water of the Treatment Unit

Sample No.	Water Type	Dilution	TC (#/100ml)
1	Reserve Filter Water after one week	20 %	0
2			0
3			1
4			0
5			2
6		10 %	1
7			0
8			0
9			0
10			0
11	Reserve Filter Water after two weeks	20%	2
12			5
13			4
14			4
15			3
16		10 %	3
17			4
18			2
19			7
20			4
21	Raw Water	100 %	9
22			17
23		10 %	17
24			27
25		2 %	23
26			31
27	Clear Filter Water	20 %	0
28			0
29		10 %	0
30			0
31		2 %	0
32			0

4.2 Filtration Rate Analysis

The amount of water that flows through the filter within unit time is the most important part of designing a filter unit. If the rate is too fast, the efficiency of bacterial removal may be reduced. If the flow rate is too slow, there will be an insufficient amount of treated water available from the filter to meet the needs of the users. The treatment unit was designed to treat raw waters filtering rate of about 15 L/hr. Considering these point, the developed surface water treatment filter was designed for combined rapid and slow sand filtration technique. The filtration rate of such a unit should be high because the rapid sand unit contains larger sand particles as filtering media. Actually the rapid sand filtering bed acts as pre-filter before load the waters to slow sand filtering bed. That does reduce the clogging of the treatment unit. It can be seen from the following Figure 4.2 that due to high turbid raw waters the filtration rate of the unit was gradually decreased. It was observed that the rate of filtration was slowed down from 19 L/hr to 8 L/hr after 175 days of its operation and treating about 2500 liters of raw waters. Actually Clogging was not noticed in that period of running. Considering the rate of filtration, the top one centimeter sand from the First column was scrapped off and did not replaced. The unit was restart for treating raw water after a pause period of two days. Till then the unit was operated successfully for a period of 242 days with the average filtration rate as shown in the filtration rate variation graph.

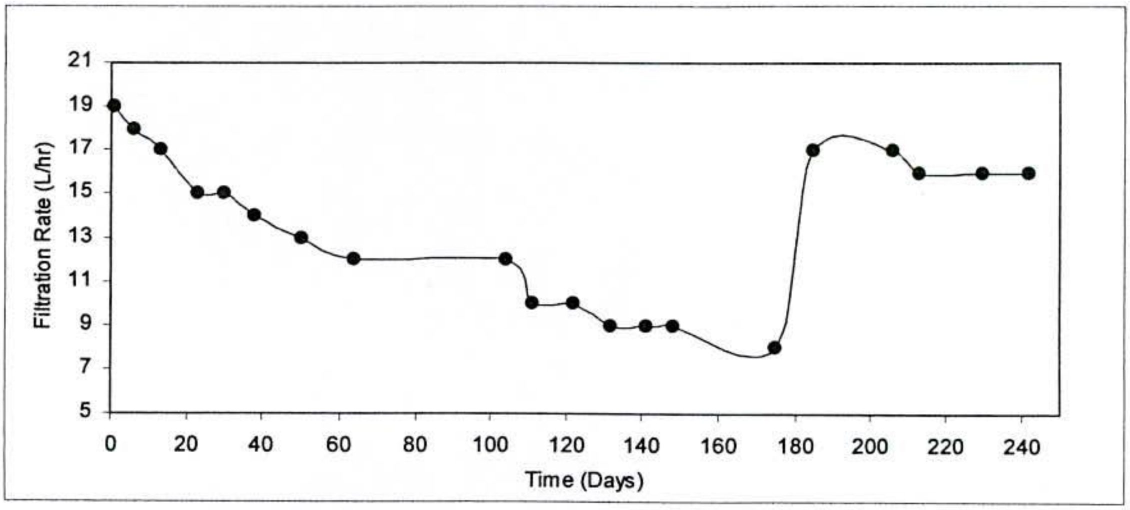

Figure-4.2: Variation of filtration rate

After observing the successful treating capacity with the designed filtration rate the pond waters were changed to river waters to study the performance of the unit considering the worst condition. The study of the treatment unit using river waters is under proceedings to find out the total life period of the unit before clogging.

The filtration rate observation results of the unit are shown in the following Table-4.2:

Table-4.2: Filtration Rate observation results

Date	Filtration rate		
	(mm/min)	(cm^3/min)	(L/hour)
17.07.07	38.1	309	19
22.07.07	36.45	295	18
29.07.07	34.63	281	17
08.08.07	31.75	257	15
15.08.07	30.23	245	15
23.08. 07	28.01	227	14
04.09. 07	26.28	212	13
18.09. 07	24.8	201	12
28.10.07	22.61	193	12
04.11.07	20.54	166	10
15.11.07	19.58	159	10
25.11.07	19.20	156	9
04.12.07	18.20	148	9
11.12.07	17.60	143	9
07.01.08	16.2	138	8
Filtration rate slowed need scraping			
27.01.08	35.90	291	17
17.02.08	35.29	286	17
24.02.08	33.80	274	16
12.03.08	33.32	270	16
24.03.08	32.33	262	16

