Microbiological Performance of Ceramic Water Filters as Household Water Treatment Technology in Bangladesh

by

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Recommendation of the Board of Examiners

The thesis titled "**Microbiological Performance of Ceramic Water Filters as Household Water Treatment Technology in Bangladesh**" submitted by Sadik Rahman, Student ID 125606 of Academic Year 2012-2013 has been found as satisfactory and accepted as partial fulfillment of the requirement for the degree of Master of Science in Civil Engineering.

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Dedication

I want to dedicate this work to my parents and wife whose encouragement and support make this work complete and successful.

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Abstract

Ceramic Water Filter (CWF) or Mineral pot filter (MPF) as household water treatment (HWT) option is becoming a widespread technology in urban and rural areas in developing countries. But the microbiological performance of CWF wasn't being investigated. A study was undertaken to evaluate the performance of CWF under realistic household usage conditions and laboratory controlled environment. A total of 75 CWFs were purchased and distributed among the preselected people of coastal area and the performance was studied microbiologically and physico-chemically as field evaluation. From baseline results, it is reported that, all the source water were contaminated by the disease causing organisms specially rain feed ponds among the sources. Field evaluation showed, CWF can remove *E. coli* in median $\log_{10}$ reduction ranged from 1.8 -2.8 in four monitoring cycles. For pond water, *E. coli* > 2 $\log_{10}$ reduction was observed inconsistently. The filters also removed *Vibrio cholerae* non-O1/non-O139 .The number of water samples satisfying the WHO no risk level increased significantly because of filtration. CWF significantly reduced health risk upto 98% in compared to source water condition. Turbidity of the water was found less than 1 NTU after filtration. In laboratory controlled experiment, 24 filters from three different CWF brands were purchased to evaluate the laboratory performance of CWF against *E. coli* bacteria, MS-2 bacteriophage virus and *Clostridium perfringens* spores according to the WHO protocol. Results showed, filter performance declined with the increasing filtration period, signified the overestimated lifespans claimed by manufacturers. Also the filters were moderately effective but inconsistent in reducing *E. coli* (1.03–2.15 $\log_{10}$ reduction), MS2 (0.52–1.52 $\log_{10}$ reduction) and less effective against *C. perfringens* spores (0.50–1.06 $\log_{10}$ reduction). These filters can effectively reduce turbidity (> 98% removal) and color (> 90% removal). In complying WHO guideline, only one brand achieved protective target in some occasions than other brands. This laboratory outcome showed close to similar results with field data and study in Cambodia in relation to the removal of bacteria, turbidity and color and WHO compliance of protective target by CWF. Laboratory results inferred that these commercially available filters, if properly maintained, can be effective and reliable in household level but more research is needed to confirm its effectiveness in reducing microbial indicators and other potential pathogens in both field and laboratory controlled environment.

CHAPTER 1: INTRODUCTION

1.1. Background

Access to safe, reliable sources of drinking water is a long-standing problem both in urban and rural areas in developing countries. In drinking point of view, safe water is a challenge because of population growth and disease control. The major cause of worldwide disease and mortality is also lack of safe water supply. World Health Organization (WHO) estimated that 884 million people (about 13% of the population of the world) (WHO & UNICEF, 2017) live without access to improved water sources and most of the cases; the households stand 1 km or far from the source (WHO, 2008). In the global population, only 35% people are getting safely managed drinking water in 96 countries of the world. One out three people in rural areas (1.9 billion) can have safely managed drinking water sources (WHO & UNICEF, 2017). With safe drinking water, reliable technology for treatment of drinking water and sanitation goes hand in hand. However, one in eight people do not have access to safe drinking water and two of five people do not have adequate sanitation worldwide (WaterAid, 2010).

The proportion of the population with at least basic drinking water services has increased by an average of 0.49 % per year between 2000 and 2015 which is still a challenge for Sustainable Development Goal (SDG) to achieve the desired targets. But with this increasing water supply situation, microbiologically safe water supply didn't improve that much in global context. Latest report also says that three out of four people (5.4 billion) use water free from contamination. A recent study has estimated that 1.2 billion, about 28% people lack access to microbiologically or chemically safe drinking water (Onda *et al*., 2012). A number of 1.8 million people die annually due to unsafe drinking water, sanitation and improper hygiene and 99.8% occur in developing countries and among them 90% were children (Nath *et al*., 2006). Waterborne diseases such as diarrhoea, cholera, enteric fever, and hepatitis cause 1.6 million deaths annually and children under five years old are especially vulnerable (WHO/UNICEF, 2006). That's why inadequate access to safe water contributes to the massive global burden of disease and death especially of children in

lower-income countries (Blakely *et al.*, 2005). Several studies shows that, in India, due to poor access to safe water is partly responsible for child mortality of about 212,000 (Liu *et al.*, 2012) or up to 535,000 (Boschi-Pinto *et al.*, 2008) deaths per year. Country like Bangladesh is also fighting with this problem of safe and reliable water sources due to population increase. Due to diarrhoeal disease in Bangladesh, every year around 50000 child deaths were accounted and most of them are aging under 5 years (WSP, 2007).

For the case of coastal areas of Bangladesh, the scenario is more complex due to want of fresh water sources and salt water intrusion. In the coastal areas, where about 28% of the country's total population lives, people have to depend on rain-feed pond water, pond sand filter (PSF) and rainwater harvesting (RWH) for drinking water. Several recent studies showed that these sources are microbiologically unsafe. The fecal coliform and *E. coli* counts were found to vary from 12 to 10,000 cfu/100 mL and 0 to 3000 cfu/100 mL (Islam *et al.*, 2011) in rain water and fecal coliforms (FC) count in PSF water were found to vary from 0 to over 4000 cfu/100 mL (Islam *et al.*, 2011; Ahmed *et al.*, 2006). Several studies (Islam *et al.*, 2011; Karim 2010; Howard *et al.*, 2006; Ahmed *et al.*, 2005) in Bangladesh showed that the rooftop harvested rainwater was also microbiologically contaminated to a great extent, which may cause significant health risks of the rural people. Studies from other countries (Despins *et al.*, 2009; Sazakil *et al.*, 2007; Meera & Ahammed, 2006) also reported microbial contamination of harvested rainwater and consumption of the water may cause a variety of infectious diseases around the world (Lye *et al.*, 2002).

The urban dwellers mostly depend on piped water supply for domestic uses, which is believed to be safe potable water. However, it was reported from developing countries that quality of the water arriving at the consumer's end points through the distribution networks is quite unsafe for human consumption (Lee-Schwab *et al.*, 2005). Several studies reported poor microbial quality of the supply water at the consumers' end points causing diarrhoeal disease and other gastrointestinal illness (Dany *et al.*, 2000; Basualdo *et al.*, 2000; Agard *et al.*, 2002; LeChevallier *et al.*, 2003; Lee-Schwab *et al.*, 2005; Hunter *et al.*, 2005). Few epidemiological studies have also established associations between declining water quality from distribution systems and increased risk of gastrointestinal illness

(Semenza *et al*., 1998; Memrin *et al*., 1999; Egorov *et al*. 2002). Chaidez *et al*. (2008) has conducted drinking water microbiological survey together with physico-chemical parameters of two municipalities of the state of Sinaloa, Mexico and found the presence of bacteria in households' tap water and widespread occurrence of *Pseudomonas* spp. and Mulamattathil *et al*. (2015) found Heterotrophic Plate Count (HPC) in the Mafikeng water distribution systems, the capital of North West province of South Africa. A recent study in Bangladesh also showed microbial contamination of pipe water supply in Khulna and Jessore (Karim *et al*., 2016). Piped water supply in Dhaka city, especially at the users end points become also contaminated by several factors like cross contamination with sewerage lines, aged pipes, illegal connections and poor maintenance and outbreaks of diarrhoea and other water borne diseases. At present, more than 15 million people are living in Dhaka city, while 35% of them are living in slums/squatter settlements. For these slum dwellers, the average user to water-point ratio is 1,000:1 (Ahmed *et al*., 2004). The drinking water condition of slum areas is microbiologically unsafe. Municipal supply water is not safe especially at the user's end point. As a result, most of the households are using household water treatment (HWT) technologies like boiling, filtration etc. to make water microbiologically safe.

As the incident and prevalence of water borne diseases are high among the municipal water user and rural community; the delivery of safe drinking water is a priority among rural and urban areas of Bangladesh. As per WHO strategy to combat diarrhoeal diseases worldwide, WHO has adopted a new strategy called household water treatment (HWT) or point-of-use (POU) technologies for providing safe water to households in developing countries with adequate water supply. The objective of HWT is to improve water quality by treating it and storing it safely at home when supply water is not safe (Sobsey *et al*., 2008). Contemporary review suggests that if drinking water can be improved at point of use than improvements at the source, a 30-40% reductions in diarrhoeal disease can be achieved (Esrey *et al*., 1985; Esrey *et al*., 1991; Clasen *et al*., 2007a; Fewtrell *et al*., 2005). Point of use (POU) treatment technologies can be an effective option to provide reliable water to prevent many of the infant and child deaths attributable to waterborne illness in developing countries (Clasen *et al*., 2007b, Arnold *et al*., 2007).

Different HWT options are available to treat water for drinking purpose. Among the technologies; boiling, coagulation, sedimentation, chlorination, filtration, solar disinfection or combination between the mechanisms are widely used. These options are sometimes manufactured locally using local methods and materials or commercially assembled from different countries. Traditional membrane technology is generally expensive and therefore less known for effectiveness when applied to small-scale drinking water treatment in developing countries. However, reverse osmosis, nano-filters and other membrane technologies are common in developed countries (Hörman *et al*., 2004) and are now in process of evaluation and field implementation in different developing countries (Boisson *et al*., 2010). Among the HWT options, ceramic water filters (CWF) are widely used because of the performance and user friendliness. Also CWF is manufactured locally in many countries according to the need of the region. So in design consideration, CWF has the flexibility to adopt different mechanisms.

Among all of the technologies tested at the laboratory and field levels, ceramic water filters (CWFs) have also shown great outcome on long-term use due to the high-adherence of users and their capacity to reduce approximately 50% of the diarrhoeal cases (Clasen *et al*., 2004; Clasen *et al*., 2005; Brown *et al*., 2008; Preez *et al*., 2008; Hunter *et al*., 2009; Levine *et al*., 2010). Sobsey *et al*. (2002) reported that, ceramic water filters (CWF) proved to be one of the five best treatment options available for reducing turbidity and bacteria by more than 99%. Although, the Ceramic Water Filters (CWFs) are supported by a number of published studies in different countries and WHO household water treatment (HWT) performance guideline (WHO, 2011) indicates microbiological effectiveness of this option. One study (Brown *et al*., 2012) shows that, ceramic water filters from different local manufacturer of Cambodia has significant reduction potential against bacteria (99.99 %+), virus (99 %+) and spore forming bacteria (88 %+) in drinking water. Another study in India (Brown *et al*., 2013) shows that, ceramic water filters can effectively reduce (up to 7 $\log_{10}$ reduction) indicator organisms responsible of disease burden of diarrhoea. But study of the effectiveness of commercially available ceramic pot filters (CWFs) under field and laboratory operating conditions is rarely available (Brown *et al*., 2012). In Bangladesh, CWFs are widely used both in urban and rural areas among variable income level of people because of the appealing outlook, low cost, attractive

microbiological efficiency claimed by the manufacturer. But no field and control study regarding microbial performance of CWFs is available despite high popularity of this low cost treatment option. As no local manufacturer produces MPF in Bangladesh, the filters are mainly imported from Malaysia, Thai land, South Korea and China. The price of MPFs in local markets ranges from US$20 to 40 in 2013. The products are marketed by the private sector with a wide range of claims including high microbial efficacy, long service life, effectiveness in a wide variety of water conditions (temperature, pH, turbidity), improvement of water taste and minerals, etc. The filters are produced by several foreign manufacturers, although the design and fabrication of the filter of each manufacturer are very similar.

This study was intended to evaluate the performance of commercially available ceramic water filters (CWF) through field based performance study and laboratory controlled experiment following the guideline of World Health Organization (WHO).

1.2. Objective

The specific objectives of this study are as follows:

1. To evaluate microbial performance (removal) of ceramic water filters under long term daily realistic use conditions in coastal areas of Bangladesh.

2. To evaluate these filter performance in accordance with recently published references and recommendations for microbial performance testing by the World Health Organization (WHO, 2011).

3. To assess the microbial health risk reduction by the filters using Qualitative Health Risk Assessment (QHRA) model.

1.3. Scope of the Study

The following tasks were carried out to achieve the objectives:

For field study:

1. Baseline physico-chemical and microbiological evaluation of different water supply sources in two coastal areas (Mongla and Dacope) of Bangladesh.
2. Distribution of 75 ceramic water filters (CWFs) among users of different income levels and monitoring the performance of filters for about six months under daily realistic uses conditions in four monitoring cycles.
3. Compare the data with related guidelines and standards and evaluate the health risk reduction by the filters of a community using QHRA model.

For laboratory controlled experiment:

4. Laboratory performance study of CWFs from well-known brands against three different organisms and physic-chemical parameters according to WHO guideline.
5. Comparative analysis between the data of field performance study and laboratory controlled study.
6. Drawing conclusion and make recommendation based on the findings of effectiveness of this household water treatment option.

1.4. Contribution of the Study

This research will provide useful information on a user friendly, low cost, popular and globally used ceramic water filter (CWF) as household water treatment (HWT) option to ensure safe water supply to user end point which is an important target of Sustainable Development Goal. Also this study will fill up the unavailability of performance and effectiveness data relevant to ceramic water filters under realistic household usage

condition and laboratory controlled environment following WHO guideline of developing country like Bangladesh.

1.5. Thesis Layout

Chapter 1: This chapter includes general introduction and background along with objectives and scopes of the study. **Chapter 2**: Literature review covers the SDGs on water supply and water borne diseases in Bangladesh with the detail of different household water treatment options. Ceramic Water Filter (CWF) is discussed based on literature review and guidelines on evaluation of treatment technologies. Recent published works on important technologies has been briefly discussed with performance data. **Chapter 3**: Detail methodology has been described in this chapter for both field and control study. Field study has been described with detailed research plan and filter performance methodology. Laboratory study has been with the followed guideline to undertake the experiment. It includes testing schedule, laboratory set up, laboratory monitoring, spiking, sampling, analysis and control of pre and post filtered water for different microbiological and physico-chemical parameters. **Chapter 4**: The summarized data of field performance of the filters have been illustrated and explained in this chapter based on previous studies. **Chapter 5**: The results of control experiment including microbiological parameters and physico-chemical values for different variations are presented in this chapter with necessary analysis. Also comparison among different branded filters has been explained based on the guideline. **Chapter 6**: This chapter includes a precise list of conclusions of the study from both the studies and provides a number of recommendations for future research with the limitation of this study to overcome.

CHAPTER 2: LITERATURE REVIEW

2.1. General

This chapter presents the literature review on the water supply options of Bangladesh, different types of water borne diseases, their causes and facts, WHO drinking water quality guideline and comparison of other standards on water treatment technology evaluation, different household water treatment options. Ceramic Water Filter (CWF) has been described with functional elements and effectiveness evidence of different case studies carried out in different countries.

2.2. Sustainable Development Goal and Drinking Water Supply in Bangladesh

To end poverty, protect the planet, and ensure prosperity for all, on September 25th 2015, countries adopted a new set of goals for the next fifteen years called as Sustainable Development Goal (SDG), which will be universally applied to all, to mobilize efforts to end all forms of poverty, fight inequalities and tackle climate change, while ensuring that no one is left behind. The 2030 SDG comprises 17 sustainable development goals and 169 targets where, Goal 6 discussed about water, sanitation and hygiene (WASH) and target 6.1 directly talks about drinking water which states “By 2030, achieve universal and equitable access to safe and affordable drinking water for all”. The target also mentions that, to deliver safe water, people must use an improved source meeting three criteria which are as follows-

- It should be accessible on premises,
- Water should be available when needed, and
- The water supplied should be free from contamination.

The contamination means free from microbiological (fecal) and chemical contamination. While affordability is an important factor for all households, regardless of service level which should not present a barrier to access or prevent people from meeting basic human needs.

An estimation of 159 million people still collect drinking water directly from surface water sources and among which 58% people live in sub-Saharan Africa. Access to drinking water in eastern and southeastern Asia up to 2015 was 94% in basic level which means- drinking water from an improved source for which collection time exceeds 30 minutes for a round trip, including queuing. Between 2000 and 2015, the population using piped supplies increased from 3.5 billion to 4.7 billion, while the population using non-piped supplies increased from 1.7 billion to 2.1 billion. Globally, two out of five people in rural areas and four out of five people in urban areas now use piped supplies. Available data show that 5.3 billion people use water supplies that tests have shown to be compliant with standards for microbial and chemical contamination. But estimates for water quality are only available for 34 % of the global population. These data suggest that levels of compliance are low in many developing countries (WHO & UNICEF, 2017).

Water supply in Bangladesh is largely dominated by source water and increased population. A recent estimate shows that, at basic level drinking water coverage, Bangladesh has improved from 95% to 97% in the period of 2000 to 2015 (WHO & UNICEF, 2017). In urban areas, only 1% people used surface water from the period of 2000 to 2015. An average 87% Dhaka city's water supply depends on groundwater resources. Even though Dhaka city is surrounded by the four big rivers namely Buriganga, Balu, Turag and Tongi Khal but only 13 % of supplied water is obtained from these rivers (WASA, 2012). Most of the municipalities or city corporations are facing two major problems in supplying water to its residents: i) gradual decrease of raw water sources and ii) discharge of large quantities of polluted water to its nearby surface water (Serajuddin *et al.*, 1993). Surface water sources from surrounding rivers and lakes have already exceeded the standard limits of many water quality parameters because of the discharge of huge amount of untreated and municipal waste materials. Alone in Dhaka city, the microbiological data of treated water ranges from 5000-5000000 cfu/100mL for total

coliform and 1-28000 cfu/100mL for fecal coliform (Sabrina *et al.*, 2013). Treatment of this water has become so expensive that water supply agencies have to depend on groundwater aquifer for drinking water production (Biswas et. al., 2010). To fulfill the daily water requirement from reliable sources, dependency on private sector is increasing day by day. A lot of city dwellers buy filtered or bottled water though they are not well aware of the quality of this water. In addition to that, another option which is called "Jar" water is not trusted in terms of water quality and safety (Unnayan Onneshan, 2011).

In rural Bangladesh, 98% of the population are under the coverage of basic drinking water among which only 1% of them depends on surface water sources up to 2015 (WHO & UNICEF, 2017). An estimated 10 million point source based water supply options (tubewells, dug wells, rainwater harvesting systems and pond sand filters) are available in rural areas, which are operated and maintained by individuals or user groups. A large number of people in Bangladesh still depends on shallow tube wells and about 97% of the rural population relies on tube wells to reduce disease from ingestion of pathogen-laden surface water. According to recent estimates, 61% of rural water supply in free from contamination (WHO & UNICEF, 2017). But this shallow tube well option is also in threat of another problem. The prevalence of Arsenic in the aquifer extracted water in a number of areas of Bangladesh, was a challenge for a long time where millions of people had poisoned by Arsenicosis. According to survey data from 2000 to 2010, an estimated 35 to 77 million people in the country have been chronically exposed to arsenic in their drinking water sources which has been described as the largest mass poisoning in history (MICS, 2009). This challenge had been addressed and initiatives had been taken to narrow down the crisis nationally.

In the coastal areas of Bangladesh, supply of safe and adequate water for this enormous population is a big concern for the human health protection. Due to non-availability of suitable surface and ground water sources (high salinity and non-existence of shallow aquifer), tubewells are not successful in the coastal areas of Bangladesh. Instead, alternative water supply options like Pond Sand Filter (PSF) and Rain-feed Ponds are the main sources of drinking water supply to the coastal population. However, the access to these options is still limited and per capita water consumption is lower in the coastal areas

as compared to other parts of the country (Islam *et al*., 2011b). But PSFs and RWHs are microbiologically unsafe. The fecal coliform (FC) counts in PSF water were found to vary from 0 to over 4000 cfu/100 mL (Islam *et al*., 2011; Ahmed *et al*., 2006) and FC was found in about 97% samples (Ahmed *et al*., 2005). Rain-feed pond waters are highly polluted due to unhygienic sanitation in and around the pond due to indiscriminant usage and lack of protection of the ponds. The FC and *E. coli* counts were found to vary from 12 to 10,000 and 0 to 3000 cfu/100 mL (Islam *et al*., 2011) respectively, together with the presence of several pathogenic bacteria. These counts are very similar to other rural areas of the country.

With the emerging necessity of safe drinking water options, rain water harvesting (RWH) is becoming very popular among the rural people especially to the coastal zone. Several studies (Islam *et al*., 2011a; Karim *et al*., 2010; Howard *et al*., 2006; APSU, 2005) in Bangladesh showed that the rooftop harvested rainwater is of high quality, free from arsenic and satisfies the national and WHO physical and chemical water quality standard. However, microbiological contamination was found to occur in harvested rain water to a great extent, which may cause significant health hazards of the rural people. Several recent studies from other countries (Despins *et al*., 2009; Sazakli *et al*., 2007) also reported microbial contamination of harvested rainwater from rooftop catchments and consumption of harvested rainwater may cause a variety of infectious diseases around the world (Lye *et al*., 2002). This indicates the need of proper treatment of rainwater, if used for drinking purpose. That's why safe drinking water is a challenge in most rural areas due to the absence of proper primary or secondary treatment options for low income community.

2.3. Water Borne Disease

Water contributes to health directly within households through food and nutrition and indirectly as a means of maintaining a healthy, diverse environment. Lack of adequate supplies of safe water and safe methods of preservation; create ideal conditions under which fecal oral diseases thrive. Water-borne disease is transmitted or spread through contaminated water. Pathogenic microbes and some parasitic organisms are responsible for

various diseases. Such infectious pathogens survive and spread in the environment using various strategies. The main source of pathogenic spread is through water.

Infectious diseases caused by pathogenic bacteria, viruses and parasites (e.g. protozoa and helminths) are the most common and wide spread health risk associated with drinking water. The pathogens which transmit through drinking water are diverse in quality, characteristics and resistance (WHO, 2011a). Between 1972 and 1999, 35 new agents of disease were discovered, and many more have reemerged after long periods of inactivity or are expanding into areas where they have not previously been reported (WHO, 2003)

Bangladesh is considered the world's one of the most densely populated countries with 2,639 people per square mile. The most common cause of illness and deaths in the developing countries like Bangladesh is a watery diarrhoea called cholera (Clasen *et al*., 2006) caused by a bacterial pathogen classified as *Vibrio cholerae* (Shultz *et al*., 2009). Among the 50 prevalent diseases in Bangladesh, 40 of them are water borne including diarrhoea, dysentery, typhoid, parasitic worm infections etc. Water borne diseases in Bangladesh cause 5 billion taka (US$ 80 million) each year for treatment in hospitals alone. A total of 1,106,000 deaths can be attributed to water, sanitation and hygiene issues in Bangladesh. Among them 109,000 deaths are directly caused by water related diseases. Diarrhoeal diseases in particular are carried through the medium of water. These diseases account for about 12% of all illnesses in Bangladesh which are alone the major causes of death from water related diseases in Bangladesh. Hence, water borne disease in Bangladesh cost numerous lives each year based on their severity.

WHO Guidelines for drinking-water quality mentions a list of pathogens transmitted through drinking water. **Table 2.1** shows different types of organisms which are responsible for important water related diseases globally based on their severity.

Table 2.1. Pathogens transmitted through drinking water (WHO, 2011b)

Pathogen	Health significance	Persistence in water supplies	Resistance to chlorine	Relative infectivity	Important animal source
Bacteria					
Burkholderia pseudomallei	High	May multiply	Low	Low	No
Campylobacter jejuni, C. coli	High	Moderate	Low	Moderate	Yes
Escherichia coli-pathogenic	High	Moderate	Low	Low	Yes
E. coli-Enterohaemorrahgic	High	Moderate	Low	High	Yes
Francisella tularensis	High	Long	Moderate	High	Yes
Leginoella spp.	High	May multiply	Low	Moderate	No
Leptospira	High	Long	Low	High	Yes
Mycoacteria (non-tuberculous)	Low	May multiply	High	Low	No
Salmonella Typhi	High	Moderate	Low	Low	No
Other *salmonellae*	High	May multiply	Low	Low	Yes
Shigella spp.	High	Short	Low	High	No
Vibrio cholerae	High	Short to long	Low	Low	No
Viruses					
Adenoviruses	Moderate	Long	Moderate	High	No
Astroviruses	Moderate	Long	Moderate	High	No
Enteroviruses	High	Long	Moderate	High	No
Hepatitis A virus	High	Long	Moderate	High	No
Hepatitis E virus	High	Long	Moderate	High	Potential
Noroviruses	High	Long	Moderate	High	Potential
Rotaviruses	High	Long	Moderate	High	No
Sapoviruses	High	Long	Moderate	High	Potential
Protozoa					
Acanthamoeba spp.	High	May Multiply	High	High	No
Cryptosporidium hominis/parvum	High	Long	High	High	Yes
Cyclospora cayetanensis	High	Long	High	High	No
Entamoeba histolytica	High	Moderate	High	High	No
Giardia intestinalis	High	Moderate	High	High	Yes
Naegleria fowleri	High	May multiply	Low	Moderate	No
Helminths					
Dracunculus medinensis	High	Moderate	Moderate	High	No
Schistosoma spp.	High	short	Moderate	High	Yes

Table 2.2 shows an estimate which gives the picture of diseases under different age groups in Bangladesh due to water supply and sanitation options.

