PERFORMANCE STUDY OF BIOSAND FILTER

A thesis submitted towards partial fulfilment

of the requirements for the degree of

Master of Engineering

In

Water Resources and Hydraulic Engineering

Submitted by: ASHADUL MALLICK

ROLL NO. : M6WRP22013

REGISTRATION NO.:150285 OF 2019-20

Under the guidance of

PROF. (DR.) ARUNABHA MAJUMDER

Emeritus Professor,

School of Water Resources Engineering, Jadavpur University

&

DR. RAJIB DAS

Assistant Professor,

School of Water Resources Engineering, Jadavpur University

Course affiliated to

Faculty of Engineering and Technology

Jadavpur University

Kolkata – 700 032

India

2022

M.E. (Water Resources & Hydraulic Engineering)
Course affiliated to
Faculty of Engineering and Technology
Jadavpur University,
Kolkata, India

CERTIFICATE OF RECOMMENDATION

This is to certify that the thesis entitled **"Performance Study of Biosand Filter"** is a bonafide work carried out by **Ashadul Mallick**under our supervision and guidance for partial fulfilment of the requirement for Master of Engineering (Water Resources & Hydraulic Engineering) in 'School of Water Resources Engineering', during the academic session 2019 - 2022.

THESIS ADVISOR

Prof. (Dr.) Arunabha Majumder
Emeritus Professor
School of Water Resources Engineering
Jadavpur University
Kolkata – 700 032

THESIS ADVISOR

Dr. Rajib Das
Assistant Professor
School of Water Resources Engineering
Jadavpur University
Kolkata – 700 032

DIRECTOR
Prof. (Dr.) Pankaj Kumar Roy
School of Water Resources Engineering
Jadavpur University
Kolkata – 700 032

DEAN
Faculty of Interdisciplinary Studies, Law and Management
Jadavpur University,
Kolkata – 700 032

CERTIFICATE OF APPROVAL**

This foregoing thesis is hereby approved as a credible study of an engineering subject carried out and presented in a manner satisfactorily to warranty its acceptance as a prerequisite to the degree for which it has been submitted. It is understood that by this approval the undersigned do not endorse or approve any statement made or opinion expressed or conclusion drawn therein but approve the thesis only for purpose for which it has been submitted.

Committee of final examination --

For evaluation of thesis --

** Only in case the thesis is approved.

DECLARATION OF ORIGINALITY AND COMPLIANCE OF ACADEMIC ETHICS

I hereby declare that this thesis contains literature survey and original research work by the undersigned candidate, as part of my Master of Engineering (Water Resources & Hydraulic Engineering) studies during academic session 2019- 2022.

All information in this document has been obtained and presented in accordance with academic rules and ethical conduct.

I also declare that, as required by this rules and conduct, I have fully cited and referred all material and results that are not original to this work.

NAME	:	**ASHADUL MALLICK**
ROLL NUMBER	:	**M6WRP22013**
REGISTRATION NO.	:	**150285 OF 2019-20**
THESIS TITLE	:	**Performance Study of Biosand Filter**

Signature: Date:

ACKNOWLEDGEMENT

I express my sincere gratitude to my supervisor **Prof. (Dr.) Arunabha Majumder**, Emeritus Professor, School of Water Resources Engineering,Jadavpur University,**Dr. Rajib Das**, Assistant Professor, School of Water Resources Engineering, Jadavpur University, under whose supervision and guidance this work has been carried out. It would have been impossible to carry out this thesis work with confidence without their wholehearted involvement, advice, support and constant encouragement throughout.
I also express my sincere gratitude to my **Prof.(Dr) Pankaj Kumar Roy**, Professor, Director, School of Water Resources Engineering, Jadavpur University,**Prof.(Dr.) AsisMazumdar**, Professor, School of Water Resources Engineering, Jadavpur University, **Dr. Subhasish Das**, Associate Professor, School of water Resources Engineering,Jadavpur University,**Dr. Gourab Banerjee**, Assistant Professor, School of water Resources Engineering,Jadavpur University for their valuable suggestion.

Thanks are also due to all the staffs of School of Water Resources Engineering, Jadavpur University for their help and support.

Also, I am grateful to all my office colleagues and my friends who are help and support during this course.

Last but not the least, I am also grateful to my parents, my wife Serina Mallick, for their earnest and continuous support and therefore, I dedicate my M.E. thesis to them.

Date : ………………………

Place : SRWE, Jadavpur University
KOLKATA-700032

Ashadul Mallick
ROLL NUMBER:M6WRP22013
REGISTRATION NO.:150285 OF 2019-20

Abstract

Clean drinking water is a necessity and recycling storm water and grey water has been more appealing in the recent decades to provide filtered water for drinking water and non-drinking water purposes. Biosand filters (BSF) have been a popular filtering system of filtering potable water in developing countries, due to their simplicity in construction, reliability in operation and availability of constituent materials. The BSF removes contaminants from water using four methods: mechanical trapping, predation, adsorption and natural death. The mechanical trapping mechanism occurs when solids and microbes suspended in the water are trapped in the small spaces between sand grains. Pathogens and suspended solids are removed through a combination of biological and physical processes that take place in the biofilm layer and within the sand layer.The aim of the study was to investigate the performance of Bio-sand filter (BSF) prepared with locally available materials in removing contaminants from surface water. The BSF was prepared with sand, gravel and plastic materials.The filter was constructed with specific grain size of sand and gravel; and the operation flow rate was 5.35ml/s. For laboratory analysis 27 water samples were collected from inlet water tank and outlet pipe at different day's interval. The collected water samples were analyzed for pH, turbidity, total dissolve solids (TDS), Chloride (Cl), Hardness and fecal coliform (FC).

The filter was highly efficient in turbidity reduction (85.24% average). The average TDS and EC removal efficiency was relatively low. This system was also highly efficient in fecal coliform reduction. It was concluded that BSF was suitable for removing contaminants from surface water and meet drinking water demand for the people who drink contaminated pond water. The device was made using locally available materials (plastic bucket, sand and gravel). Overall study results revealed a greater portion of turbidity reduction in the filtrate. The filter was found to reduce fecal coliform, though it is not capable of consistently meeting the IS guideline fecal coliform.

Keywords: Bio-sand Filter, Coliform Bacteria, Local Resource, Turbidity, Water Purification, Diarrhea, Household water treatment, Wash, Low-Cost Water Supply, Public Health

Contents

Chapter – 1

Introduction

1.1 Water quality of surface water

Water is a prime resource that is very vital for nature. It forms the chief constituent of ecosystem. Water is utilized in different fields of agriculture, forestry, and livestock production, industrial and other creative activities. It is the primary need for industrial, agricultural and other growing household affairs. The quality of water can be defined by its physical, biological and chemical characteristics. Water deterioration occurs due to growing populations or urbanization, anthropogenic activities and the tremendous increasein industrialization Human health is being affected by waterborne diseases that have caused up to 5–10 million deaths worldwide. To maintain a stable civilization on Earth, good water quality has a significant role, therefore water needs to be monitored and managed properly. Physico-chemical and biological parameters are mostly used to monitor the quality of water that should fall under set standards and guidelines. The occurrence of these parameters beyond the defined limit can be harmful for human health. To express water quality in some standard form researchers have come up with several water qualityindices, which are the most effective tools, used to describe the quality of water. Water Quality Index (WQI) is a mathematical tool that represents the water quality class by categorizing different water parameters into a standard numerical value. In this study the quality of water of study area is determined using the various physico -chemical and biological parameters such as PH, Total Dissolved Solids (TDS) , Cl, SO4, Na, K, Ca, MG, Total Hardness (TH), DO, BOD, COD, Fecal Coliform, Ammonia-N, Nitrate – N,Conductivity, Fluoride, Phosphate – P, Total Alkalinity (TA), TFS and Turbidity Total Coliform.

Water quality is an important contributor touching on all aspects of ecosystems and human well-being and a significant tool in determining the human poverty, wealth, and education levels (UN Water 2010). The ecosystem services of water from rivers and lakes are directly or indirectly contribute to both human welfare and aquatic ecosystem (Costanza et al. 1997; Kar 2007, 2013). The increase in pollution of water sources like lakes and rivers is a major concern for the global scenario as most of the water bodies around the world are the source for water supply including human consumption and domestic purposes (Kazi et al. 2009; Dey and Kar 1987). The health of the aquatic ecosystem is determined by the water quality parameter which includes the physical, chemical, and biological characteristics (Kar 1990; Sargaonkar and Deshpande 2003; Venkatesharaju et al. 2010). Therefore, a particular problem with water quality monitoring is a complex issue associated with analyzing a large number of associate measures of variables (Boyacioglu 2007) and the high variability among the variables is due to increase in anthropogenic activities including natural influences (Simeonov et al. 2002). The anthropogenic discharges constitute a constant polluting source, thereby reducing the water quality. Human activities are the major factor determining the quality of water (Niemi et al. 1990; Kar 2010). Environmental pollution of water resources has become a major global issue, including developing countries which have been suffering from the impact of pollution due to poor socio economic growth associated with the exploitation of natural resources. As a result of it, water is considered as the highest risk to the world for future due to increase in demand as well as increase in pollution (Kar 2013; Global Risks 2015)

1.2 Surface water Resources

Surface water is any body of water found on the Earth's surface, including both the saltwater in the ocean and the freshwater in rivers, streams, and lakes. A body of surface water can persist all year long or for only part of the year. The ocean, despite being saltwater, is also considered surface water. Surface water participates in the hydrologic cycle, or water cycle, which involves the movement of water to and from the Earth's surface. Precipitation and water runoff feed bodies of surface water. Evaporation and seepage of water into the ground, on the other hand, cause water bodies to lose water. Water that seeps deep into the ground is called groundwater.

Surface water and groundwater are reservoirs that can feed into each other. While surface water can seep underground to become groundwater, groundwater can resurface on land to replenish surface water. Springs are formed in these locations.

There are three types of surface water: perennial, ephemeral, and man-made. Perennial, or permanent, surface water persists throughout the year and is replenished with groundwater when there is little precipitation. Ephemeral, or semi-permanent, surface water exists for only part of the year. Ephemeral surface water includes small creeks, lagoons, and water holes. Man-made surface water is found in artificial structures, such as dams and constructed wetlands.

Since surface water is more easily accessible than groundwater, it is relied on for many human uses. It is an important source of drinking water and is used for the irrigation of farmland. In 2015, almost 80 percent of all water used in the United States came from surface water. Wetlands with surface water are also important habitats for aquatic plants and wildlife.

The planet's surface water can be monitored using both surface measurements and satellite imagery. The flow rates of streams are measured by calculating the discharge—the amount of water moving down the stream per unit of time—at multiple points along the stream. Monitoring the flow rate of streams is important as it helps determine the impact of human activities and climate change on the availability of surface water. Keeping track of vegetation around bodies of surface water is also important. The removal of vegetation, either through natural means such as fires, or through deforestation, can have a negative impact on surface water. Loss of vegetation can lead to increased surface runoff and erosion, which in turn can increase the

India is a water rich country with 4% of world's water resources (India-WRIS wiki 2015). The annual estimate of surface water in India is 1, 86,900 crore cubic metre. Most of the surface water flows through rivers. These are many rivers of large size and length in India which keep the land green and prosperous. In the western part of India having Thar Desert however, there is no perennial river, though the artificially constructed Indira Gandhi Canal irrigates large areas in this desert. In southern India also there are many rivers. The total length of rivers of India is 2 lakh miles.

1.3Filtration process

The resultant water after sedimentation will not be pure, and may contain some very fine suspended particles and bacteria in it. To remove or to reduce the remaining impurities still further, the water is filtered through the beds of fine granular material, such as sand, etc. The process of passing the water through the beds of such granular materials is known as Filtration.

- **How Filters Work: Filtration Mechanisms**

There are four basic filtration mechanisms:

SEDIMENTATION : The mechanism of sedimentation is due to force of gravity and the associate settling velocity of the particle, which causes it to cross the streamlines and reach the collector. ***INTERCEPTION***: Interception of particles is common for large particles. If a large enough particle follows the streamline,that lies very close to the media surface it will hit the media grain and be captured. ***BROWNIAN DIFFUSION***: Diffusion towards media granules occurs for very small particles, such as viruses. Particles move randomly about within the fluid, due to thermal gradients. This mechanism is only important for particles with diameters < 1 micron.

INERTIA: Attachment by inertia occurs when larger particles move fast enough to travel off their streamlines and bump into media grains.

- **Filter Materials**

Sand: Sand, either fine or coarse, is generally used as filter media. The size of the sand is measured and expressed by the term called effective size. *The* effective size, i.e. D_{10} may be defined as the size of the sieve in mm through which ten percent of the sample of sand by weight will pass. The uniformity in size or degree of variations in sizes of particles is measured and expressed by the term called uniformity coefficient. The uniformity coefficient, i.e. (D_{60}/D_{10}) may be defined as the ratio of the sieve size in mm through which 60 percent of the sample of sand will pass, to the effective size of the sand.

Gravel: The layers of sand may be supported on gravel, which permits the filtered water to move freely to the under drains, and allows the wash water to move uniformly upwards.

Other materials: Instead of using sand, sometimes, anthrafilt is used as filter media. Anthrafilt is made from anthracite, which is a type of coal-stone that burns without smoke or flames. It is cheaper and has been able to give a high rate of filtration.

- **<u>Types of Filter</u>**

Slow sand filter: They consist of fine sand, supported by gravel. They capture particles near the surface of the bed and are usually cleaned by scraping away the top layer of sand that contains the particles. ***Rapid-sand filter:*** They consist of larger sand grains supported by gravel and capture particles throughout the bed. They are cleaned by backwashing water through the bed to 'lift out' the particles.

- **<u>Slow Sand Filters vs. Rapid Sand Filters</u>**
  - ***Base material:*** In SSF it varies from 3 to 65 mm in size and 30 to 75 cm in depth while in RSF it varies from 3 to 40 mm in size and its depth is slightly more, i.e. about 60 to 90 cm.
  - ***Filter sand:*** In SSF the effective size ranges between 0.2 to 0.4 mm and uniformity coefficient between 1.8 to 2.5 or 3.0. In RSF the effective size ranges between 0.35 to 0.55 and uniformity coefficient between 1.2to1.8.
  - ***Rate of filtration:*** In SSF it is small, such as 100 to 200 L/h/sq.m. Of filter area while in RSF it is large, such as 3000 to 6000 L/h/sq.m. Of filter area.
  - ***Flexibility:*** SSF are not flexible for meeting variation in demand whereas RSF are quite flexible for meeting reasonable variations in demand.
  - ***Post treatment required:*** Almost pure water is obtained from SSF. However, water may be disinfected slightly to make it completely safe. Disinfection is a must after RSF.
  - ***Method of cleaning:*** Scrapping and removing of the top 1.5 to 3 cm thick layer is done to clean SSF. To clean RSF, sand is agitated and backwashed with or without compressed air.

- ***Loss of head:*** In case of SSF approx. 10 cm is the initial loss, and 0.8 to 1.2m is the final limit when cleaning is required. For RSF 0.3m is the initial loss, and 2.5 to 3.5m is the final limit when cleaning is required.