4.3 Laboratory Tests and Analysis using River Water

4.3.1 General

The objective of developing the treatment unit was that the unit should treat surface water. The main sources of surface water are ponds, rivers, lakes etc. The qualities of different surface water bodies are different. Rivers water contains more color and turbidity as well as diseases producing micro-organisms than the other surface water sources. The basic water quality of those are different so as to their treatment. As stated earlier (Art-2.1.1) that about 17% of ponds in the country are derelict and probably dry up in dry season. Considering this problem, rivers water was taken as key source to solve the domestic purposes of those problematic areas. Hence, after finding successful results for treating ponds water, the performance of the treatment unit was studied using rivers water. Although, rivers water may contain heavy metals, oils or other chemicals, the emphasize was not given to treat those contaminants. Because of the fact that sand filter alone can not remove heavy metals or such contaminants. Samples were collected from the nearest river and tested as early as possible to determine the selected water quality parameters.

4.3.2 Bacteriological quality Test (TC & FC Removal)

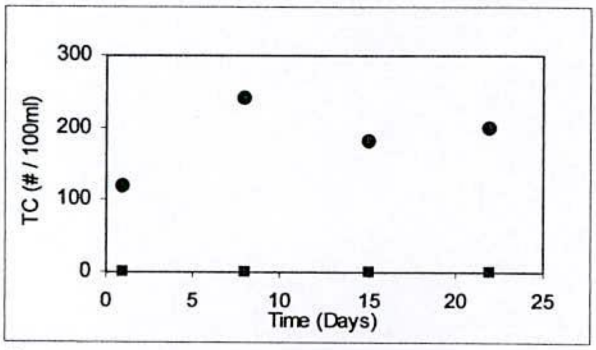

Figure-4.3 (a): TC removal efficiency

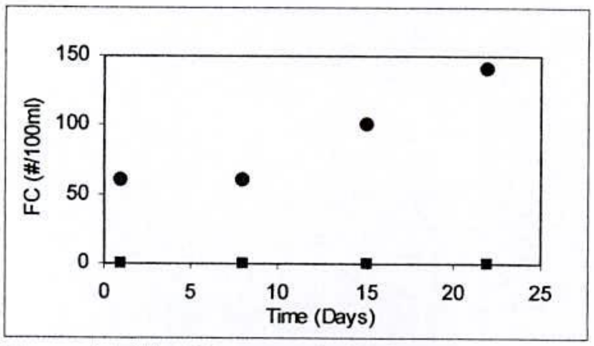

Figure-4.3 (b): FC removal efficiency

Due to high turbidity and color, the river water was diluted to 20% (i.e.5 ml raw water and 95 ml distilled water) and tested for TC & FC. The results of raw and filtered water are described in Figure 4.3 (a) and 4.3 (b) for TC and FC respectively. High bacteriological contamination was observed in raw water. The concentration came down to zero after passing through the treatment unit.

So, the bacteriological removal efficiency of the treatment unit is100 percent also for rivers water.

4.3.3 Color and Turbidity Removal Efficiency

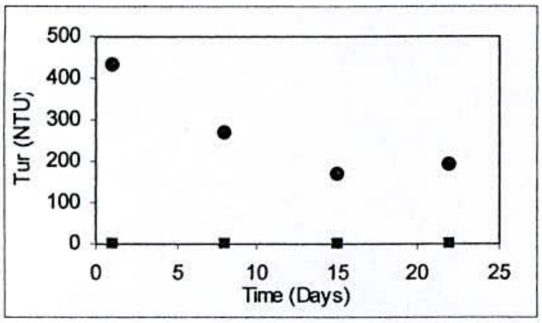

Figure-4.3 (c): Turbidity removal efficiency

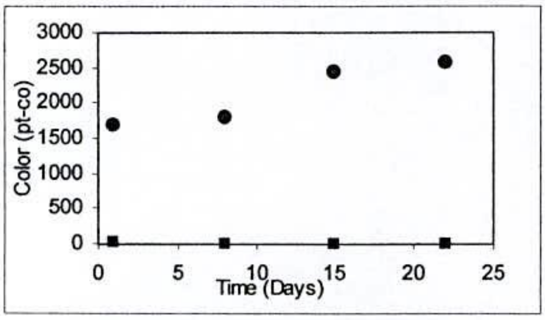

Figure-4.3 (d): Color removal efficiency

High color and turbidity value were observed in the river water. The raw water was diluted for finding its color value. It was found from the results that the turbidity and color value of filtered water was reduced over 98% and 97 % respectively after passing through the treatment unit. The turbidity and color removal efficiency are illustrates in the following Figure 4.3 (c) and 4.3 (d) respectively.