Table 2.2. Total annual deaths and water borne disease in different age groups (WSP, 2007)

Cause of death	Children under age 5	Children ages 5-14	Persons ages 15+	Total persons
Diarrhoea (direct)	43,126	121	5,415	48,661
ALRI	12,597			12,597
Measles	4,137			4,137
Malaria	199			199
Other causes*	18,647			18,647
Helminthes (direct)	49	259	20	328
Total mortality	78,755	380	5,435	84,569
*Excluding diarrhoea, malaria, ALRI, measles, intestinal helminthes, and all perinatal causes.				

2.4. Household Water Treatment (HWT) Options

Since the quality of drinking water is hard to control for millions of inhabitants of the developing world, water from unimproved sources is often supplied to communities. This problem is further amplified by the fact that water frequently becomes contaminated after collection but before consumption (Wright *et al*., 2004). This is a particular problem for households who must travel long distances to collect water (Mellor *et al*., 2012 b). In both rural and urban areas, household based treatment has been shown to be about twice as effective in reducing endemic diarrhoea as the conventional treatment at the source or point of distribution (Clasen & Cairncross, 2004; Fewtrell *et al*., 2005).

The point-of-use (POU) water treatment devices or HWT devices are encouraged to apply as a means of improving health by achieving clean water (Clasen *et al*., 2010). Therefore, the implementation of POU water treatments (**Figure 2.1**) has been proposed as an alternative solution where improving the feed water quality is a challenge for drinking purpose. In contrast to centralized, larger capacity systems that treat water for a whole community, POU systems are decentralized and treat water at the household level. These POU technologies offer the advantages of being easily maintained and simple to use.

The POU interventions have demonstrated reduced bacterial contamination in water which leads to human health improvements (Clasen *et al*., 2004; Sobsey *et al*., 2002).

Chlorination seems to be effective against bacterial agents since the median reduction in endemic diarrhoeal disease is 46%. Filtration technologies provide a median reduction of 40%, followed by flocculation and combination of flocculation/disinfection with 38% in median reduction. Somewhat less efficient are solar radiation and heating methods accounting for a median reduction of 35% (Clasen & Cairncross, 2004).

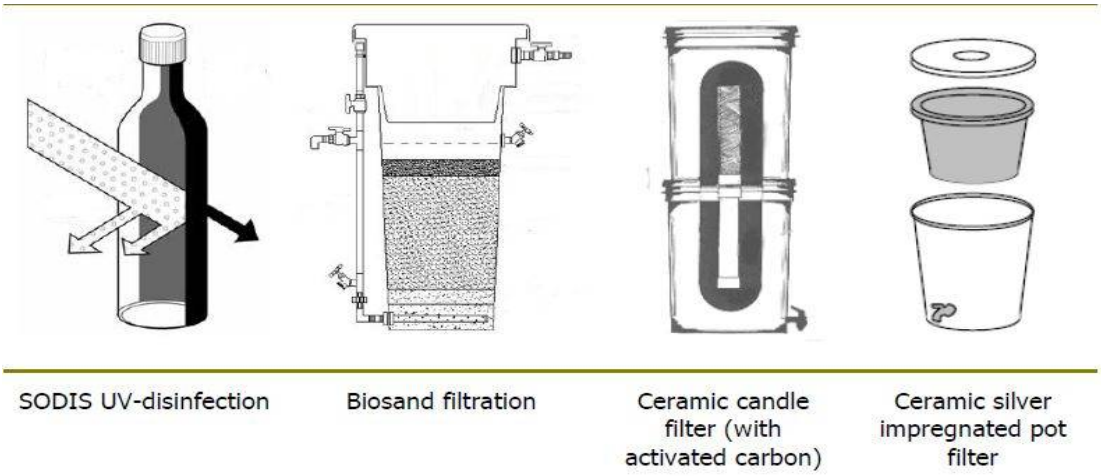


Figure 2.1. Different Household Water Treatment (HWT) options

The POU technologies mostly cover the following water treatment mechanisms:

i. disinfection (chlorination, solar disinfection (SODIS), solar pasteurization, UV irradiation with lamps, and boiling),
ii. particle filtration (cloth fiber; ceramic filter, bio-sand and other slow sand filter technologies),
iii. adsorption media (granular activated carbon, and activated alumina, clay),
iv. other approaches (plain sedimentation settling, safe storage, coagulation / flocculation with iron or alum salts, membrane processes).

Along with these options, combination of these methods simultaneously or sequentially (e.g. coagulation combined with disinfection) often yield more effective results as "multi-barrier" technologies (Souter *et al.*, 2003). Other combination or multiple barriers are media filtration followed by chemical disinfection, media filtration followed

by membrane filtration or composite filtration combined with chemical disinfection. The above mentioned reviews as well as other reviews of technologies have suggested that the success of interventions is highly context specific, with no one technology or method representing a universal best solution (Clasen *et al.*, 2007). The availability of materials, the quality of feed water available, cultural factors and user preferences or cost may determine which technology is most suited to HWT applications in resource-limited settings, such as technologically less developed countries. Mwabi *et al*. (2011) mentions that the most appropriate technology will depend on the following issues:

a. the situation,
b. the quality of the feed water,
c. the availability of the required materials and equipment,
d. the time frame in which it is to be used,
e. the customs, preferences and education levels of the local population and
f. the availability of personnel to provide the necessary training and monitoring for the technology to be successfully implemented.

Some of the important treatment options have been briefly discussed below:

2.4.1. Boiling

Boiling is the most common and probably one of the oldest method for treating small quantities of water globally, with an estimated 1.2 billion people using it as a means of household water treatment (HWT) (Rosa *et al*., 2010 a; Yang *et al*., 2012; Rosa *et al*., 2012). It is such a technique that is being widely accessible and effective against all classes of pathogens if properly done (Sobsey *et al*., 2002), although it may be locally expensive, energy-intensive, and more environmentally costly than other options for water treatment. It is also, in many places, an ingrained cultural practice. Boiling is now being proposed to evaluate as the standard HWT method against which other methods can be evaluated (Clasen *et al*., 2008a).

Boiling water is a widespread practice despite its cost in both fuel and time. A temperature of 55°C or above over a period of several hours will inactivate most bacteria. Because of monitoring issues raised during the thermal process, householders are usually recommended to heat to a vigorous or rolling boil. In theory, the heat treated water should be stored in the same container it was boiled in, but in practice, householders stores treated water in comparatively smaller containers. The main drawback of handling large volumes of boiling water is a hazard and time consuming process to cool the water and disperse it into appropriate suitable containers.

As a technology, boiling has the effectiveness of reducing thermotolerant coliforms (TTC) by 86–99% **(**Clasen *et al*., 2008a; Clasen *et al*., 2008b; Psutka *et al*., 2011; Rosa *et al*., 2010b). A mean *E. coli* reduction of 98.5% in stored boiled water samples was observed in a study (Brown *et al*., 2012) where there is also some reports of negative LRV (log_{10} reduction) in treated water (Desmarais *et al*., 2002; Wright *et al*., 2004; Jensen *et al*., 2002).

2.4.2. SODIS

SODIS (Solar Disinfection) is a technique which was introduced by the American University in Beirut, Lebanon and the Swiss institute EAWAG (Swiss Federal Institute of Aquatic Science and Technology) has improved solar disinfection by adding steps using settlement or filtration to remove turbidity and increasing the effectiveness of UV inactivation by aeration, for instance, by shaking the container to aerate the water (Kehoe *et al*., 2001).

PET bottles (Polyethylene Tetrapthalete) are recently being used in SODIS as it is easier to handle and less likely to release dangerous chemical products. The formation of free radicals derived from oxygen under the influence of UV radiation may play a significant part in removing pathogens through oxidation process.

Sometimes, even with an adequate educational programme, people would not use the technology. This was the case for a successful field study undertaken in Nepal which reduced the fecal coliform count by 90% using SODIS as water treatment but the study

revealed that the method was subsequently adopted by only 10% of the households, despite the fact that the implementation was followed by an educational programme (Rainey & Harding, 2005).

In another study in the coastal areas of Bangladesh shows that the median health risk reduction by SODIS was more than 96 and 90% for pond and RWHS, respectively. Also turbidity has reduced to 5NTU, except pond water. In this case only 34% of the participating households routinely adopted SODIS during the study (Islam *et al*., 2015).

2.4.3. Chlorination

Chlorination was one of the oldest of the disinfection mechanism at the household level. It was first used to disinfect public water supplies in the early 1900s, and helped drastically reduce waterborne disease in cities in Europe and the United States (Gordon *et al*., 1987).

It is available to a broad range of forms (e.g. pills, solution). It has the potential to kill bacteria and viral water borne pathogens. However, at low concentrations normally used for water treatment, chlorine lacks activity against protozoal cysts. The production of chlorinated disinfection by-products was for long considered as a threat to human health at high concentrations but according to report WHO, (2004), the “risk to health from these products are extremely small in comparison to the risks associated with inadequate disinfection.

In association with Pan American Health Organization (PAHO) and US Centers for Disease Control (CDC), Safe Water System (SWS) implemented a trial project where, in four randomized controlled trials, the SWS reduced the risk of diarrhoeal disease by 44–84% using chlorination (Luby *et al*., 2004; Semenza *et al*., 1998).

Studies showed a lot of prevention potential of diarrhoeal disease in developing countries using chlorination. *E. coli* level has reduced to < 1/100mL when using 1-5mg/L dose of hypochlorite. Also *Clostridium perfringens* and heterotrophic plate count have been reduced a lot in chlorine interventions. This resulted into 43% less diarrhoea in

communities where using this treatment in Bolivia and 24% less potential of diarrhoea in Bangladesh (Sobsey *et al.*, 2003).

2.4.4. Sedimentation, Coagulation and Flocculation

Sedimentation is one of the most used techniques among the household treatments as it requires only settling down the water in a container to allow the floating and suspended solids to sediment. The main use of this method is as a pre-treatment or first stage of treatment of the water to remove large inorganic materials. A few hours is needed to settle larger particles. Different pathogens also settle down unless those which are too small are in need of a settlement with coagulation. The main down sides of this technique are the vessels that are used, need to be frequently cleaned and sediments need to be removed. Microbial films growing on the vessel walls need to be removed by scrubbing or by chemical disinfection. Nath *et al*. (2006) found that as a pre-treatment process, sedimentation is "very cost effective requiring only a suitable vessel, labor and time".

Coagulation and flocculation processes are important methods for water treatment. In household level, sachets or tablets are being used to combine both coagulation and flocculation. It involves adding a coagulant to vessel of water, mixing rapidly to spread the coagulant followed by stirring to enable the formation of large flocs. These flocs are responsible to charge the particles which attract the colloidal particles and micro-organisms among themselves. The advantage of the method is that it makes significant improvements in terms of turbidity and removes until 90-99% of pathogenic bacteria and viruses under optimum conditions. However the drawback is that the bacteria can be accumulated on flocs and to cause recontamination of the water. Therefore settlement or filtration is needed after the process. Studies show that this technology can reduce fecal coliforms of 280 – 500 MPN/ 100 mL to 5 – 10MPN /100 mL (Babu & Chaudhuri, 2005).

2.4.5. Filtration

Among the Point of Use (POU) processes, filtration is one of the most promising approaches because, the main advantage of filters are, they are easy to use and are made of local materials such as sand, gravels and ceramic which are familiar to many communities. Filtration covers a wide range of technologies from simple removal of large particles (including cloth or plastic gauze) to sophisticated membrane systems operating under high pressure capable of removal of particles down to the nanometer size. It is becoming more popular in developing countries where chemical disinfection or boiling may not always be practical or effective (Colwell *et al.*, 2003).

Filtration is a way to remove particles and at least some microbes from water. Several processes take place simultaneously during filtration

- Mechanical trapping
- Adsorption of suspended matter, chemical, microorganisms
- Biochemical processes (biodegradation, grazing by protozoan etc.)

For domestic filtration treatment, two general principles are used:

• **Straining:** This is used when the size of the pores in the filter medium is smaller than the particle being removed. This can occur on the filter surface or within the depth of the filter wherever the water flow channels narrow to a size smaller than the particles. This refers to ceramics and granular media filtration.

• **Depth filtration:** when particles passing through the channels become trapped on the surface of the channel wall by a variety of physical mechanisms. This refers to granular media filtration.

A number of studies (**Table 2.3**) show that this HWT or POU technique is very effective in a large variation of water sources against disease burden specifically diarrhoeal diseases (Clasen *et al.*, 2007; Sobsey *et al*., 2002). In addition to that, WHO has emphasized

this treatment option constitutes simple, socially acceptable and low cost interventions with significant potential to reduce global waterborne disease and death (Clasen *et al*., 2006).

Studies shows a good reduction potential of different filtration techniques. In some cases, 48% reduction of cholera was seen in the verification study of filtration. (Colwell *et al.*, 2003). Other study of ceramic water filter shows up to 6 $\log_{10}$ reduction of *E. coli* and 3 $\log_{10}$ reduction of MS-2 virus (Brown *et al*., 2012).

In a follow up meta-analysis done by Clasen *et al*. (2007) showed that, POU technologies at individual household level are more protective in improving water quality and substantially reducing diarrhoeal illness than those interventions implemented in sources to protect water up to consumption.

Table 2.3. Different types of filtration mechanisms and their performance criteria (Sobsey *et al.*, 2002)

Type of filter	Media	Availability	Ease of use	Effectiveness	Cost
Granular media, rapid rate depth filter	Sand, gravel, diatomaceous earth, other minerals	High	Easy to moderate	Moderate	Low to moderate
Slow sand filter	Sand	High	Easy to moderate (community level)	High in principle but often low in practice	Low to moderate
Vegetable and animal derived depth filters	Coal, sponge, charcoal	Medium to high	Moderate to difficult	Moderate	Low to moderate
Fabric, paper, membrane, canvas filter	Cloth, other woven fabric, synthetic polymers	Low to high	Easy to moderate	High to low (according to pore size and composition)	Low (natural) to high (synthetics)
Ceramic and other porous cast filters	Clay, other mineral	From high to low, with material availability and fabrication skills	Moderate (regular cleaning are needed)	From high to low (according to pore size and ceramic filter quality)	From high (imported) to moderate (local)
Septum and body feed filter	diatomaceous earth, other fine media	Varies	Moderate to difficult	Moderate	Varies

Table 2.4 shows the factors influencing the performance of some of the used technologies as POU treatment option. These factors are important parameter of options in improving their performance and efficacy.

Table 2.4. Factors influencing performance efficacy of different treatment options

Treatment options	Factors influencing performance efficacy
Porous ceramic filtration	Varies with pore size/structure, tortuosity, flow rate, filter medium composition, augmentation with silver or other chemical agents that enhance microbe inactivation or retention. (Lantagne *et al*., 2001; Sobsey *et al*., 2002; Brown *et al*., 2007a; Brown *et al*., 2007b)
Biosand filtration (BSF)	Varies with pore size/structure, tortuosity, flow rate, filter medium composition, augmentation with silver or other chemical agents that enhance microbe inactivation or retention. (Hijnen *et al*., 2004; Stauber *et al*., 2006)
SODIS	Depends on water oxygenation, sunlight intensity, exposure time, temperature, turbidity, and size of vessel (depth of water) (Sobsey *et al*., 2002; Wegelin *et al*., 1994; Reed *et al*., 1997; Meyer *et al*., 2001; Mendez *et al*., 2005; McGuigan *et al*., 2006)
Free chlorine	Turbidity and chlorine demand reduce efficacy; contact time predicts efficacy; Minimally effective against *Cryptosporidium parvum* oocysts.(Venczel *et al*., 2004; Schlosser *et al*., 2001)
Coagulation/chlorination	Possible physical removal of chlorine-resistant pathogens by coagulation-flocculation; turbidity may inhibit performance; reductions differ among viruses. (Power *et al*., 1994; Souter *et al*., 2003).

Table 2.5 illustrates the performance estimation of different water treatment technologies against diarrhoeal disease in addition to their compliances.

Table 2.5. Diarrhoeal disease reduction by POU Technologies in controlled studies

Technology	Diarrhoeal disease reduction Estimate (95% CI)	Compliance (estimates of self-reported and/or measured % user compliance)
SODIS (solar UV radiation + thermal effects)	31% (26%-37%)(Clasen *et al*., 2007)	78% compliance during study(Rose *et al*., 2006); however, post study compliance rates may drop as low as 9% (Rainey *et al*., 2005)
Free chlorine and safe storage	37% (25%-48%) (Clasen *et al*., 2007) 29% (Arnold *et al*., 2007)	60-73% of households were self-reported users, but only approximately 30-40% of those who reported use had detectable free chlorine levels (Ram *et al*., 2007; Makutsa *et al*., 2001; Colindres *et al*., 2007)
Coagulation/chlorination	31% (18%-42%) (Clasen *et al*., 2007) 29% (Arnold *et al*., 2007)	usage rates may drop to as low as 10% after intervention ends (MacGregor-Skinner *et al*., 2003)
Ceramic filtration through candle filters	63% (51%-72%) (Clasen *et al*., 2007)	high until filter breaks; in a trial in Bolivia, compliance was 88% over 6 months (Brown *et al*., 2003)
Ceramic filtration through ceramic water purifiers, biosand filtration	46% (29%-59%) (Brown *et al*., 2007a) 47% (21%-64%) (Stauber *et al*., 2007)	dependent on filter breakage rates (Brown *et al*., 2007a, Brown *et al*., 2007b) >85% post-implementation (Linag *et al*., 2007; Aiken *et al*., 2007)

[a]Summary estimates stratified by type of intervention (from a meta-analysis of drinking water quality interventions and diarrhoeal disease reductions).
[b]Summary estimate from meta-analysis on POU chlorination (includes both free chlorine disinfection and combined coagulation-disinfection).

2.5. Performance Evaluation Guidelines for Household Water Treatment Options

Quality of drinking water depends mainly on the microbial safety. From the source to the consumer, the pathogenic contamination can be happen at multistage and affects the quality of the water. So there should have some combined approaches to treat the pathogenic contamination and increase the safety by reducing the entry of pathogens. In

general terms, the greatest microbial risks are associated with ingestion of water that is contaminated with pathogenic bacteria, viruses, protozoa and helminthes.

To ensure safe water, World Health Organization (WHO) proposes different treatment mechanisms based on country specific settings. Organizations and NGOs developed their own mechanisms and techniques to purify drinking water against pathogenic threat. Different source water including pipe water and other supply water are no longer safe due to various contamination in intermediary stages; household water treatment (HWT) is becoming a point of concern for public health safety (UNICEF & WHO, 2009). For household level treatment, point of use (POU) treatment is very effective against contaminated source water. WHO has specified HWT and POU as synonymous mechanisms. It has stated that- for the purposes of treating water at the household level or at the point of use in other settings, such as schools, health-care facilities and other community locations, a range of technologies, devices or methods can be employed which will be termed as household water treatment (HWT) or point of use (POU) treatment (WHO, 2011b).

2.5.1. Log Reduction Value (LRV)

In evaluating microbial effectiveness of any technology, Log Reduction Value (LRV) or $\log_{10}$ reduction is used to define the reduction potential of the technology. LRV is a simple logarithmic mathematical tool which is evaluated in microbe concentration in comparison to the source water quality. Generally LRV means the logarithmic reduction of microbes used to show the relative number of live microbes eliminated from a surface by disinfection or cleaning.

The determination of LRV is simply noted as follows:

$\log_{10}$ reduction (LRV) = ($C_{\textbf{untreated water}} / C_{\textbf{treated water}}$),

where C = microbe concentration in water.

All the standards and guidelines mention performance evaluation of any water treatment technology through LRV. So in performance testing, until epidemiological data are obtained and/or where epidemiological studies may not be practical or appropriate, experimental options must be used to verify through control measures in a wide variety of settings based on $\log_{10}$ reduction (LRVs) (WHO, 2011b). So it can be exemplified as follows:

1. 1 $\log_{10}$ reduction (LRV) is equal to 90 % reduction; 2- $\log_{10}$ reduction equals 99 %; 3-log reduction equals 99.9 % and so forth. A requirement of 5- $\log_{10}$ reduction, or 99.999 %, is a much stricter than 2- $\log_{10}$ reduction or 99%.
2. A technology which can be effective against bacteria by 5 $\log_{10}$ reduction, that means lowering the number of microorganisms by 100,000-fold, or
3. If water contains 100,000 pathogenic microbes in it, a 5- $\log_{10}$ reduction would reduce the number of microorganisms to one.

To evaluate any technology, it should demonstrate the reduction potential against three important organisms of disease that is bacteria, virus and protozoa. So for evaluation, LRV has to be calculated based on the reduction of specific organisms.

Globally different countries and organizations developed their own set of guidelines or standards to accommodate the evaluation of treatment facility based on their preferences and demands. **Table 2.6** provides a list of different standards and their recommended LRV for water treatment technologies.

Table 2.6. Different standards and their recommended LRV for water treatment technologies (Andrew *et al*., 2012)

Sl No	Standard	Log_{10} reductions	Application	Comments
1.	US EPA Guide Standard-1987	Bacteria: 6 Virus: 4 Cyst: 3	Covers multiple technologies; covers unknown water conditions, including highly turbid.	A seminal and very well-known guide standard, it has far-reaching influence, although it leaves significant room for interpretation.
2.	Israel SI 1505 Part 1, Part 2	Bacteria: 7 Virus: N/A Cyst: N/A	Covers filtration, UV and RO systems; covers only clean-water applications and not highly turbid.	
3.	Japan JIS 3835	Bacteria: report results only Virus: N/A Cyst: N/A	Covers membrane filters; covers only clean- water applications and not highly turbid.	A test method to establish ratings for membrane filters.
4.	Mexico NOM-ISO-SSA	Bacteria: 4/1.3 Virus: N/A Cyst: N/A	Covers domestic water treatment equipment; covers only clean-water applications and not reduction of highly turbid.	Requires 4-log reduction of E. coli and 1.3-log aerobic bacteria.
5.	Australia/New Zealand AS/NZS 4348	Bacteria: 6 Virus: 4 Cyst: 3	Covers multiple technologies; covers unknown water conditions, including highly turbid.	Influenced by the US EPA Guide Standard.
6.	Brazil ABNT NBR 14908	Bacteria: 2 Virus: N/A Cyst: N/A	Covers plumbed-in filtration systems, covers only clean-water applications and not highly turbid.	
7.	Brazil ABNT NBR 15176	Bacteria: 2 Virus: N/A Cyst: N/A	Covers gravity-fed filtration systems, covers only clean-water applications and not highly turbid.	
8.	Venezuela COVENIN 3377	Bacteria: claims verification only Virus: N/A Cyst: N/A	Covers non-ceramic filtration systems and ozonation systems, covers only clean-water applications and not highly turbid.	Serves to verify claims only, without pass/fail criteria established.

9.	Venezuela COVENIN 2840	Bacteria: claims verification only Virus: N/A Cyst: N/A	Covers ceramic filtration systems, covers only clean-water applications and not highly turbid.	Serves to verify claims only, without pass/fail criteria established
10.	California Guidelines 2004	Bacteria: 6 Virus: 4 Cyst: 3.3	Covers multiple technologies; covers unknown water conditions including highly turbid.	Influenced by the US EPA Guide Standard
11.	WQA ORD0901	Bacteria: 3 Virus: 3 Cyst: N/A	Covers gravity-fed filtration systems, covers only clean-water applications and not highly turbid.	Intended for application in developing nations
12.	Proposed supplemental standard NSF/ANSI 244-3	Bacteria: 6 Virus: 4 Cyst: 3.3	Covers mechanical filtration systems, covers only clean-water applications and not highly turbid.	Influenced by US EPA Guide Standard. Intended to provide certification for filtration systems that could be used regularly to protect against conditions that later trigger boil-water advisories.
13.	WHO HWT Guidelines 2011/ NSF P415	Highly protective Bacteria: 4 Virus: 5 Cyst: 4 Protective Bacteria: 2 Virus: 3 Cyst: 2 Interim requires 'protective' in two categories, plus documented Health gains.	Covers multiple technologies; covers unknown water conditions, including highly turbid.	Influenced by US EPA Guide Standard Intended for use by local governments and others in developing nations. WHO HWT Guidelines provide guidance on test methodology, but are not prescriptive in terms of how the testing is performed. NSF P415 uses NSF P231 as the testing methodology and the log reductions from the WHO HWT Guidelines to establish claims

Bangladesh standard for drinking water quality is mentioned in Environmental Conservation Rule (ECR) 1997; which descriptively talks about the physic-chemical and briefly about microbiological parameters. But for evaluation of such kind of water treatment systems, no guideline value is provided in Bangladesh standard.

2.5.2. Targeted Pathogens

In practice, there are two basic criteria for evaluation of any technology against organisms. First, those technologies which can show efficiency against bacteria only. Second, those technologies which is efficient against all three kinds of pathogens: bacteria, viruses and protozoan cysts or spore forming bacteria. But requiring treatment of all three types of organisms is much protective than requiring treatment of bacteria only (Andrew *et al*., 2012).

For any kind of treatment evaluation for drinking purpose, targets are derived for reference pathogens representing three classes of pathogens: bacteria, viruses and protozoa. These three classes of pathogens are represented because each class is uniquely distinct in regard to the physic-chemical and biological properties of the pathogens within the class and in terms of resistance to various treatment technologies (WHO, 2011b).

All these pathogens are found widely in drinking water supplies in low and high income countries and are associated with enteric disease of children in countries with a high burden of disease (Levin *et al.*, 2009).

The selection of organisms were based on some of the following criteria mentioned in WHO guideline (WHO, 2011b) which states-

- The reference pathogens for bacteria, viruses and spore forming bacteria or cysts were selected based on their relative characteristic, high public health importance and conservativeness with respect to dose response and infectivity. In other words, if treatment options were in place to control these reference pathogens, there would be the expectation that other important pathogens within each class of pathogen would also be controlled.