1.4Rapid Sand Filtration

Rapid sand filtration is a purely physical drinking water purification method. Rapid sand filters (RSF) provide rapid and efficient removal of relatively large suspended particles. Two types of RSF are typically used: rapid gravity and rapid pressure sand filters. For the provision of safe drinking water, RSFs require adequate pre-treatment (usually coagulation-flocculation) and post-treatment (usually disinfection with chlorine). Both construction and operation is cost-intensive. It is a relatively sophisticated process usually requiring power-operated pumps, regular backwashing or cleaning, and flow control of the filter outlet. Rapid sand filtration is common in developed countries for the treatment of large quantities of water where land is a strongly limiting factor, and where material, skilled labour, and continuous energy supply are available.

➢ **Advantages:**

- Highly effective for removal of turbidity (usually < 0.1-1 NTU)
- High filter rate (4’000 – 12’000 litres per hour per square metre of surface), small land requirements
- No limitations regarding initial turbidity levels (if coagulant or flocculant is available and correctly applied)
- Cleaning time (backwashing) only takes several minutes and filters can be put back into operation instantly

➢ **Disadvantages:**

- Not effective in removing bacteria, viruses, fluoride, arsenic, salts, odour and organic matter (requires pre- and post-treatment)
- High capital and operational costs
- Frequent cleaning (backwashing) required (every 24-72h)
- Skilled supervision essential (e.g. for flow control and dosage of disinfectant)
- High energy input required
- Backwashing water and sludge needs treatment; sewage system or stabilization ponds required

➢ **Health aspects:**

Rapid sand filtration is a highly effective method to remove turbidity if it is correctly applied (BRIKKE & BREDERO 2003). Equally, solids formed during pre-treatment, i.e. **coagulation-flocculation**, are filtered. A well-operated RSF reduces turbidity to less than 1 NTN and often less than 0.1 NTU (WHO 1996). Regarding the removal of most other contaminants, the RSFs are ineffective. If combined with adequate pre-treatment measures and final disinfection, rapid sand filtration usually produces safe drinking water.

Table-1.1

Moderately effective for:	Somewhat effective for:	Not effective for:
- Turbidity - Iron, manganese	- Odour, taste - Bacteria - Organic matter	- Viruses - Fluoride - Arsenic - Salts

Typical treatment performance of rapid sand filters if freshwater has been pre-treated with coagulation-flocculation. Adapted from: BRIKKE & BREDERO (2003), DEBOCH & FARIS (1999), SDWF (n.y.) and WHO (n.y.)

➢ **Applicability:**

Rapid sand filtration requires very complex technical installations, highly skilled workers for construction and operation as well as large energy inputs. Unless pre-treatment and disinfection is applied, the filtered water is not safe for drinking. Its application is hence reserved for industrialized countries or urban areas where land is a limiting factor. RSF can provide a very efficient method in larger urban water supply systems if preconditions are met. For any other areas, RSFs are usually economically unreasonable.

1.5Slow Sand Filtration

Slow sand filtration is a type of centralized or semi-centralized water purification system. A well-designed and properly maintained slow sand filter (SSF) effectively removes turbidity and pathogenic organisms through various biological, physical and chemical processes in a single treatment step. Only under the prevalence of a significantly high degree of turbidity or algae-contamination, pre-treatment measures (e.g. sedimentation) become necessary. Slow sand filtration systems are characterized by a high reliability and rather low lifecycle costs. Moreover, neither construction nor operation and maintenance require more than basic skills. Hence, slow sand filtration is a promising filtration method for small to medium-sized, rural communities with a fairly good quality of the initial surface water source. As stated by the WHO, slow sand filtration provides a simple but highly effective and considerably cheap tool that can contribute to a sustainable water management system.

➢ **Principles of Slow Sand Filtration**

- In a slow sand filter impurities in the water are removed by a combination of processes: sedimentation, straining, adsorption, and chemical and bacteriological action.
- During the first few days, water is purified mainly by mechanical and physical-chemical processes. The resulting accumulation of sediment and organic matter forms a thin layer on the sand surface, which remains permeable and retains particles even smaller than the spaces between the sand grains.
- As this layer(referred to as "Schmutzdecke") develops, it becomes living quarters of vast numbers of micro-organisms which break down organic material retained from the water, converting it into water, carbon dioxide and other oxides.
- Most impurities, including bacteria and viruses, are removed from the raw water as it passes through the filter skin and the layer of filter bed sand just below. The purification mechanisms extend from the filter skin to approx. 0.3-0.4 m below the surface of the filter bed, gradually

decreasing in activity at lower levels as the water becomes purified and contains less organic material.

- When the micro-organisms become well established, the filter will work efficiently and produce high quality effluent which is virtually free of disease carrying organisms and biodegradable organic matter.

  They are suitable for treating waters with low colors, low turbidities and low bacterial contents.

➢ **Advantages:**

- Very effective removal of bacteria, viruses, protozoa, turbidity and heavy metals in contaminated fresh water
- Simplicity of design and high self-help compatibility: construction, operation and maintenance only require basic skills and knowledge and minimal effort
- If constructed with gravity flow only, no (electrical) pumps required
- Local materials can be used for construction
- High reliability and ability to withstand fluctuations in water quality
- No necessity for the application of chemicals
- Easy to install in rural, semi-urban and remote areas, Simplicity of design and operation
- Long lifespan (estimated >10 years)

➢ **Disadvantages:**

- Minimal quality and constant flow of fresh water required: turbidity (<10-20 NTU) and low algae contamination. Otherwise, pre-treatment may be necessary
- Cold temperatures lower the efficiency of the process due to a decrease in biological activity
- Loss of productivity during the relatively long filter skimming and ripening periods
- Very regular maintenance essential; some basic equipment or ready-made test kits required to monitor some physical and chemical parameters
- Possible need for changes in attitude (belief that water that flows through a green and slimy filter is safe to drink without the application of chemicals), Chemical compounds (e.g. fluorine) are not removed
- Natural organic matter and other DBPs precursors not removed (may be formed if chlorine is applied for final disinfection)
- May require electricity
- Requirement of a large land area, large quantities of filter media and manual labour for cleaning, Low filtration rate

➢ **Health aspects:**

Slow sand filtration is an extremely efficient method for removing microbial contamination and will usually have no indicator bacteria present at the outlet. SSFs are also effective in removing protozoa and viruses (WHO n.y.). If the effluent turbidity is below 1.0 nephelometric turbidity units (NTU), a 90 to 99% reduction in bacteria and viruses is achieved (NDWC 2000). Yet, slow sand filtration is generally not effective for the majority of chemicals (WHO n.y.). However, it can be argued that chemical standards for drinking water are of secondary concern in water supply subject to severe bacterial contamination (WHO 1996).

Table-1.2

Highly effective for	Somewhat effective for	Not effective for
- Bacteria - Protozoa - Viruses - Turbidity - Heavy metals (Zn, Cu, Cd, Pb)	- Odour, Taste - Iron, Manganese - Organic Matter - Arsenic	- Salts - Fluoride - Trihalomethane (THM) Precursors - Majority of chemicals

Typical treatment performance of slow sand filters. Adapted from: BRIKKE & BREDERO (2003), LOGSDON (2002) and WHO (n.y.)

Although SSFs are very effective for the removal of microbiological pathogens, disinfectants (e.g. **chlorination**) are often used in treatment facilities as a step subsequent to the SSF unit. Firstly for the purpose of inactivating any remaining bacteria as the final unit of treatment, and secondly, for the provision of a residual disinfectant that will remove any bacteria introduced during **storage** and/or **distribution** (WHO n.y.). Chlorine is generally added after the filter unit in order to not affect the biological process. If the water contains high amounts of natural organic matter (NOMs), e.g. surface waters in tropical regions, chlorination should be avoided due to the risk of the formation of disinfection by-products (DBPs). When attacked by chlorine radicals, NOMs form trihalomethane (THM) and other organic DBPs, which are known to be carcinogenic.

- **Applicability:**

SSFs require an influent turbidity below 30 NTU and preferably below 10 NTU. Else, pre-treatment measures (e.g. sedimentation) become necessary to ensure that the filters do not become overloaded (WHO n.y.). Moreover, climatic conditions have to be in a moderate range: SSFs are less effective in removing microorganisms from cold water because the biological activity within the filter bed and the ‘schmutzdecke’ declines as temperatures decrease (NDWC 2000). Hence, the adequacy of application is mainly given for the treatment of **surface water** in small, rural communities where available land is no limiting factor. Alternatively, SSFs may be applicable as a polishing step in wastewater treatment.
Since construction, operation and maintenance are straightforward and do not need more than basic skills, slow sand filtration is a treatment method that is highly self-help compatible and therefore can help to improve water management systems in many regions in developing countries. Although SSFs automatically accommodate minor fluctuations in fresh water quality, temperature, and climatic conditions and are able to cope with short periods of excessive turbidity without breaking down, proper and regular maintenance must be ensured (HUISMAN 1974).

1.5 Biosand Filter

- **What is the Biosand Filter?**

The biosand filter (BSF) is an adaptation of the traditional slow sand filter, which has been used for community water treatment for almost 200 hundred years. The biosand filter is smaller and adapted for intermittent use, making it suitable for households. The filter container can be made of concrete or plastic and is filled with layers of specially selected and prepared sand and gravel.

➢ History of the Biosand Filter

Dr. David Manz developed the household biosand filter in the 1990s at the University of Calgary, Canada. Dr Manz has trained many organizations on the design, construction, installation, operation and maintenance of the biosand filter. He also co-founded CAWST in 2001 to provide the professional services needed for the humanitarian distribution of the filter in developing countries. As of June 2009, CAWST estimates that over 200,000 biosand filters have been implemented in more than 70 countries around the world.

The biosand filter (BSF) is a simple household water treatment device, which is an innovation on traditional slow sand filters specifically designed for intermittent use. A BSF consists of a concrete or plastic container filled with specially selected and prepared sand and gravel. As water flows through the filter, physical straining removes pathogens, iron, turbidity and manganese from drinking water. A shallow layer of water sits atop the sand and a biofilm (Schmutzdecke) develops. The biofilm contributes to the removal of pathogens due to predation and competition for food of non-harmful microorganisms contained in the biofilm and the harmful organisms in the water.

➢ **Advantages:**

- High removal of pathogens
- Removal of turbidity, colour, odour and iron (water tastes and looks good)
- Relatively high flow-rates can be achieved (over 30 L per hour)
- One-time installation with few maintenance requirements and negligible operation costs
- Long life
- Can be fabricated from locally available materials generating an opportunity for local businesses
- Easy to operate and maintain

➢ **Disadvantages**

- Biological layer takes 2o to 30 days to develop to maturity
- Low rate of virus inactivation
- High turbidity (> 50 NTU) will cause filter to clog and requires more maintenance
- Requires that the filter be used on a regular basis
- Cannot remove dissolved compounds
- Lack of residual protection (risk of re-contamination)
- Requires that the filter be used on a regular basis

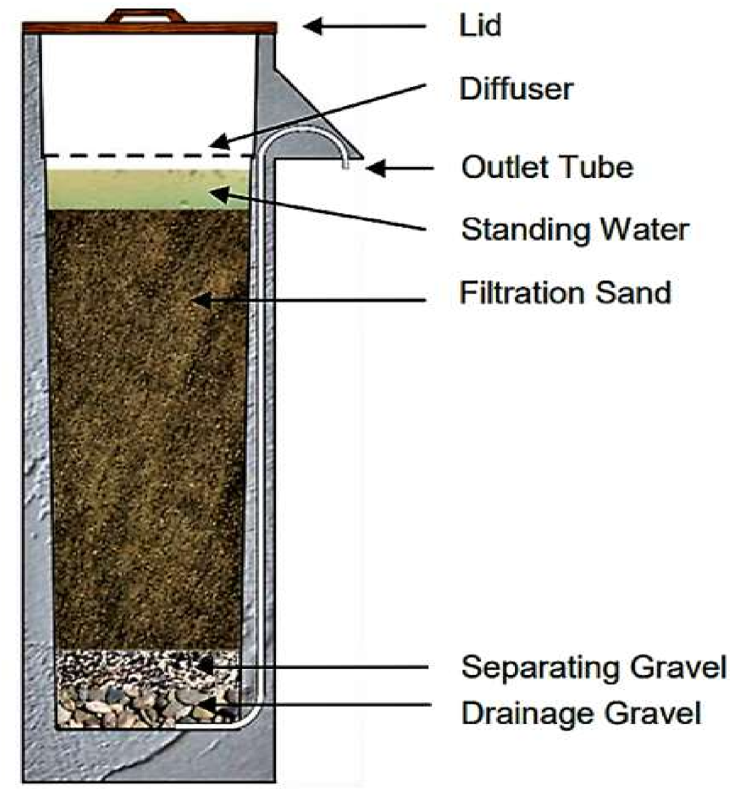

Fig.1.1 Biosand filter components. Source: CAWST (2009)

The biosand filter is an innovation on traditional slow sand water filters (which have been used for community water treatment for hundreds of years CAWST 2009), specifically designed for intermittent or household use. The BSFs was developed by Dr. David Manz in the 1990s at University of Calgary, Canada.

The filter is simple to use and can be produced locally anywhere in the world because it is built using materials that are readily available. Their capital costs depend on the local material and labour costs. However, they require no consumables and the operating costs are negligible.

BSFs consist of a simple container with a lid, enclosing layers of sand and gravel, which traps physically sediments, pathogens and other impurities from the water. A biofilm, which forms as a shallow layer of water, sits atop the sand column and contributes to the elimination of pathogens.

- **How does it work?**

The filter container can be made of concrete, plastic or any other water-proof, rust-proof and non-toxic material. The most widely used version is however the concrete container, approximately 0.9 m tall and with a surface of 0.3 m2 (LANTAGNE et al. 2006). The concrete filter box is cast from a steel mould or made with a pre-fabricated pipe (CAWST 2009). The container is filled with layers of sieved and washed sand and gravel, also referred to as filter media (CAWST 2009). There is a standing water height of 5 cm above the sand layer, which is maintained by adjusting the height of the outlet pipe (LANTAGNE et al. 2006; CAWST 2009). It is this design feature that allows the formation of a biofilm layer and distinguishes the BSF from other slow sand filters, allowing for small-scale construction and intermittent use (see **cawst.org**). A diffusion layer avoids that water reaches the sand surface too fast, which could disturb the biofilm layer.

The filter operation is very simple. Water is poured onto the top of the filter as needed. Then the water will travel slowly through the sand and gravel bed. At the base of the filter the water is collected in a pipe and is drained through plastic piping out of the filter for be collected and stored in a clean water container. Concrete filters have the outlet pipe embedded in the concrete, protecting it against breaks and leaks (CAWST 2009).

The treated water should be collected by the user in a safe storage container placed on a block or stand, so that the container opening is just under the outlet, minimizing the risk for recontamination (CAWST 2009).

Fig.1.2 Plastic version of biosand filter connected to traditional water storage recipient (canari). Source: left: WORLD NEWS INC. (n.y.); right: HYDRAID (n.y.)

The BSF removes contaminants from water using four methods: mechanical trapping, predation, adsorption and natural death. The mechanical trapping mechanism occurs when solids and microbes suspended in the water are trapped in the small spaces between sand grains.

Pathogens and suspended solids are removed through a combination of biological and physical processes that take place in the biofilm layer and within the sand layer. These processes include mechanical trapping, predation, adsorption, and natural death (NGAI et al. 2007; EAWAG/SANDEC 2008; CAWST 2009).

- Mechanical trapping and sieving: Suspended solids and pathogens are physically trapped in the spaces between the sand grains.