4.3.4 Variation of pH and Dissolved Oxygen

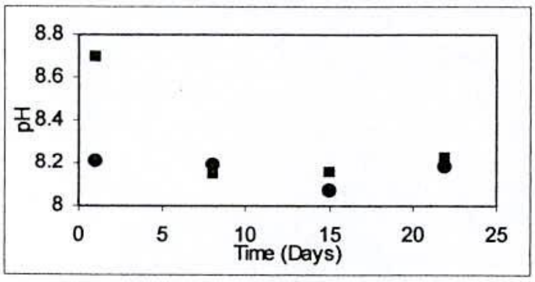

Figure-4.3 (e): Variation of pH value

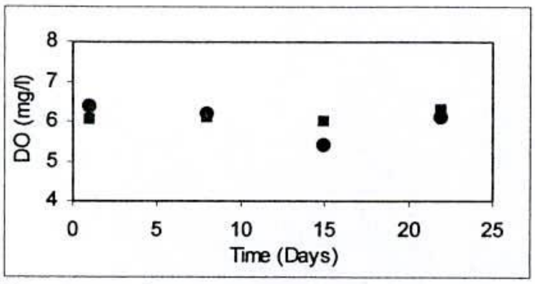

Figure-4.3 (f): Variation of dissolved oxygen

Dissolved oxygen level of the treatment unit showed that aerobic condition was prevailing throughout the whole treatment operations of the laboratory unit. It was observed that the treated water of the unit always showed a value greater than almost 6 mg/l. An increasing nature of pH was observed after treating the river water. The pH level of the treated water always noticed alkaline conditions. The observed pH value of the treated water of the laboratory unit was always under 8.5. The variation of pH and DO are shown in Figure 4.3 (e) and 4.3 (f) respectively.

4.3.5 Performance study of the Treatment unit using River Water

The developed surface water treatment unit study at the laboratory using rivers water is under proceedings. The performance study results of the laboratory model unit collected so far are represented in the following Table- 4.3:

Table-4.3: Performance study of the Treatment unit using River Water

Parameter		TC	FC	pH	Turbidity	Color	DO
Date	Unit	# / 100ml	# / 100ml	-	NTU	pt-co	mg/l
	BD. Standards	0	0	6.5~8.5	10	15	6
02.06.08	Raw Water	120	60	8.21	434	1676	6.37
	Filtered Water	0	0	8.70	0.66	25	6.03
09.06.08	Raw Water	240	60	8.19	269	1788	6.17
	Filtered Water	0	0	8.15	0.30	0	6.08
16.06.08	Raw Water	180	100	8.07	170	2425	5.40
	Filtered Water	0	0	8.16	1.32	0	6.00
22.06.08	Raw Water	200	140	8.18	192	2561	6.11
	Filtered Water	0	0	8.23	1.41	2	6.26

Chapter Five

Engineering Significance and Economic aspect

The Treatment Unit has two columns with down flow –up flow process. The sand column acts as rapid sand filtration while synthesis raw water passing through it. Comparatively larger suspended particles precipitate and settle at the top of the sand column with a small detention time. It reduces various impurities through mechanical straining, sedimentation and adsorption. Other fine and coarse particles precipitates at the beginning of the activated carbon layer through lateral movement. The final removal of bacteria and other fine particles are done in slow sand portion of the Second column. This column was constructed on the basis of simple methodological technique of slow sand filtration under submerged condition i.e. stable bio-film slime layer. Partial treated water up-flowed at very slow rates through fine sands to retain suspended solids in the interstices between the sand grains. The pores in the sand grains bring the fine particles and bacteria in contact with sand surfaces, where they adhere because of physical attraction and presence of gelatinous coating. During the filtration process, the coating of micro-organisms formed around the sand grains was responsible for the removal of organic matters and bacteria.

It was observed from the laboratory tests that the removal efficiency was sufficient for both Total Coliform and Faecal Coliform counts. The water quality of relevant selected parameters in the treated water was also found satisfactory. The selected water quality parameters of the laboratory unit were within the acceptable limit of Bangladesh standards.

The clogging process of the developed treatment unit was a major concern for laboratory study. It was observed that the clogging of the unit did not appear but the rate of filtration was slowed down from 19 L/hr to 8 L/hr after 175 days of its operation and treating about 2500 liters of raw waters. Considering the rate of filtration, the top one centimeter sand from the First column was scrapped off and did not replaced. The unit was restart for treating raw water after a pause period of two days. Till then the unit was operated successfully for a period of 242 days with the average filtration rate.

The total cost of constructing the household surface water treatment filter unit was about Tk. 1950/-. The cost of second column made of sliver can (special type vertical plastic column) is

Tk. 1250/-. The activated carbon of about 2.5 kg were used in the unit costs Tk. 500/-. The cost of all other locally available materials used for constructing the unit is Tk. 200/-.