- Separate individual treatment units should be used for effectiveness testing against each separate microbe (e.g. *Escherichia coli*, coliphages, *Clostridium perfringens* spores) to prevent any interaction between these microbes that could potentially influence the validity of the treatment performance and test microbe assays.
- The choice of target microbes is an important consideration in technology verification studies. It is preferable to do such studies with the microbes that are known to be present in the source water and pose the highest waterborne disease burden. If the important waterborne pathogens are not known or studies with the known, relevant pathogens are not possible, it is recommended that test challenge waters be spiked with sufficient concentrations of indicator bacteria, viruses and spore forming bacteria to follow the extent and possibly the kinetics of inactivation over time.

The WHO recommended indicator bacteria, viruses and spore forming bacteria are, respectively, *Escherichia coli*, bacteriophages of *E. coli* and spores of either *Clostridium perfringens* or *Bacillus* spp. to document $\log_{10}$ reductions of treatment technologies. Different performance evaluation studies were done using these indicator organisms to understand the potential of microbial effectiveness of those technologies against contamination in India, Cambodia and other countries. (Brown *et al*., 2012; Bhathena *et al.*, 2013; Bhathena *et al*., 2014)

2.5.3. Specific Performance Target for Each Organism

WHO (2011b) has mentioned three recommended levels of performance for the technologies to reduce bacteria, viruses and protozoa or spores are illustrated in **Table 2.7**.

Table 2.7. Criteria of Log_{10} reduction for technologies to establish health-based HWT performance targets

TARGET	Log_{10} reduction required: Bacteria	Log_{10} reduction required: Virus	Log_{10} reduction required: Protozoa
Highly protective	**≥ 4**	**≥ 5**	**≥ 4**
protective	**≥ 2**	**≥ 3**	**≥ 2**
Interim*	**Achieves "protective" target for two classes of pathogens and results in health gains**		
* Treatment options classified as "interim" should be recommended only when credible epidemiological evidence indicates that use of such devices results in reductions in waterborne disease.			

These criteria show three different targets or levels for bacteria, virus and spores. These range from a top tier target "highly protective" reference level of risk of 10^{-6} DALY per person per year to a bottom tier, "interim" target relevant to the performance of currently available, low cost technologies that have demonstrated health improvements.

The top tier standard of "highly protective" represents those technologies that, if used correctly and consistently over an entire year, will limit drinking-water disease burden to 10^{-6} DALY per person. This is an extremely conservative health based target and from a health perspective, such technologies should be unequivocally recommended for use.

The second tier, "protective", has been established to allow for a less stringent level of tolerable disease excess, yet is still consistent with the goal of providing high-quality, safer water. The "protective" target defines pathogen removals that achieve a health-based target of 10^{-4} DALY per person per year. In areas with a suspected high burden of waterborne disease, technologies that meet the log removal standards in the second tier would still result in significant health benefits. Both the "highly protective" and "protective" targets are based on the removal of all three classes of pathogens.

Highly protective and to a lesser extent, protective targets are conservative and that achievement of these targets may not be the most cost effective or achievable option in some situations, an "interim" target has been set. The "interim" target applies to those technologies that achieve "protective" removal targets for two classes of pathogens and have a proven impact on reducing diarrhoeal and waterborne infections. Achievement of

this lower tier target should be seen as an initial step in an effort to incrementally improve towards the ultimate target of “highly protective”.

2.5.4. Water Sampling for Performance Evaluation

According to the guideline (WHO, 2011b) any treatment technology that will be evaluated should be effectively monitored for five consecutive samplings for necessary physic-chemical and microbiological parameters.

Filters having a structured porous barrier to retain microbes and other contaminants should be tested according to the manufacturer’s recommendation. A flow rate, average volume treated per day (minimum 20 litres) and other operational parameters that closely represent actual household use conditions should be monitored. It is because of the variation of performance over time corresponding to an anticipated use cycle before routine maintenance, cleaning or replacement should be taken under consideration for verification testing. The guideline recommends that challenge testing with spiked water should take place throughput per filters at intervals of 0%, 25%, 50%, 75% and 100% of the life cycle (in terms of volumetric filtration) or the cleaning cycle of the filter and should include challenge testing with spiked water into the next cycle of use after cleaning to document continued performance. In some other studies (Bhathena *et al.*, 2013), it is observed that, 60% of the life cycle (sampling point) is also added for conservative evaluation for more accuracy.

Some effectiveness study of CWF, like in Cambodia, 1500 liters of filtration volume has been selected as the performance target for the filters (Brown *et al.*, 2012; Brown *et al.*, 2013). It can be done when the consumables of the filters do not have any specific life year or the manufacturers don’t claim any design life year for the filters all together. Other studies (Clasen *et al.*, 2006b; Brown *et al.*, 2012; L. Guerrero-Latorre *et al.*, 2015) also evaluated filter effectiveness considering the 1500 liters or less as performance target.

2.6. Ceramic Pot Filter/ Mineral Pot Filter

Ceramic water filters (CWFs) or Mineral pot filters (MPFs) are one such technology that can be produced locally using methods and materials that do not need to be imported and are an environmentally sound technology. Among household based water treatment interventions, these filters have been shown to be particularly protective against diarrhoeal disease (Clasen *et al*., 2006). It is widely used around the globe and in an estimate in 2009; there were about 35 ceramic pot filter factories in 18 countries worldwide with a monthly production of 20,175 filters (Rayner *et al*., 2013).

Cartridge or ceramic water filter (CWF) is widely used in urban areas of Bangladesh as a household intervention for drinking water to treat pipe water supply or any surface water. Due to its reliability to the users, the technology has spread out to some semi urban and rural areas of Bangladesh. As no local manufacturer produces CWF in Bangladesh, the filters are mainly imported from Malaysia, Thailand, South Korea and China (Karim *et al*., 2016). Except few, most of the brands assemble different parts of the filter from different sources. These filters are available in the local market all over the country at a reasonable price (BDT. 1300 to 3000) having a good outlook. All the body parts are made of plastic or rubber and hence the weight of the product is less. It is a lightweight, portable, low-cost, free from chemicals, gravity driven device without the need for any external energy sources; this provides safe water storage, requiring only periodic cleaning and giving a filter life of at least 0.5 –1 year (WSP, 2007). Sometimes a cloth or fiber pre filtration or boiled water may be used before the ceramic filtration. Treatment elements consist of a ceramic candle or other microporous, solid filter element followed by granular media filtration. Units were designed to operate as ‘tabletop’ filters, rather than plumbed in devices such as point-of-entry (POE) or under-sink technologies. A typical CWF is shown in **Figure 2.2**.

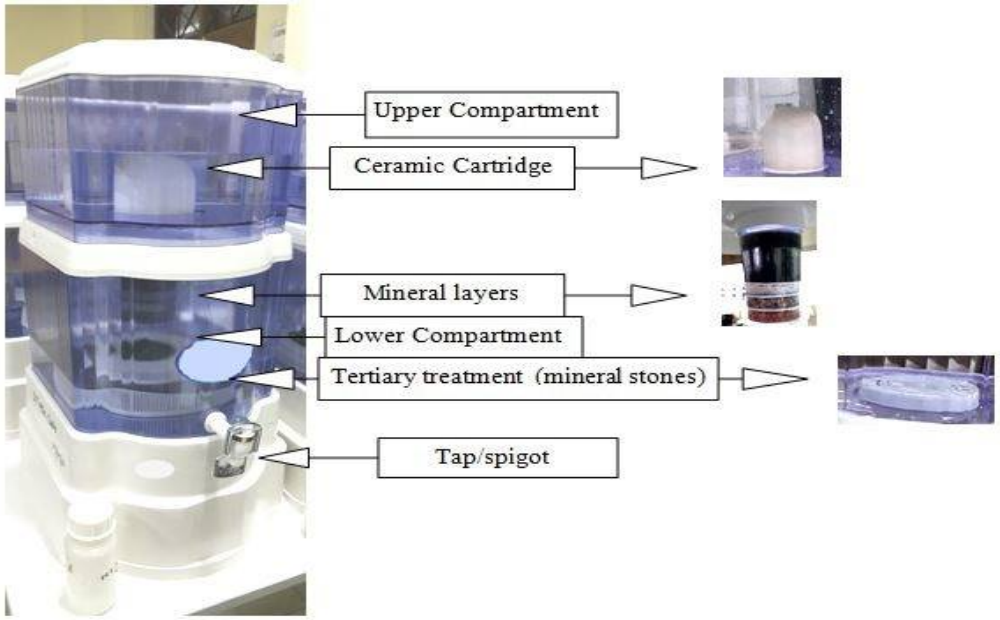


Figure 2.2. Typical CWF filters and different components

A "mineral stone" cartridge containing additional mixed granular media in contact with product water imparts a distinctive mineral taste to the water. The design and fabrication of the filter of every company is very much similar, having a dome type ceramic filter at the top chamber and followed by a cartridge filter comprised of an activated carbon filter and a four layered filter (silica sand, zeolite, mineral sand, stone and other unspecified media) at the bottom chamber as shown in **Figure 2.2**. In some brands, they provide a box of mineral gravels in lower compartment of the filter for tertiary filtration. Pathogens are removed as contaminated water passes through the candles in the top compartment to the lower holding compartment. Feed water is poured at the top chamber; water is passed through both the ceramic filter and cartridge filter and stored in the bottom chamber. The system allows water to pass slowly to lower compartment which enables the feed water to sediment the suspended matters on the upper compartment. So sedimentation is coupled with filtration. The filtered water can only be accessed from the lower compartment by a tap or spigot, thus protecting it from the risk of recontamination prior to consumption (Clasen *et al.*, 2003).

There are lots of variations in manufacturing ceramic pot filters depending on the materials available. Lots of country specific studies (Karim *et al*., 2016; Mohamed *et al*., 2016; Bhathena *et al*., 2014; Murphy *et al*., 2010; Clasen *et al*., 2007; Van Halem, 2006) showed variations of manufacturing and performance based on their materials and quality. Also social need of those filters was a driving force to establish this kind of technologies in the developing nations.

2.6.1. Review Studies on HWT Options

1. A pilot study was conducted by UNICEF to assess the viability of scaling HWTs across rural Tanzania. A total of 603 households (292 in Kisarawe and 311 in Geita Districts) were selected for the study and evaluation procedures were approved by Medical Research Coordinating Committee of the National Institute for Medical Research.

Six technologies namely i) boiling; ii) ceramic siphon filters; iii) 1.25% sodium hypochlorite solution, iv) 67 mg NaDCC tablets; v) flocculent/disinfectant sachets and vi) locally produced silver treated ceramic pot filters were selected by UNICEF and the study team for field testing. The primary outcome variable was reduction of thermo-tolerant coliforms (TTC) in house-hold drinking water after the use of the technologies in situ. Boiling as an HWTS method was prevalent across the four communities before the trial, whereas other methods were generally new to users. A total of 1202 pairs of samples were included in the analysis, collected from 390 households.

Table 2.8 shows great reduction potential against TTC to improve microbial water quality at point of use. Almost all of these technologies showed similar type of performance and the approach didn't allow detecting fine differences between LRVs and detecting high reductions. All technologies consistently met WHO criteria for "protective" treatment of drinking water on the basis of bacterial reduction.

Table 2.8. Mean LRV of two studied districts for different treatment methods.

	Log_{10} mean (cfu/100mL) untreated$_a$		Log_{10} mean (cfu/100mL) Treated$_b$		Combined log_{10} mean reduction	Mean combined % reduction
Method	**Geita**	**Kisarawe**	**Geita**	**Kisarawe**		
Boiling (n_a =157, n_b =157)	3.0	2.7	0.44	1.2	≥ 2.2 (1.97-2.31)	≥ 99.3
Ceramic pot filter (n_a =90, n_b =90)	2.8	2.9	0.60	0.57	≥2.3 (2.01-2.49)	≥ 99.5
PuR (n_a =86, n_b =86)	2.8	2.9	0.24	0.80	≥ 2.4 (2.18-2.53)	≥ 99.6
Ceramic Siphon filter (n_a =83, n_b =83)	2.9	3.0	0.34	0.44	≥ 2.5 (2.35-2.73)	≥ 99.7
Water guard (n_a =91, n_b =91)	3.0	2.5	0.39	0.73	≥ 2.2 (1.96-2.45)	≥ 99.4
Aquatabs (n_a =94, n_b =94)	2.9	2.9	0.34	0.59	≥ 2.5 (2.31-2.64)	≥ 99.5

In this study, ceramic pot filters (with a 30 liters safe storage container) significantly improved water quality, achieving a mean overall TTC reduction of 99.5% (95% CI 99.1–99.7%) in compared to studies from Cambodia reporting *E. coli* reductions of 99% (95% CI 98.9–99.4%, n = 485) and 98% (95% CI 96.8–98.7%, n = 203) (Brown *et al.*, 2008, Brown *et al.*, 2010). 14% of the boiled water samples contained 101–1000 TTC/mL, consistent with high microbial risk (WHO, 1997), possibly due to post-treatment contamination. Safe storage containers may not have been washed well or could have been washed with contaminated water. User behavior has been shown to be closely related to effectiveness (Levy *et al.*, 2014).

2. This study was intended to evaluate three most common CWF brands on the domestic market in Cambodia in 2010, from an informal survey of retail outlets in Phnom Penh undertaken by WaterSHED Asia: i) Nova, ii) Korea King, and iii) Seoul. Four of each device was purchased and units were assembled according to manufacturer instructions in the laboratory according to WHO (2011) performance testing recommendations.

Approximately 10 liters of water was dosed daily and the performance was monitored for 1500 liters. Challenge waters were spiked with microbes daily in the morning, allowed filtering for approximately 6 h and samples for analysis were taken from

the post treatment storage container as a composite of that day's filtrate. Filters were challenged with all three microbes daily, (1) *Escherichia coli* as the model bacterium, (2) the bacteriophage MS2 as the model virus and (3) spores of *Bacillus atrophaeus* as a surrogate for *Cryptosporidium oocysts* and other encysted protozoans. Spiked samples were added to test water at concentrations sufficient to determine up to 5 $\log_{10}$ reductions (99.999%). Untreated and treated waters were assayed once per week per microbe. A comparison of concentrations in pre and post treatment water was used to determine the $\log_{10}$ microbial reductions.

Table 2.9. Summary of CWF microbiological effectiveness over 1500 Liters

	$\log_{10}$ reduction over 1500 liters throughput, arithmetic means (95% CI)					
	dechlorinated tap water			**dechlorinated tap water with 1% sterilized untreated wastewater**		
parameter	Nova	Korea King	Seoul	Nova	Korea King	Seoul
***E. coli* (49)**	5.6 (5.0−6.1)	4.2 (3.6−4.9)	4.7 (4.1−5.3)	4.2 (3.6−4.9)	4.2 (3.6−4.7)	4.1 (3.5−4.7)
MS2 (28)	3.0 (2.7−3.3)	3.1 (2.9−3.4)	3.0 (2.7−3.2)	2.0 (1.6−2.3)	2.2 (1.9−2.6)	2.0 (1.8−2.3)
B. atrophaeus (52)	2.5 (1.9−3.1)	1.3 (1.0−1.6)	1.6 (1.3−2.0)	1.9 (1.4−2.4)	0.93 (0.76−1.1)	1.2 (0.86−1.5)
Turbidity (224)	0.74 (0.67−0.80)	0.64 (0.58−0.69)	0.58 (0.49−0.66)	0.67 (0.61−0.74)	0.74 (0.69−0.80)	0.62 (0.57−0.68)

The results from **Table 2.9** suggest that at least one filter (Nova) could meet WHO recommended performance levels for the "protective" level but not consistently across test waters. The three filters were as effective or more effective than other locally available drinking water treatment options, including ceramic filters (Brown *et al.*, 2010, Brown *et al.*, 2008) biosand filters (Elliot *et al.*, 2006, Elliot *et al.*, 2008) and boiling (Brown *et al.*, 2012). Fluctuation in performance over time may be related to unmeasured changes in water chemistry, variations in pretreatment concentration or other factors which may also vary under use conditions. As measured by mean performance, however, the results indicate that the CWF devices tested have potential to deliver microbiologically safer drinking water to users over extended use.

3. A systematic review of five Point of use (POU) treatment technologies namely i) Chlorination with Safe Storage, ii) Combined Coagulant-Chlorine Disinfection Systems, iii) SODIS, iv) Ceramic Filter, v) Biosand filter was conducted to understand the performance potential against drinking water causing infectious diseases. This study provides a timely opportunity to compare them on the basis of key criteria for effectiveness and sustainability. This review examined these POU technologies based on available evidence in a rigorous framework for holistic comparisons of their microbial efficacy, health impacts and sustainability. The results tabulated in **Table 2.10** are mostly based on highest quality of epidemiological evidence for diarrhoeal disease reductions comes from randomized controlled trials (RCTs) and prospective cohort studies.

Table 2.10. Estimates of Baseline and Maximum Effectiveness of POU Technologies

Treatment process	Pathogen Group	Baseline LRV [a]	Maximum LRV [b]
Porous ceramic filtration	Bacteria	2	6
	Virus	0.5	4
	Protozoa	4	6
Biosand filtration (BSF)	Bacteria	1	3
	Virus	0.5	3
	Protozoa	2	4
SODIS	Bacteria	3	5.5 +
	Virus	2	4+
	Protozoa	1	3+
Free chlorine	Bacteria	3	6+
	Virus	3	6+
	Protozoa	3	5+
Coagulation/chlorination	Bacteria	7	9
	Virus	2-4.5	6
	Protozoa	3	5

[a]Baseline LRV: LRV typically expected in actual field practice when done by relatively unskilled persons who apply the treatment to waters of varying quality and where there are minimum facilities or supporting instruments to optimize treatment conditions and practices.
[b]Maximum LRV: LRV possible when treatment is optimized by skilled operators who are supported with instrumentation and other tools to maintain the highest level of performance in waters of predictable and unchanging quality.

This extensive study includes a lot of performance and practice behavior regarding the five technologies to understand the summarized issues using a scoring technique from

1 to 3. Score 1 means low efficient and score 3 is the most efficient or good technology based on some criteria. The scoring for ceramic water filter is as follows:

From the scoring we can see that ceramic pot filter has showed a great potential to be an efficient POU technique. Study showed a good number of evidences to improve diarrhoeal diseases. Also in producing good quantity water, ceramic filter was scored 2 as it can produce approximately 8 liters in 4 hours and 20 liters in about 10 hours having a flow rate. Flow rates are about 1-3 liters per hour, but decline with use and accumulation of impurities on filter element surfaces. In considering technical robustness against the wide range of water quality, it can remove turbidity, organic matter, and microbes. Also it is simple to clean manually to restore efficacy and flow rate if too much particulate matter accumulates. That's why it has been scored 3 the maximum. Water is poured into the top of the filter as needed and flows by gravity into a storage vessel for immediate use. Filter elements require periodic cleaning by manually scrubbing and rinsing to remove the accumulated impurities. So score: 2. In terms of cost, a filter unit is $ 8-10 and a replacement porous ceramic pot element is $ 4-5. So it has been scored 3. In case of supply chain requirement filter units provide long use periods with one time purchase, but require a supply chain for replacement of broken parts (filter elements and container faucets). So score: 2.

Acceptance and continued ceramic filter usage has been observed to be high. However, breakage of ceramic filter elements and container faucets results in declining use if replacement parts are not available, highlighting the importance of a supply chain to replace broken parts. Overall, ceramic filters provide long periods of effective use for a modest one time purchase cost and no ongoing costs except those for occasionally replacing broken parts (Brown *et al.*, 2007a; Brown *et al.*, 2007b).

4. Another study was conducted to evaluate three widely available, gravity-driven, household-scale drinking water filtration devices in the Indian market namely i) Tata Swatch (Granular media filtration and inactivation via contact with silver nanoparticles) ii) Kent Gold (Hydrophilic ultrafiltration, removal of suspended impurities, activated carbon filter augmented with silver nanoparticles) iii) Aquasure PCTi ('Positively charged

attractors' that trap microbes, proprietary 'microfibre mesh' employing nanotechnology). The objective was to evaluate the performance of those devices to remove microbes from water over long term daily realistic use conditions and in accordance with recently published guidance and recommendations for microbial performance testing by the World Health Organization (WHO, 2011b). The main microbiological parameters representing indicator bacteria, virus and spore forming bacteria are *Escherichia coli*, male-specific MS2 bacteriophage, 3 µm microspheres and *Bacillus* spp. spores, which have been used as to understand efficiency of the technologies.

Table 2.11. Challenge effectiveness against test microbes (log_{10} reduction values) over defined lifespan

Spike point	***E. coli***		**MS2**		***B. subtilis***		**3 µm Microspheres**	
Mean temp	30°C		30°C		30°C		30°C	
Challenge water	1	2	1	2	1	2	1	2
Tata swatch	Design life = 3000litres, Flow rate (mL/min)=20-100, treated water storage volume(L)= 18							
0%	2.0	2.7	7.1	7.0	2.0	2.4	1.0	1.1
25%	1.0	0.7	1.7	1.5	0.8	0.3	0.2	0.3
50%	2.9	2.8	1.7	2.1	1.2	0.2	0.2	0.2
60%	1.8	1.5	0.8	0.8	0.0	0.4	0.2	0.2
75%	1.9	1.3	0.9	0.8	0.0	0.1	0.2	0.2
100%	0.9	1.1	0.6	0.6	0.0	0.5	0.1	0.2
Kent Gold	Design life = 4000litres, Flow rate (mL/min)=20-130, treated water storage volume(L)= 20							
0%	1.4	7.2	2.7	2.0	2.1	6.8	1.6	1.8
25%	1.5	3.8	0.1	0.0	0.9	1.9	0.4	0.4
50%	1.5	2.9	1.7	1.8	1.1	1.0	0.3	0.4
60%	1.1	0.1	0.9	1.7	0.1	0.6	0.3	0.3
75%	0.6	0.8	0.6	0.6	0.0	1.4	0.2	0.3
100%	0.5	0.7	0.6	0.6	0.0	1.3	0.1	0.2
Aquasure PCTi	Design life = 750litres, Flow rate (mL/min)=20-45, treated water storage volume(L)= 20							
0%	3.5	7.2	7.1	7.0	6.1	6.8	1.6	2.2
25%	2.5	3.5	1.0	0.8	2.0	1.4	0.1	0.2
50%	3.0	2.2	1.5	0.8	1.3	0.7	0.6	0.4
60%	0.8	2.7	1.5	0.8	0.8	0.1	0.7	0.5
75%	2.6	3.3	1.5	2.1	2.3	2.0	0.3	0.3
100%	2.7	2.9	2.2	2.0	1.6	1.6	0.2	0.3

From the results (**Table 2.11**) it can be summarized that the three brands did not show that much mean reduction potential against the pathogens as recommended values

though inconsistently they have some good reduction potential seen from high LRV values. For each analysis, it has been observed that with time the performance has been decreased though initially filters showed high reduction potential. All units exhibited clogging and markedly reduced flow rates after 75% of life span was achieved, particularly with the higher turbidity challenge water 2. Also the manufacturer claims regarding the filters were overestimated regarding their performance in term of microbiological reduction.

5. A comprehensive evaluation of the effectiveness of ceramic filters impregnated with silver nanoparticles was conducted both in laboratory and field environments (where filters are produced and used by local residents). In the laboratory, filters have been manufactured by using clay collected from field study site, and different configurations were applied to optimize and verify their performance. The study was focused to know the effects of different porosities and silver nanoparticle solution uptake volumes on bacterial removal. The study evaluated 62 filters for 23 months for the same clay for bacteria and turbidity removal during regular use by local residents in the Guatemalan community of San Mateo Ixtatán. Household filtered and unfiltered samples were collected 10 times over 23 months and analyzed for turbidity and percent removal of total coliform and *E. coli* bacteria.

The bacteria removal values obtained were 4.56 $\log_{10}$ reduction (99.997%), 3.52 $\log_{10}$ reduction (99.97%), and 2.55 $\log_{10}$ reduction (99.71%) for filters with 4%, 9%, and 17% sawdust, respectively. These results goes similar with other previous results that the main mechanism for bacteria removal in ceramic filters was retention of the cell in the small pores of the filters.

Over the course of the study, 468 treated and untreated samples were compared. The overall percent reduction of total coliform bacteria was 87.11% (standard deviation = 6.02) and *E. coli* bacteria was 92.82% (standard deviation = 9.31). Looking only at filtered water *E. coli* concentrations, 71.46% of treated water samples had zero bacteria and 96.16% had less than 10 cfu/100 mL, qualifying as low risk, according to the WHO.

Chapter 3: METHODOLOGY

3.1. General

Methodology chapter is divided into two segments, first one is related to field study and other is related to laboratory control study. The field based study was conducted to evaluate the filter performance under daily realistic uses conditions of the filters. The laboratory study was conducted to verify the filter performance according to WHO protocol. This chapter describes the working procedure of the various stages of this study, conducted in filed and laboratory, data that were evaluated from both field and laboratory studies, with the help of WHO protocol and others related information.

3.2. Field Based Study

3.2.1. Study Area

The field based study was conducted in Dacope and Mongla areas of Khulna and Bagerhat districts, located in the southwest coastal areas of Bangladesh (**Figure 3.1**). These two areas were considered as representative of coastal areas of Bangladesh regarding water supply. People in these two areas are mainly depending on water from pond sand filter (PSF), rainwater harvesting (RWH) and rain-feed pond for drinking water supply as the fresh groundwater is rarely available, mostly saline and surface water is highly turbid and saline.