- **Adsorption** and attachment: Pathogens become attached to each other (and thus more easily sieved), suspended solids in the water, and the sand grains.
- Predation: Pathogens are consumed by other microorganisms in the biological layer. This biological layer matures over one to three weeks, depending on volume of water put through the filter and the amount of nutrients and micro-organisms in the water.
- Natural death: Pathogens finish their life cycle or die because there is not enough food or oxygen for them to survive.

➢ **Effectiveness**

The biosand Filter is a proven technology, which removes pathogens such as bacteria, protozoa and helminth. BSFs are also somewhat effective for the removal of virus (CAWST 2009). Physical parameters such as turbidity and iron are also eliminated from drinking water. However, dissolved chemicals (such as organic pesticides or arsenic) are not removed. The treated water generally has an agreeable colour, taste and odour.

Table-1.3 The table below shows the biosand filter treatment efficiency in removing pathogens, turbidity and iron (adapted from CAWST 2009).

	Bacteria	Viruses	**Protozoa**	**Turbidity**	Iron
Laboratory	Up to 96.5% (BUZUNIS 1995; Baumgartner 2006)	70 to >99% (Stauber et al. 2006)	>99.9% (Palmateer et al.1997)	95% (BUZUNIS 1995);	Not available
Field	87.9 to98.5% (Earwaker 2006; Duke & Baker 2005)	Not available	Not available	85% (Duke & Baker 2005)	90-95% (NGAI et al. 2004)

Health impact studies estimate a 30 to 47% reduction in diarrhea among all age groups, including children under the age of five, an especially vulnerable population group. Source: SOBSEY (2007); STAUBER et al. (2007)

➢ **Operation & maintenance**

The flow rate through the filter will slow down over time as the pore openings between the sand grains become clogged. For turbidity levels greater than 50 NTU (Nephelometric Turbidity Units), the water should first be strained through a cloth or sedimented before using the BSF (CAWST 2009). When the flow rate drops to a level that is inadequate for the household use the filter needs to be cleaned. This is done by a simple 'swirl and dump' procedure performed on the top of the sand, and only takes a few minutes (CAWST 2009).

The swirl and dump process consist in agitating the surface sand, thereby suspending captured material in the standing layer of the water (see **cawst.org**). The dirty water is than removed and dumped away. The process can be repeated as many times as necessary to regain the desired flow rate. The need for cleaning depends on the amount and quality of water being put through the filter.If the water is relatively clean (turbidity less than 30 NTU), the filter can likely run for several months without this maintenance procedure.

When a BSF is used for the first time, there is no biofilm yet. The biological layer typically takes 20 to 30 days to develop to maturity in a new filter depending on inlet water quality and usage (CAWST 2009). Removal efficiency and the subsequent effectiveness of the filter increase throughout this period. After cleaning, a re-establishment of the biological layer takes place, quickly returning removal efficiency to its previous level.

- **Applicability**

BSF are suitable for the treatment of water at household-, school- or community-level. BSF can efficiently and directly treat contaminated surface or ground water since it also removes turbidity and iron. However, it is recommended not to use water with turbidity more than 50 NTU. Further, dissolved chemicals (e.g. organic pesticides or arsenic) are not removed.

Chlorinated water should not be poured into this filter as chlorine kills microorganisms presented in biofilm resulting in low pathogen removal performance. Nevertheless, the water can be chlorinated after filtration in order to improve the security for elderly or infant members of the household/community.

A BSF should be constructed only by trained technicians. Though the construction and installation look very simple, incorrect filter design and installation can lead to poor filter performance. However, materials are generally locally available and the construction by trained local staff may create opportunities for local business.

Chapter – 2

Objective and Scope of Work

2.1 OBJECTIVE

There were two significant research objectives and one minor research objective that were focused on during this project.

- The first significant objective was to identify the most effective filter media layering arrangement for the sand filtration system while incorporating the innovative materials.
- The second significant objective was to analyze the longevity of the sand filtration system over a 30 to 50-day testing period

An attempt has been made to investigate the performance of Bio-sand filter (BSF) prepared with locally available materials in removing contaminants from surface water

This study investigated the feasibility of use bio-sand filters for household water treatment as an option to improve drinking water quality at household level

2.2 SCOPE OF WORK

The scope of work will comprise the following:

I) Collection of sand whose effective size (D_{10}) is 0.2-0.35 mm and uniformity co-efficient (C_u) 2.2 average.

II) Collection of gravel whose size is 3-20 mm.

III) Collection of two plastic container and necessary pipes fitting with them

IV) Collection of contaminated raw water from river

V) Fixation of filtration rate of sand filter as per requirement

VI) Collection of filter water in plastic bottles

VII) Testing of raw water sample and filter water sample. The parameters to be tested are pH, turbidity and fecal coliform.

VIII) Necessary conclusion made based on obtained results, analysis and performance of sand filter.

Chapter – 3

Literature review

Literature review

The formations of the biofilm layer in the biosand filters are very similar to the slow sand filters. The key difference is that the required oxygen needed to form the biofilm is provided to the system from the standing water layer rather than continuous flow using the slow sand filtration system (Lynn et al., 2013). The filtration rate is a key component in establishing that the biofilm layer has possibly formed. The flow rate will decrease if the biofilm formed.

The filtration rate can decrease to a standstill if proper maintenance cleaning is not completed. For household biosand filtration systems, the most common method is to agitate the top part of the sand layer and scoop out the suspended biofilm from the water and replaced with non-chlorinated water (Kubare & Haarhoff, 2010; Napotnik et al., 2017). There are multiple standards that have been used to determine when to remove the biofilm layer which include when the flow rate drops below 0.5 L/min (Lynn et al., 2013) or when the

Flow rate drops below half the initial flow rate (Napotnik et al., 2017). However, it is important to note that a low flow rate does not affect the quality of the filtered water (CAWST, 2009). Regular cleaning of the filter, diffuser plate, outlet tub, and storage tanks are needed to minimize further contamination.

Lynn et al. (2013) completed a biofilm test using biosand filters. A 107-day study was completed with regular cleaning if the flow rate was less than 0.5 L/min. After the 107-day cycle was completed, the filter media was collected at different depth in the biofilm layer and sand layer. On visualization the depth of the biofilm layer was 1.3 cm (Lynn et al., 2013). The biofilm layer sample and sand samples were analyzed using a kit with bicinchoninic acid. The total protein concentration in the biofilm layer was 22% which was tripled the amount of protein the sand layers (Lynn et al., 2013). Therefore, the biofilm layer has higher chances through filtration and adsorption to have bacteria growth and retaining microbes than the sand layer.

- **History of Slow Sand Filtration**

Earliest records of drinking water treatment date back to 4000 B.C., where Sanskrit and Greek text mention the aesthetic improvement of drinking water by means of charcoal filtration, straining, sunlight exposure, and boiling. Around 1500 B.C., chemical alum was first used by the Egyptians to clarify water by flocculation and sedimentation. 3300 years after Egypt's discovery of alum clarification, slow sand filtration finally surfaced as a common method of drinking water treatment (EPA 2000).

The first recorded slow sand filter for water treatment was experimentally developed by John Gibb in 1804 for his bleachery in Paisley, Scotland, where surplus treated water was sold to the public. Practical details of slow sand filtration were improved upon by Gibb and others, which resulted in the installation of a slow sand filtration system in London for the Chelsea Water Company in 1829 by James Simpson. The advantages of water filtration were so evident in aesthetic water quality that all water collected from the River Thames within 5 miles of St Paul's Cathedral was to be 4

Filtered prior to public distribution under the metropolis water act of 1852(Huisman and wood 1974)Although water filtration was seen as advantageous to water quality during the mid-1800's, water quality was primarily determined by visual means; filters were simply viewed as a mechanical method of removing turbidity and suspended solids (Huisman and Wood 1974). In 1855, epidemiologist John Snow monitored a cholera outbreak in London. Dr. Snow determined that the disease was caused by consumption of water from a public well that had been contaminated by sewage. By the end of the 1800's,

Louis Pasteur had established "germ theory", which described the transmission of disease by microorganisms via water and other media. Such discoveries shifted the focus of drinking water quality toward pathogens and methods of contamination removal (EPA 2000).
The effectiveness of pathogen removal by sand filtration was demonstrated by another cholera epidemic along the River Elbe in 1892, where neighboring cities of Hamburg and Altona both drew their drinking water. Hamburg distributed water without filtration, while down-stream Altona filtered its entire water supply. Cholera infections in Hamburg caused the death of 1.3% of its population, while Altona largely avoided the epidemic with less than 0.3% drop in population due to cholera. Many of 5

- ***Biosand Filtration and Traditional Slow Sand Filtration***

The Biosand filter is a point-of-use (POU) water treatment technology developed in the 1990's by Dr. David Manz, who hypothesized that the primary component responsible for contaminant removal in slow sand filters is the biological layer, known as the *Schmutzdecke* (Buzunis 1995). However, little direct evidence of significant removal of contaminates by biological mechanisms in Biosand filters is present in literature, with the exception of virus removal (Elliott, DiGiano, and Sobsey 2011). Unlike traditional slow sand filters (TSSF) which are continuously operated, the Biosand filter was designed to be intermittently operated by the use of a swan-necked effluent pipe which maintains a resting supernatant depth of approximately 5 cm, 6 allowing for the diffusion of oxygen to the *Schmutzdecke* while the filter is not in use. The ability of the BSF to operate intermittently eliminates the necessity of engineered water supply, distribution, and storage systems that are cost-prohibitive in many situations. The filter bed depth of BSFs is smaller than it is for TSSFs, ranging from 0.8 m to 2 m in total height, where TSSFs are 3.5 m to 4 m. Another important difference between TSSFs and BSFs is the cleaning and maintenance process; the surface media of BSFs are gently agitated by hand and a significant portion of the supernatant is removed such that no filter media is lost. TSSFs use a system of harrowing (raking the filter surface) and scraping (removing media from the filter surface) to maintain acceptable filtration rates (Manz 2008).

- **BSF Performance Comparison with Other Point-of-Use Water Treatment Technologies**

The majority of Biosand filter research to date has assessed filtration performance by one of three general methods: recording diarrheal disease reduction after BSF implementation in households, measuring the removal and inactivation of indicator organisms, and measuring the removal and inactivation of indicator viruses. Research on the removal of arsenic and indicator viruses with iron-amended BSFs has also been conducted. Field studies that recorded instances of diarrheal disease amongst communities where BSFs were implemented have shown approximately 40 to 60 % reduction of diarrheal disease (Stauber, Ortiz, and Sobsey 2007; Stauber, Ortiz, et al. 2009; Stauber, Fabiszewski, et al. 2009; Jenkins, Tiwari, and Darby 2011). During the initial 6 months of BSF implementation in Bonao (Dominican Republic), households with BSFs reported 45% less diarrheal disease than households without BSFs (Stauber, Ortiz, and Sobsey 2007). Further study of BSF implementation in Bonao showed that incidents of diarrheal disease in households with BSFs were 53 % of incidents recorded in control households (Stauber, Ortiz, et al. 2009). In Ghana and Cambodia, a case study showed that households with BSFs reduce cases of diarrheal disease by 60% (Stauber, Fabiszewski, et al. 2009).

Reduction of incidents of diarrheal disease is particularly important because 90% of diarrheal disease related deaths occur in children under the age of 5 (WHO 2004). Along the River Njoro (Kenya), mothers of households were asked how many days their children (less than or equal to 15 years of age, with at least one child 4 years old or younger) had diarrhea on a weekly basis. The 30 households with BSFs reported that children spent 2.0% of days with diarrhea while the 29 households in the control group reported 5.2% (Tiwari et al. 2009). Although recording instances of diarrheal disease is the most direct method of determining the impact of the implementation of a technology, all of the formerly discussed studies lack methodology to determine any biased over- or under-reporting of diarrheal episodes

Indicator organisms, like *E. coli*, have been used to assess the performance of BSFs in both controlled laboratory experiments and in-the-field assessments. Membrane filtration methods have frequently been used for the enumeration of indicator bacteria in both situations (Buzunis 1995; Palmateer et al. 1999; Stauber et al. 2006; Elliott et al. 2008; Jenkins, Tiwari, and Darby 2011). Previous field studies in Bonao (Dominican Republic), and along the River Njoro (Kenya), have shown greater than 80% mean reduction of indicator bacteria in BSFs and 50-66% lower mean indicator bacteria concentrations in drinking water of households with BSFs when compared to households without BSFs (Stauber et al. 2006; Stauber, Ortiz, et al. 2009; Jenkins, Tiwari, and Darby 2011).

Laboratory studies of BSFs frequently report greater than 90% reductions of indicator bacteria (Buzunis 1995; Stauber et al. 2006; Elliott et al. 2008; Jenkins, Tiwari, and Darby 2011) and 99.98% removal of Cryptosporidium oocysts and 100% removal of Giardia cysts in BSFs has been observed (Palmateer et al. 1999). However, variables such as pause time between filter dosing, volume of the dosing, influent water characteristics, and duration of filter operation can influence indicator bacteria removal efficiency. Like traditional slow sand filters, BSFs require a maturation period to achieve high removal efficiencies; however the duration of this period may differ due to varying influent water properties, dosing regimens, operator behavior, filter media properties, and environmental conditions (Buzunis 1995; Baumgartner, Murcott, and Ezzati 2007; Elliott et al. 2008; Kubare and Haarhoff 2010). Although many operational observations have been made in literature regarding dosing volume, pause time between dosing, and their relation to indicator bacteria removal efficiency, further research is needed to determine relationships to describe the optimum operational parameters for a particular household's water volume requirement (Baumgartner, Murcott, and Ezzati 2007).

Indicator viruses have been used to assess the BSF for the removal of pathogenic viruses and have been conducted with Echovirus type 12, PRD-1, and MS-2 viruses. Echovirus type 12 exhibited removals in BSFs ranging from 1 log unit to greater than 3 log units (90% to greater than 99.9%), while the geometric mean of reduction after 30 days was 2.1 log units (99.2%) (Elliott et al. 2008). Removal of bacteriophages MS2 and PRD-1 have ranged from 0 logs to 1.3 log units (0 to 95%), while geometric mean of reduction has been reported at 0.5 log units (70%) (Elliott et al. 2008). Due to differences in removal between Echovirus type 12 and Bacteriophages, virus reduction in BSFs may be dependent on the specific virus (Elliott et al. 2008). Continued research on MS2 and PRD-1 reduction in BSFs showed that reduction did not occur when microbial activity was inhibited by sodium azide, where first order reduction of MS2 and PRD-1 normally occurred during the idle time in BSFs (Elliott, DiGiano, and Sobsey 2011).

Iron amended BSFs have also shown promise in removal of viruses and arsenic from drinking water. Over 20 pore volumes of dosing water, a sand-only column exhibited 0.5 log units removal of MS2 bacteriophage, where an iron-amended sand column removed 5 log units, and iron amended BSFs performed above 4 log units removal (Bradley et al. 2011). However, influent phosphate concentrations greater than 0.5 mg/L and iron concentrations less than 5 mg/L have been observed to hinder arsenic removal in amended BSFs (Chiew et al. 2009).

Point-of-use water treatment is not limited to slow sand filtration; solar disinfection (SODIS), chlorination and safe storage, chlorination and coagulation, and ceramic filtration are other well documented methods. These water treatment methods have been compared and evaluated by sustainability criteria, including water quantity, water quality, ease of use, cost, and required supply chain. Each water treatment method was rated on a scale of 1 to 3 for each sustainability criteria. BSFs were determined to be the most sustainable technology, closely followed by ceramic filters. Although more expensive to initially implement than ceramic filters, BSFs are capable of producing a larger quantity of water and require practically no supply chain after implementation due to the greater durability of BSFs (Sobsey et al. 2008).