The most important point behind the cost is that the unit is reusable. The bed materials of the unit could be replaced by new materials after clogging both the column. Thus the unit could be replaced easily for treating raw water. The replacing cost is not more than Tk. 700/.

The developed household surface water treatment filter Unit is more economical than the other available household water treatment unit because of the following:

- A treatment Unit without using any chemicals.
- Materials used in the Unit are locally available.
- A complete Unit for Total and Faecal Coliform removal.
- A treatment Unit of ease in Operation and Maintenance.
- A reusable treatment Unit.

The available household technologies to treat contaminated ground water in the country are divided in to arsenic and iron removal types. It was observed that those removal technologies have improved significantly during the last few years but reliable, cost effective and sustainable treatment technologies are yet to be identified and further developed to meet the requirements [Ref 05]. The major issues relating to the prospects for the technologies and for sustainable use are the risk of bacteriological contamination and the acceptability of the technologies to prospective users [Ref 19].

The good achievement for the developed household surface water treatment filter unit is that the treated water produced in the unit is completely free from bacteriological contamination. The major findings from unit are the clarity of the treated water. It has observed that the unit produced sparkling clear water with no bacteria both for ponds and rivers water used as raw water.

So, from the engineering point of view it could be concluded that the developed unit is cost effective, sustainable and user-friendly treatment unit. The customers who rely on private surface water sources for household use, the developed unit may be an effective choice for water treatment for their domestic purposes.

Chapter Six

Conclusion and Recommendation

6.1 Conclusion

The project works focused on the development of a sustainable household surface water treatment filter. Detailed laboratory model tests and analysis were carried out to determine some important selected water quality parameters of the Treatment Unit. Considering different water quality of the surface water sources, the unit was operated using pond water and river water. The performances of the Unit were studied with respect of the removal efficiency of bacteria, color, turbidity, TDS and TS. Clogging of the developed Unit was a major part of the laboratory performance study. Identifications of the problems in operation and maintenance of the Unit have been observed during the laboratory study. The engineering significance and economic aspect for developing the Unit has also been focused thoroughly. The main findings drawn from this study are as follows:

(1) Complete removal of Total and Faecal Coliform was achieved in the developed Treatment Unit while the average filtration rate (controlled by sand size) was maintained around 15 L/hr.

(2) The clogging of the developed Unit was dependent on the turbidity and total solids concentration of raw water. Since the treatment unit was constructed with the combination of rapid and slow sand filtration process, higher turbidity did not clogged the treatment Unit.

(3) The operation and maintenance of the treatment unit were simple and scraping of sand did not require skilled labors.

(4) The total raw water treating capacity of the unit is under proceedings. Although the unit already treated about 4000L of pond water contains maximum turbidity of 25 NTU and about 350 L of rivers water containing maximum turbidity concentration of 434 NTU.

(5) The expected duration of service of the developed Unit is nine to twelve months depending on the turbidity concentrations in the raw water.

(6) Translucent and sparkling treated water was produced in the developed Unit. The treated water had the color value always less than 15 pt-co unit and turbidity value less than 2.3 NTU both for ponds and rivers water.

(7) The variation of pH and dissolved oxygen was observed during the tests. The Dissolved oxygen level of the treated rivers water of treatment processes showed that aerobic condition was prevailing throughout the treatment operations.

(8) The construction cost of the developed Unit was around Tk.1950.00.

6.2 Recommendation for future work:

On the based of the performance study of the developed treatment unit, the following recommendations can be made for future work:

1. To study on performance of the developed Unit in mass scale under various surface water quality conditions.
2. To study on installing another bucket carrying raw water.
3. To study on provision for flow control device.
4. Further study on clogging after replacing bed materials.
5. To study on reduction of the weight of the treatment Unit.

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Appendix – A

Elaborated Recommendations

The available surface water sources in the country are ponds, rivers, lakes, reservoirs etc. There is a wide variation of water quality conditions of these surface water bodies. The water quality parameters in pond water and their concentration ratios are not same for all other surface water sources. They vary significantly with their concentrations and types of flow. Therefore, it is significantly need to study the performances of the developed Treatment Unit in mass scale under various surface water quality conditions.

Surface waters available in the country are highly turbid in both dry and wet seasons. In dry season, there is excessive growth of algae in relatively stagnant pond and river waters. Higher turbid surface water demands pre-treatment which can actually reduce the load on slow sand filters for longer operation between washings. Again filtration rate is an important one for any filtration based removal technology. It was observed during the laboratory study of the unit that the raw water pouring capacity in the First column was only 2.5 L at a time which seemed impractical. It felt that it needs much attention during pouring of raw water. It should be mentioned that removal efficiency did not appear to have been affected much by this action.