Dacope upazila with an area of 99,158 km^2, is bounded by Batiaghata upazila on the north, Pashur river on the south, Rampal and Mongla upazilas on the east, Paikgachha and Koyra upazilas on the west. The main rivers are Pasur, Sibsa, Manki, Bhadra. The southern part of this upazila is surrounded by Sundarban (11790.13 hectors).The total population in Dacope upazila is 143,131, of which 52.25% are male and 47.75% are female. Among the population, Muslim are 37%, Hindu 61%, Christian 1%, ethnic and

others 1%. The average literacy rate is 37.6%; of which male is 47.8% and female is 26.4%. Regarding occupations, agriculture (about 46.95%) is the main occupation of the people in this area. Other occupations are fishing (2.38%), agricultural labor (17.26%), wage labor (4.84%), commerce (9.48%), service (3.44%) and others (13.65%). Total cultivable land is 28544.4 hectares of which single crop is about 92.92% and double crop is about 7.08%. The upazila is connected to Khulna by road and waterways (BBS, 2011).

Mongla Upazila (Bagerhat district) with an area of 1461.22 km^2, is bounded by Rampal upazila on the north, the Bay of Bengal on the south, Morrelganj and Sarankhola upazilas on the east and Dacope upazila on the west. As of 1991 population census, total population was 137,947, of which male were 54.73% and female were 45.27%. Among the population, Muslim were 71.31%, Hindu 24.95% and others 3.74%. The average literacy rate was 42.8% as compared to the national average of 32.4%. Main occupations are agriculture (21.41%), fishing (6.23%), agricultural laborer (2.41%), wage laborer (13.39%), commerce (15.09%), transport (1.94%), service (16.27%) and others (13.26%) (BBS, 1991).

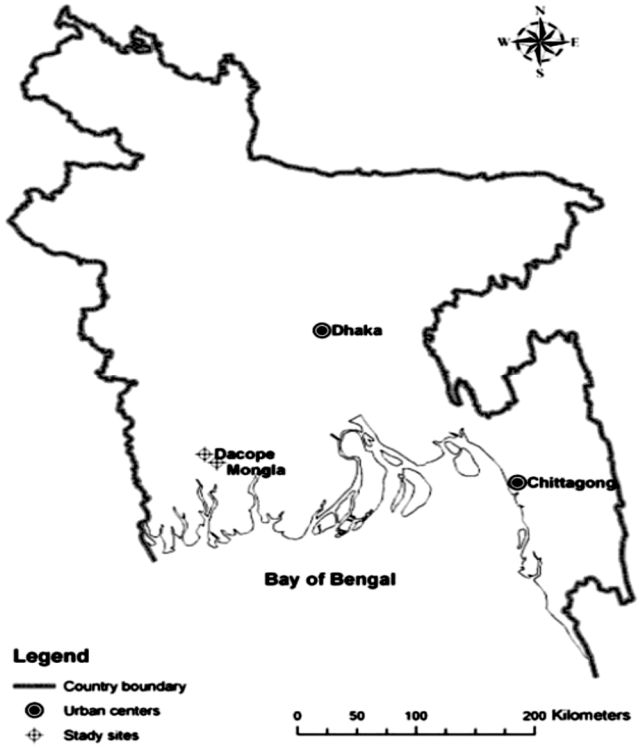


Figure 3.1. Map of Bangladesh and the study areas

3.2.2. Household Selection

A preliminary list of 100 households was made by field visits as representative samples to the study sites in March, 2013 considering the sources of drinking water (PSF, RWH or pond water). The households were interviewed about drinking water sources, health problems, in-house water treatment (if any) and knowledge about in-house filtration using ceramic filter and others. Based on their answers, a total of 75 households were finally selected for filter distribution in two study sites considering the followings:

- ✓ Representative households (samples) for each option (tried to maintain 25 households for each option)
- ✓ Ease of communication during the rainy season for subsequent sampling
- ✓ Willingness for household filtration.
- ✓ Considering the differences of filter users based on income and other social factors to get a balanced outcome.

The list of households for filter distribution is provided in **Appendix A**.

3.2.3. Source Water Sampling for Baseline Study

For assessing the baseline situation regarding water quality and associated health risk with each water supply options, water samples were collected from PSF, RWH and pond water in the study area and analyzed for the physical, chemical and microbial water quality parameters. A total of 39 samples were collected and details of the water supply sources for base line analysis and water quality parameters tested are presented in **Table 3.1 and Table 3.2** respectively. Water from different water supply options was collected following the standard procedures (APHA, 2012). For microbiological analysis, 250 or 500 mL water samples were aseptically collected in sterile Nalgene plastic bottles. All samples were placed in an insulated box filled with ice packs and transported on the same day to the Environmental Engineering Laboratory of Islamic University of Technology (IUT) and Environmental Microbiology Laboratory of the International Center for Diarrhoeal Disease Research, Bangladesh (icddr,b) for bacteriological analysis.

For physical and chemical analysis, 250 mL of water from each source was collected into plastic bottles and water samples were analyzed at the Environmental Laboratory of Environmental Science Department of Khulna University.

Table 3.1. Sources of water samples for baseline analysis

Sampling source	No of samples
Pond water	18
Pond Sand Filter (PSF)	6
Rainwater Harvesting (RWH)	15

Table 3.2. Water quality parameters for baseline analysis

Water Quality Parameters		Laboratory
Microbiological	TC	Environmental Engineering Lab, IUT
	FC	
	E. coli	
	HPC	
	*Vibrio Cholera(*non-O1/non-O139*)*	icddr,b
	Salmonella spp.- Only for baseline study	
	Shigella spp.- Only for baseline study	
	Pseudomonas spp.- Only for baseline study	
Physic-chemical	pH	Environmental Lab of Environmental Science Discipline, KU
	Electric Conductivity	
	Turbidity	
	Salinity	

3.2.4. Filter Water Sampling

Paired water samples (feed and filtered water) from each filter were collected during water sampling from May 2013 to November 2013 at an interval of 1.5 months in 4 monitoring cycles and samples were tested for physical, chemical and microbial parameters. The feed water sample was collected from the top chamber (first sampling

point) and the filtered water sample was collected directly from the filter tap (**Figure 3.2**). For microbiological analysis, both feed and filter water samples were collected into 250 mL sterilized plastic bottles. All the samples were placed in an insulated box filled with ice packs immediately after sampling and transported to the Environmental Engineering Laboratory of IUT for Total Coliforms (TC), Fecal Coliforms (FC) and *Escherichia coli* analysis and to the Environmental Microbiology Laboratory of the International Center for Diarrhoeal Disease Research, Bangladesh (icddr,b) for *Vibrio cholerae, Salmonella* spp. *Shigella* spp. *and Pseudomonas* spp. analysis. For physical and chemical analysis (pH, Electric Conductivity, Turbidity and Salinity), about 250 mL samples were collected into plastic sampling bottles and analysis was done at the Water Research Laboratory of Khulna University, Khulna, Bangladesh. Before sampling, households were asked about the source of water used for filtration and noted in the field book. Removal efficiency of the bacteriological parameters and turbidity was evaluated from the analysis data of both feed and filtered water.

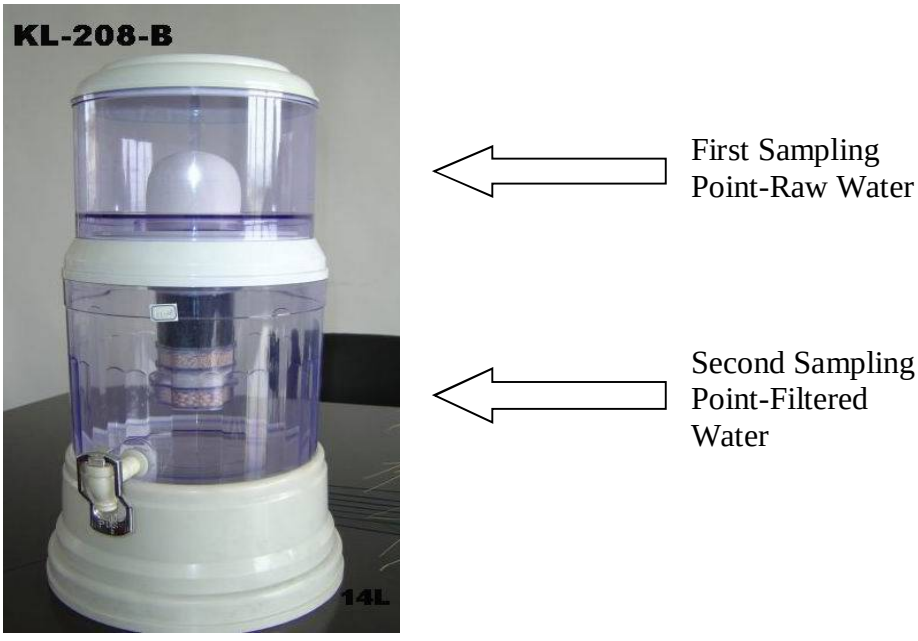


Figure 3.2. A typical picture of the ceramic/cartridge water filter used in this study

3.2.5. Analysis of Samples

Detection of Indicator Bacteria

For enumeration of Total Coliform (TC), Fecal Coliform (FC) and *Escherichia coli* (*E. coli*), 100 mL water samples were filtered through a 0.22 µm pore-size membrane filter paper (Millipore Corp., Bedford, MA, USA), and the filter papers were then placed on membrane faecal coliform (mFC) and m-ENDO agar plates, respectively, following standard procedures (APHA 2012). The mFC plates for TC and m-ENDO plates for *E. coli* were incubated at 37°C for 22 to 24 hr to enumerate and the mFC plates for FC were incubated at 44°C for 22-24 hr to enumerate the FC. Characteristic blue colonies were counted as FC and TC and golden metallic sheen colonies were counted as *E. coli*. All samples were expressed as colony forming units (cfu) / 100 mL. The samples were tested for heterotrophic plate count (HPC) using a dilution drop plate method, the samples were diluted for ¾ times and well vortexed and dropped as 100 µL on Nutrient agar (NA) plates and incubated for 37°C for 22-24 hours for enumeration.

Isolation of Pathogenic Bacteria

For qualitative analysis of *Vibrio cholerae*, 50 mL water samples were enriched with 25 mL triple strength alkaline peptone water (APW) and incubated for 6 h at 37^0C. Next, two loops of the enriched sample were plated onto thiosulfate citrate bile salt sucrose (TCBS) agar (BD, USA) and CHROMagar Vibrio (CV) agar (CHROM agar, Paris, France) plates. Following overnight incubation at 37^0C, yellow colonies with a diameter of 2-3mm on TCBS agar plates and pale blue colonies on CV agar plates were presumptively selected as *V. cholerae* (Hara-Kudo *et al*., 2001). The selected colonies were then confirmed based on their colonial characteristics after transferring the same colony to fresh TCBS and CV agar plates using sterile toothpicks. Following overnight incubation at 37^0 C, characteristic colonies of *V. cholerae* were selected and further characterized using a previously described procedure (Islam *et al*., 1995). Briefly, strains were only identified as *V. cholerae* if they fulfilled the following criteria: Gram negative, oxidase positive, produced acid from

sucrose but not inositol and decarboxylated lysine and ornithine but not arginine. Strains were serotyped according to the procedure described by Kelly *et al*., (1992).

For the qualitative analysis of *Shigella, Salmonella* and *Pseudomonas* spp., 50 mL water samples were enriched in 25 mL triple strength Selanite broth and then incubated overnight at 37^0C. For isolation of *Shigella* and *Salmonella* spp., two loops full of overnight enrichment broth were sub-cultured on Salmonella Shigella agar and then incubated overnight at 37^0C. After overnight incubation, characteristic colonies of *Shigella* and *Salmonella* were confirmed by number of biochemical tests (Baron and Finegold 1990). For isolation of *Pseudomonas* spp., two loops full of enrichment broth were taken and inoculated onto Cetrimide agar, which were then incubated overnight at 37^0C. After overnight incubation, green-yellow to blue green colonies were identified as *Pseudomonas* spp. (United States Pharmacopeial Convention, 2007).

Physico-chemical Analysis

All water samples were tested for pH, electrical conductivity (EC), turbidity and salinity. Physico-chemical analyses were performed according to the APHA (1998).

Water samples in baseline were analyzed for TC, FC, *E. coli, V. cholerae*, *Shigella* spp., *Salmonella* spp. and *Pseudomonas* spp .Water samples from the filters were analyzed for TC, FC, *E. coli* and *V. cholerae* as well as physical and chemical parameters.

3.2.6. Health Risk Assessment

A Quantitative Health Risk Assessment (QHRA) model developed by the Arsenic Policy Support Unit (APSU) of Bangladesh (Ahmed *et al.*, 2005) was used to quantify the prediction of disease burdens in Disability-Adjusted Life Years (DALYs) for arsenic and three reference pathogens: rotavirus, cryptosporidium and *E. coli* for viral, protozoal and bacterial disease, respectively, associated with arsenic and microbial concentrations in the baseline condition, feed and filtered water. The benefit of using this model is that it allows comparisons to be made among different technologies based on easily acquired data. The

model assists in evidence based decision making. Where assumptions were not well supported, the model assists in hypothesis and research priority.

This QHRA model is a simple deterministic spreadsheet; the details of the model assumptions regarding pathogen and indicator organisms and the dose-response relationship can be found in Ahmed *et al*. (2006); Howard *et al.* (2006) and Howard *et al.* (2007). WHO has quite extensively used DALYs to evaluate public health priorities and to assess the disease burden associated with environmental exposures. The basic principle of the DALY is to weight each health effect for its severity from 0 (normal good health) to 1 (death). A reference level of risk of 10^{-6} Disability-Adjusted Life-Years (DALYs) is proposed which is roughly equivalent to a lifetime cancer risk of 1 case per 100,000 people (WHO, 2004). The uses of the model in calculating DALYs have been well documented in literature (Islam *et al*., 2011; Karim 2010; Howard *et al*., 2007; Howard *et al*., 2006). The outputs of the model include the median health burden as well as higher (95th percentile) and lower (5th percentile) limits of health burdens at 90% confidence interval. The usefulness of this output is, it allows to compare between different options. Also the outputs can be presented in comparison to the reference value of WHO. In this study, the *E. coli* data was used as input in the model to estimate the likely disease burden in DALYs. The outputs of the model were used to assess the potential microbial health risk reduction consequential to the filters used.

3.2.7. Data Analysis

Statistical analysis was performed by SPSS V.16 statistical software. Non-parametric tests rather than parametric tests were used to compare samples medians, arithmetic means and ranges for descriptive purposes. Because the filter performance data were not normally distributed and skewness in the data would be found. Also the data had ordinal data and outliers which can be easily handled by nonparametric test. Non parametric Mann-Whitney *U* test was employed to compare bacterial concentrations between feed and filtered water. Relevant assumption were made to run the analysis. The

results were presented in group rank differences rather than group mean differences. Calculation of the Mann-Whitney U test is presented below-

$$U = n_1 n_2 + \frac{n_2(n_2+1)}{2} - \sum_{i=n_1+1}^{n_2} R_i$$

Where:

U=Mann-Whitney U test

N_1 = sample size one

N_2= Sample size two

R_i = Rank of the sample size

The Kruskal-Wallis test (one-way ANOVA on ranks) was used to compare between options for drinking water. The test was done using the following equation:

$$H = (N-1)\frac{\sum_{i=1}^{g} n_i(\bar{r}_{i\cdot} - \bar{r})^2}{\sum_{i=1}^{g}\sum_{j=1}^{n_i}(r_{ij} - \bar{r})^2},$$

Where,

- n_i is the number of observation in group i
- r_{ij} is the rank (among all observations) of observation j from group i
- N is the total number of observations across all groups
- $\bar{r}_{i\cdot} = \frac{\sum_{j=1}^{n_i} r_{ij}}{n_i}$ is the average rank of all observation in group i
- $\bar{r} = \frac{1}{2}(N+1)$ is the average of all the r_{ij}

The Friedman test was used for detection of fluctuations in four monitoring cycles. It was used to compare ranked outcomes. Friedman test was done using the following equations:

- $\bar{r}_{\cdot j} = \frac{1}{n}\sum_{i=1}^{n} r_{ij}$
- $\bar{r} = \frac{1}{nk}\sum_{i=1}^{n}\sum_{j=1}^{k} r_{ij}$
- $SS_t = n\sum_{j=1}^{k}(\bar{r}_{\cdot j} - \bar{r})^2,$
- $SS_e = \frac{1}{n(k-1)}\sum_{i=1}^{n}\sum_{j=1}^{k}(r_{ij} - \bar{r})^2$

In the majority of analyses, an alpha of 0.05 is used as the cutoff for significance. If the p-value is less than 0.05, we reject the null hypothesis that there's no difference between the means and conclude that a significant difference does exist. If the p-value is larger than 0.05, we cannot conclude that a significant difference exists.

Data were analyzed by technology type in relation to both Bangladesh Standards (BDS) (ECR, 1997) and WHO Guidelines for drinking-water quality. The filter performance data was analyzed using $\log_{10}$ reduction and percent reduction values using the tested results of the microbial level of the feed and filtered water of each filter. These values are commonly used in guidelines for any kind of performance evaluation.

3.3. Laboratory Control Experiment

3.3.1. Market Survey and Filter Selection

Different markets were surveyed in Dhaka city and a number of CWF filters were found in the market with different prices. Filters from three well-known and popular brands were selected for the laboratory study based on market demand, manufacturers' claims, good outlook and affordable price.

Based on above criteria, the following three brands have been chosen:

1) Brand 1(B-1)
2) Brand 2(B-2) and
3) Brand 3(B-3)

The basic information of these brands and manufacturer's claim, specification and effectiveness are provided in **Table 3.3** and **3.4** respectively.

Table 3.3. Information of the selected brands for lab testing

Brand Name	Wholesale price (BDT)	Wholesale price (USD)	Configuration	Distinct feature (visual)
B-1	1500-2000	19-25	Similar	Tight mineral layers
B-2	2500-3000	31-37	Similar	Tight mineral layers
B-3	1400-1600	17-20	Similar	Less compact and layered mineral layers

Table 3.4. Manufacturers claims, specification and effectiveness of CWF filters

Brand Name	Claims	Ceramic Pore size	Effectiveness	Effective lifetime
B-1	Comprised of different mineral nutrients and 19 blended raw materials in one setup at high pressure and temperature. The filter gives the clean, clear and safe water against any polluted source with the minimum water wastage yet provide good water nutrient.	0.2 micron (can work against 0.5-1.0 micron bacteria)	It can filter all dirts, sand, bacteria, color, chemical and heavy metal. It can keep water free from typhoid, cholera and amoeba.	Manufacturer doesn't claim any lifetime for the whole filter but only the mineral layers are claimed to have 5000 liter lifetime or 6-12 months lifetime.
B-2	Good water treatment technology for a household composed of 2-3 persons consuming tap water of about 6-8liters daily. The ceramic filter is designed of micro-filtration. The cartridge filter composed of activated carbon, zeolite, silica sand, mineral sand, coral sand. The mineral stone is composed of 20 kinds of inorganic substance and has both a strong absorptive power of heavy metal and Bio function.	0.2-0.5 micron	**Ceramic filter**: removing rust strains, fine earth powder, sediments, other solid foreign substances. **Cartridge filter**: removing chlorine, THM, radioactive substances, detergents, agriculture chemicals, odors, color, and other chemicals. **Mineral stone**: controlling water's pH and keeping water fresh and activating with mineral and oxygen.	**Ceramic filter**: need to change in 1-2 years or when the surface of ceramic filter is cracked or broken. **Cartridge filter**: should be changed after 6-12 months when it smells chlorine or others in purified water. Can purify about 5000 liters. **Mineral stone**: need to boil the mineral stone in 2-3 months.
B-3	The filter gives the clean, odorless water. Comprised of different mineral nutrients and 19 blended raw materials in one setup at high pressure and temperature.	0.2 micron (can work against 0.6-1.0 micron bacteria)	It can filter all dirts, sand, bacteria, color, chemical and heavy metal. It can keep water free from typhoid, cholera and dysentery.	Manufacturer doesn't claim any lifetime for the whole filter.
Sources: Information manual and printed information on filter packaging boxes.				

3.3.2. Filter Installation and Test Setup

According to guideline (WHO, 2011), a minimum of two filtration units should be tested in parallel using the challenged waters and test microbes to document performance variation and effect of different waters on removal of the test microbes. After purchasing the filters, the boxed filters have been transported to the Environmental Engineering laboratory of IUT and each filter was installed after proper cleaning and washing. For three individual indicator organisms (*E. coli,* MS-2 bacteriophage and *Clostridium perfringens*), three batches of filter consisting eight filters were installed in each batch for each organism. Two filters from three brands have been installed in each batch setting six filters in each batch. **Table 3.5** provides the information of the filter setup for control study in the laboratory.

In addition, two filters were added in each brand to see the effect of contamination induced by the filters by themselves. These filters were named as **negative control** which were non-spiked with any kind of organism but only seeded or unseeded with autoclaved waste water. So if any microbiological contamination happens, it can be understood from the result to understand filters contribution in contamination. Thus the total number of filters in each batch is eight (total 24 filters). To facilitate spiking the filters with indicator organisms and challenged water, all the filters have been organized in pairs. **Figure 3.3** shows the lab setup of filters for the study.

Table 3.5. Filter setup in laboratory for control study

	B-1		B-3		B-2	
	Input Water 1(NS)	Input Water 1(S)	Input Water 1(NS)	Input Water 1(S)	Input Water 1(NS)	Input Water 1(S)
E. coli	 Filtered Water 2	 Filtered Water 2	 Filtered Water 2	 Filtered Water 2	 Filtered Water 2	 Filtered Water 2
	Input Water 1(NS)	Input Water 1(S)	Input Water 1(NS)	Input Water 1(S)	Input Water 1(NS)	Input Water 1(S)
MS2 bacteriophage	 Filtered Water 2	 Filtered Water 2	 Filtered Water 2	 Filtered Water 2	 Filtered Water 2	 Filtered Water 2
	Input Water 1(NS)	Input Water 1(S)	Input Water 1(NS)	Input Water 1(S)	Input Water 1(NS)	Input Water 1(S)
Clostridium perfringens	 Filtered Water 2	 Filtered Water 2	 Filtered Water 2	 Filtered Water 2	 Filtered Water 2	 Filtered Water 2
	Input Water 1(NS)	Input Water 1(S)	Input Water 1(NS)	Input Water 1(S)	Input Water 1(NS)	Input Water 1(S)
Negative Control	 Filtered Water 2	 Filtered Water 2	 Filtered Water 2	 Filtered Water 2	 Filtered Water 2	 Filtered Water 2
NS= Non seeded with waste water; S= Seeded with waste water						

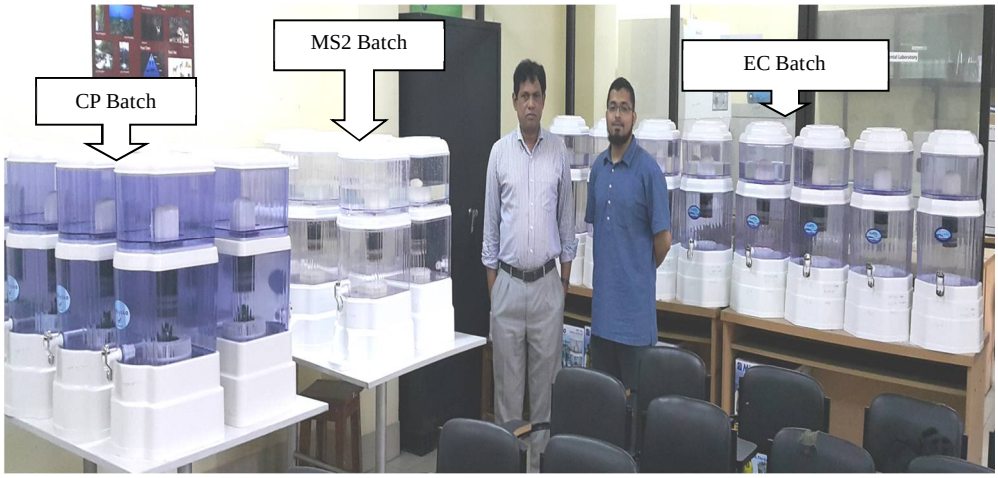


Figure 3.3. Laboratory setup of filters based on pathogens

3.3.3. Challenged Water

Two types of test water were used for each filter.

i. IUT ground water spiked with required microorganism (non-seeded with wastewater)
ii. Ground water (seeded) with 1% by volume (of filter capacity) of sterilized untreated wastewater spiked with required microorganism.

Characteristics of test waters were presented in the following **Table 3.6** and were consistent with WHO guidance on appropriate challenge waters for the testing of filtration technologies for household water treatment.

Table 3.6. Characteristics of challenged water

Parameter	Challenged water 1 (Non Seeded)	Challenged water 2 (Seeded)
	IUT ground water spiked with required microorganism	IUT ground water seeded with 1% by volume of sterilized untreated wastewater autoclaved at 121 °C for 20 min and spiked with required microorganism
Mean pH,	7.5	7.6
Mean turbidity, NTU,	<1	1.15-1.5

For preparing challenged water 2, sewage water was collected from IUT sewage drains. Then it was autoclaved at 121°C for 20 minutes and stored properly. At the beginning of every filtration, 1% by volume of autoclaved waste water of the filter capacity was added to the raw water. The amount of supplemented autoclaved waste water is shown in **Table 3.7**

Table 3.7. Filter capacity and amount of seeded waste water (mL)

Brand Name	**Claimed Capacity**		**Actual Capacity (A.C)**	**Amount of seeded wastewater; 1% by (v/v) of A.C of U.C**
B-1	28 liters	Upper compartment (**U.C**)	8 liters	80 mL
		Lower compartment	20 liters	
B-2	32 liters	Upper compartment (**U.C**)	11 liters	110 mL
		Lower compartment	21 liters	
B-3	32 liters	Upper compartment (**U.C**)	11 liters	110 mL
		Lower compartment	21 liters	
A.C = Actual Capacity; U.C= Upper compartment.				