In a meta-regression study which compared various POU water treatment technologies, ceramic filters were determined to be the most effective technology for the prevention of waterborne disease over the duration of 52 weeks. However, only three un-blinded studies of Biosand filters have been included in the meta-regression, none of which exceeded 26 weeks of data, suggesting that at least one large-scale, preferably blind, 52 week-long study is needed to properly assess the disease risk with the implementation of Biosand filters (Hunter 2009). Nonetheless, the meta-regression study indicates that chlorination, SODIS, and chlorination with coagulation (disinfection methods) have little or no health benefit over a 12 month period when implemented in developing country situations (Hunter 2009).

The failure of disinfection methods to reduce disease risk may be linked to the decrease in post-implementation compliance (Rainey and Harding 2005; Sobsey et al. 2008; Hunter 2009). Compliance with BSFs is greater than 85% and ceramic filters can be as high as 88% post-implementation, but ceramic filters are prone to breakage and sub sequential abandonment (Sobsey et al. 2008). Although post-implementation compliance may be initially higher for ceramic filters, the more durable BSFs are arguably a superior long-term solution for POU water treatment.

Biosand filters depend on the availability of crushed quarry rock, which in some locations may not be available, or the material cost may be unaffordable. When such situations occur, the implementer of the BSF technology has historically replaced the crushed quarry rock with the best available media, including, but not limited to aggregate and sand from rivers and beaches (Manz 2007). However, research investigating the use of alternative filter media in BSFs is lacking, with the exception of iron-amended BSFs. In order to identify the best alternative media sources and media preparation practices, BSFs with various types of media and preparation practices need to be evaluated and compared to traditional BSFs using crushed quarry rock.

The death in Altona was suspected to have occurred as a result of infection while visiting neighboring Hamburg (Gainy and Lord 1952).
The first slow sand filters in the United States were installed in 1885, and in 1899, the first automatic pressure filters were patented in England. Various improvements, modifications, and variations of the

slow sand filter have since been developed, but these changes have primarily focused on the construction, operation, and control of the filter (Huisman and Wood 1974).
The death in altona were suspected to have occurred as a result of infection while visiting neighboring humburg (Gainy and Lord 1952)

The first slow sand filters in the United States were installed in 1885, and in 1899, the first automatic pressure filters were patented in England. Various improvements, modifications, and variations of the slow sand filter have since been developed, but these changes have primarily focused on the construction, operation, and control of the filter (Huisman and Wood 1974).

- **Function:**

According to Huisman et. Al (1974), biological filtration is the best water treating method to improve surface water's physical, chemical and bacterial quality. As the water is flowing within the filter, it is being exposed to mechanisms that can improve the water quality of the influent water. Mechanisms acting within the filter to improve the water's quality are; transport mechanisms, attachment mechanisms and purification mechanisms. The mechanisms are interdependent to each other to improve the best water quality in the effluent water (Huisman et al. 1974).

Some of the mechanisms are dependent of the flow rate through the filter. The flowrate through the filter is proportional to the cross-sectional area of the sand, the water loading head (hydraulic head) above the outlet of the sand filter, length of the sand filter, properties of the flowing fluid and properties of the sand. By using coarser sand particles, or decreasing the sand height, will result in high flow rates through the filter bed (Biosand filter, 2004). Smaller sand particles provide higher surface area per unit volume than coarser once, which increases the flow resistance. The pressure drop will increase further if the flow is turbulent inside the filter. The sand particles within the filter will reduce the area where the water can flow through. With reduced area, the fluid will have to squeeze through the grains of sand which will increase the velocity within the sand bed (Holdich, 2002).

Transport mechanisms

Transportation is a mechanism which brings impurities, e.g. particles andMicroorganisms, within the water into contact with the sand grains. Transport mechanisms depend primarily on the physical properties (i.e. size, shape and density) of the particles (Thames Water and University of Surrey, 2005).
According to Huisman et al. (1974), some of the transport mechanisms are; straining,sedimentation, inertial and centrifugal forces, diffusion and electrometric attraction. According to Binnie et al. (2002), the transport mechanisms are; sedimentation, diffusion and hydrodynamic action.
Straining, occur when the particle size is larger compared to the pore opening between the sand grains and is independent of the filtration rate. It takes place almost entirely at the surface of the filter (Huisman et al. 1974). Particles in the influent water decreases the pore volume within the filter as it settles between the sand grains, which increases the straining and head loss across the upper sand layer. Therefore, straining should be avoided in the sand filter by a pre-treatment method.
So the bigger particles are being removed (Thames Water and University of Surrey, 2005). Also, the straining mechanism increases due to the development of the schmutzdecke which is a purification

mechanism within the filter that will be described later (Huisman et al. 1974). **Sedimentation** uses the gravitational forces to remove particles from the influent water. It is dependent of the settling velocity of the suspended matter and the velocity of the fluid through the filter, which makes large and dense particles to be, removed more effectively (Binnie et al. 2002).

Compared to a conventional settling tank, the sedimentation within the filter utilizes the total upward-facing surface of the grain media and not only the bottom (Huisman et al. 1974).**Inertial and centrifugal forces.**A mechanism when suspended particles leave the stream lines,due to higher density than the water, and come into contact with the sand grains (Huisman et al. 1974). Greater surface load increases the inertial mechanism (Thames Water and University of Surrey, 2005) since the mechanism does not occur when the velocity and Reynolds numbers are low (Binnie et al. 2002). **Diffusion**, also called Brownian movement in fluids, occur in the whole depth of the filter (Huisman et al. 1974). It mainly brings very small suspended matter (Binnie et al. 2002) into contact with the filtration media and is independent of the filtration rate, even when the water is not flowing in the filter (Huisman et al. 1974). The particles in the influent water will move randomly between streamlines till it collides with a media grain (Thames Water and University of Surrey, 2005).

Diffusion depends on the water's temperature and size of the suspended matter and 10 media grain size, higher temperature and small suspended matter and media grain size increases the diffusion (Binnie et al. 2002).
Electrostatic and electrometric attraction keeps the particles stuck to the grain of media after it have been brought in contact.

Hydrodynamic action is dependent on the velocity gradient of the suspendedmatter near the media grains.Due to the velocity gradient, the particles within the influent water tend to rotate which causes a pressure difference across the particles that later brings into contact with the grains of media. This is not a main mechanism within the filter (Binnie et al. 2002).

- **Attachment mechanisms**

Helps the particles to be attached to the grain of media once they have been brought to contact.The attachment mechanisms are; electrostatic attraction, Van der Waals force and adherence**.** The particles in the influent water may be either attracted to or repelled by the grain of media depending on the electrostatic charge of the particular matter (Huisman et al. 1974). Particles will follow the stream through the filter till it is being attracted to a grain of media with an opposite charge.

Van der Waals force helps the particles to stay at the grain surface once they have been brought into contact. In some cases, the particles can be drawn to the grain of media even though the force is small (Huisman et al. 1974)**.** As water is flowing through the filter, organic matter is being arrested on the grain of sand at the sand surface. Later, it develops a slimy layer, called zoogloea, of organisms and bacteria over the schmutzdecke which adhere particles of organic and inert matter in the influent water. The organic matter is later being a part of the zoogloea while the inert matter will be removed once sand is being removed (Huisman et al. 1974)

- **Purification mechanisms**

Compared to the rapid sand filter, slow sand filter has the ability to develop a biological layer, called schmutzdecke, which improves waters biological and chemical quality (Huisman et al. 1974).The word schmutzdecke comes from
Germany and means 'dirty layer' in English (Binnie et al. 2002).It appears as a reddish-brown sticky film, consisting of algae, protozoa, bacteria and other form of decomposing organic matter. The schmutzdecke is removing and breaking down organic matter and microorganisms in the influent water which improves the quality of the water. The schmutzdecke uses organic matter and microorganisms as food in the influent water as energy for their metabolism (dissimilation) and to form cell material (assimilation). The bacterial activity goes down to a depth of 30-40 cm and is dependent of the organic material in the influent water. There is bacterial below 30-40 cm, but since much of the food is being consumed in earlier stages the activity is low compared to the top (Huisman et al. 1974). To obtain a good biochemical oxidation of organic matter, the time, concentration of oxygen and temperature is important.

It is also important for microorganisms to have aerobic conditions within the filter. An anaerobic condition will encourage production of odor- and taste-producing substances, like hydrogen sulfide and ammonia. Also, low concentration of dissolved oxygen will produce dissolved metals, like iron and manganese, which make it inappropriate to use be used as a water source for drinking and washing. To avoid anaerobic conditions should the average dissolved oxygen concentration be at least 3 mg/l (Huisman et al. 1979).

Chapter – 4

Methodology of the work

4.1 Field methodology

- **Biosand Filter Components:**

1. Lid – Tightly fitting lid prevents contamination and unwanted pests.
2. Diffuser – Prevents disturbing the filtration sand layer and protects the biolayer when water is poured into the filter
3. Outlet Tube – Required to conduct water from the base to the outside of the filter..
4. Filter Body – Holds the sand and gravel layers.
5. Filtration Sand Layer – Removes pathogens and suspended solids.
6. Separating Gravel Layer – Supports the filtration sand and prevents it from going into the drainage layer and outlet tube.
7. Drainage Gravel Layer – Supports the separating gravel layer and helps water to flow into the outlet tube.

- **How Does the Biosand Filter Work?**

The biosand filter has five distinct zones:

1) Inlet reservoir zone,
2) Standing water zone,
3) Biological zone,
4) Non-biological zone, and
5) Gravel zone.

1. Inlet Reservoir Zone - Where water is poured into the filter
2. Standing Water Zone – This water keeps the sand wet while letting oxygen pass to the biolayer
3. Biological Zone – Develops at the top 5-10 cm (2-4") of the sand surface. The filtration sand removes pathogens, suspended particles and other contaminants.

As in slow sand filters, a biological layer of microorganisms (also known as the biolayer or schmutzedecke) develops at the top 1-2 cm (0.4-0.8") of the sand surface.

4. Non-Biological Zone – Contains virtually no living microorganisms due to the lack of nutrients and oxygen.
5. Gravel Zone – Holds the sand in place and protects the outlet tube from clogging.

Fig.4.1 full setup of Biosand filter

Pathogens and suspended solids are removed through a combination of biological and physical processes that take place in the biolayer and within the sand layer. These processes include: mechanical trapping, predation, adsorption, and natural death.

Mechanical trapping: Suspended solids and pathogens are physically trapped inthe spaces between the sand grains.

Predation: Pathogens are consumed by other microorganisms in the biolayer.

Adsorption: Pathogens become attached to each other, suspended solids in the water, and the sand grains.

Natural death: Pathogens finish their life cycle or die because there is not enough food or oxygen for them to survive. Contaminated water is poured into the reservoir on an intermittent basis. The water slowly passes through the diffuser and percolates down through the biolayer, sand and gravel. Treated water naturally flows from the outlet tube.

➢ **METHOD**

The filter media that are used in the biosand filtration system are sand and gravel. The sand is primarily used as the filtering medium to remove suspended solids and chemicals. However, the gravel is used to prevent clogging in the system.

- **Sand:**

Two types of sand were used to analyze the change in filtration based on the sand size and shape. The particle size distribution was determined for the two types of sand.

Performing a sieve analysis following the ASTM C136-14 (2014) standard.A plot of cumulative percent passing versus particle size was created. From this plot, the effective size (D10) and uniformity coefficient (Cu) were determined. The D10 is the diameter from the particle size distribution curve at 10% finer. Cu is the ratio of D60 and D10 and is primarily used to determine the gradation of the sand. The coarse sand had a D10 of 0.16 mm and Cu of 2.8 while the fine sand had a D10 of 0.21 mm and Cu of 2.23. Based on research, for sand filtration systems the D10 should be 0.15-0.20 mm and Cu should be 1.5-2.5 (Elliot et al. 2008). These recommended values have a direct relationship to the desired flow rate of the sand filtration system which is 0.5-1.1 L/min. Exceeding the desired flow rate can create craters in the filter media and reduce the efficiency of the filter. Therefore, the D10 values are within the range with some tolerances. However, the Cu values are outside the range which must be considered a factor if inadequate filtration rate occurs. The specific gravity of both sands was determined following the ASTM C128-15 (2015) standard. This procedure involves oven drying the material, weighing a fully dried pycnometer, adding the sample to the pycnometer and adding de-aired water to the pycnometer. The specific gravity is determined by dividing the mass of the pycnometer and water by the differences in mass of the pycnometer and water and the mass of the oven-dried soil. The specific gravity of the coarse sand was determined to be 2.68. The specific gravity of the fine sand was determined to be 2.8. Based on the conditions for well graded sand, both sands were poorly graded.

Fig.4.2 sand sample

- **Gravel:**

Two sizes of gravel are generally added to the sand filtration system to prevent clogging in the outlet tube of the filter and provide structural support of the sand layer. The specific gravity of the gravel was determined following the ASTM C127-15 (2015). This procedure involves oven drying the material, submerging the material in room temperature water, and saturated-surface-dry sample. The specific gravity was calculated by dividing the mass of oven dried sample by the difference of submerged mass and saturated-surface-dry mass. The larger gravel had a size of 15 mm(av) with a specific gravity of 2.63 while the smaller gravel had a size of 8 mm (av) with a specific gravity of 2.56

Plastic container, sand from crushed rock, gravel, filter fittings, pond water and Commercial "Bleaching powder" as free chlorine source to analyze free chlorine residual. The BSF was made by using locally available plastic container, sand and gravel .The containers was first cleaned with tap water, and were filled with 25cm gravel and 25 cm sand layer in succession. Water was present in the containers before loading the filter media to avoid any occurrence of air spaces and short circuiting.

The outlet pipe was provided in such a manner that a standing water layer depth of 3 cm is maintained over the filter media. A plastic diffuser plate was placed on the lip of the filter to avoid disturbance to the top layer of sand during daily charging of the filter with source water. The filters had a pore volume of 12 L

The test was conducted at room temperature, and water temperature varied in the range of 26– 34°C during the testing period. River water was used as feed water for the filter, and the

Freshly filtered water was collected from the BSF outlet pipe. Time between collection and analysis was minimized and analysis was done immediately after collection of the last sample and it was no longer than three to four hours.

Fig.4.3 gravel sample

- **Preparation of filter media**

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

Fig.4.4 Biosand filter

- **Study area:**

The raw water collected from Ramkrisnapur ghat, Ganga ghat and its surrounding areas which are located on the west bank of river Hooghly within the Howrah Corporation of west Bengal have been identified as study area. The latitude of Howrah, west Bengal, India is 22.595770 and the longitude is 88.263641. Howrah is a municipality and a large district in the state of west Bengal, India. This is one of the most eastern parts of the country known for its specific flora and fauna, plenty of places of interest, and soft climate.

- **Testing of sample:**

The collected water samples were filtered through the sand filter upon arrival in the laboratory. Filtration was carried out for 3h with the assumption that enough purified water would have been produced over this period of time for drinking and cooking. Different volumes of filtrates were collected at 1h intervals over the 3h period of filtration. This was done to establish whether there was a difference in the reduction of chemical contaminants at different times and to make the necessary adjustments and recommendations. The collected samples were analyzed in triplicate to determine the water quality after filtration.