So, it is recommended that the raw water pouring capacity must be increased. This could be done by installing another bucket near the First column. Another important point is to provide the flow control device to control the raw water flow which should not only increase the duration of service of the treatment unit but also increase the removal efficiency remarkably. The recommended typical treatment unit should be as following:

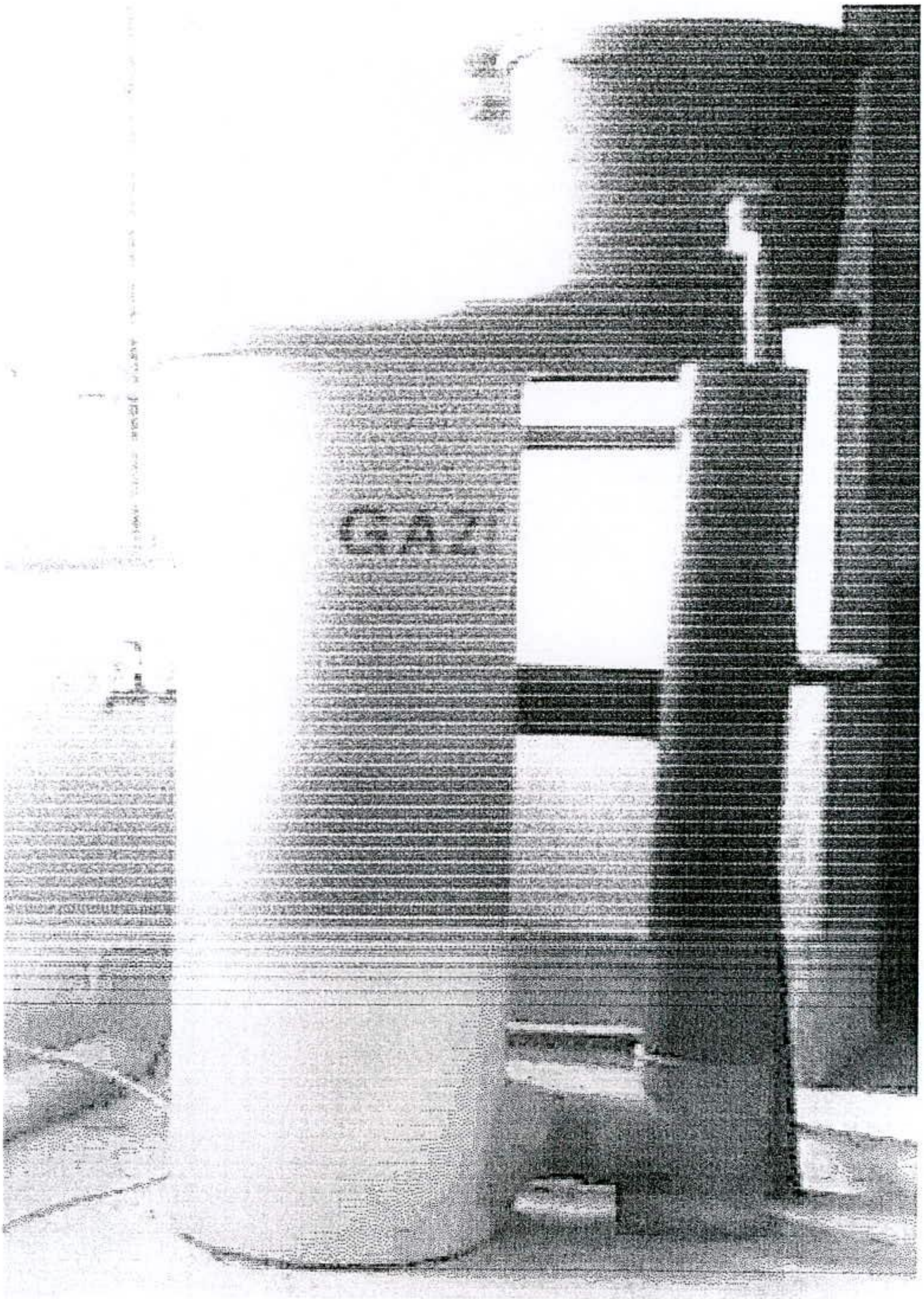

Figure-A: Recommended surface water treatment filter.