3.3.4. Flow Rate Measurement and Regular Monitoring

Flow rate tests were performed on each of the three ceramic filter types. Filters were allowed to be saturated with water before starting the filtration (**Figure 3.4**). B-3 and B-2 filters were filled with the same quantity of water than B-1 as they both have the same upper container capacity (**Table 3.7**). The measured flow rate was calculated by quantifying the volume of water filtered from each filter at hour intervals. Flow rate was calculated by dividing the volume of water filtered by the time it took for that volume to be filtered.

Flow rate (L/hour) = Volume Filtered (L) / Elapsed Time (hour)

Filtered water volume was recorded every day to know the different filtration situation of each filter and also to define different sampling time based on cumulative filtered volume. Before the experiment, 1500 liters was taken as design volume for

filtration. But due to difference in performance, each filter showed different filtration volume for a same period of experimental duration.

Figure 3.4. Daily input of water for filtration

All the filters were graduated into volume (liters) according to their capacity (**Figure 3.5**) to facilitate volume count and filtration. Every day filtration volume was recorded and kept for data analysis and filtration effectiveness.

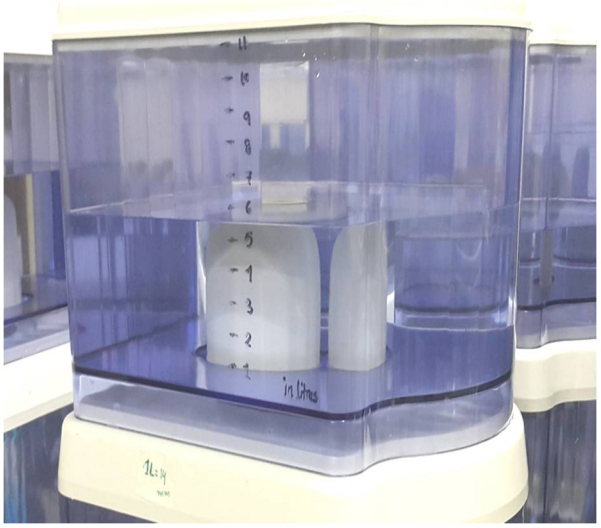


Figure 3.5. Volumetric graduation for daily reporting

3.3.5. Microbiological Spiking

For this study, the targeted pathogens considering the indicator bacteria, viruses and spore forming bacteria for which the microbial effectiveness of the technology were evaluated were as follows

1. *Escherichia coli* (*E. coli),*
2. Bacteriophages of *E. coli* (bacteriophages) - MS-2 bacteriophage
3. Spores of *Clostridium perfringens (C.P)*

For everyday filtration, stock cultures (**Figure 3.6**) of these three indicator organisms were kept prepared. Before filtration the challenged water was spiked with these organisms and allowed to filter. The procedure for spiking the indicator organisms were presented below:

Figure 3.6. Stock solution of organism and autoclaved wastewater

3.3.6. *Escherichia coli* (*E. coli*) Spiking

E. coli ATCC 25922 strain was collected from the stock culture of the Environmental Microbiology Laboratory of International Centre for Diarrhoeal Disease Research, Bangladesh (icddr,b), Dhaka. Then the strain was sub-cultured on to MacConkey agar. After 24 hours of incubation at 37°C, isolated colonies were sub-cultured on mTEC agar medium and incubated at 37°C for initial 2 hours, and then at 44.5°C for 18–24 hours. Differentiation and enumeration of *E. coli* is possible through one step and one medium method using modified mTEC agar. Method 1603, published by the EPA in 2002, recommends this media as a measure of fresh, estuarine and marine water quality (dll

version method 1603: *E. coli*). So in this experiment, this medium was used to enumerate *E. coli* in challenged water.

Suspension of *E. coli* was prepared in normal saline using fresh culture of *E. coli* ATCC 25922 cells grown on mTEC agar overnight. 100 µl of diluted suspension was cultured using drop plate technique and the final concentration of *E. coli* was found to be 10^7-10^9cfu/mL. This cultured concentrated stock is transported in Environmental Engineering Laboratory of IUT and preserved of -20ºC. At the time of spiking, the stock sample was normalized in to room temperature. The daily spiking of *E. coli* was done with the cultured solution at a concentration of about $10X10^5$ cfu/100mL. **Figure 3.7** shows the *E. coli* spiking procedure for this experiment.

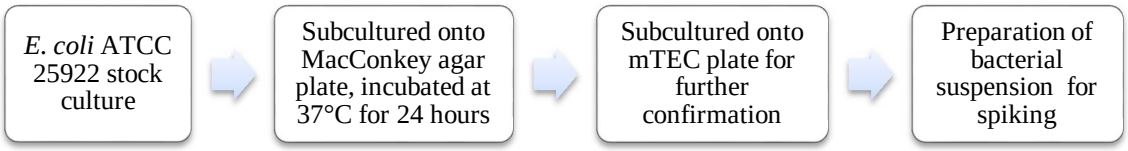


Figure 3.7. *E. coli* spiking sample preparation flowchart

3.3.7. MS-2 bacteriophage Spiking

MS2 Bacteriophage are bacteriophages that infect and replicate in coliform bacteria. They appear to be present wherever total and fecal coliforms are found. Correlations between bacteriophages and coliforms bacteria in fresh water generally show that bacteriophages may be used to indicate the sanitary quality of water (Isbister *et al.*,1982, Kennedy *et al.*, 1985, Kott *et al*., 1974,Wentsel, 1982). Because bacteriophages are more resistant to chlorine disinfection than total or fecal coliforms, they may be a better indicator or disinfection efficiency than coliform bacteria (Kott *et al.*, 1974).

Sewage samples were collected in a sterilized container and transported immediately to the Environmental Microbiology Laboratory for analysis. At first, collected sewage sample was filtered through a Whatman filter paper for reduction of suspended solids. After that, the filtrate were centrifuged (Eppendorf Centrifuge 5415ºC) at 2500 rpm

for 20 minutes to eliminate the gross debris. The resultant supernatants were again filtered through a bacteria retaining membrane filter (0.22 µm filter paper, Sartoriousstedim, Gottingen, Germany) to remove any bacteria present there. As the phage particles are usually present in low concentrations in natural habitats, to enumerate this low number of phages, addition of an enriched susceptible host cell culture (in this case, *E. coli*) to the collected sample may be necessary to increase the number of phage particles already present there.

A measured 5 mL of Luria-Bertani (LB) broth, 5 mL of freshly prepared young *E. coli* culture and 45 mL of the processed sewage sample was added aseptically into a conical flask and incubated for 24 hours at 37º C. Following the incubation, the phage infected culture was transferred into several micro centrifuge tubes and the tubes were centrifuged at 2500 rpm for 20 minutes to separate bacteria and phage from components of media. The supernatant was collected and filtered through 0.22 µm sterile membrane filter and phage containing filtrate was taken as stock culture for viral spiking which is bacterium free. This cultured concentrated stock is transported in Environmental Engineering Laboratory of IUT and preserved in -20ºC. At the time of spiking, the stock sample was normalized in to room temperature. The daily spiking of bacteriophages was done with the cultured solution at a concentration of about $5X10^5$ cfu /100mL. **Figure 3.8** shows the bacteriophages spiking procedure for this experiment.

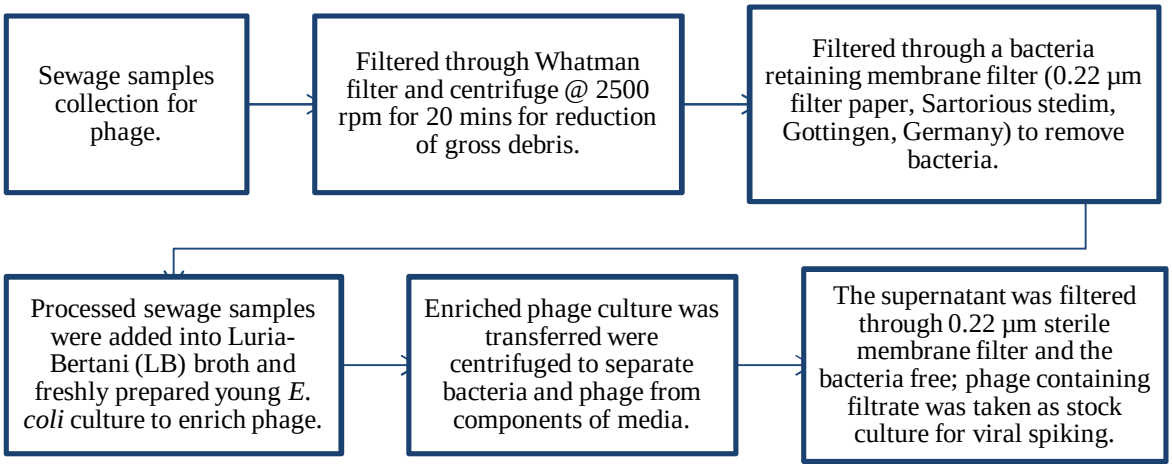


Figure 3.8. MS2-bacteriophage spiking sample preparation flowchart

3.3.8. *Clostridium perfringens* Spiking

Clostridium perfringens was obtained from environmental water samples. Suspension was prepared in normal saline using fresh culture of *C. perfringens* cells grown anaerobically overnight on *C. perfringens* - ChromoSelect (Sigma-Aldrich) agar which is a selective chromogenic media for isolation and enumeration of *Clostridium perfringens*. This agar is more reliable and easier to handle for detection of *C. perfringens* and the color does not diffuse in the agar and confirmation is not required since the green coloration is specific for *C. perfringens.* 100 µL of diluted suspension was cultured using drop plate technique and the final concentration of *C. perfringens* was found to be 10^3–10^5 cfu /mL.

This cultured concentrated stock is transported in Environmental Engineering Laboratory of IUT and preserved in - 4ºC. At the time of spiking, the stock sample was normalized in to room temperature. The daily spiking of *C. perfringens* was done with the cultured solution at a concentration of about $10X10^3$ cfu /100mL.

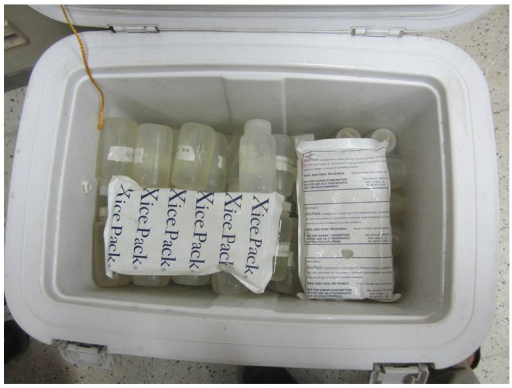
3.3.9. Water Sampling

The filters were fed with microbe-spiked challenged water every day manually and fed volume was recorded to calculate the spiked concentration of microorganism in spiked water. According to the guideline, the sampling was planned at 0%, 25%, 50%, 60%, 75% and 100% of the manufacturer recommended lifespan of the device, approximately 1500 liters throughput per filter. The 60% sampling was added for having another effectiveness data supported by some works done in Cambodia and India (Brown *et al.*, 2012; Bhathena *et al.*, 2014). At these sampling points (0%, 25%, 50%, 60%, 75% and 100%), 500mL of feed water and filtered water were collected from each filter (**Figure 3.9a)** in autoclaved and sterilized bottles and kept ready for sampling with proper labeling for microbiological and physic-chemical analysis. These two samples were taken from both the upper and lower compartment of each filter maintaining proper hygiene to avoid any secondary contamination. Two negative control filters from each brand were also sampled in pair following the same methodology to check any microbiological contamination is happening

by the filter systems. After collecting the samples, the bottles were kept tight and preserved in refrigerator (**Figure 3.9b)** at 4°C temperature so that the actual control condition can be evaluated with no anomaly. Because at 4°C temperature, no microbiological growth is formed with in small span of time in refrigeration. The microbiological samples **(Figure 3.9c)** were carried to Environmental Microbiology Laboratory of icddr,b within 24 hours for evaluating *E. coli*, MS-2 *bacteriophage* and *C.P*. Physic-chemical tests were conducted at the Environmental Engineering Laboratory of IUT for pH, Turbidity, Electric conductivity and Color using standard procedure. (**Table 3.8**)

a. Water Sampling

b. Preservation of samples



c. Samples transporting to microbiological testing

Figure 3.9. Sample preparation for laboratory analysis

Table 3.8. Control study analysis

Water Quality Parameters		Laboratory
Microbiological	Bacterial Indicator-*E. coli*	Icddr,b
	Viral Indicator- MS2 bacteriophage	
	Spore forming bacteria- *Clostridium perfringens*	
Physic-chemical	pH	Environmental Engineering Lab, IUT
	Color	
	Electric Conductivity	
	Turbidity	

The following **Table 3.9** presents the organism wise filter setup and corresponding filter and sample ID for laboratory analysis.

Table 3.9. Sample ID and Filter ID illustrations

	E. coli			**MS-2 *bacteriophage***			***Clostridium perfringens***		
	Brand Name	**Filter ID**	**Sample ID**	**Brand Name**	**Filter ID**	**Sample ID**	**Brand Name**	**Filter ID**	**Sample ID**
NS →	B-1	J-1	J-1-1, J-1-2	B-1	J-5	J-5-1, J-5-2	B-1	J-3	J-3-1, J-3-2
S →	B-1	J-2	J-2-1, J-2-2	B-1	J-6	J-6-1, J-6-2	B-1	J-4	J-4-1, J-4-2
NS →	B-2	M-1	M-1-1, M-1-2	B-2	M-5	M-5-1, M-5-2	B-2	M-3	M-3-1, M-3-2
S →	B-2	M-2	M-2-1, M-2-2	B-2	M-6	M-6-1, M-6-2	B-2	M-4	M-4-1, M-4-2
NS →	B-3	N-1	N-1-1, N-1-2	B-3	N-5	N-5-1, N-5-2	B-3	N-3	N-3-1, N-3-2
S →	B-3	N-2	N-2-1, N-2-2	B-3	N-6	N-6-1, N-6-2	B-3	N-4	N-4-1, N-4-2
NC →	B-1	J-7	J-7-1, J-7-2	B-3	N-7	N-7-1, N-7-2	B-2	M-7	M-7-1, M-7-2
NC →	B-1	J-8	J-8-1, J-8-2	B-3	N-8	N-8-1, N-8-2	B-2	M-8	M-8-1, M-8-2
NS= Non seeded with waste water; S= seeded with waste water; NC= negative control.									

Each of the filter is provided an identification (ID) number. For B-1, B-3 and B-2, the IDs were J, N and M respectively. Odd and even numbered filter ID represents filters with non-seeded and seeded with waste water respectively. Filters numbered by 7 and 8

from all brands were negative controls which mean these filters were non spiked with any kind of organisms but only seeded or non-seeded with autoclaved waste water. The description of sample ID is exemplified in the following **figure 3.10**.

Figure 3.10. Description of Sample ID (Exemplified)

3.3.10. Microbiological Testing

3.3.10.1. E. coli Testing

A water sample of 250 mL was collected from the compartments of filters for *E. coli* enumeration by membrane filtration technique. **Figure 3.11** shows the process flow of *E. coli* enumeration. For each sample, 1 mL was filtered through membrane filters with 0.22 µm pores (Sartorious Stedim, Gottingen, Germany). Filters were placed on mTEC agar (Difco, MD, USA) and incubated at 37°C for the initial 2 hours, and then at 44.5°C for 18–24 hours.

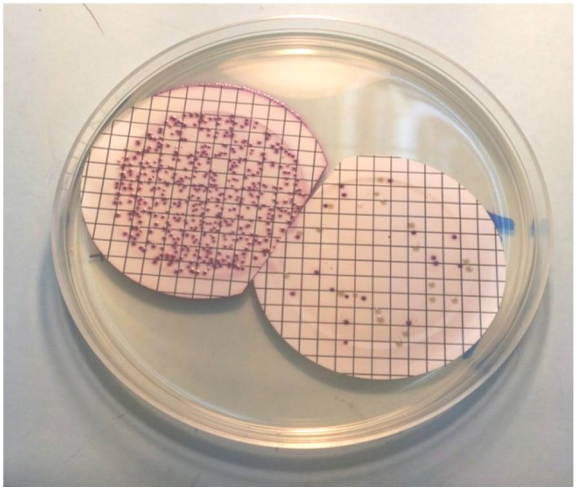


Figure 3.11. mTEC plate showing typical *E. coli* colonies

Colonies with typical color (**Figure 3.12**), size and shape of *E. coli* were counted. The samples were preserved at 4°C for the purpose of future testing. If the count obtained from 1 mL was too numerous to count, lower volume (100 µL) and in case of too few numbers of colonies, higher volume (100 mL) was processed in the next day. In case of the filtered water, 100 mL of the sample was processed for enumeration of *E. coli* and if the colony number was too numerous to count, lower volume (1 mL) was processed in the next day.

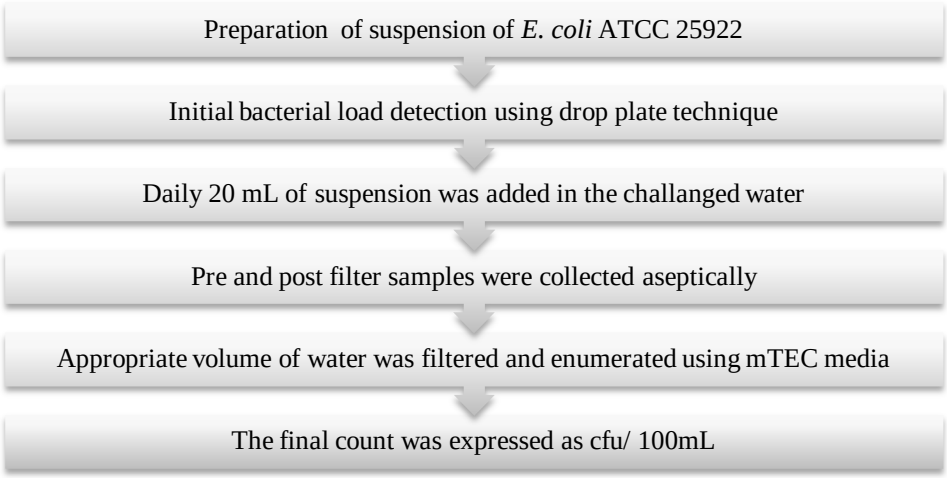


Figure 3.12. *E. coli* enumeration process flow

3.3.10.2. Detection of Bacteriophage

In this study, 20 mL of this phage suspension was added in each type of challenged water and after gently mixing the suspension in the water; 250 mL water was collected using a sterile pipette. Pre and post filtered challenged water was enumerated using double layer agar method.

Double agar method is widely used procedure to enumerate phages from a sample. **Figure 3.13** shows the process flow of MS-2 Bacteriophage enumeration. At first the sample containing unknown titer of bacteriophage was subjected to serial dilution. 0.1 mL of the sample was added to 9.9 mL of normal saline water, for making a 100 fold dilution. Once the final dilution was made, 100 µL of the sample was added to tubes containing 4.0 mL of nutrient soft agar that had been melted in a boiling water bath and equilibrated to

approximately 50ºC. The mixture was mixed gently by rubbing the tubes in the hands with caution and this mixture was poured onto nutrient agar plate and briefly swirled by gentle sidewise movement for even and uniform distribution of the top agar over the base layer containing nutrient agar medium. The top agar was left to solidify, the plates were incubated at 37ºC overnight and the plaques were observed on the bacterial lawn. The count was expressed as plaque forming units per mL (pfu /mL).

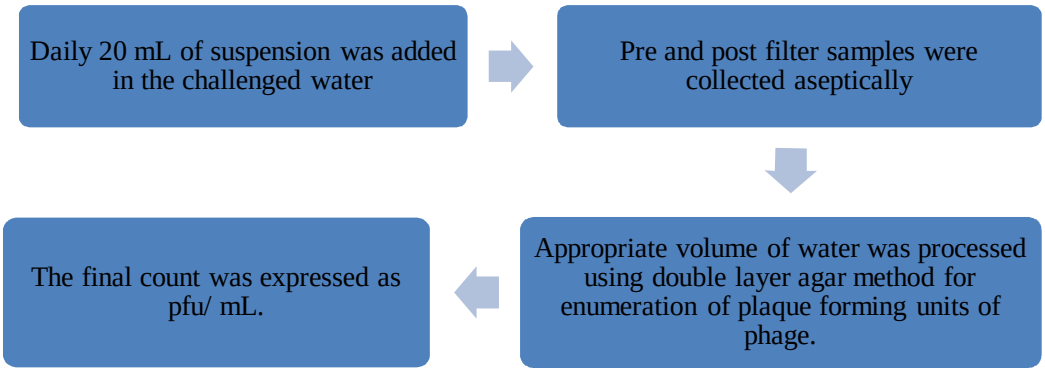


Figure 3.13. MS2-bacteriophage enumeration process flow

3.3.10.3. Detection of *Clostridium perfringens*

A measured 20 mL of this cell suspension was added in each type of challenged water and after gently mixing the suspension in the water; 250 mL water was collected using a sterile pipette. **Figure 3.14** shows the process flow of *C. perfringens* enumeration. Pre and post filtered challenged water was enumerated using membrane filtration technique. In brief, 100mL of samples dilutions were filtered through 0.22 µm pore size cellulose nitrate membrane filter and placed on *C. perfringens* Chromo Select Agar. After the filtration, plates were inverted and incubated under anaerobic conditions at 44 °C for 24 hours. Appeared green color colonies were counted as *C. perfringens*. These colonies (**Figure 3.15)** were counted and expressed as colony forming units (CFU) present per 100mL of sample.

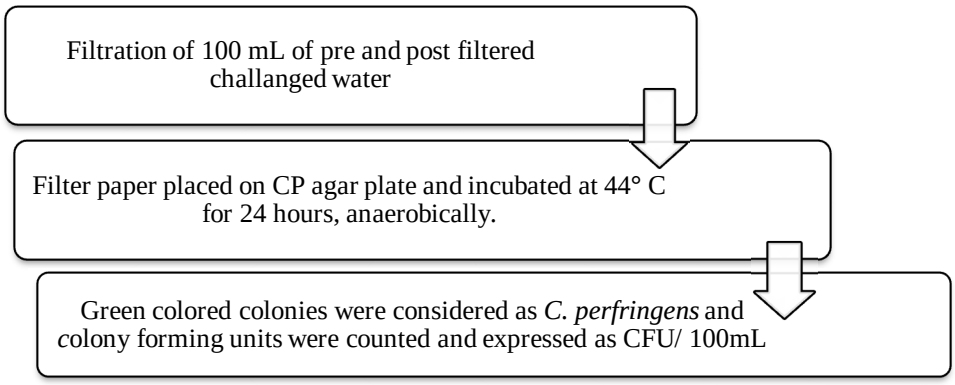


Figure 3.14. *C. perfringens* enumeration process flow

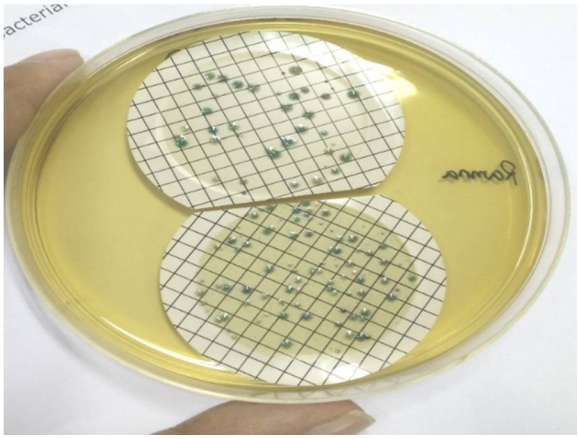


Figure 3.15. *C. perfringens* – Chromo Select plate showing typical *C. perfringens* colonies

3.3.11. Evaluation of Turbidity and Color reduction efficiency with increased turbidity level

This type of filters are sometimes used for improving aesthetical quality of water having high initial turbidity and color. To check this performance of the filters, a separate week long experiment was carried out having water with high initial turbidity and color to see the turbidity and color removal efficiency.

3.3.12. Physic-Chemical Testing

Four physic-chemical parameters namely pH, turbidity, color and electric conductivity were measured for both feed and filtered water. Also the temperature of the laboratory was tried to maintain according to the field condition. The following methods were used to evaluate these parameters.

pH

pH was measured by a calibrated HACH® pH meter (HACH sensION^{+} PH31).

Turbidity

Turbidity measurement was performed using proprietary nephelometric instrument. Turbidity is expressed as Nephelometric Turbidity Units (NTU). The apparatus used for turbidity evaluation is HACH® series portable turbidimeter (HACH 2100Q).

Color

Laboratory based apparatus HACH® Spectrophotometer (HACH DR2800) was used to determine color concentration. Color is usually expressed in platinum-cobalt (pt.co units) which is based on the intensity of color.

Electric Conductivity

Electric conductivity was tested using a calibrated HACH® conductivity probe (HACH CDC40101). Electric conductivity is expressed as micro-siemens/cm (µs/cm)

3.4. Data Analysis

Result from before and after filtrations were analyzed by$\log_{10}$ reduction and % reduction value for different sampling times using Microsoft office excel. These results were calculated using the tested results of the microbial level of the feed and filtered water of each filter. Microbiological data were sorted and compared in relation to WHO Guidelines for drinking-water quality (WHO, 2011). Physic-chemical parameters were also discussed based on the evaluated results. Also control data were compared with field data and reviewed literature to understand the performance of the filters.