In all the above cases, after collection of sample, immediately the same was tested for presence offecal coliform bacteria by bacteria coliform detection kit / bacteria detection kit (H_2S strip). The resultin this process indicated the presence of total coliform or not. At the same time, the samples were analyzed for physiochemical test for different parameters thatis **pH**, **turbidity**, **total dissolved solid** (TDS), **total hardness** (TH), **chloride** and**fecal coliform**as perprocedure as laid down in APHA.

4.2 Laboratory method

- **Parameter analysis procedure:**

Sl no	Parameter	Analysis procedure
1	pH	➢ Ph is measured by Ph meter. ➢ Switch on the meter ➢ Calibrate Ph combination electrode with 3 point calibration by pH solution(I.e. 4,7and 14),then the meter will enter Ph measuring working state automatically. ➢ Immerse the pH electrode in sample and the pressrun" button, the meter enter pH measuring working state and shows the present pH value, temperature value of the solution and percentage slope and selected iso-potential point of the electrode of measured solution
2	Total Dissolved Solid(TDS)	➢ Total dissolved solid is measured by TDS meter. ➢ Switch on the meter ➢ Calibrate TDS combination electrode with 500 mg/l NaCl solution, then the meter will enter TDS measuring working state automatically ➢ Immerse the TDS electrode in sample and then press RUN button, the meter enters TDS measuring working state and shows the present TDS value, temperature value of the solution.
3	Turbidity	➢ Turbidity is measured by turbidity meter ➢ Switch on the meter. ➢ Calibrate turbidity meter with 100 NTU, 20 NTU,AND 10 NTU SOLUTION,then the meter will enter turbidity measuring working state automatically ➢ Pour the sample in sample cell and insert in the proper place (i.e. sample holder)of turbidity meter and then press RUN button the meter enter turbidity measuring working state and shows the present turbidity Value
4	Chloride	➢ Chloride is measured Argentrometric method ➢ Standardization of $AGNO_3$=(volume of NaCl)x(strength of NaCl)/(volume of $AgNO_3$) ➢ Reagent blank value is obtained by titrating chloride free water with Agno3 solution of known strength. ➢ Finally,we have to take 50 ml sample in a measuring cylinder,0.5 ml K_2CrO_4 indicator has to be added to the sample. Then titrate it with standard $AgNO_3$ Titrant with pinkish yellow end point. ➢ Chloride content per sample(mg/l)

		=[(V_S-V_A)XS X35.45X1000]/A =(V_S-V_AX10 Where V_S=volume of $AgNO_3$ titrant for sample V_B=volume of $AgNO_3$ titrant for distilled water A=amount of sample taken=50ml S=exact strength of $AgNO_3$=0.0141(N)
5	Total hardness	➢ Total hardness is measured EDTA titration method ➢ Take 25 ml of sample ➢ Add(1-2) ml buffer solution ➢ Add (1-2)drops of indicator solution ➢ Then titrate with the standard EDTA titrant by adding slowly with continuous stirring until the last reddish colour disappears from the solution.the colour of the solution at the end point is blue under normal condition ➢ Total hardness(EDTA) as $CaCO_3$=(AXBX1000)/C mg/l Where A=ml of EDTA used in titration B= mg $CaCO_3$ equivalent to 1.00 ml EDTA titrant=1 C= ml of sample used for the test=25ml
6	Fecal coliform	➢ H_2S strip test is a simple device based on hydrogen sulphide indicator bacteria for carrying out bacteriological examination of drinking water. ➢ H_2S paper strip method: The hydrogen sulphide paper strip method developed byManja et al (1982) is an onsite testing method for assessing the microbial quality of drinking water, based ondetection of hydrogen sulphide producing bacteria rather than the coliform bacteria. Human faces contain a highconcentration of sulphate reducing bacteria and some of the enteric bacteria such as salmonella, proteus, citrobacter and some strain of lebsiella, also produce Hydrogen sulphide. ➢ Sterilized paper strip treated with media is kept in sterilized glass bottle. ➢ The water sample is filled in the bottle and kept for 24 to 48 hours at room temperature (25 to 37 c).if bacteria are present in the sample, they produce hydrogen sulphide, and ehich convert the colour of water sample into black. ➢ Procedure followed: As per H_2S paper strip manufacturer's specification andinstruction I filled the water sample in the tube containingH_2S paper strip up to the identified mark.The sample tubewas kept in a biological incubator at a constant temperature of 37.5 c for 24 hours. At the end of thisperiod the water sample which showed black colourindicated presence of bacteria. On the other hand thesample free from bacteria indicated no colour changes after the said incubation period.

Chapter – 5

Parameter and drinking water standard

5.1pH

Natural water sources mayhave a lower pH due to acid rain and higher pH due to contamination fromlimestone areas. The pH does not have any direct impact on the consumers, but it isan important parameter in distribution systems since water with a pH lower than 7are more likely to be corrosive. Failure to minimize corrosion can result in thecontamination of drinking-water and in adverse effects on its taste and appearance if corrosion would occur it will have an unfavorable impact on tasteand appearance.

pH is an important measurement of water. Not only does the pH of a stream affect organisms living in the water, a changing pH in a stream can be an indicator of increasing pollution or some other environmental factor.pH is a measure of how acidic/basic water is. The range goes from 0 - 14, with 7 being neutral.ph of less than 7 indicate acidity, whereas a pH of greater than 7 indicates a base.pH is really a measure of the relative amount of free hydrogen and hydroxyl ions in the water. Water that has more free hydrogen ions is acidic, whereas water that has more free hydroxyl ions is basic. Since pH can be affected by chemicals in the water, pH is an important indicator of water that is changing chemically.pH is reported in "logarithmic units". Water with a pH of 5 is ten times more acidic than water having a pH of 6.

Importance: The pH of water determines the solubility (amount that can be dissolved in the water) and biological availability (amount that can be utilized by aquatic life) of chemical constituents such as nutrients (phosphorus, nitrogen, and carbon) and heavy metals (lead, copper, cadmium, etc.).For example, for heavy metals, the degree to which they are soluble determines their toxicity. Metals tend to be more toxic at lower pH because they are more soluble.*pH and water quality*: Excessively high and low pH can be detrimental for the use of water. High pH causes a bitter taste, water pipes and water-using appliances become encrusted with deposits, and it depresses the effectiveness of the disinfection of chlorine, thereby causing the need for additional chlorine. Low-pH water will corrode or dissolve metals and other substances. Pollution can change pH of water, which in turn can harm animals and plants living in the water.

As per IS-10500 the pH for drinking water should be between6.5-8.5.

5.2 TURBIDITY

The turbidity is presented by nephelometric turbidity units (NTU) and can be seenby the naked eye by 4 NTU. Turbidity describes the amount of suspended particlesor colloidal matter in water that prevent the light from transmission through the water. The cloudiness in the water may be caused by inorganic or organic matter. Turbidity itself is not a threat to the human health, but it is an important indicator since microorganisms, like bacteria, viruses and protozoa, has the characteristics of being attached to particulates which may contaminate the water. Methods ofreducing the turbidity are by coagulation, sedimentation and filtration. Filtrationwill also reduce the contaminations of microorganisms (WHO, 2011). To ensureeffectiveness of disinfection the turbidity level should not be more than 1 NTU.According to WHO (2011), large scale water supplies should be able to achievewater with a turbidity of 0.5 NTU or less. Small scale water supplies, on the otherhand, may not be able to produce low turbidity water due to economic aspects andlimited resources. Where the treatment is limited, the aim should be to achieve turbidity of 5 NTU or less (WHO, 2011). Guidelines from The Swedish NationalFood Agency shows that water treatment plants should be able to produce waterwith a turbidity of

0.5 NTU. Water in costumers tap or bottled water should not bemore than 1.5 NTU (Swedish Food Agency, 2015)

Turbidity is the measure of relative clarity of a liquid. It is an optical characteristic of water and is an expression of the amount of light that is scattered by material in the water when a light is shined through the water sample.The higher the intensity of scattered light, the higher the turbidity. Material that causes water to be turbid is suspended solids such as include clay, silt,finely divided inorganic and organic matter, algae, soluble colored organic compounds, and plankton and other microscopic organisms. Turbidity makes water cloudy or opaque. Excessive turbidity, or cloudiness, in drinking water is aesthetically unappealing, and may also represent a health concern. Turbidity can provide food and shelter for pathogens. If not removed, turbidity can promote re-growth of pathogens in the distribution system, leading to waterborne disease outbreaks, which have caused significant cases of gastroenteritis. Although turbidity is nota direct indicator of health risk, numerous studies show a strong relationship between removal of turbidity and removal of protozoa. The particles of turbidity provide "shelter" for microbes byreducing their exposure to attack by disinfectants. Microbial attachment to particulate material has been considered to aid in microbe survival. Fortunately, traditional watertreatment processes have the ability to effectively remove turbidity when operated properly.

As per IS-10500 acceptable limit of turbidity are 1 NTU and permissible limit in the absence of alternate source are 5 NTU.

5.3 TOTAL DISOLVED SOLID

TDS stands for Total Dissolved Solids and refers to the total concentration of dissolved substances in drinking water. TDS comprises inorganic salts and a small amount of organic matter as well. Inorganic salts are made up of the positively charged cations (calcium, magnesium, potassium and sodium) and negatively charged anions (carbonates, nitrates, bicarbonates, chlorides and sulfates). The TDS level is how much of the total dissolved solids are present in the water.

TDS in drinking water originates from places like natural sources, sewage, urban run-offs, industrial wastewater, chemicals in the water treatment process, chemical fertilizers used in the garden and plumbing. Water is a universal solvent and easily picks up impurities and can absorb and dissolve these particles quickly. Although elevated levels of TDS in drinking water is not a health hazard, it does lend the water a bitter, salty, or brackish taste. Calcium and magnesium, two minerals commonly found in TDS, can also cause water hardness, scale formation, and staining.The TDS level recommended by WHO is **300 ppm**.

Water is a good solvent and picks up impurities easily. Pure water is often called the universal solvent. Dissolved solids" refer to any minerals, salts, metals, cations or anions dissolved in water. Total dissolved solids (TDS) comprise inorganic salts (principally calcium, magnesium, potassium, sodium, bicarbonates, chlorides and sulphates) and some small amounts of organic matter that are dissolved in water. TDS in drinking-water originate from natural sources, sewage, urban run-off, industrial wastewater, and chemicals used in the water treatment process, and the nature of the piping or hardware used to convey the water, i.e., the plumbing. In general, the total dissolved solids concentration is the sum of the cations (positively charged) and anions (negatively charged) ions in the water.

Therefore, the total dissolved solids test provides a qualitative measure of the amount of

Dissolved ions, but does not tell us the nature or ion relationships. Therefore, the total dissolvedsolids test is used as an indicator test to determine the general quality of the water. Many dissolved solids are undesirable in water. Dissolved minerals, gases and organicconstituents may produce aesthetically displeasing colour, taste and odour. Some chemical maybe toxic and some dissolved constituents have been shown to be carcinogenic. Quite often, two ormore dissolved substances will combine to form a compound whose characteristics are moreobjectionable than those of either of the original materials. Not all dissolved substances areundesirable in water. For example, essentially pure, distilled water has a flat taste. Additionally, water has an equilibrium state with respect to dissolved constituents.

According to the Bureau of Indian Standards (BIS), the upper limit of TDS levels in water is 500 ppm.However permissible limits in the absence of alternate source 2000 ppm.

5.4 HARDNESS

The hardness of water is due to the presence of soluble bicarbonates, chlorides and sulfates of calcium and magnesium. Water which does not give lather with soap is hard water.

Water is the most important compound that is needed for the survival of life on earth. Water is present in the oceans, rivers, ponds, lakes, glaciers, etc. Rainwater is considered pure water because it does not contain any salt dissolved in it thought there are dissolved gases present.

Water can be classified as hard water and soft water.

- **Soft water:** It lathers with soap. Water which is obtained from the rains is soft water. This water is suitable for household purposes for example laundry and cleaning.
- **Hard water:** It is known as hard water because of the presence of salts of calcium and magnesium. Hard water does not lather with soap but instead forms a precipitate

Types of Hardness of Water

The hardness of water can be classified into two types:

- **Temporary Hardness**
- **Permanent Hardness**

Temporary Hardness of Water:

The presence of magnesium and calcium carbonates in water makes it temporarily hard. In this case, the hardness in water can be removed by boiling the water.

When we boil water the soluble salts of $Mg(HCO_3)_2$ is converted to Mg $(OH)_2$which is insoluble and hence gets precipitated and is removed. After filtration, the water we get is soft water.

Permanent Hardness of Water:

When the soluble salts of magnesium and calcium are present in the form of chlorides and sulphides in water, we call it permanent hardness because this hardness cannot be removed by boiling.

We can remove this hardness by treating the water with washing soda. Insoluble carbonates are formed when washing soda reacts with the sulphideand chloride salts of magnesium and calcium and thus, hard water is converted to soft water.

Disadvantages of Hardness

1. Wastage of soap
2. Wastage of fuel
3. Formation of scales on metallic boilers.

As per IS-10500 acceptable limit of total hardness are 200 mg/l as $CaCO_3$ and permissible limit in the absence of alternate source are 600 mg/l as $CaCO_3$.

5.5 CHLORIDE

Chloride is an ion, specifically, because it has a negative charge, an anion. It forms from the element, chlorine. The difference between an ion and an element is that an element (and a compound) has a balanced charge while ions do not. One very common compound (balanced charges) of chlorine is sodium chloride (ordinary table salt). When sodium chloride is dissolved in water, the sodium forms a positively-charged ion (a cation) and the chlorine forms the negatively-charged chloride anion.

Chloride is present in rainwater, streams, groundwater, seawater, wastewater, urban runoff, humans (our blood is quite salty), geologic formations, and animal waste streams. Chloride is also present in your kitchen table in the salt shaker (sodium chloride). We mine large salt deposits for road salt and water treatment salt based chemicals and also you abandon salt mines to store natural gas (source) and even store nuclear waste. Chloride is commonly associated with other ions, such as sodium, potassium, carbonates, and sulfate (sea water has loads of all of these). Elevated chloride levels can be associated with oil / natural gas drilling, saltwater intrusion, landfill leachate, fertilizers, septic system effluent, road salt storage, salt mining, deicing agents, and saline/brine water deposits. High levels of chloride can attack and weaken metallic piping and fixtures (it promotes corrosion) and inhibit the growth of vegetation.

Chloride is regulated as a secondary drinking water standard because of the aesthetic, cosmetic, and technical effects that chloride can have on your body, and appliances and plumbing in your home.

Chloride is widely distributed in nature, generally as the sodium (NaCl) and potassium(KCl) salts. By far the greatest amount of chloride found in the environment is in the oceans.Sodium chloride is widely used in the production of industrial chemicals such as caustic soda(sodium hydroxide), chlorine, soda ash (sodium carbonate), sodium chlorite, sodium bicarbonate and sodium hypochlorite. Potassium chloride is used in the production of fertilizers.The presence of chloride in drinking water sources can be attributed to the dissolution of saltdeposits, leaching of marine sedimentary deposit, seawater intrusion in coastal areas, effluentsfrom chemical industries, oil well operations, sewage, irrigation drainage etc. Each of these

Sources may result in local contamination of surface water and groundwater. The chloride ion ishighly mobile and is eventually transported into closed basins or to the oceans. Chloride is an essential element and is the main extracellular anion in the body. It is a highly mobile ion that easily crosses cell membranes and is involved in maintaining proper osmotic pressure, water balance and acid-base balance the toxicity of chloride salts depends on the cation present; that of chloride itself is unknown. Although excessive intake of drinking-water containing sodium chloride at concentrations above 2.5 g/l has been reported to produce hypertension, this effect is believed to be related to the sodium ion concentration. Chloride toxicity has not been observed in humans except in the special case of impaired sodium chloride metabolism, e.g. in congestive heart failure. Healthy individuals can tolerate the intake of large quantities of chloride provided that there is a concomitant intake of fresh water. Little is known about the effect of prolonged intake of large amounts of chloride in the diet. As in experimental animals, hypertension associated with sodium chloride intake appears to be related to the sodium rather than the chloride ion.