Appendix – B

Line joint graphical representation of different water quality parameter

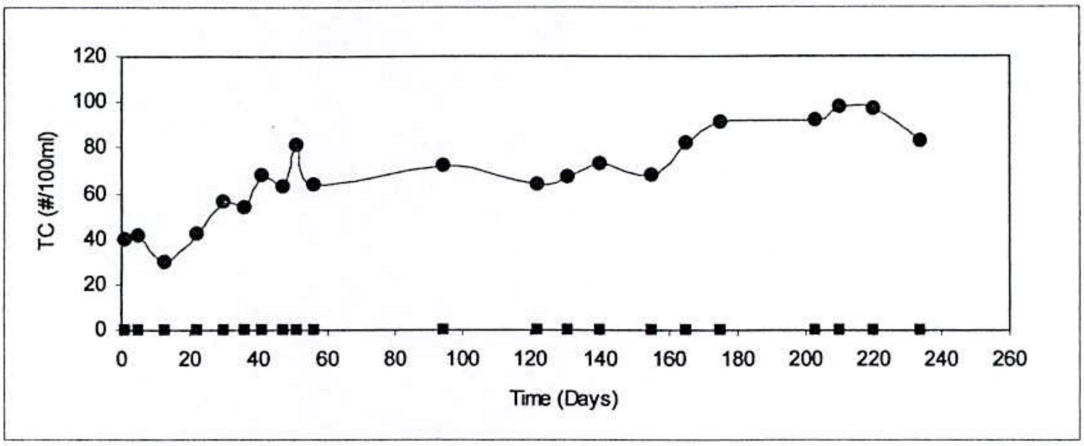

Figure-(a): Removal efficiency of Total Coliform

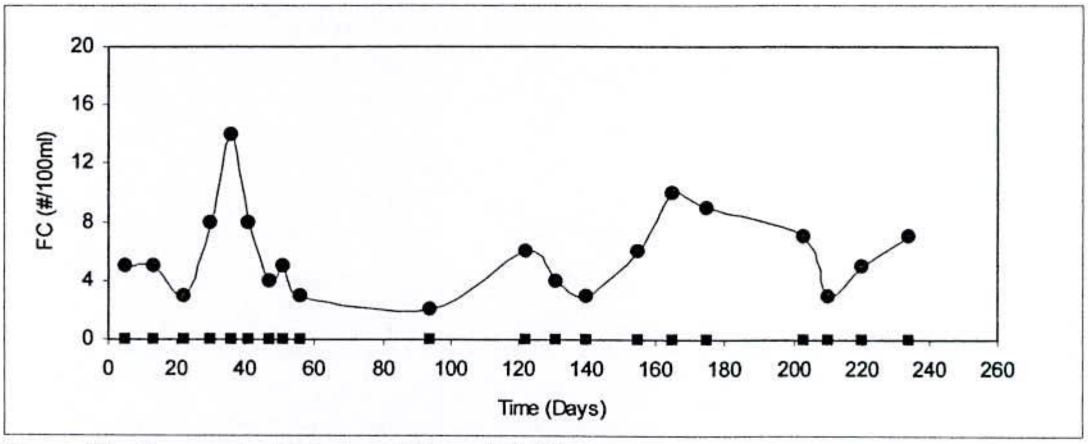

Figure-(b): Removal efficiency of Faecal Coliform

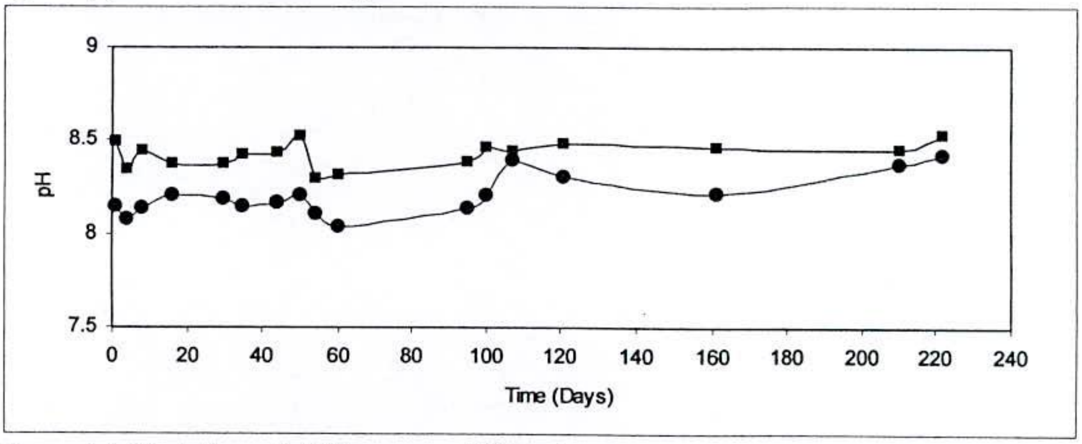

Figure-(c): Variation of pH for raw and filtered water