CHAPTER 4: FIELD BASED EFFECTIVENESS OF FILTERS

4.1. General

The field based performance is presented in this chapter with the baseline evaluation of the source water and periodical sampling results of distributed filters. The health risk is discussed based on model results.

4.2. Source Water Quality Analysis (Baseline)

To assess the baseline situation of water quality of water supply options and the associated health risk, water samples were collected in April 2013 from preselected pond, PSF and RWH systems from Dacope and Mongla study areas. A total of 39 water samples were collected and analyzed for microbial water quality parameters like TC, FC, *E. coli*, HPC, *Vibrio cholerea, Shigella, Salmonella and Pseudomonas* spp. **Table 4.1** shows the average, maximum, minimum and median concentration of TC, FC, *E. coli* and HPC for each water supply option in the study areas.

Table 4.1. Concentration of indicator organisms in source water options.

Indicator Bacteria	Sampling Sources	Average	Max	Min	Median
TC (cfu/100 mL)	Pond	5,219	15,000	140	3,500
	PSF	75	200	20	28.5
	RWH	177	1,000	0	10
FC (cfu/100 mL)	Pond	635	1,550	120	535
	PSF	34	100	3	23
	RWH	90	570	0	0
E. coli (cfu/100 mL)	Pond	737	7,000	10	200
	PSF	28	100	0	3.5
	RWH	23	200	0	0
HPC (cfu/10 mL)	Pond	96,413	250,000	2,500	106,000
	PSF	97,533	254,000	16,600	26,200
	RWH	15,911	94,000	2,500	11,100

. The concentration of the indicator organisms for ponds water is very high compared to other two options. The maximum and minimum *E. coli* concentrations in ponds water were 7000 and 10 cfu/100 mL, respectively. Other indicator organisms presence in ponds water samples are also very high, indicating that pond water is highly microbiologically contaminated and not suitable for drinking without any in-house treatment.

The median and mean values differ widely in almost all water quality parameters indicating that the data has a skewed distribution within the ranges of maximum and minimum values. It is due to the non-normal distribution because bacteriological concentration doesn't follow any linear or parametric relationship in field level. Often microbiological data contain many zero data points, which can display skewness in most microbiological monitoring data. The median and average of FC for PSF were found to be 23 and 34 cfu/100 mL, respectively. The median and mean values of FC for RWHs were found to be 0 and 90 cfu/100 mL, respectively. The median and average of *E. coli* for PSF were found to be 3.5 and 28 cfu/100 mL, respectively, while the median and mean values of *E. coli* for RWHs were found to be 0 and 23 cfu/100 mL, respectively. Higher HPC concentrations were found in all options; however the greatest median concentration of HPC was observed in pond water indicating unhygienic surrounding and non-cleanliness of the pond. The mean, maximum and minimum HPC in PSF water were higher than pond water (**Table 4.1**).

Both WHO guidelines (WHO, 2004) and Bangladesh Drinking Water Quality Standard (ECR, 1997) adopted a very strict standard for microbiological water quality for drinking water and according to both standards, the presence of any indicator organism per 100 mL drinking water must be zero. Drinking water with a concentration of TC, FC or *E. coli* more than 0 cfu/100 mL is classified as 'unacceptable' (WHO, 1997). **Table 4.2** shows the percentage of drinking water samples with unacceptable levels of TC, FC and *E. coli*. All the pond waters are unacceptable for drinking according to TC, FC or *E. coli*. For PSF, all the water samples are unacceptable as per TC and FC and 66.7% are unacceptable according to the presence of *E. coli*. Rainwater was found to be better microbiological quality and the percentages of unacceptable samples were found to be lowest for both FC

and *E. coli*. However, in the case of TC, more than 50% RWHs samples were found to be unacceptable and according to *E. coli* presence, only 13.3% RWHs were found to be unacceptable.

Table 4.2. Percentages of unacceptable drinking water samples according to the level of indicator organisms

Water supply options	Unacceptable (%)		
	TC	FC	*E. coli*
Pond	100	100	100
PSF	100	100	66.7
RWH	53.4	33.3	13.3

As shown in **Table 4.3**, *Vibrio cholerae* non-O1/non-O139 were isolated from about 78% pond water samples. For PSFs, the proportion of samples containing *V. cholera* non-O1/non-O139 was higher (83%) than pond water samples and much lower for RWHs samples (40%). No toxigenic *Salmonella and Shigella* spp. were isolated from any of the samples, probably due to non-survival of these spp. in saline water. Moreover, *Pseudomonas* spp. were isolated in 39% pond water samples and 40% RWH samples and no *Pseudomonas* spp. was isolated in PSF samples. Islam *et al*. (2011b) investigated the details microbial water quality of pond water, PSF and harvested rainwater in the same study areas during both dry and wet seasons. According to Islam *et al*. (2011a), *Vibrio cholerae* non-O1/non-O139 were isolated from about 95% of the pond samples during both seasons. For RWHSs, CRWHSs, and PSFs, the proportion of samples containing *V. cholerae* non-O1/non-O139 increased from 20% to 35%, 29% to 57% and 47% to 100%, respectively, during the wet season. No toxigenic *V. Cholerae* O1/O139 or *Salmonella* and *Shigella* spp. were isolated from any of the samples. The isolation of *Pseudomonas* spp. increased from 10% to 91% during the wet season.

Table 4.3. Isolation of *Vibrio cholera, Shigella, Salmonella* and *Pseudomonas* spp.

Sampling Sources	*Vibrio cholera* non-O1 /non-O139	*Shigella* spp.	*Salmonella* spp.	*Pseudomonas* spp.
Pond	14 (78)	0	0	7 (39)
PSF	5 (83)	0	0	0
RWH	6 (40)	0	0	6 (40)
N.B. Figure in the parenthesis indicates the percent of samples isolated.				

A summary of the physico-chemical data for the water samples is shown in **Table 4.4**. The pH of the water samples was within the recommended range of 6.5 to 8.5. The highest pH of 8.23 was observed for RWH sample stored in RCC tanks. The average electrical conductivity (EC) value for both pond water and PSF water are much higher than 1000 µS/cm, indicating the presence of higher total dissolve solids in water. The amount of dissolved solids present in water is an important consideration of its suitability for drinking and other domestic purposes. The lower EC values of RWHs samples indicate the presence of fewer minerals in harvested rainwater. Turbidity of all pond water samples exceeds the maximum recommended level of 5.0 NTU. The average turbidity of PSF and RWH samples were within the maximum recommended value for drinking water. Turbidity occurs in most surface waters due to the presence of suspended clay, silt, finely divided organic and inorganic matters, plankton (algae) and microorganisms. The salinity of both pond water and PSF water are much higher.

Table 4.4. Summary of physico-chemical parameters of source water supply options.

Physico-chemical parameters	Sampling Sources	Average	Max	Min	Median
pH	Pond	7.31	7.66	6.77	7.30
	PSF	7.44	7.74	7.27	7.38
	RWH	7.50	8.23	6.92	7.6
EC (µS/cm)	Pond	2,004	6,300	492	1,680
	PSF	2,381	4,890	1,460	1,670
	RWH	221	572	52.4	200
Turbidity (NTU)	Pond	59.4	219	16.4	43.75
	PSF	3.54	7.80	0.66	3.26
	RWH	1.35	5.7	0.42	0.96
Salinity (ppt)	Pond	1.0	3.17	0.24	0.84
	PSF	1.19	2.45	0.73	0.84
	RWH	0.09	0.28	0.01	0.08

The worst bacterial quality was found in ponds' water, which are the principle drinking water option during the dry season in the coastal areas of Bangladesh. Environmental circumstances around the drinking water options are also very important

considerations for keeping the options safe. During field surveys, almost all of the ponds were found to be affected by surface runoff, and some were used for washing and bathing purposes. It is likely that the high level of contamination is due to the flow of poorly disposed fecal matter into the ponds. The association between *E. coli* and polluted stream flows into the pond and latrine within 10 m from the pond suggests that unprotected ponds were the major sources of fecal contamination for PSFs. Rural ponds in Bangladesh that are used for bathing, washing utensils and drinking water options have high concentrations of FC (Islam *et al*., 2000). However, Islam *et al*. (1994) found that if a pond is protected from human use, has a high bank and no drain, it can provide water with a FC count <1 cfu/100 mL year round. Therefore, to improve the quality of pond water the ponds should be protected from surface runoff and human use. Proper maintenance of PSFs is always a matter of concern. The mean HPC concentrations in PSF water were higher than that presence in pond water. The possible sources of this contamination may have been supply lines, sand beds or collection taps. In the present study, most of the PSF taps were found to be defective. Improper cleanliness and maintenance are the major causes of high level of HPC in the PSF water.

V. cholerae non-O1/non-O139 were isolated from about 78% of the ponds and 83% of PSF water, which revealed the extent of contamination of these sources by potentially pathogenic bacteria. During the field observations, few people treat pond or PSF water before consumption; therefore, drinking pond or PSF water may cause gastroenteritis and bacteremia (WHO, 2004). Islam *et al*. (2011b) observed that following filtration by PSFs, 50% of pond water samples no longer contained *V. cholerae* non-O1/non-O139, but the removal efficiency may depend on the contamination level of the ponds and the efficiency of the PSFs. The *toxigenic V. cholera* was not observed in any water samples from pond, PSF and RWHs from the study sites (Islam *et al*., 2011b). However, presence of toxigenic *V. cholerae* has been isolated from ponds in coastal areas of Bangladesh by other studies (Huq *et al*., 2005; Alam *et al*., 2006; Stine *et al*., 2008). Momba *et al*. (2006) found toxigenic *V. cholera* in surface water that is actively used for drinking purposes in rural areas of South Africa. *Pseudomonas* spp. were isolated from about 40% of pond and RWHs samples and no *Pseudomonas* spp. was detected in PSF water. Islam *et al*. (2011) showed the isolation of *Pseudomonas* spp. in few PSFs and ponds during the dry season; while, in

the wet season almost all samples showed presence of *Pseudomonas* spp. It seemed that the major source for such contamination was surface runoff into the ponds during the wet season.

The harvested rainwater appeared to be a comparatively better option according to the water quality data, as the occurrence of indicator organisms as well as specific bacteria was found to be less. In the present study, few samples were found to be unacceptable for drinking purposes based on the FC and *E. coli* counts. Several other studies (Lye *et al*., 1987; Crabtree *et al*., 1996; Uba & Aghogho, 2000; Simmons *et al*., 2001; Handia *et al*., 2005; Despins *et al*., 2009; Horak *et al*., 2010; Karim *et al*., 2010; Islam *et al*., 2011b) conducted in various parts of the world clearly showed that harvested rainwater often does not meet the microbiological drinking water quality standards. Karim *et al*. (2010) investigated the water quality of the harvested rainwater both from coastal and arsenic affected areas of Bangladesh. The study findings revealed that microbial contamination of the harvested rainwater was found to occur to some extent, although the counts of TC, TTC and *E. coli* were relatively lower as compared to this study. TC were detected in 33.33%, 17.86%, 33.33% and 39.52% water samples collected from plastic, brick, ferrocement and RCC reservoirs, respectively. FC and *E. coli* were also detected and the maximum percentage of water samples exceeding both Bangladesh Drinking water standard and WHO GV were only 12.62% for FC and 13.25% for *E. coli*. A study by Howard *et al*. (2006) also showed the regular microbial contamination of harvested rainwater, 60% of the water samples exceeded the Bangladesh standard in dry season and the mean value of TTC was found to 14 and 43.9 No. /100 mL in dry and monsoon seasons, respectively. This is because although rainwater is safe in terms of pollution by pathogens, its quality may deteriorate during the process of harvesting. Lack of first flushing during rainwater collection was also a common problem in the study area. Sanitary survey showed that manual abstraction of water from the storage tanks, improper cleaning of gutter and down pipe system and irregular cleaning of storage tanks are the major risk factors for microbial contamination of harvested tank water. Therefore, the results of this study clearly demonstrate the importance of proper collection and extraction of rainwater for RWHSs. Sanitary inspections were only conducted during baseline analysis of water supply

situation, repeated inspections may be useful to gain a better understanding of maintenance problems.

The maximum permissible limit of HPC in drinking water is 500 cfu/mL (USEPA, 2003). As a group, organisms identified in heterotrophic plate counts do not present a risk to water consumers, although a HPC > 500/mL indicates that more hygienic practices are required to maintain the drinking water quality. In the present study, presence of HPC was observed in all the water supply options. Several studies have shown that roof-collected rain water may contain higher HPC values than were observed in the present study (Lye *et al.*, 1987; Crabtree *et al.*, 1996; Simmons *et al.*, 2001). RWHSs also showed some degree of contamination by *V. cholerae* non-O1/non-O139 that mayhave been due to poor operation and maintenance. Uba & Aghogho (2000) also found a high prevalence of *Vibrio* spp. in rainwater collected from different types of roof catchments. *Salmonella and Shigella* spp. were not isolated from any of the samples in the present study; however, high prevalence of *Salmonella and Shigella* spp. in rainwater has been reported from a study (Uba & Aghogho, 2000). *Salmonella* spp. were also isolated from roof collected rainwater in New Zealand (Simmons, 2001). In the present study, *Pseudomonas* spp. were the most dominant opportunistic pathogens isolated from rain water samples. For RWHSs, roof and gutter of the collection systems and water collection from the tank manually may have contributed to higher contamination. The presence of *Pseudomonas* spp. in drinking water may cause infections to immune compromised populations.

4.2.1. Health Risk (Baseline Situation)

The microbial health burdens associated with the consumption of untreated water from the rain-feed pond, PSF and RWHs were estimated by QHRA model using the observed *E. coli* counts of the water supply options. All *E. coli* data of each water supply option was processed and analyzed to derive 95^{th} percentile, mean, maximum and minimum value to understand its concentration distribution to provide input in the QHRA model. The output of the model (disease burden) has been expressed in disability adjusted life years (DALYs) per person as recommended by WHO (2004). The microbial DALYs

were estimated for three reference pathogens like rotavirus, *Cryptosporidium* and *E. coli* O157:H7 for viral, protozoal and bacterial disease, respectively in predicting the likely total disease burden caused by these three disease causing organisms using the relationship algorithm embedded in the model.

The results of mean, lower (5^{th} percentile) and upper (95^{th} percentile) disease burden estimates for each drinking water option were shown in **Figure 4.1, Figure 4.2 and Figure 4.3** respectively. The mean disease burden estimates (**Figure 4.1**) showed that pond water has the highest disease burden of 4,691 µDALY/person.yr. Contribution of both bacterial and viral disease burden to the total burden were almost equal. Thus, both viral and bacterial diseases dominated the total disease burden estimation (mean), whereas the contribution by spore forming bacteria to the total microbial DALY is negligible. RWH showed the lowest disease burden as compared to other two options (rain-feed pond and PSF).

In the lower estimates (**Figure 4.2**), which means only 5% of DALY estimates due to these organisms were below these estimates. According to result, RWHs and PSF showed little disease burden. However, ponds showed higher disease burden, among other lower estimates of source water. The WHO (2004) recommended a reference level of risk per contaminant is 1.0 µDALY/person.yr. The lower bound of the total disease burden estimates for ponds is about 1,416 µDALY/person.yr. which is much higher than the reference level. The upper (95^{th} percentile) disease burden is shown in **Figure 4.3,** which means only 5% of the DALY estimates are above this estimate and the rest 95% values lie below the estimate. At the upper bound, the disease burden for pond water is found to about 15,584 µDALY/person.yr, whereas mean disease burden is found to be 4,691 µDALY/person.yr. It signifies, pond water is the most responsible sources of disease burden in this community. For PSF, the estimated mean disease burden is found to be 523 µDALY/person.yr, which also exceeds the maximum reference level of health burden. For RWHs, the lower bound of total health is found to be lower than the recommended level and exceeds at other two estimations. Viral disease dominates the total health burden at lower estimation, whereas, bacterial disease dominates at upper estimation.

The estimation shows that viral and bacterial pathogen concentrations dominated the disease burden estimates for the microbial DALY results with spore forming bacterial risks contributing relatively negligible risks to the total. At the lower estimation, the viral disease burden was the most significant contributor of the total. At higher estimation; the bacterial disease burden began to dominate the total disease burden for pond water. For RWH, both viral and bacterial burden dominates the total disease burden. Similar findings were observed in RAAMO (2005) studies. Study by Karim *et al*. (2010) showed a significant microbial health risk associated with drinking untreated rainwater and both viral and bacterial pathogens dominate the microbial disease burden. The upper disease-burden estimated for rainwater harvesting is 5 to 6 times higher than the level of risk with arsenic at 50 µg/L (Bangladesh standard for Arsenic). A study reviewed by Lye *et al*. (2002) identified the diseases attributed to the consumption of untreated rainwater include bacterial diarrhoeas due to *Salmonella* and *Campylobacter*, bacterial pneumonia due to *Legionella*, botulism due to *Clostridium*, tissue helminthes and protozoal diarrhoeas from *Giardia* and *Cryptosporidium*.

In general, the estimated disease burdens associated with the currently practiced water supply options were much higher than the WHO recommended risk level of 1.0 µDALY/person.yr. The disease burden was primarily dominated by bacterial and viral pathogens. In most cases, people drink pond, PSF and rain water without any in-house treatments, thus microbial health risks associated with the drinking water supply options require proper attention to enabling a safe and sustainable water supply in the coastal areas of Bangladesh.

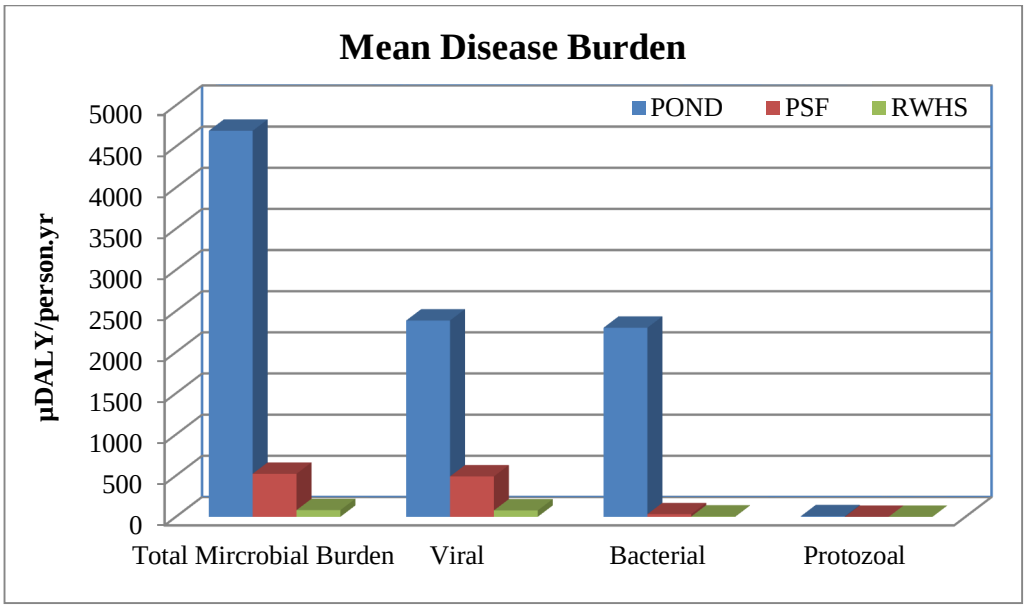


Figure 4.1. Estimated mean disease burden of the drinking water supply options

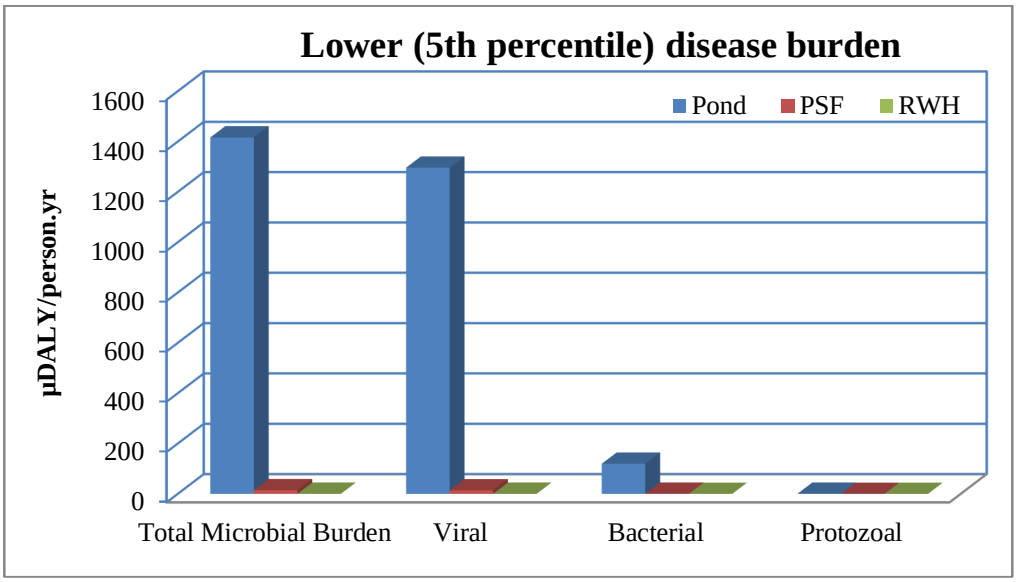


Figure 4.2. Estimated lower (5th percentile) disease burden of the drinking water supply options.

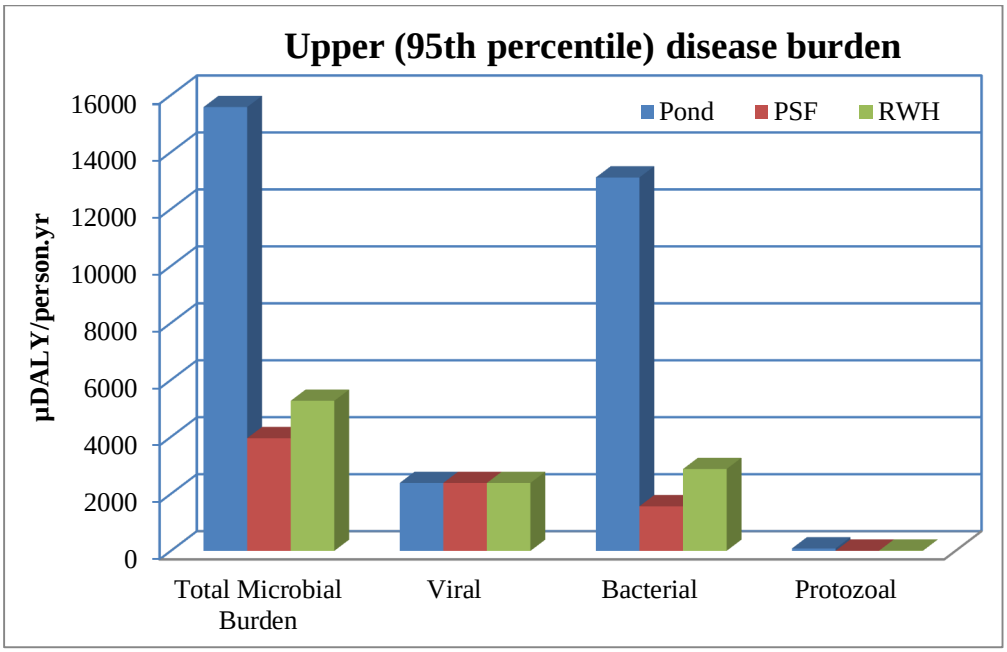


Figure 4.3. Estimated upper (95th percentile) disease burden of the drinking water supply options.

4.3. Effectiveness of Filters in Field Use Condition

4.3.1. Microbiological Evaluation

The evidence base for microbial effectiveness of ceramic filters in field use remains limited despite widespread and increasing use of the filters in Bangladesh and worldwide. To evaluate the performance of the filters, paired samples of both unfiltered (feed) and filtered/treated water from each filter in four cycles were collected and tested as shown below (**Table 4.5**). All the water samples were tested for physical, chemical and microbiological water quality parameters.

Table 4.5. Monitoring and sampling of distributed filters in the study area

Sampling/Monitoring Cycle	Sampling Period
First Cycle	3 May 2013 to 9 June 2013
Second Cycle	15 June 2013 to 14 July 2013
Third Cycle	27 August 2013 to 15 September 2013
Fourth Cycle	1 November to 15 November 2013

Table 4.6 shows the range, mean and median values of TC, FC, and *E. coli* concentrations for the feed water and filtered water. The CWFs reduced TC, FC and *E. coli* concentrations significantly ($p < 0.05$) in all monitoring cycles. The average reductions of *E. coli* were 83.65% (0.78 $\log_{10}$ reduction), 84.34% (0.8 $\log_{10}$ reduction), 97.18% (1.55 $\log_{10}$ reduction) and 77.85% (0.65 $\log_{10}$ reduction) in four monitoring cycles and TC and FC showed significant variation ($p < 0.05$) in filtered water in all monitoring cycles. For *E. coli*, the median $\log_{10}$ reduction > 2 was achieved in first, third and fourth cycles; however $\log_{10}$ reduction < 2 was observed for second cycles. This is because of the median $\log_{10}$ concentration of *E. coli* in the feed water was less than 2. A household filtration device like CWF is protective enough against bacteria if a $\log_{10}$ reduction > 2 is achieved (WHO, 2011).