As per IS-10500 acceptable limit of chloride are 200 mg/l and permissible limit in the absence of alternate source are 1000 mg/l.

5.6 FECAL COLIFORM

Coliforms are bacteria that are always present in the digestive tracts of animals, including humans, and are found in their wastes. They are also found in plant and soil material.

Water pollution caused by fecal contamination is a serious problem due to the potential for contracting diseases from pathogens (disease causing organisms). Frequently, concentrations of pathogens from fecal contamination are small, and the number of different possible pathogens is large. As a result, it is not practical to test for pathogens in every water sample collected. Instead, the presence of pathogens is determined with indirect evidence by testing for an **"indicator"** organism such as coliform bacteria. Coliforms come from the same sources as pathogenic organisms. Coliforms are relatively easy to identify, are usually present in larger numbers than more dangerous pathogens, and respond to the environment, wastewater treatment, and water treatment similarly to many pathogens. **As a result, testing for coliform bacteria can be a reasonable indication of whether other pathogenic bacteria are present.** The most basic test for bacterial contamination of a water supply is the test for **total coliform bacteria**. Total coliform counts give a general indication of the sanitary condition of a water supply.

A. **Total coliforms** include bacteria that are found in the soil, in water that has been influenced by surface water, and in human or animal waste.

B. **Fecal coliforms** are the group of the total coliforms that are considered to be present specifically in the gut and feces of warm-blooded animals. Because the origins of fecal coliforms are more specific than the origins of the more general total coliform group of bacteria, fecal coliforms are considered a more accurate indication of animal or human waste than the total coliforms.

C. **Escherichia coli (E. coli)** are the major species in the fecal coliform group. Of the five general groups of bacteria that comprise the total coliforms, only E. coli is generally not found growing and reproducing in the environment. Consequently, E. coli is considered to be the species of coliform bacteria that is the best indicator of fecal pollution and the possible presence of pathogens.

As per IS-10500 coliform shall not be detectable in any 100 ml solution

Chapter – 6

RESULT AND DISCUSSION

6.1 Reduction of pH

Table-6.1 pH of raw water

Date	pH of raw water
21-05-2022	8.47
28-05-2022	7.35
10-06-2022	7.35
28-06-2022	7.54
06-07-2022	7.5
15-07-2022	7.58

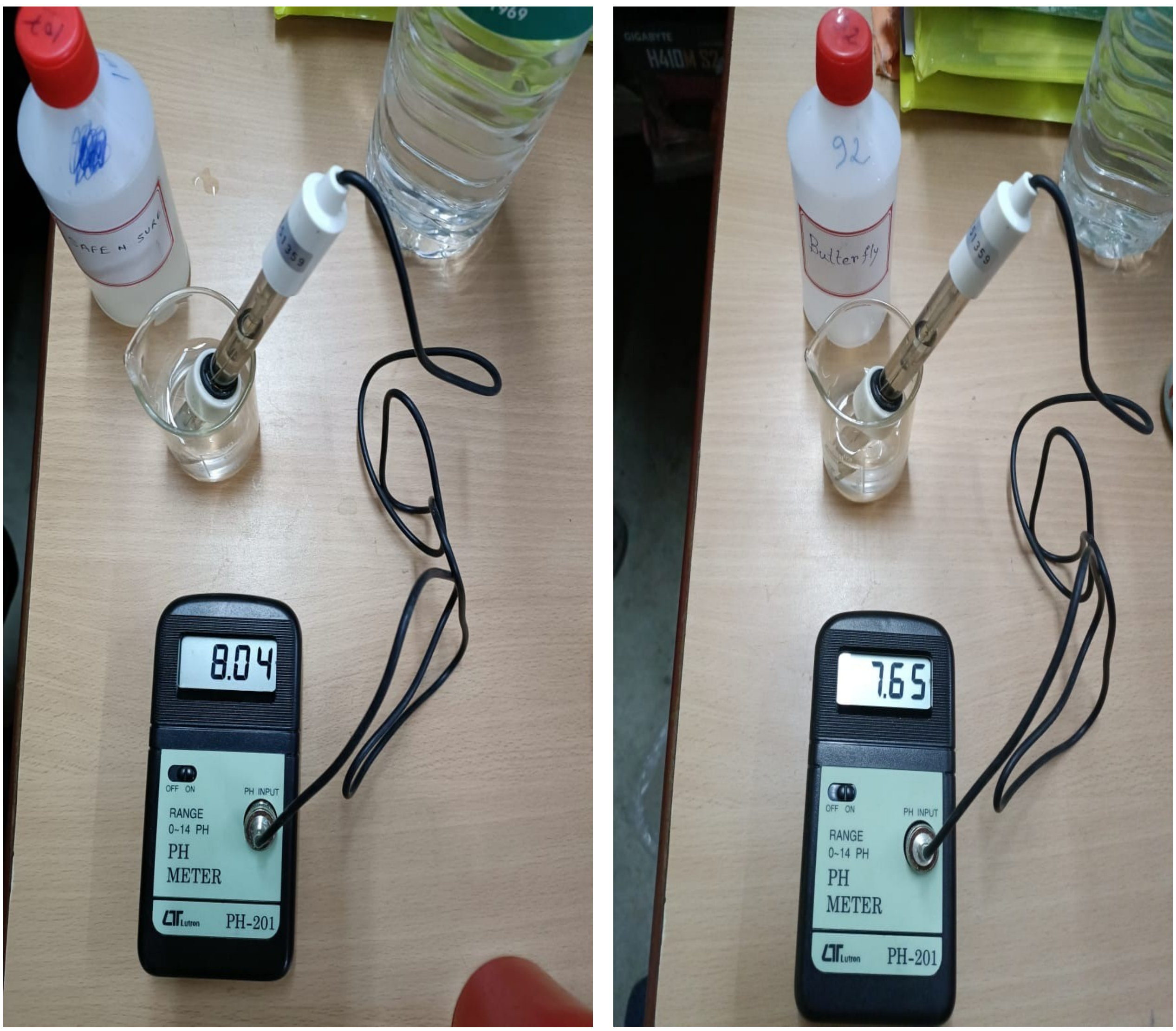

Fig.6.1 pH meter

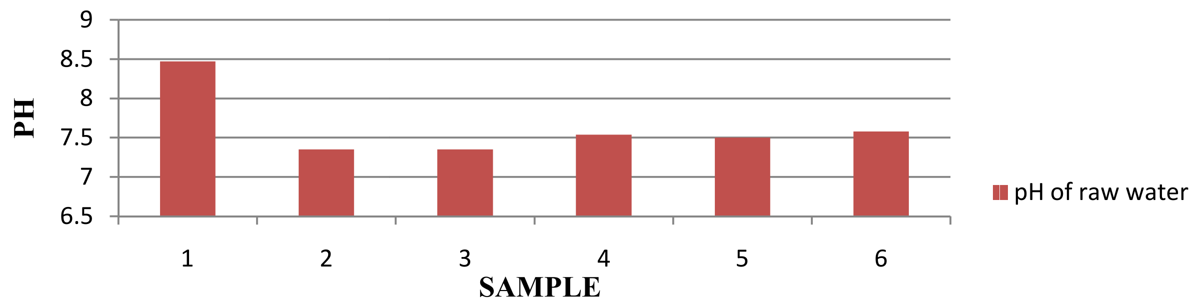

Fig. 6.2 pH vs raw water sample

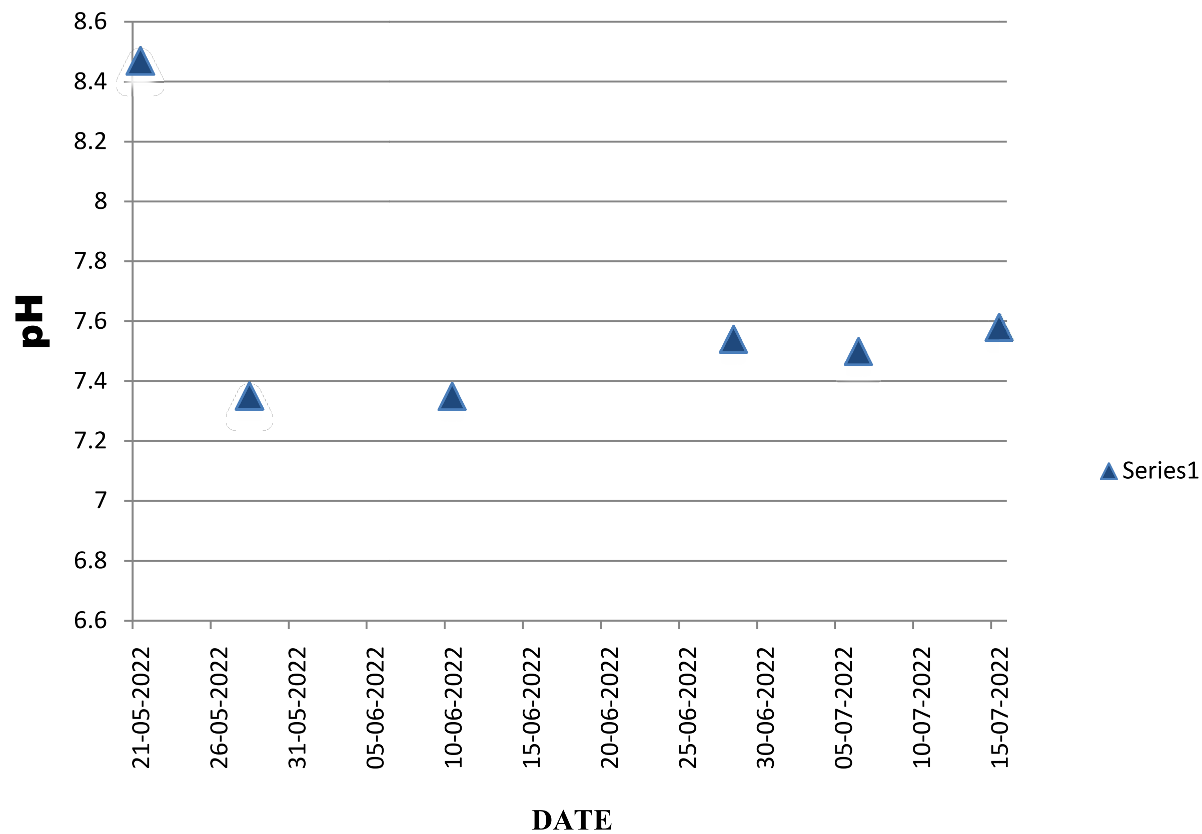

Fig.6.3 pH VS date of sample

Table-6.2 pH of filtered water

Date	Sample name	pH of filtered water
27-05-2022	Filtered water(1)	8.9
27-05-2022	Filtered water(2)	8.74
27-05-2022	Filtered water(3)	8.71
02-06-2022	Filtered water(1)	7.72
02-06-2022	Filtered water(2)	7.63
02-06-2022	Filtered water(3)	7.65
18-06-2022	Filtered water(1)	8.14
18-06-2022	Filtered water(2)	8.12
02-07-2022	Filtered water(1)	8.14
02-07-2022	Filtered water(2)	7.95
02-07-2022	Filtered water(3)	8.12
13-07-2022	Filtered water(1)	7.82
13-07-2022	Filtered water(2)	7.75
13-07-2022	Filtered water(3)	7.76
20-07-2022	Filtered water(1)	7.74
20-07-2022	Filtered water(2)	7.72
20-07-2022	Filtered water(3)	7.65
20-07-2022	Filtered water(4)	7.75
20-07-2022	Filtered water(5)	7.81
20-07-2022	Filtered water(6)	7.71
20-07-2022	Filtered water(7)	7.75