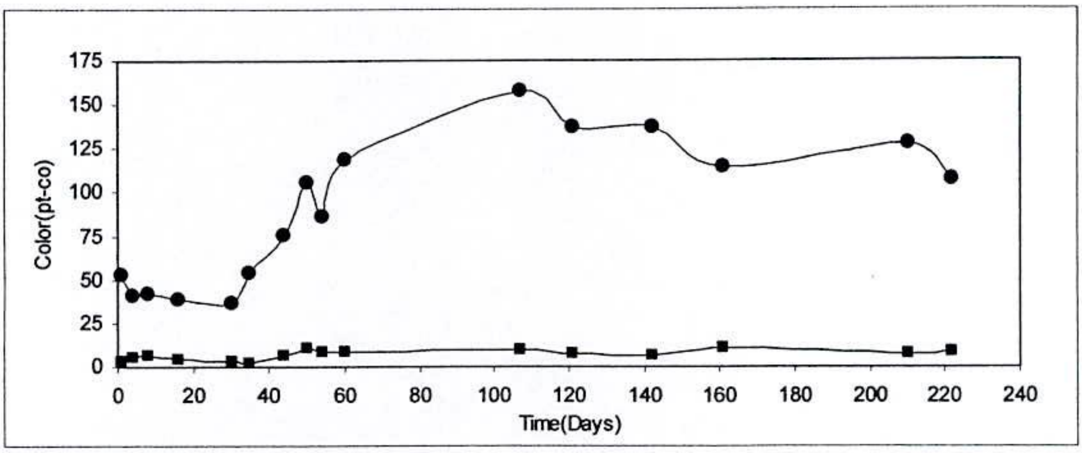

Figure-(d): Color removal efficiency

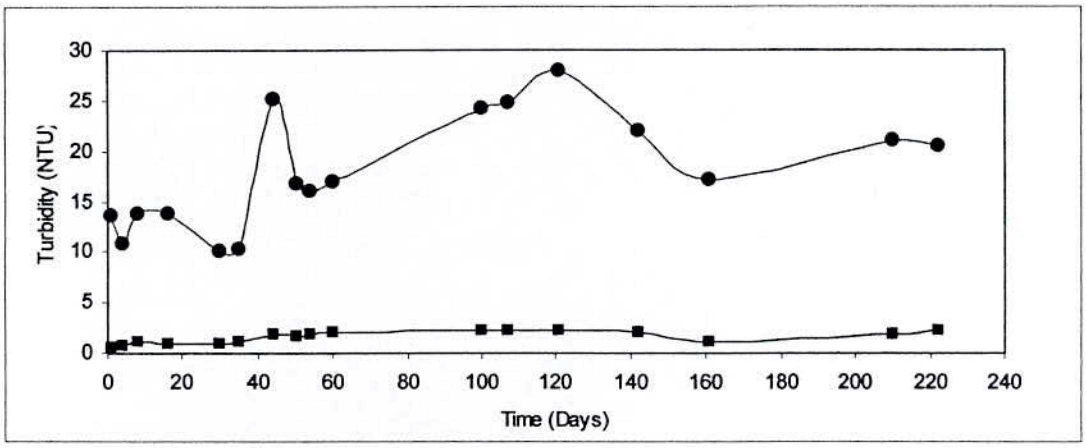

Figure-(e): Turbidity removal efficiency

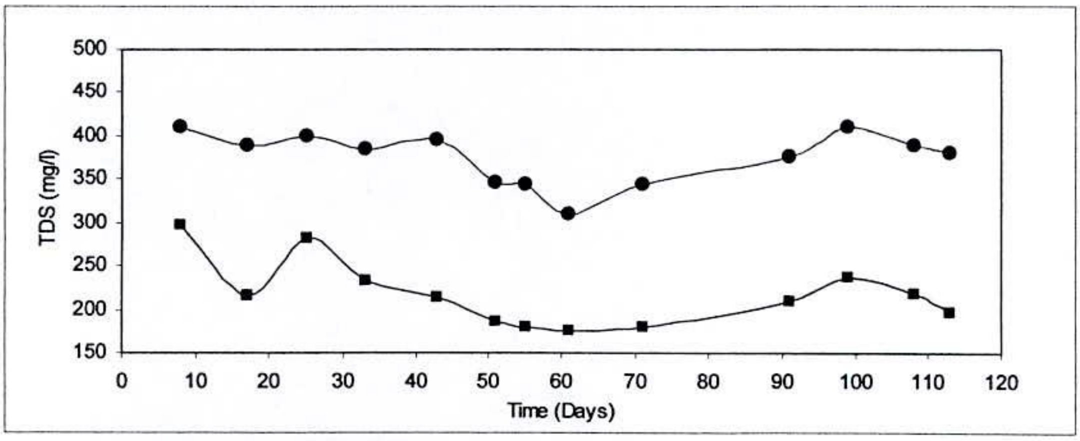

Figure-(f): TDS removal efficiency

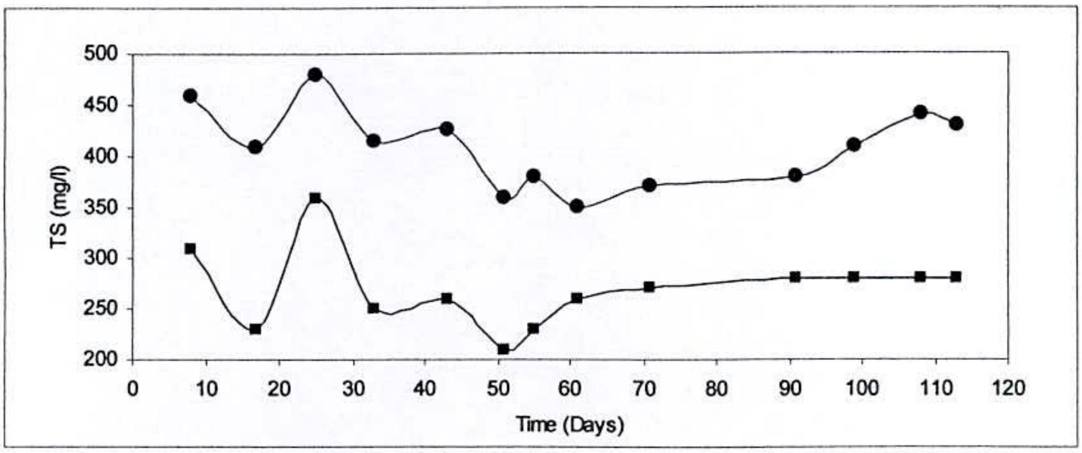

Figure-(g): TS removal efficiency

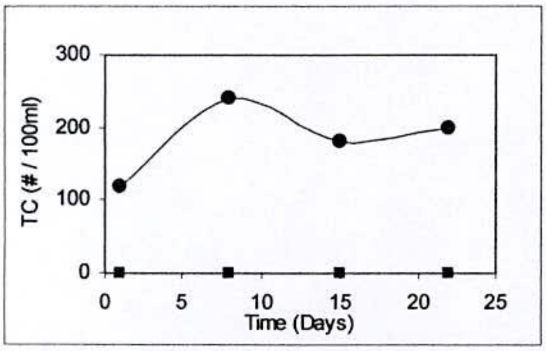

Figure-(h): TC removal efficiency