Table 4.6. Microbial counts (cfu/100 mL) of both feed and filtered water and overall reduction of microbial counts by the filters

Parameter		Feed			Treated			Median Log_{10} reduction
		Range	Mean	Median	Range	Mean	Median	
First cycle (n=69)	TC	0 - 900,000	45,010	6000	0-272,000	8176	300	1.30
	FC	0- 470,000	15,209	2000	0-14,000	1063	30	1.82
	E. coli	0- 48,000	3814	520	0-6,000	296	<1	2.72
Second cycle (n=67)	TC	0- 52,000	5969	980	0-29,000	1130	64	1.19
	FC	0- 42,000	3114	400	0-5,700	338	7	1.76
	E. coli	0- 7,000	420	60	0-1400	71	<1	1.78
Third cycle (n=66)	TC	0- 43,000	4345	2300	0-3,300	365	<1	3.34
	FC	0- 30,000	1967	350	0-15,000	124	<1	2.54
	E. coli	0- 7,200	552	100	0-1,200	36	<1	2.00
Fourth cycle (n=62)	TC	0-87,000	5691	1300	15,000	1150	<1	3.11
	FC	0-26,000	2458	350	12,000	463	<1	2.54
	E. coli	0-18,000	1586	200	11,000	301	<1	2.30

Note: E. coli 0 cfu/100 mL = no risk; E. coli 1–10 cfu/100 mL = low risk (WHO, 2006). Figures within the parenthesis indicate the number of samples.(n is the number of water sample)

The source-wise filters' performances were also examined and **Table 4.7** shows the removal efficiency of indicator bacteria by MPFs. A $\log_{10}$ reduction of *E. coli* > 2 was observed for pond water, whereas < 2 was observed for PSF and harvested rainwater. This is because of the presence of low microbial concentration (< 2 $\log_{10}$ reduction) in PSF and

rainwater samples. For pond, the water samples satisfying *E. coli* standard of 0 cfu/100 mL increased from 12 (20%) to 48 samples (80%) after filter. For PSF, out of 36 samples, only 6 (16.67%) untreated samples satisfied the drinking water standard, whereas 23 (63.88%) filtered samples satisfied the *E. coli* standard for drinking water. Among 150 RWH samples, 66 untreated samples (44.0%) satisfied *E. coli* standard; whereas 126 treated samples (84.0%) satisfied *E. coli* standard. For TC and FC, a significant reduction was also observed (**Table 4.6 and Table 4.7**). TC and FC concentrations in filtered water differed significantly among the different options as indicated by the Kruskal-Wallis test ($p<0.05$) (**Table 4.7**).

Table 4.7. Source-wise microbial counts (in cfu/100 mL) of both feed and filtered water and overall reduction of microbial counts by the filters (n is the number of water samples).

Source water and Parameter		Feed Water			Filtered Water			Median Log_{10} reduction
		Range	Mean	Median	Range	Mean	Median	
Pond Water (n=60)	TC	0- 270,000	19175	5050	0-41,000	4,209	200	1.40
	FC	0- 49,000	6610	2000	0-14,000	1094	26	1.89
	E.coli	0- 48,000	3,037	500	0-11,000	380	<1	2.70
PSF Water (n=36)	TC	0- 90,000	39,623	4400	0-24,000	2384	130	1.53
	FC	0- 47,000	18,705	1300	0-10,000	872	6	2.34
	E.coli	0- 40,000	2917	75	0-6,000	258	<1	1.87
Harvested Rainwater (n=150)	TC	0- 621,000	9,766	1000	0-272,000	2406	30	1.52
	FC	0- 42,000	2278	315	0-5700	186	<1	2.50
	E.coli	0- 19000	666	50	0-1800	63	<1	1.70

Table 4.8 shows the percentage of water samples satisfying the no risk level and also the recommended low risk level as indicated by WHO (2006) . By the introduction of CWFs at the households, the number of water samples satisfying the no risk level increased significantly. At the lower risk level (< 10 cfu/100 mL), the samples satisfying the WHO criteria also increased in all the four cycles. However, the removal efficiency was found inconsistent in four monitoring cycles, thus household intervention using MPFs only is not enough for microbial safety of rain-feed pond water, PSF water and harvested rainwater

for drinking. The isolation of *V. cholerae* non-O1/non-O139 was found to decrease in the filtered water. *V. cholerae* non-O1/non-O139 was isolated in 41, 38, 31 and 10 feed water samples in the first, second, third and fourth monitoring cycles respectively; whereas this pathogen was isolated only in 24, 19, 16 and 6 filtered water samples of the corresponding cycle. Thus, the filters can remove *Vibrio cholerae* non-O1/non-O139 from the feed water and may reduce the health risk from the potentially pathogenic bacteria. Nevertheless, the removal of *V. cholerae* was not found consistent in all the four cycles.

Table 4.8. Percentage of water samples (%) satisfied the drinking water quality standard.

Cycle	Parameters	No risk		Low risk	
		Feed Water	Filtered	Feed Water	Filtered
First cycle (n=69)	TC	2.90 (2)	14.50 (10)		
	FC	7.29 (5)	40.58 (28)		
	E. coli	14.50 (10)	68.12 (47)	15.94 (11)	68.12 (47)
Second cycle (n=67)	TC	1.50 (1)	19.40 (13)		
	FC	5.97 (4)	41.80 (28)		
	E. coli	22.40 (15)	58.21 (39)	26.87 (18)	67.16 (45)
Third cycle (n=66)	TC	9.10 (6)	57.58 (38)		
	FC	27.27 (18)	75.76 (50)		
	E. coli	46.97 (31)	86.36 (57)	48.48 (32)	87.88 (58)
Fourth cycle (n=62)	TC	17.74 (11)	54.84 (34)		
	FC	27.42 (17)	72.58 (45)		
	E. coli	41.94 (26)	71.42 (48)	41.94 (26)	79.03 (49)
N.B. Figures within the parenthesis indicate the no of samples.					

Isolation of *V. cholerae* non-O1/non-O139 both in feed water and treated water is shown in **Table 4.9.** As indicated, the isolation of *V. cholerae* non-O1/non-O139 decreases significantly in the treated water. That means the filter can remove the *Vibrio cholerae* species from the feed water and thus reduce the health risk significantly from the potentially pathogenic bacteria. However, isolated *V. cholerae* non-O1/non-O139 was detected both in the feed and treated water samples (**Table 4.9**) due to non-removal and very few samples were found to be re-contaminated. Again, the removal of *V. cholerae* was not found consistent in all the four cycles.

Table 4.9. Isolation of *V. cholerae* in the untreated and treated samples.

Cycle	Untreated	Treated	Sample with *V. cholerae* both in treated and untreated samples (%)	% Re-contaminated
First cycle (n=69)	59.42 (41)	34.78 (24)	33 (23)	1.45 (1)
Second cycle (n=67)	50.0 (33)	28.8 (19)	19.7 (13)	9.09 (6)
Third cycle (n=66)	47.7 (31)	24.62 (16)	21.54 (14)	3.08 (2)
Fourth cycle (n=62)	14.87 (10)	9.52 (6)	3.17 (2)	6.35 (4)
N.B. Figures within the parenthesis indicate the no of samples.				

Figure 4.4, Figure 4.5 and Figure 4.6 show the removal of indicator organisms by the filters in four monitoring cycles. In general, bacterial removal ranged from 0 to 100% for each filter depending on feed source water. In some cases, higher level of microbial counts was observed in the treated/filtered water than the untreated feed water. The possible reason for the contamination of the filtered water is mainly due to change of feed source water, introducing of bacteria from the filters to the effluent possibly through contaminated spouts or other filter elements. Several other studies also reported sporadic presence of higher microbial level in the filtered water than feed water by ceramic filters (Murphy *et al*., 2010).

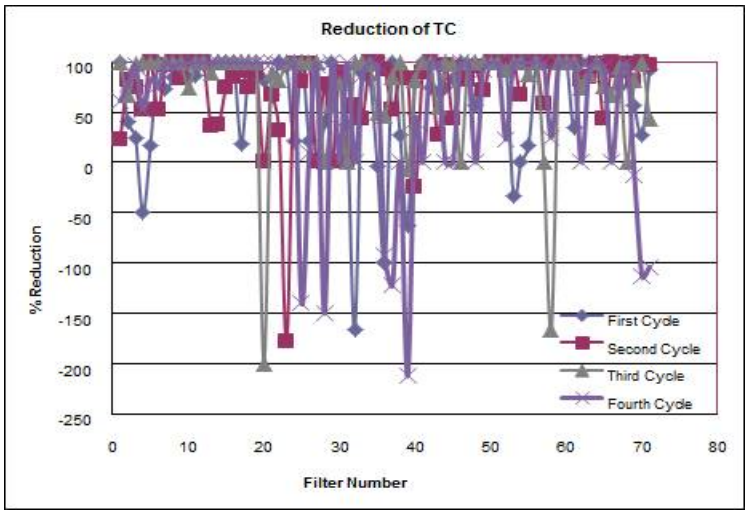


Figure 4.4. Reduction of total coliform (TC) in four monitoring cycles.

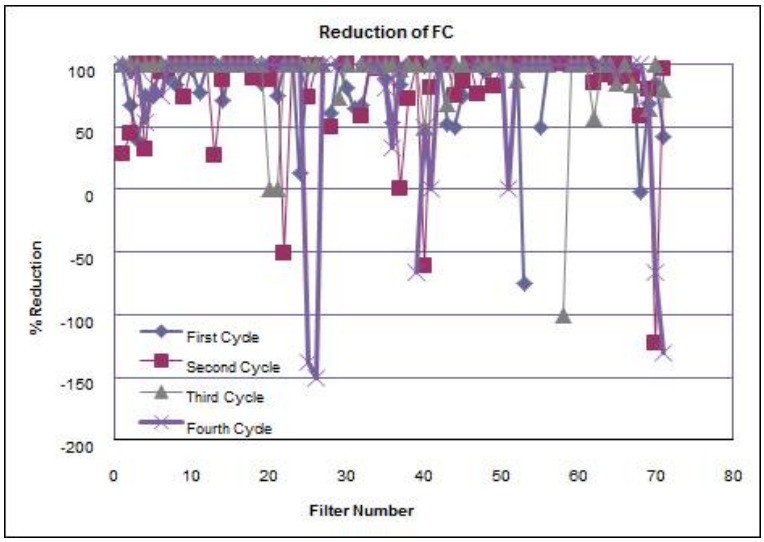


Figure 4.5. Reduction of fecal coliform (FC) in four monitoring cycles

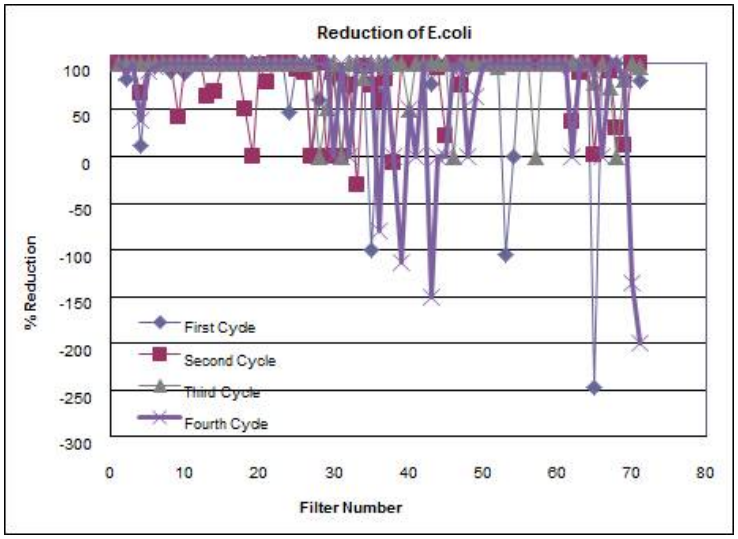


Figure 4.6. Reduction of *E. coli* in four monitoring cycles.

4.3.2. Physic-Chemical Evaluation

A summary of the physical and chemical parameters of the water samples were shown in **Table 4.10**. The pH value of the water samples was remaining within 6.5 to 8.5 except for 2 samples in the second cycle, whose pH value exceeded 8.5. These were the harvested rainwater samples collected from RCC tank and pH value of stored rainwater in RCC is normally found to be higher (Karim *et al*., 2010) due to leaching of calcium oxide from the cement used for RCC tanks construction. For both pond and PSF water, higher

electrical conductivity (EC) was observed, indicating presence of higher dissolved substances in water. The turbidity of all filtered water samples were well below 5 NTU. The average removal of turbidity by the filters was found to be 78%, 78%, 73% and 53 %, respectively in four cycles. The CWFs reduced turbidity significantly ($p < 0.05$) in all monitoring cycles and the mean turbidity of the filtered water was less than 1.0 NTU. Thus the water becomes very clear and transparent after filtration, which is more acceptable for drinking aesthetically.

Table 4.10. Physical and chemical water quality of the feed and filtered water samples.

Parameter		Feed water		Filtered		Ave % reduction (turbidity)
		Range	Mean	Range	Mean	
First cycle (n=69)	pH	6.20-8.45	7.43	6.40-8.18	7.52	78.17
	EC(µS/cm)	25.4-4,150	729.16	42.8-3,820	825.83	
	Salinity (ppt)	0-2.08	0.357	0.01-1.92	0.404	
	Turbidity (NTU)	0.34-33.1	3.65	0.22-3.32	0.80	
Second cycle (n=67)	pH	6.40-9.20	7.26	6.4-8.5	7.32	77.85
	EC(µS/cm)	16-3,720	573.53	15-4,170	564.61	
	Salinity (ppt)	0-1.88	0.28	0-2.1	0.28	
	Turbidity (NTU)	0.29-58.5	3.34	0.19-3.84	0.74	
Third cycle (n=66)	pH	6.90-7.80	7.35	6.9-7.8	7.37	73.28
	EC(µS/cm)	6.9-1,717	223.79	7.1-1,560	244.61	
	Salinity (ppt)	0-7.5	1.77	0-0.87	0.16	
	Turbidity (NTU)	0.3-47.2	2.33	0.13-3.04	0.62	
Fourth cycle (n=62)	pH	6.5-8.0	7.19	6.5-7.8	7.22	53.21
	EC(µS/cm)	14.6-3860	451.28	18.1-3720	398.77	
	Salinity (ppt)	0-6.7	0.30	0-1.86	0.19	
	Turbidity (NTU)	0.26-8.05	1.20	0.2-2.23	0.56	
n is the number of water samples						

4.3.3. Health Risk Reduction

The estimated median health burden reduction by the filters with respect to baseline and feed water conditions is presented in **Figure 4.7** For pond water, a median health burden reduction > 98% and 99% with reference to baseline and feed water conditions, respectively was observed. For PSF, the corresponding median health burden reduction >

84% and 96% was observed. Harvested rainwater showed the median health burden reduction > 97% with reference to feed water; however no health burden reduction was observed with reference to baseline condition because the baseline concentration was zero for *E. coli*. The median health risks for filtered water do not meet the reference level, although at the lower disease burden estimation (5^{th} percentile), it was found much lower than the WHO recommended level of 1.0 μDALY / person.yr. For the filtered pond water, the reduction of disease burden was observed to be more than 99.99% at the lower disease burden estimation (5th percentile). However, at higher disease burden estimation (95th percentile), an insignificant reduction of health burden was observed and bacterial disease dominated the estimated health burden. The similar health burden reduction was observed for PSF water at the lower and upper estimations. For harvested rainwater, the health risk reduction at the lower burden estimation was found to be about 56% and 99% with respect to baseline and feed water conditions, respectively. However, at higher disease burden estimation (95th percentile), an increased in health burden was observed with respect to baseline condition and about 47% health risk reduction was observed with respect to feed water condition. In general, CWFs have potential in reducing the microbial health burden associated with the coastal water supply options.

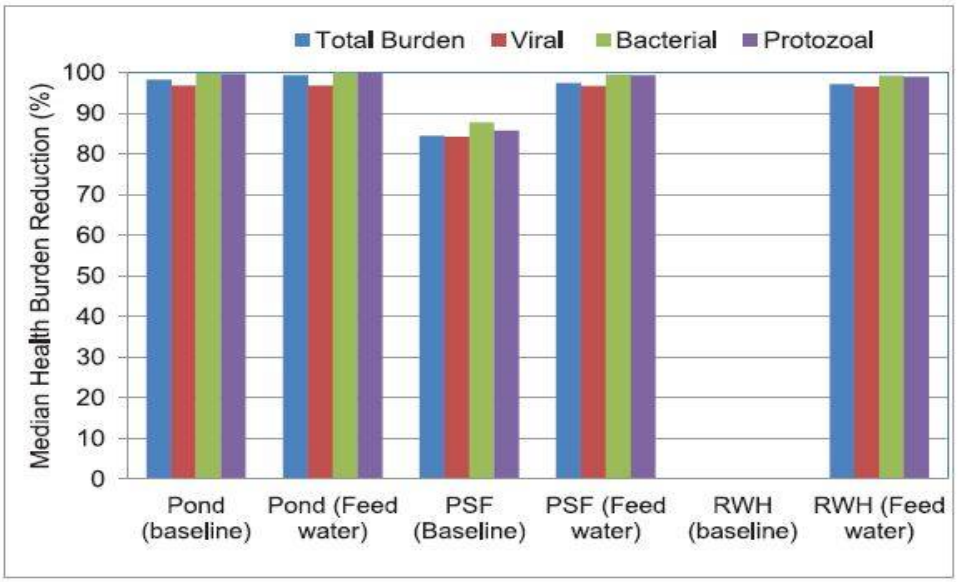


Figure 4.7. Reduction of median health burden by the filters with respect to baseline and feed water conditions based on QHRA model outputs

CHAPTER 5: FILTER PERFORMANCE UNDER LABORATORY CONTROL STUDY

5.1. General

The control study was based on the guideline of WHO protocol for household water treatment technology evaluation. CWF filters of three well-known brands were evaluated in the laboratory control experiment to know the performance against three microbiological organisms and physical parameters. The results of the experiments have been presented and also conclusion of this study based on WHO protocol has been presented in this chapter.

5.2. Flow Rate Analysis

The laboratory experiment was conducted in 23 weeks with throughput volume of approximately 1500 liters by each of 24 filters. On each day of filtration, an average of 10-20liters of water was filtered. Daily spiking was done on each filter based on the test set up and wastewater was added according to the guideline. The complete filtration cycle of each branded filters have been reported in the **Appendix B**. In a complete cycle of filtration, six sampling points based on the filtered volume were planned. **Table 5.1** shows the average filtration rate and filtered volume in each sampling time.

Table 5.1. Averaged filtration rate and filtered volume at six sampling times

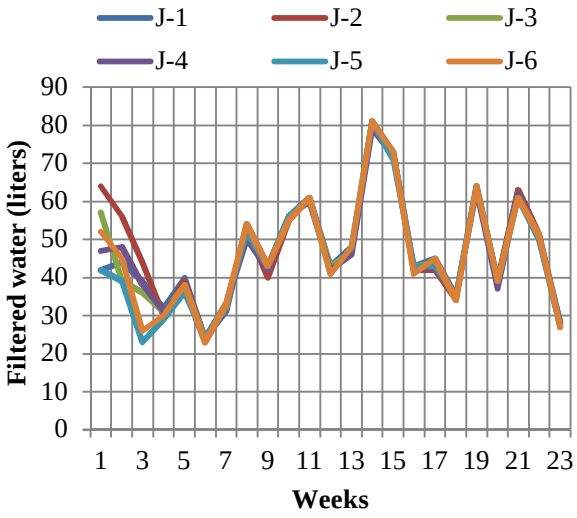
	Average and percentage filtration volume		
Sampling	**B-1**	**B-2**	**B-3**
1st Sampling	0	0	0
2nd Sampling	(254.83 L) 19.19%	(359.67 L) 23.91%	(394.67 L) 24.25%
3rd Sampling	(508.17 L) 47.43%	(717.50 L) 47.77%	(790 L) 48.56%
4th Sampling	(750.67 L) 70.07%	(1059.67 L) 70.58%	(1165 L) 71.61%
5th Sampling	(892.67 L) 83.33%	(1259.83 L) 83.93%	(1368.67 L) 84.14%
6th Sampling	(1071.11 L) 100%	(1500.83 L) 100%	(1662.67 L) 100%

CWF is a gravity driven filtration system, so it is not possible to maintain a specific filtration rate. Although it was planned initially to sample at 0%, 25%, 50%, 60%, 75%, 100% of the design capacity of the filters (1500 liters), it was not exactly maintained due to variation of filtration rate. Actual sampling was done as shown in **Table 5.1.** Among B-1 filters, the total amount of water filtered in 23 weeks were 1079, 1103, 1075, 1064, 1041 and 1065 liters respectively. The J-2 was slightly quicker than other B-1 filters. First sampling was done at the starting of filtration cycle for all the filters. The average weekly filtered volume (for 23 weeks) (**Table B.4**) by all B-1 filters was 47 liters.

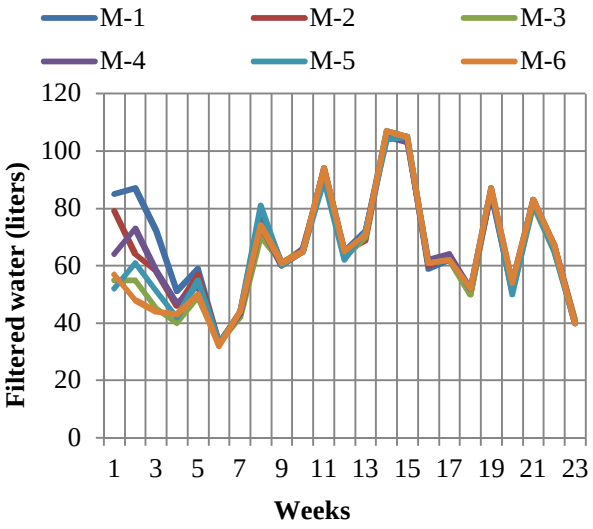
For the B-2 filters, the total amount of water filtered in 23 weeks were 1583, 1520, 1451, 1509, 1476 and 1466 liters respectively. It has been seen that M-3 was slightly slower. The average weekly volume (for 23 weeks) filtered (**Table B.4)** by all B-2 filters was 65 liters.

For B-3 filters, the total amount of water filtered in 23 weeks were 1669, 1632, 1617, 1629, 1623 and 1590 liters respectively. All the filters were consistent throughout the cycle despite the added wastewater. The average weekly volume (for 23 weeks) filtered (**Table B.4)** by all B-3 filters was 71 liters.

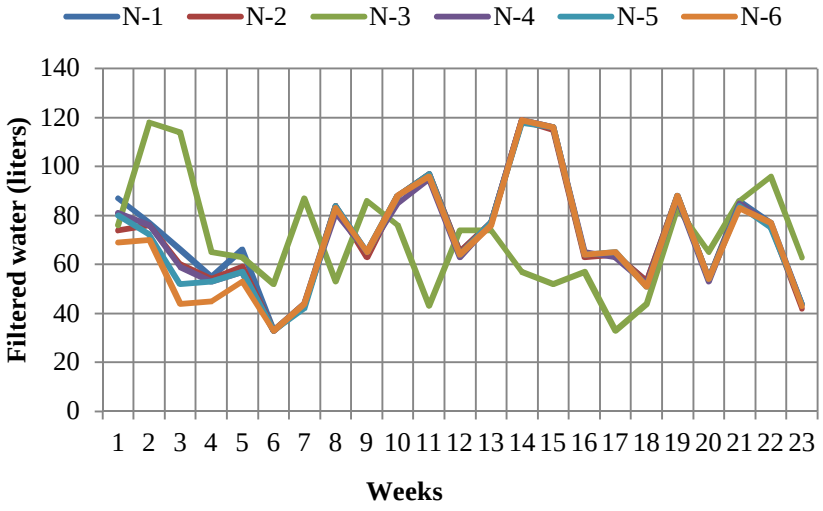
The weekly filtration of each filter of three brands were shown in **Figure 5.1 (a, b, c).** All B-1, B-2 and B-3 filters have unique flow rate but filtration trends were very much similar. At the beginning within 7 weeks, filters showed similar fashion of filtration but the performance trend was variable among the brands. It may take some time to reach the good state of filtration by all the filters from the beginning. For all the filters as shown in **Figure 5.1,** between 13^{th} to 16^{th} weeks the filters achieved their maximum filtration rate of 80, 110 and 120 liters for B-1, B-2 and B-3, respectively. It may be due to the cleaning of filters after 14^{th} week. The fluctuation of filtration signifies the variable filtration rate of each filters and the presence of organic and suspended matter clogged the unit and the rate was increased when periodic cleaning was done. After the 21^{st} week, all the filters showed very decreasing trend of filtration which may not be retrievable to its original flow rate. The filters may need replacement, if decreasing rate of filtration continues further.



a. Weekly filtration of B-1 filters



b. Weekly filtration of B-2 filters



c. Weekly filtration of B-3 filters

Figure 5.1. Weekly filtration of different filters

From individual brand analysis for filtration, all B-1, B-2 and B-3 filters were quite similar in terms of their material quality which was not matched with the hypothesis made earlier, that there may have some differences in material quality provided by the retailer. Among the three brands (**Figure 5.2)**, B-3 was reported with higher filtration volume throughout the filtration time. The reason was may be, B-3 has less compacted mineral layers (from external view of the mineral strata) causing the water to pass quickly than B-

1 or B-2. After B-3, the throughout from B-2 is less than B-1. Both B-1 and B-2 have a relatively compact layer of minerals and activated carbons, which cause less filtration volume during the experimental period.