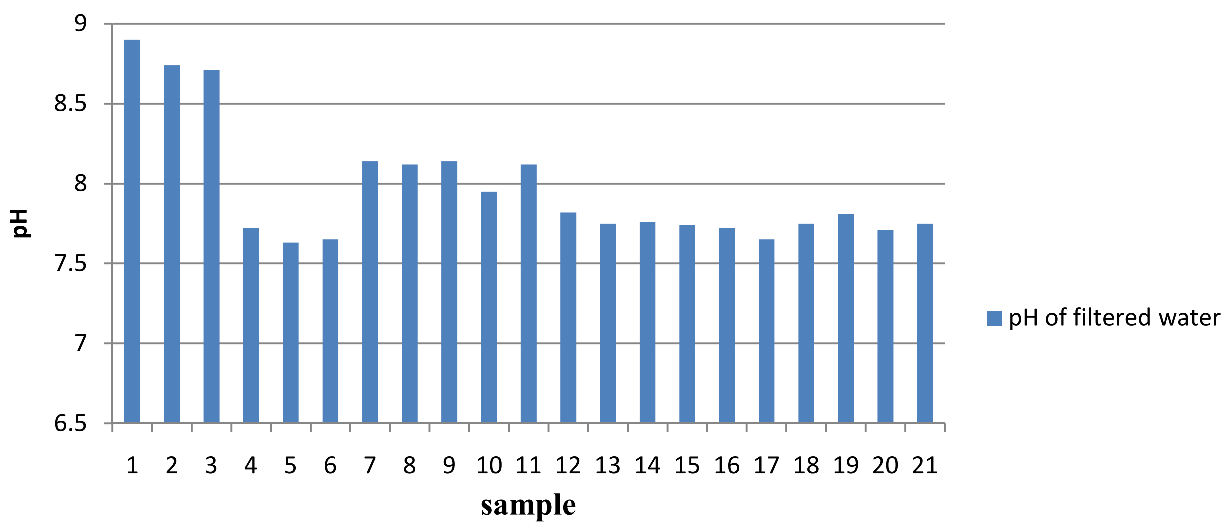

Fig.6.4 pH vs filtered water sample

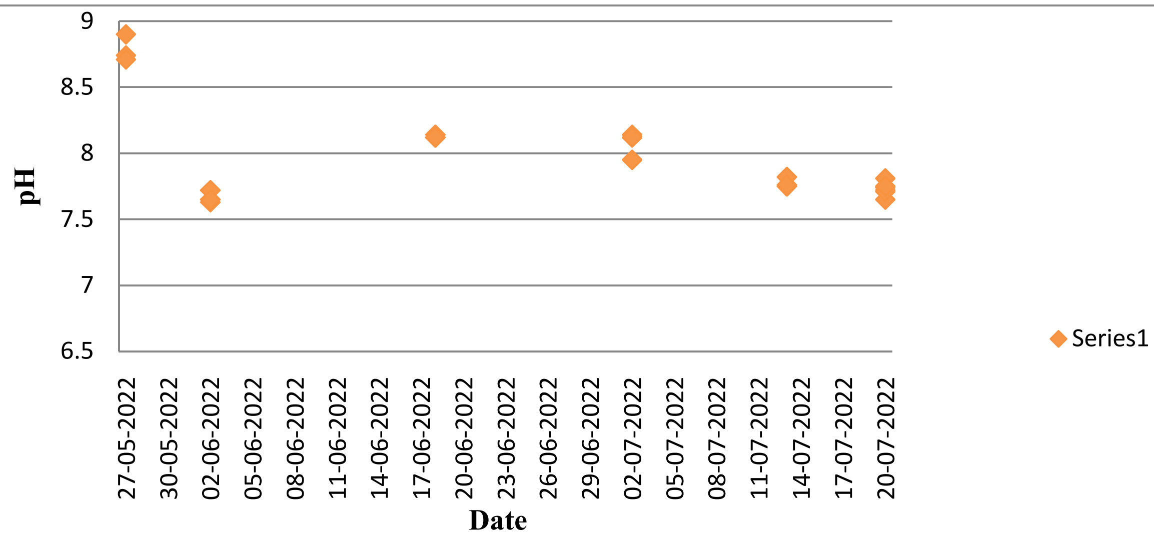

Fig.6.5 pH vs date of sample

`

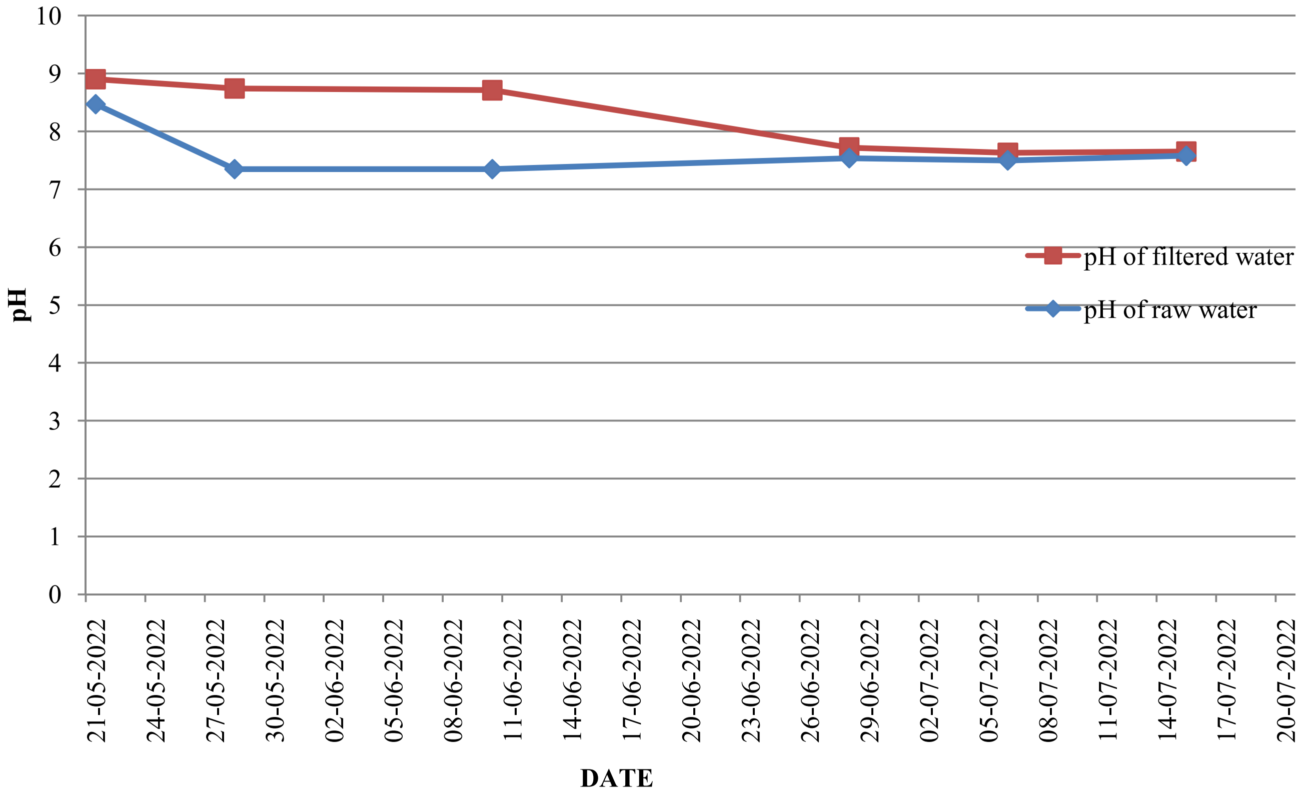

Fig.6.6 pH comparison of Raw water and filtered water

Above tables and chartsshows the influent and effluent pH values for BSFs throughout the experiment.Ph of raw water vary from 7.35 to 8.47 and that of filter water vary from 7.63 to 8.9.Filtered water from BSF had consistently higherr pH values than the influent, showing that some alkaline formingreaction was occurring within the filter medium. But after some days as the operational time increases the pH value of filtered water decrease from the pH value of raw water. pH reduction efficiency of the filter was medium capacity.

6.2 Reduction of Turbidity

Table-6.3

Date	Raw water Turbidity	Turbidity after sedimentation	% Removal
21-05-2022	12	8.5	29.17
28-05-2022	14	6.5	53.57
10-06-2022	20	7	65
28-06-2022	23.9	8.5	64.44
06-07-2022	13	6.5	50
15-07-2022	14	6	57.14

Fig.6.7 Turbiditymeter

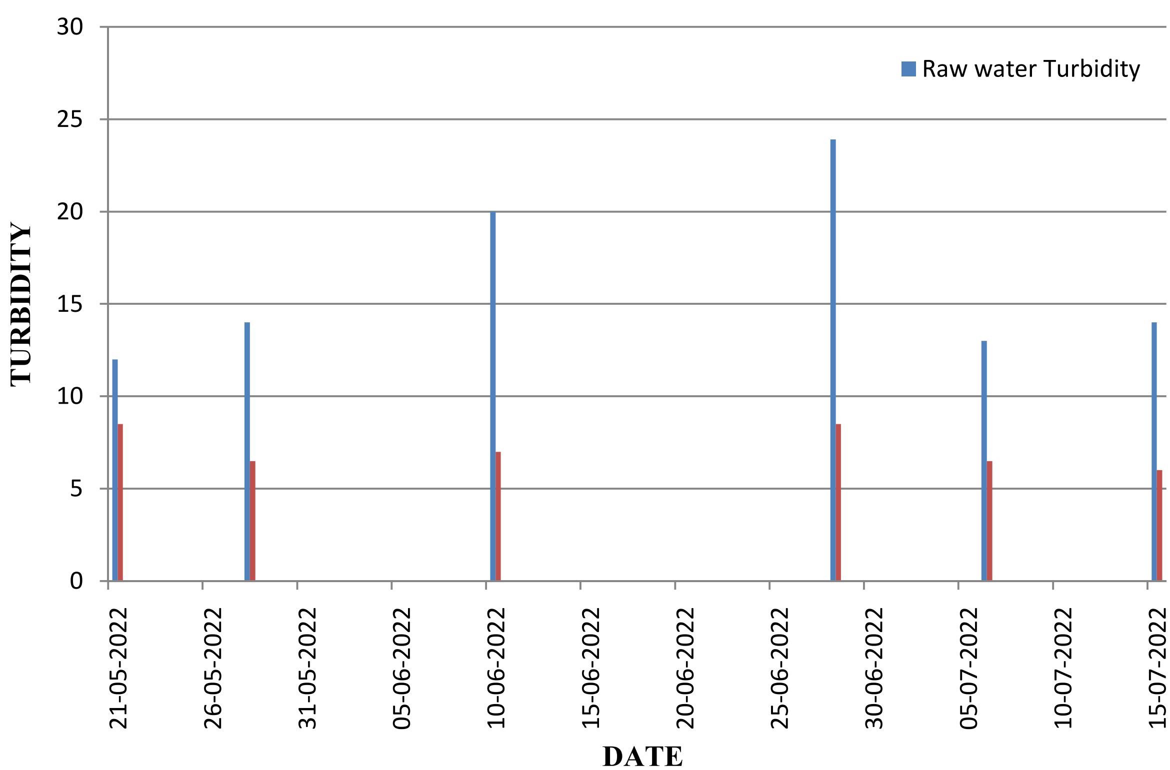

Fig.6.8 Plot of Turbidity removal after sedimentation

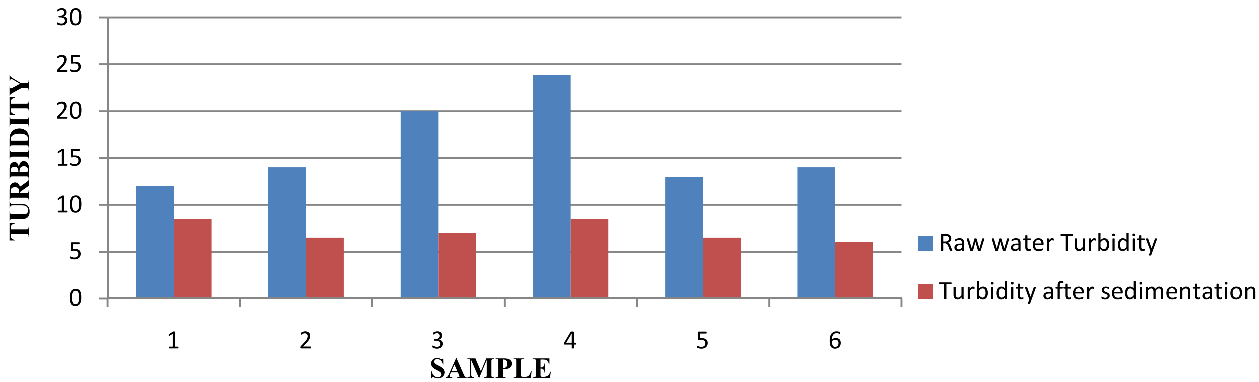

Fig.6.9 comparison of Turbidity Removal after sedimentation

Table-6.4

Date	Turbidity of inlet water to biosand filter	Turbidity of outlet water from biosand filter	% Removal
27-05-2022	8.5	0.9	89.41
27-05-2022	8.5	0.69	91.88
27-05-2022	8.5	0.85	90
02-06-2022	6.5	0.91	86
02-06-2022	6.5	0.93	85.69
02-06-2022	6.5	0.93	85.69
18-06-2022	7	1.6	77.14
18-06-2022	7	0.98	86
02-07-2022	8.5	1.9	77.65
02-07-2022	8.5	1.3	84.71
02-07-2022	8.5	0.99	88.35
13-07-2022	6.5	0.97	85.08
13-07-2022	6.5	0.92	85.85
13-07-2022	6.5	0.92	85.85
20-07-2022	6	0.93	84.5
20-07-2022	6	0.94	84.33
20-07-2022	6	0.94	84.33
20-07-2022	6	0.93	84.5
20-07-2022	6	0.95	84.16
20-07-2022	6	0.93	84.5
20-07-2022	6	0.94	84.33