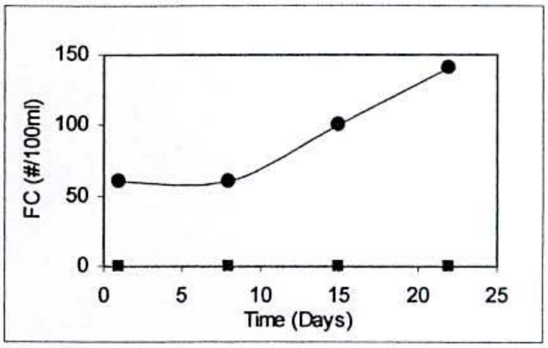

Figure-(i): FC removal efficiency

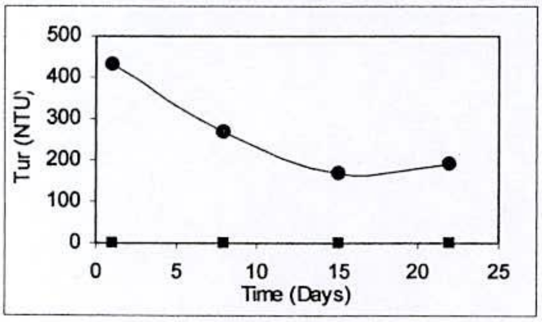

Figure-(j): Turbidity removal efficiency

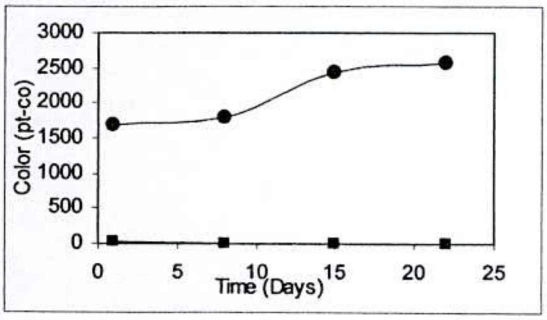

Figure-(k): Color removal efficiency

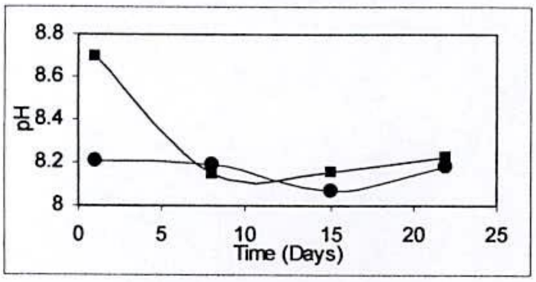

Figure-(l): Variation of pH value

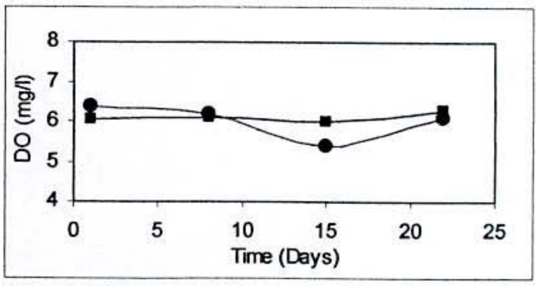

Figure-(m): Variation of dissolved oxygen