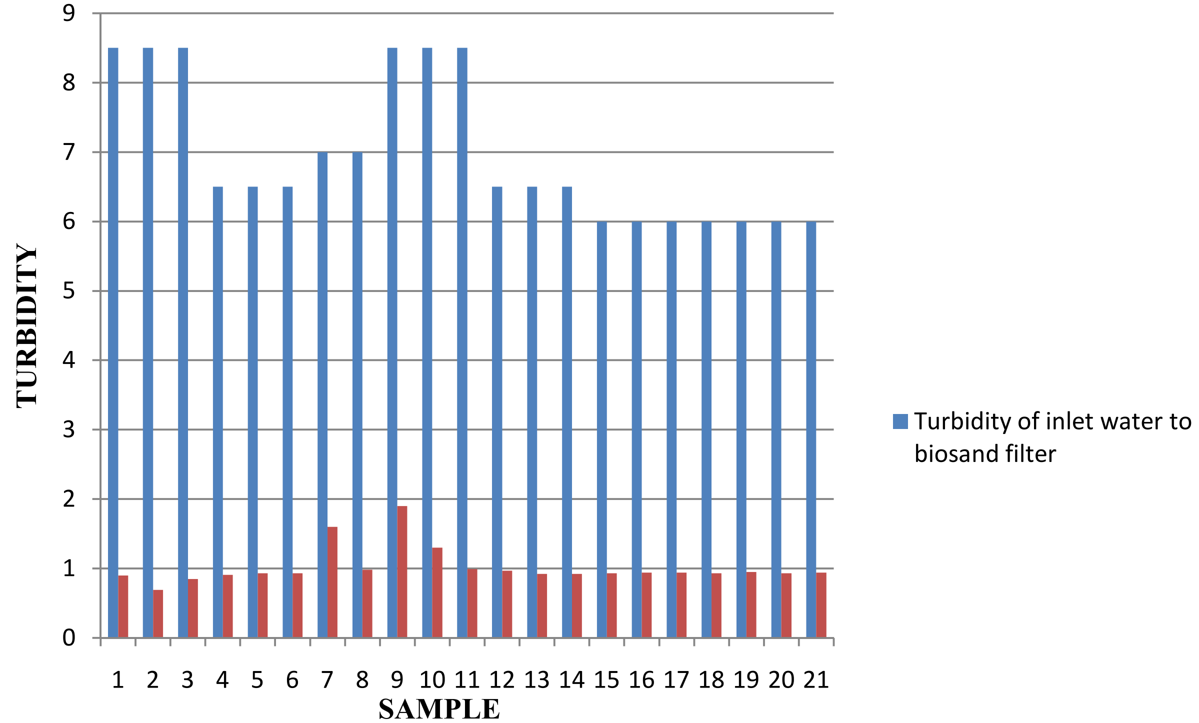

Fig.6.10 plot of Turbidity removal after filtration

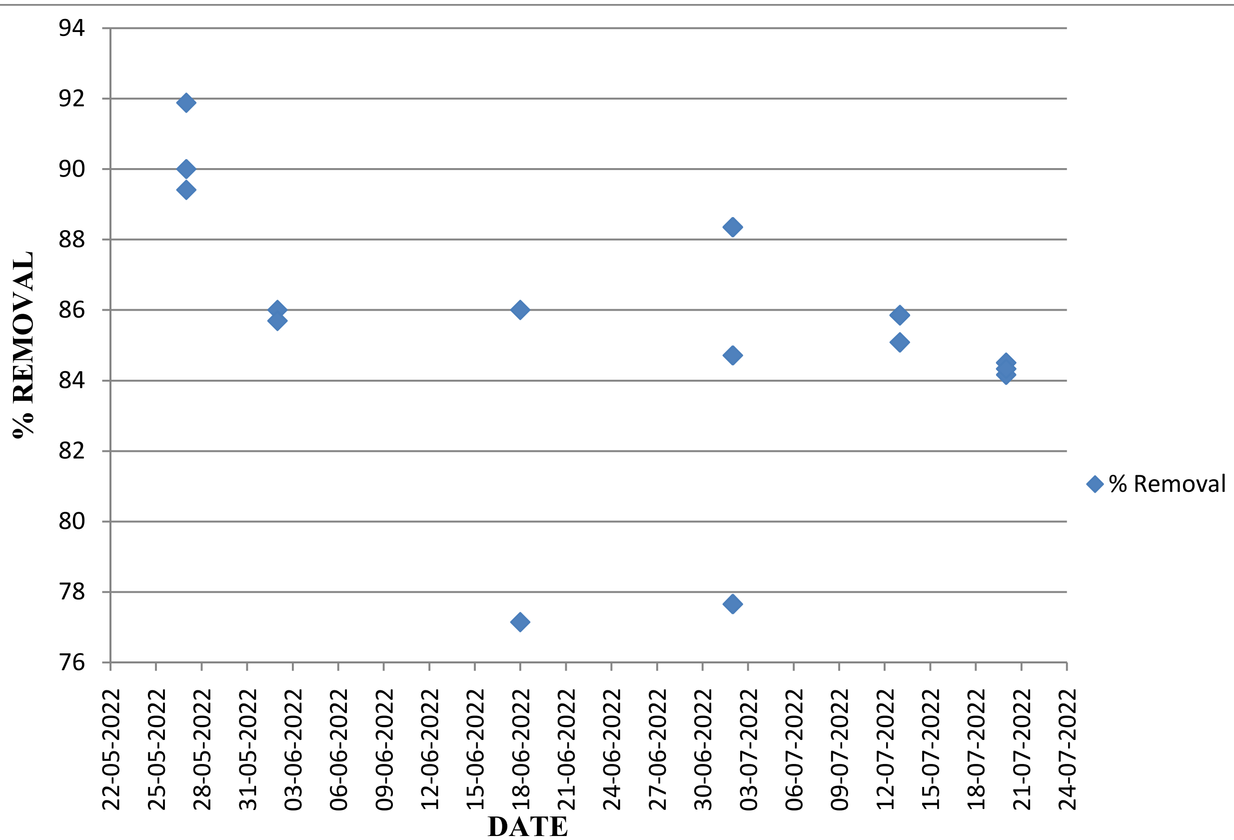

Fig.6.11 plot of Turbidity removal efficiency after filtration

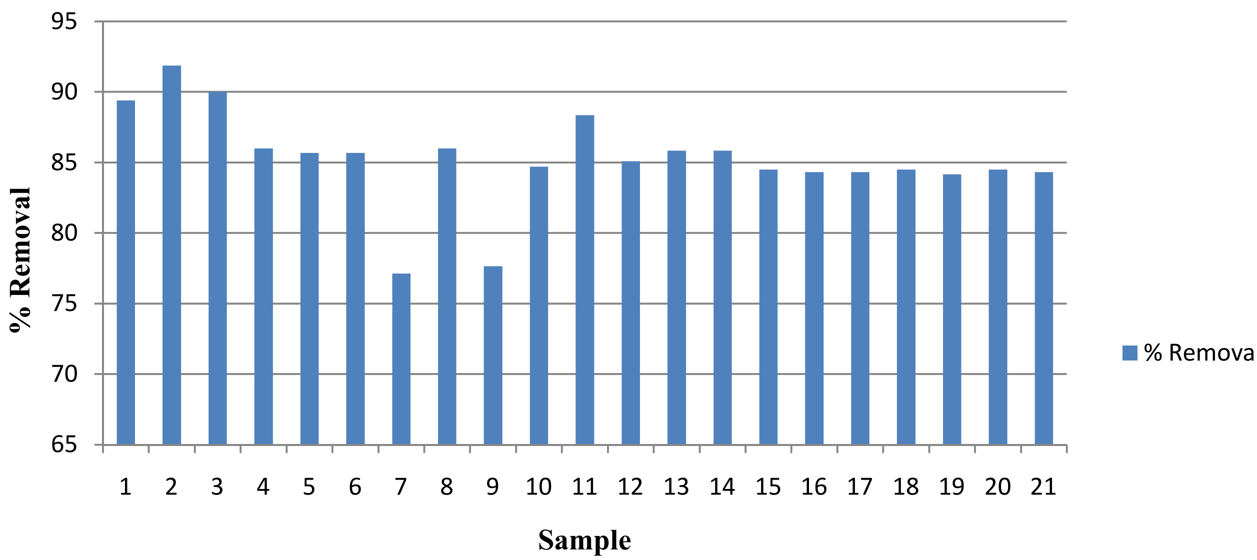

Fig.6.12 plot of percentage Removal Efficiency

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

A significant reduction of turbidity in the filtrate than source water and performance consistency can be notedThe BSF is highly efficient in turbidity removal and its efficiency increased with operational time. The BSF maximum turbidity removal efficiency was 91.88% and lowest performance was 77.14%. The average removal efficiency was 85.24%.

The turbidity of this Biosand Filter was within acceptable and permissible limit As per IS-10500

6.3 Reduction of Fecal Coliform

Table-6.5

Date	Sample name	FECAL COLIFORM/P/A)
21-05-2022	Raw Water	P
28-05-2022	Raw Water	P
10-06-2022	Raw Water	P
28-06-2022	Raw Water	P
06-07-2022	Raw Water	P
15-07-2022	Raw Water	P

P-Present,A-Absent

Fig.6.13 H_2S strip for bacteriological test

Table-6.6

Date	Sample name	Fecal coliform in the outlet of biosand filter(P/A)
27-05-2022	Filtered water(1)	P
27-05-2022	Filtered water(2)	A
27-05-2022	Filtered water(3)	A
02-06-2022	Filtered water(1)	A
02-06-2022	Filtered water(2)	P
02-06-2022	Filtered water(3)	P
18-06-2022	Filtered water(1)	P
18-06-2022	Filtered water(2)	A
02-07-2022	Filtered water(1)	P
02-07-2022	Filtered water(2)	A
02-07-2022	Filtered water(3)	P
13-07-2022	Filtered water(1)	P
13-07-2022	Filtered water(2)	P
13-07-2022	Filtered water(3)	A
20-07-2022	Filtered water(1)	P
20-07-2022	Filtered water(2)	A
20-07-2022	Filtered water(3)	P
20-07-2022	Filtered water(4)	P
20-07-2022	Filtered water(5)	A
20-07-2022	Filtered water(6)	P
20-07-2022	Filtered water(7)	P

P-Present,A-Absent

Fig.6.14 bacteriological test by H_2S strip

The safe water doesn’t contain any fecal coliform bacteria. The BSF was highly efficient in removal of fecal coliform from contaminated water and its performance increase with operational time.

Initially, the fecal coliform was present in the filtered water.After some days when operational time increases the fecal coliform did not find in the filtered water. Maximum filtered samples were absent from fecal coliform.There was a gentle decrease over the experimental period in fecal coliform concentration in BSF1 while BSF2 and BSF3 exhibited a rapid decrease during the first four days. However, the all filtered water samples were not within the drinking water guidelines of 0 cfu/100 mL (WHO, 2011) but in some cases fecal coliform was found in the filtered water samples.

Therefore chlorine can be applied @0.2 mg/l

Chapter – 7

CONCLUSION

CONCLUSION

The study represents that in first few days the BSFs performance is relatively low. After some days the average turbidity reduction was 85.24%. The BSF shows high performance in FC removal from surface water. The BSF are able to remove 100% of bacteria when the contamination level is low. Finally the BSF is the best and locally available technology to provide turbidity and bacteria free water to the poorest community.

The study concluded that untreated well water is not safe to drink and exhibited high levels of contamination indicators with most parameters exceeding the drinking water guidelines ranges.Thus treatment of the well water before consumption should be considered. The introduction of reactive iron mixed with sand could improve the performance of the bio-sand filter significantly especially for the removal of coliforms. Based on these findings, it is feasible to use bio-sand filters for household water treatment for water abstracted from wells. Although the quality of the effluent improved significantly it could not meet the IS standards and WHO drinking water guidelines. However the levels of coliforms were substantially reduced implying that bio-sand filters can be used as a pre-treatment for point of use disinfection. Thus appropriate point of use disinfection such as application of chlorine tablets or boiling of the treated water is still recommended

Pond water is the only available source of drinking water in many places.The filter removed turbidity (>85%) and microbial contamination significantly from river water. Though the BSF could reduce a significant amount of microbial contamination in the effluent, it does not meet the microbiological standards by WHO of Fecal Coliform (less than 1CFU per 100ml).Post-chlorination of the filtrate analysis result meets up the WHO recommendations of having the residual free chlorine level over 24 hours to protect stored water from recontamination. The filter reduces the risks of contamination between the water source and the home, by providing drinking water through treatment at the household level. Overall the Bio-Sand filter is, and will continue to be a simple, effective, low-cost household level water treatment device for drinking water supply in the hazard-prone hard-to-reach coastal areas.

REFERENCE

IS 10500: (**2012**, Indian Standard, Drinking Water- Specification, and Second Revision**)**

WHO Guidelines for Drinking water Quality, (**2008**), fourth ed., World Health Organization.

Garg, S.K., Environmental Engineering (Vol-I), (**1996**), Water Supply Engineering, Khanna Publishers, New Delhi

Howard S. Peavy, Donald R. Rowe, George Tchobanglous, (**1985**), Environmental Engineering, McGraw-Hill International Editions, Singapore

APHA (American Public Health Association), (**2012**.), Standard Methods for the Examination of Water and Wastewater, 22 edi.

American Water Works Association, and Raymond D Letterman 1999.*Water quality and treatment: a handbook of community water supplies*. New York: McGraw-Hill.

Biosand filters. 2004. *Flow rates*. Available: http://www.biosandfilter.org/biosandfilter/ Filtration-process/flow-rates/

CAWST(2009). *Biosand Filter Manual - Design, Construction, Installation,Operation and Maintenance*.Center for Affordalbe Water and SanitationTechnology

Huisman, L. & Wood, W.E. (1974). *Slow Sand Filtration*. Geneva: World Health Organization (WHO).

WHO, World Health Organization.(2011).*Guidelines for drinking-water quality*. 4th ed. Geneva: World Health Organization.ISBN 978-92-4-154815-1.

WHO, World Health Organization (2007).*pH in drinking water*.Geneva: World Health Organization. (WHO/SDE/WSH/07.01/1)

WHO, World Health Organization.(1997). *Guidelines for drinking-water quality,Volume 3*. 2nd ed. Geneva: World Health Organization. ISBN 92 4 154503 8

..https://sswm.info/sswm-university-course/module-6-disaster-situations-planning-and-preparedness/further-resources-0/rapid-sand-filtration

https://sswm.info/sites/default/files/reference_attachments/CAWST%202009%20Biosand%20Filter%20Manual.pdf

UN-Water Annual Report 2010

NGAI et al. 2007; EAWAG/SANDEC 2008; CAWST 2009).

Lynn et al., 2013,Household slow sand filters in intermittent and continuous flows to treat water containing low mineral ion concentrations and Bisphenol A

(EPA 2000) The History of Drinking Water Treatment

Buzunis 1995 Schmutzdecke- A Filtration Layer of Slow Sand Filter

Elliott, DiGiano, and Sobsey 2011 Biosand Filter (BSF): Types and Mechanisms behind Its Efficiency

Manz,2008, BIOSAND FILTER MANUAL DESIGN, CONSTRUCTION, INSTALLATION, OPERATION AND MAINTENANCE

Stauber, Ortiz, and Sobsey 2007; Stauber, Ortiz, et al. 2009; Stauber, Fabiszewski, et al. 2009; Jenkins, Tiwari, and Darby 2011 Removal of E. coli with Alternative Media Biosand Filters

Tiwari et al. 2009 Educational Concerns of Implementing Biosand Water Filters in Rural Uganda

Buzunis 1995; Palmateer et al. 1999; Stauber et al. 2006; Elliott et al. 2008; Jenkins, Tiwari, and Darby 2011Removal of E. coli with Alternative Media Biosand Filters.

Binnie et al. **2002** Evaluation of biosand filter as a water treatment method in Ghana

Holdich, 2002 Optimization of Slow Sand Filtration Design by Understanding the Influence of Operating Variables on the Suspended Solids Removal

Chiew et al.2009 Biosand Filter (BSF): Types and Mechanisms behind Its Efficiency

Schmidt & Cairncross **2009**; **Hunter 2009** Laboratory and Field Performance of the Biosand Point of Use Water Filtration System in the Artibonite Valley, Haiti

Huisman et al. 1979 Evaluation of biosand filter as a water treatment method in Ghana

Thames Water and University of Surrey, 2005 Water-E,Slow sand filter

Biosand filter, 2004 Evaluation of biosand filter as a water treatment method in Ghana

Gainy and Lord 1952 Slow sand filtration for small water systems

Manz 2007 BioSand Water Filter Technology Household Concrete Design Manz 2007

Rainey and Harding 2005; Sobsey et al. 2008; Hunter 2009Removal of E. coli with Alternative Media Biosand Filters

.https://archive.nptel.ac.in/content/storage2/courses/105104102/Lecture%2010.htm#:~:text=In%20RSF%20the%20effective%20size,6000%20L%2Fh%2Fsq

https://sswm.info/sswm-university-course/module-6-disaster-situations-planning-and-preparedness/further-resources-0/slow-sand-filtration

Lynn et al., 2013Dynamic performance of biosand filters

https://doi.org/10.5942/jawwa.2013.105.0116

Kubare & Haarhoff, 2010; Napotnik et al., 2017Rational design of domestic biosand filters

https://doi.org/10.2166/aqua.2010.008

Napotnik et al., 2017Influence of sand depth and pause period on microbial removal in traditional and modified biosand filters

https://www.researchgate.net/publication/347523276_Influence_of_sand_depth_and_pause_period_on_microbial_removal_in_traditional_and_modified_biosand_filters

L. Huisman and W. E. Wood, "Slow Sand Filtration," World Health Organization, Geneva, 1974, pp. 47-79.
http://www.who.int/water_sanitation_health/publications/ssfbegin.pdf

Elliott, DiGiano, and Sobsey 2011Virus Attenuation by Microbial Mechanisms During the Idle Time of a Household Slow Sand Filter

https://www.researchgate.net/publication/51211631_Virus_Attenuation_by_Microbial_Mechanisms_During_the_Idle_Time_of_a_Household_Slow_Sand_Filter

Stauber, Ortiz, and Sobsey 2007; Stauber, Ortiz, et al. 2009; Stauber, Fabiszewski, et al. 2009; Jenkins, Tiwari, and Darby 2011Evaluation of the Impact of the Plastic BioSand Filter on Health and Drinking Water Quality in Rural Tamale, Ghana

https://doi.org/10.3390%2Fijerph9113806

Stauber, Fabiszewski, et al. 2009Cluster Randomized Controlled Trial of the Plastic BioSand Water Filter in Cambodia

https://www.researchgate.net/publication/51841904_Cluster_Randomized_Controlled_Trial_of_the_Plastic_BioSand_Water_Filter_in_Cambodia

Tiwari et al. 2009The BioSand Filter for Improved Drinking Water Quality in High Risk Communities in the Njoro Watershed, Kenya

https://www.researchgate.net/publication/237401898_The_BioSand_Filter_for_Improved_Drinking_Water_Quality_in_High_Risk_Communities_in_the_Njoro_Watershed_Kenya

Baumgartner, Murcott, and Ezzati 2007Reconsidering 'appropriate technology': the effects of operating conditions on the bacterial removal performance of two household drinking-water filter systems

https://iopscience.iop.org/article/10.1088/1748-9326/2/2/024003/pdf

Bradley et al. 2011**Iron oxide amended biosand filters for virus removal**

https://doi.org/10.1016/j.watres.2011.05.045

https://sswm.info/sites/default/files/reference_attachments/THAMES%20WATER%20and%20UNIVERSITY%20OF%20SURREY%202005%20Slow%20Sand%20Filters.pdf