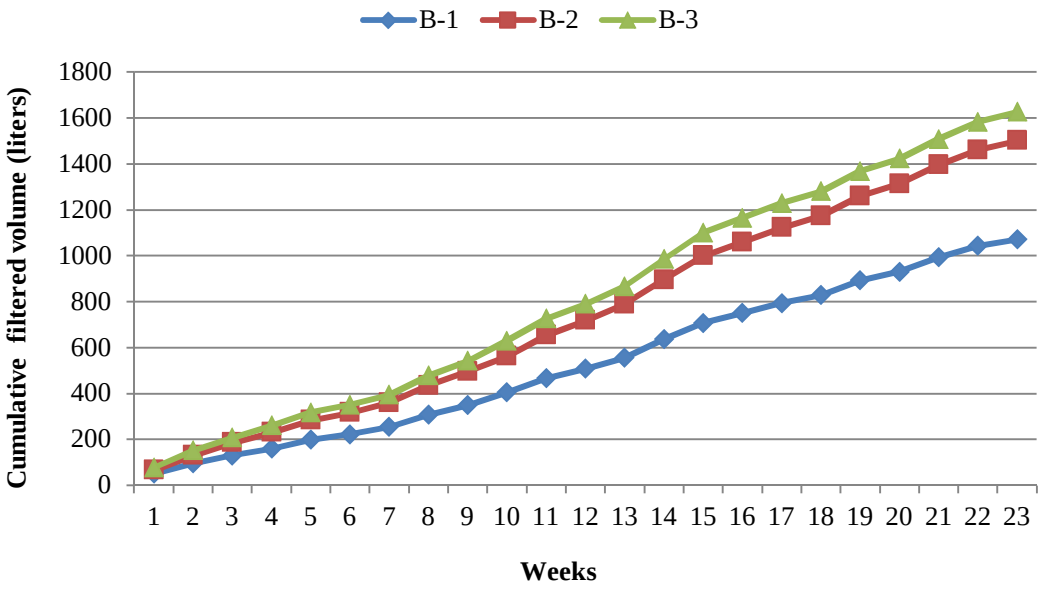


Figure 5.2. Weekly filtration (Cumulative) of different brands

The average weekly filtration as shown in **Figure 5.3,** a decreasing trend in filtration was observed initially because of clogging by suspended particles in the feed water (van Halem *et al.*, 2007). It continues up to the cleaning or general rinsing the compartments of the filters with deionized water. In 14th or 15th week, the average filtration was found to increase due to periodic cleaning of the filters and it decreased again with time because of accumulation of suspended particles present in raw water at continuous use. The filtration period of 23 weeks in **Figure 5.3** shows that within, the performance of filters is not according to the manufacturer's claim of effectiveness because of age of the filter materials. The flow rate generally declined with time, but can be increased with periodical cleaning and washing of filtration unit.

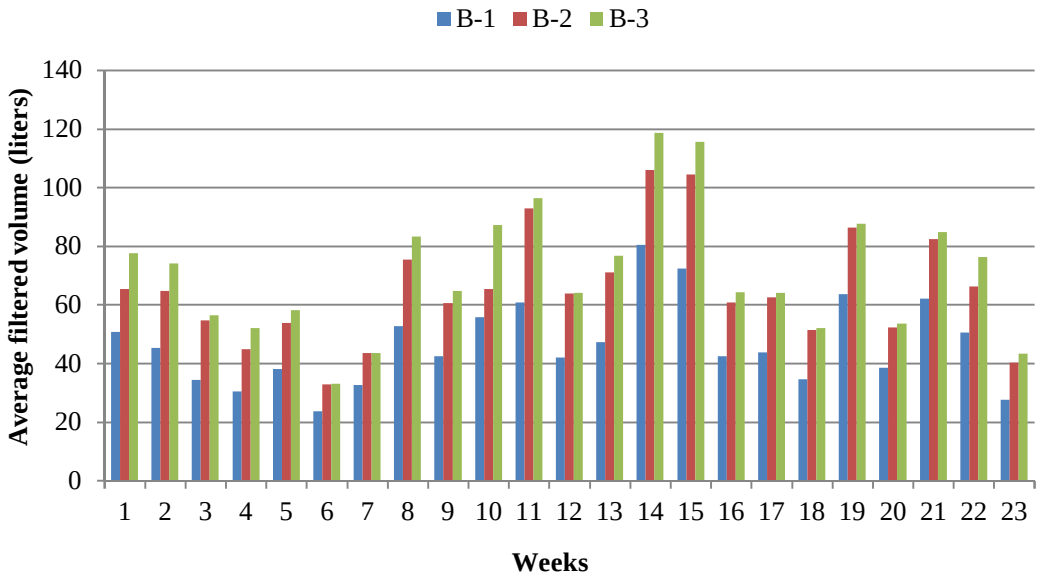


Figure 5.3. Weekly average filtration of different brands

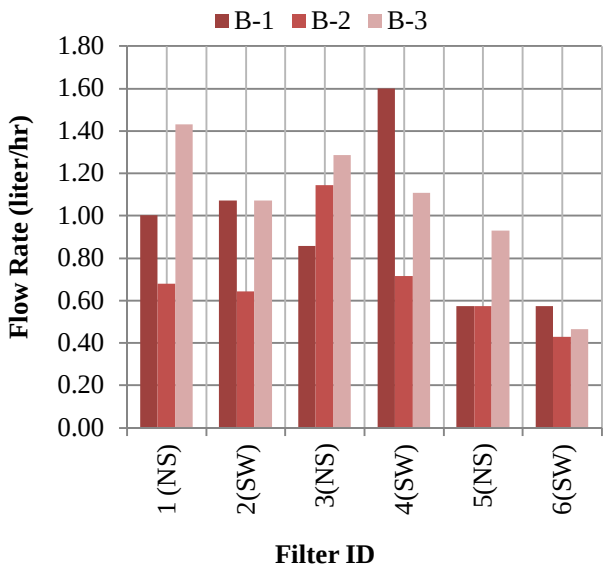
The even numbered filters (9 filters) were seeded with wastewater and it was observed that organic and suspended materials of the wastewater may not affect the overall flow rate. It may happen due to early settlement of the suspended matters on the upper container. It has been seen that the level of turbidity was below 5NTU in most cases, which is not a big concern (Mohamed *et al.*, 2016; WHO, 2011) for analysis. During maintenance, it has been observed that after a week or two, the bottom rubber seals of the candle on the upper compartment became loose which could certainly increase the passing rate. So the tightness of the rubber seal was kept in a permissible limit to maintain a good flow rate when noticed loose.

In most of the studies, where the ceramic filters (CWF) were composed of ceramic candles only but no other secondary or tertiary layers of filters, the flow rates were higher (van Halem *et al.*, 2009; Bloem *et al.*, 2009; Mwabi *et al.*, 2011; Hagan *et al.*,2013) than this study. In this study, the filters that were used have 4 to 6 compact layers of minerals after the ceramic candle which necessarily reduced the flow rate. Also depending on different types of minerals, the filtration may vary.

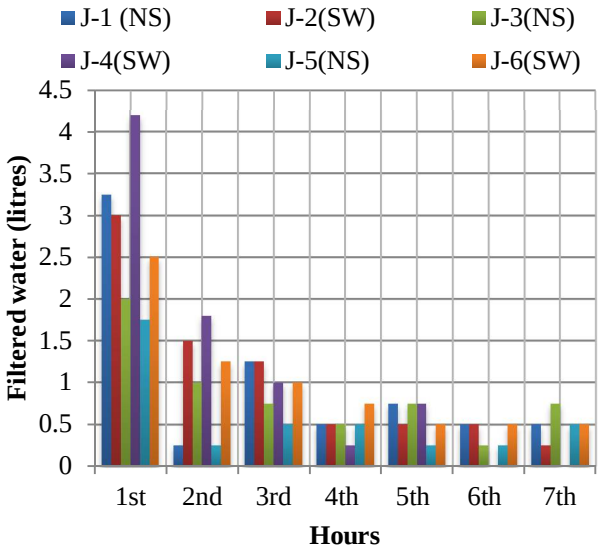
The presented **Figure 5.4** shows the hourly flow rates of B-1, B-2 and B-3 respectively. At the beginning the flow rate was high. It was because of the higher water

pressure of higher water level at the beginning and the pressure decreased with time which was attributable with the situation. Form the above mentioned graph (**Figure 5.4a)** shows that the maximum flow rate observed was 1.6 liter/hour (l/h) in B-1, 1.41 l/h in B-2 and 1.43 l/h for B-3. But the average flow rate of B-1 was 0.95 l/h. And 0.70 l/h for B-2 **(Figure 5.4c)** and 1.05 l/h for B-3 **(Figure 5.4d).** From **Figure 5.4b**, B-1 filters with non seeded (NS) wastewater and filters with seeded waste water (SW) have not much difference in filtration rate. It was because the added wastewater mostly contains suspended materials which settle initially on the upper container. According to (van Halem *et al*., 2009 & Hagan *et al*., 2013), a sustainable household water treatment system (HWTS) should provide sufficient water for a family long-term, for which it should have a flow rate >2 l/h or within 1.5–3.5 l/h respectively. According to this evidences, none of the filters of this study comply the standard flow rate. Bloem *et al*. (2009) stated that, the normal flow rate ranges from 1-3.5 l/h, which B-3 can barely achieve. From these facts, it can be inferred that, these filters cannot provide sufficient water for a family for long term. More frequent cleaning may have a positive effect on the outcome variables (Mellor *et al*., 2014).

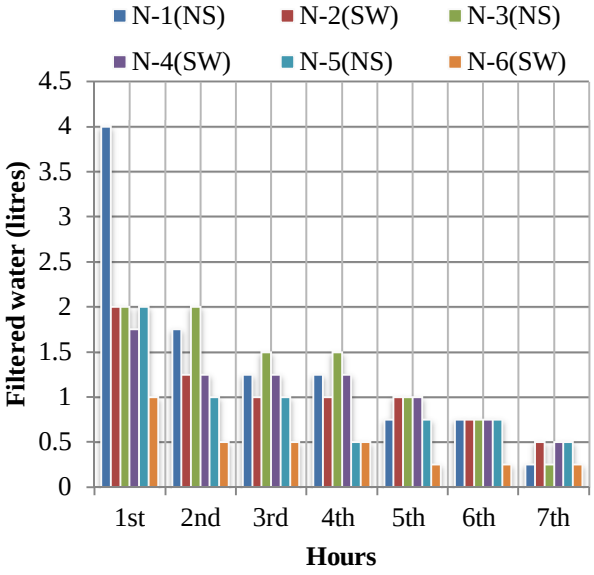
Results from the negative control filters (**Table B 8 – Table B 25)** show that all the negative control filters had no contamination of any of the organisms in both the feed and filtered water by the systems. It means the filter device is not a source of contamination by itself. Different studies showed that, temporary or longer storage time of water sometimes cause secondary contamination by the reservoir but in this study the lower compartment (temporary storage) of the filters didn't contribute to the secondary contamination like other field study or control experiments (Van der Laan *et al*., 2014).



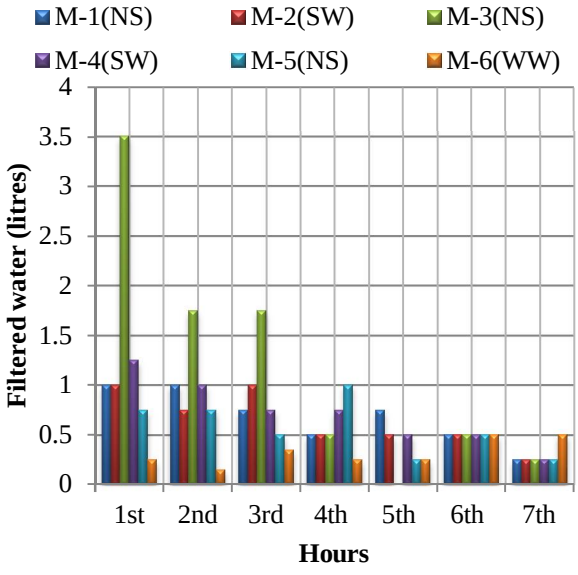
a. Average flow rate comparison of different brands



b. Typical hourly filtration performance of B-1



c. Typical hourly filtration performance of B-3



d. Typical hourly filtration performance of B-2

Figure 5.4. Hourly flow rate of the filters

5.3. Spiking Concentrations and Effect of Laboratory Temperature

All the filters have been spiked with *E. coli, C. perfringens (*CP*)* and MS2 bacteriophage daily at the beginning of the filtration. **Table 5.2** gives the number of spiked organism present in feed and filtered water at each sampling point. As shown in **Table 5.2,** *E. coli* level in the feed water ranged from 2000 cfu/100mL - 0.98 x 10^6 cfu/100mL and 0 cfu/100mL - 0.746 x 10^6 cfu/100 mL in the filtered water. The average concentration of *E. coli* in feed water was 314212 cfu/100mL and in filtered water was 73791 cfu/100mL.

For the case of spore forming bacteria *C. perfringens* ,the concentration ranged from 10 cfu/100mL- 4750 cfu/100 mL and 0 cfu/100mL - 3325 cfu/100mL in feed and filtered water, respectively. The average concentration in feed water was 1578 cfu/100mL and in filtered water was 630 cfu/100mL.

MS2 bacteriophage, the viral surrogate concentration in the feed water ranged from 68000 pfu/100mL - 0.576 x 10^6 pfu/100 mL and 2000 pfu/100mL - 0.28 x 10^6 pfu/100mL for filtered water. The average concentration in feed water was 231900 pfu/100mL and in filtered water was 75642 pfu/100mL.

Microbes can be roughly classified according to the range of temperature at which they can grow. The highest, lowest and optimum temperature for growth rates varies with different organisms. As would be expected from the core temperature of the human body, 37 °C (98.6 °F), is the optimal temperature for normal human microbiota and pathogens (e.g., *E. coli, Clostridium perfringens, Vibrio cholerae, Salmonella* spp) for mesophiles ("middle living organisms") having growth temperatures ranging from room temperature (about 20 °C) to about 45 °C. Laboratory study was carried out in temperature of 25˚C - 30˚C for the entire study period. This temperature range was below the field temperature but it was within the temperature range of mesophilic bacteria. In the laboratory based study, samples were collected just after filtration and the samples were stored at 2˚C to 8˚C to stop bacterial regeneration until it was processed in the laboratory. That's why, regeneration of organism didn't happen in the control study.

Table 5.2. Spiking of feed and filtered water with microorganisms and concentration

Sampling Points	*E. coli*			
	Feed water (cfu/100mL)		Filtered water (cfu/100mL)	
	Max	Min	Max	Min
1st	64400	2000	2423	7
2nd	270000	1140	665	0
3rd	300000	138000	65000	190
4th	980000	120000	148000	30000
5th	888000	95000	624000	400
6th	855000	57000	14500	300
Average	314212		73791	
Sampling Points	*C. perfringens*			
	Feed water (cfu/100mL)		Filtered water (cfu/100mL)	
	Max	Min	Max	Min
1st	83	10	15	3
2nd	3000	32	865	8
3rd	380	190	190	0
4th	4750	950	1900	20
5th	2590	860	790	40
6th	5225	860	3325	400
Average	1578		630	
Sampling Points	MS2 bacteriophage			
	Feed water (pfu/100mL)		Filtered water (pfu/100mL)	
	Max	Min	Max	Min
1st	133200	68000	52500	10400
2nd	300000	66400	67200	12400
3rd	152000	84000	58000	2000
4th	512000	104000	32000	2000
5th	368000	251200	236800	34400
6th	576000	168000	280000	120000
Average	231900		75642	

Table 5.3. Microbiological performance of different brands against *E. coli, Clostridium perfringens* (CP) and MS2 bacteriophage

		***E. coli* (Bacteria)**				**MS2 bacteriophage (Virus)**				***C. perfringens* (spore forming bacteria)**			
		LRV		**% Reduction**		**LRV**		**% Reduction**		**LRV**		**% Reduction**	
B-1	**Sampling**	**1**	**2**	**1**	**2**	**1**	**2**	**1**	**2**	**1**	**2**	**1**	**2**
	1st	3.96	0.66	99.99	77.97	2.78	3.04	100	100	0.72	1.32	80.77	95.18
	2nd	5.43	1.20	100	93.75	2.78	0.63	100	76.72	1.45	0.24	96.49	43
	3rd	1.24	2.39	94.2	99.59	1.31	0.98	95.1	89.47	2.28	2.58	99.47	99.74
	4th	0.31	0.62	50.67	75.84	1.80	0.98	98.4	89.44	0.70	0.80	80	84
	5th	0.69	0.15	79.75	29.73	0.19	0.22	35.65	39.79	0.59	0.76	74.5	82.69
	6th	1.25	2.45	94.44	99.64	0.29	0.21	48.57	38.71	0.06	0.68	12.8	79.22
Mean value		**2.15**	**1.24**	**86.51**	**79.42**	**1.52**	**1.01**	**79.62**	**72.36**	**0.97**	**1.06**	**74.01**	**80.64**
B-2	**Sampling**	**1**	**2**	**1**	**2**	**1**	**2**	**1**	**2**	**1**	**2**	**1**	**2**
	1st	0.94	0.47	88.6	65.8	0.64	0.93	77.25	88.34	0.84	0.44	85.41	63.41
	2nd	0.73	0.63	81.38	76.47	0.79	0.65	83.68	77.6	0.98	0.70	89.47	80.26
	3rd	2.82	3.20	99.85	99.94	1.66	1.17	97.82	93.18	2.15	0.98	99.29	89.47
	4th	0.45	0.96	64.29	88.98	1.41	1.39	96.15	95.94	1.68	0.55	97.9	71.93
	5th	1.16	0.61	93.14	68.42	0.39	0.91	58.99	87.71	0.30	0.57	50	73.36
	6th	1.50	2.45	96.84	99.96	0.33	0.34	52.78	54.55	0.20	0.72	36.36	81.05
Mean value		**1.27**	**1.39**	**87.35**	**83.26**	**0.87**	**0.90**	**77.78**	**82.89**	**1.02**	**0.66**	**76.41**	**76.58**
B-3	**Sampling**	**1**	**2**	**1**	**2**	**1**	**2**	**1**	**2**	**1**	**2**	**1**	**2**
	1st	0.93	0.24	88.13	43	0.29	0.44	48.33	63.53	0.52	0.45	70	64.52
	2nd	0.76	0.73	82.81	81.25	0.32	0.50	52.1	68.42	0.60	0.54	75	71.17
	3rd	0.61	1.43	75.38	96.25	0.27	0.73	46.3	80.95	0.85	0.18	85.79	33.33
	4th	0.60	1.00	75	90	2.09	0.98	99.19	89.47	0.76	0.30	82.46	50
	5th	2.38	1.15	99.58	92.84	0.48	0.33	66.88	53.68	1.30	1.33	95	95.35
	6th	1.93	1.66	98.82	97.82	0.15	0.15	30	28.57	0.15	0.21	28.42	38.94
Mean value		**1.20**	**1.03**	**86.62**	**83.53**	**0.60**	**0.52**	**57.13**	**64.10**	**0.70**	**0.50**	**72.78**	**58.89**

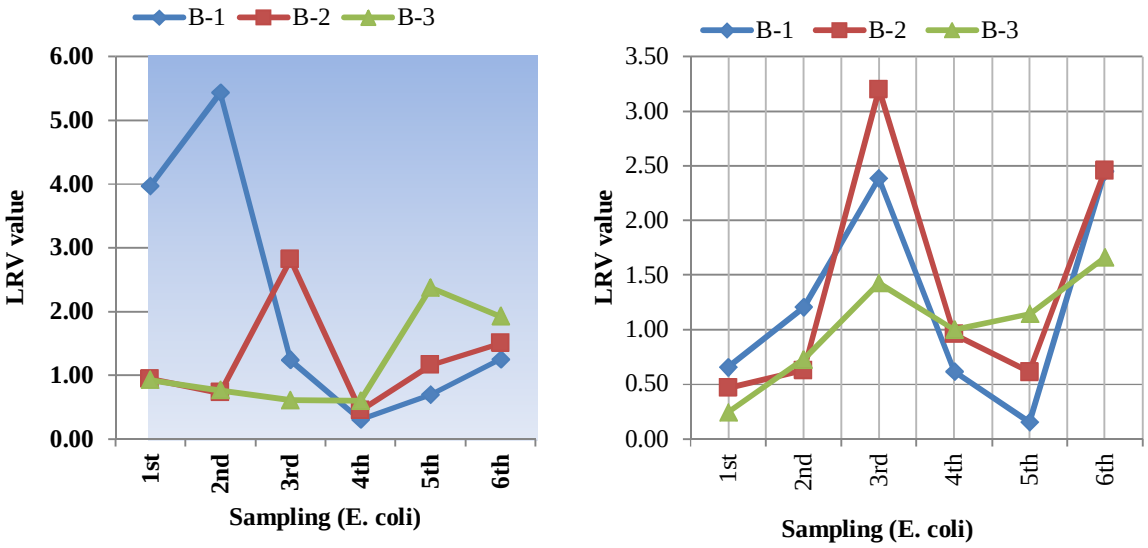
1= Non seeded with waste water
2= Seeded with waste water

5.4. *E. coli* (Bacteria) Removal Performance

The filter performance in removing the microorganisms under control experiments with both seeded and non-seeded wastewater has been illustrated in **Table 5.3**. The results show that with non-seeded wastewater, the maximum (100%) reduction was observed at 2nd sampling and minimum (50.67%) reduction at 4th sampling for B-1. For B-2, maximum (99.85%) reduction was observed at 3rd sampling and minimum (64.29%) reduction was observed at 4th sampling. For B-3, the maximum (99.58%) reduction at 5th sampling and minimum (75%) reduction at 4th sampling were observed. But addition of wastewater showed different removal efficiency (**Table 5.3**) for the filters of the three brands. With wastewater, the maximum reduction was 99.64% at 6th sampling and minimum reduction was 29.73% at 5th sampling. For B-2, maximum reduction was 99.94% at 3rd samplingand minimum reduction was 65.8% at 1st sampling. B-3 has maximum (97.82%) reduction observed at 6th sampling and minimum (43%) reduction has at 1st sampling.

Filter performance against *E. coli* is illustrated in **Figure 5.5,** for challenged water non seeded (**Figure 5.5a)** and seeded (**Figure 5.5b**) with wastewater in $\log_{10}$ reduction value (LRV) for six sampling times. With no seeded waste water (**Figure 5.5a)**, all the filters showed variable performance in *E. coli* reduction. The average LRV for B-1 was 2.15 (0.31-5.43), B-2 was 1.27 (0.73-2.82) and B-3 was 1.20 (0.61-2.38). B-1 showed higher *E. coli* removal efficiency at the beginning with LRV 3.96 and 5.43 at 1st and 2nd sampling respectively but with time, it reduced to 0.31 at 4th sampling and increased again. For B-2 with no seeded waste water, initially had lower value LRV <1 (<90% reduction) upto 2nd sampling. After that, it increased in efficiency and reached at maximum LRV (2.82) but started decreasing afterwards. For B-3, with no seeded waste water, initially the value was LRV<1 (<90% reduction) upto 4th sampling and on 5th sampling it increased up to maximum LRV2.38. After the cleaning at 4th sampling, B-1 and B-2 showed increasing LRV trend which may continue upto last sampling. It is may be due to good quality filter material in the system. But for B-3, after 5th sampling the LRV decreased, may be due to the low quality material used in the filter. With unseeded waste water, B-1 showed the maximum LRV (5.43) and the minimum

LRV (0.31). It seems that the performance in removing *E. coli* by the filter is not consistent.

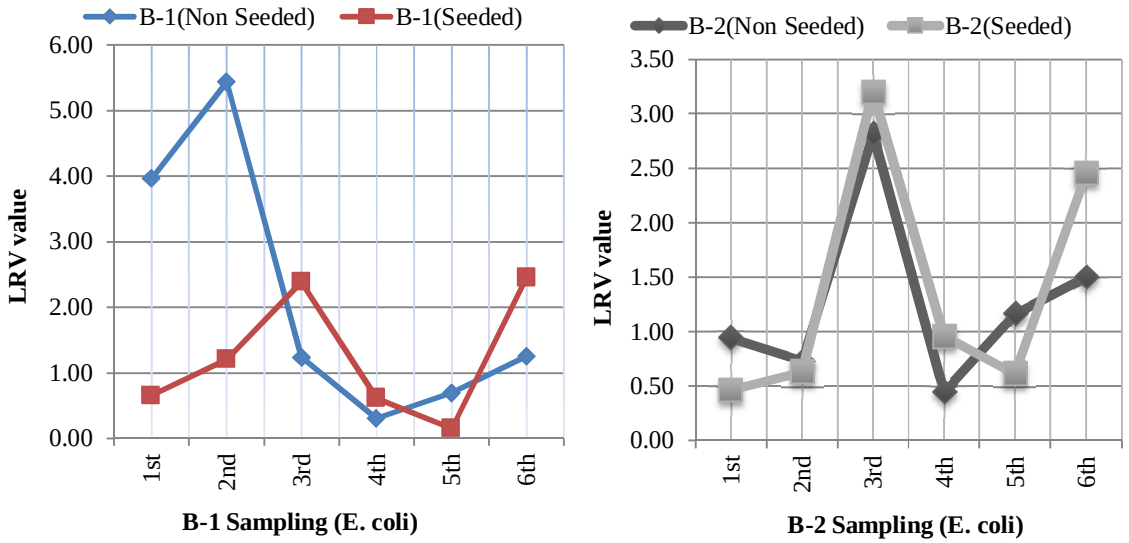


a. *E. coli* LRV in six sampling times (Non seeded) **b. *E. coli* LRV in six sampling times (Seeded)**

Figure 5.5. *E. coli* Log_{10} reduction value in six sampling times

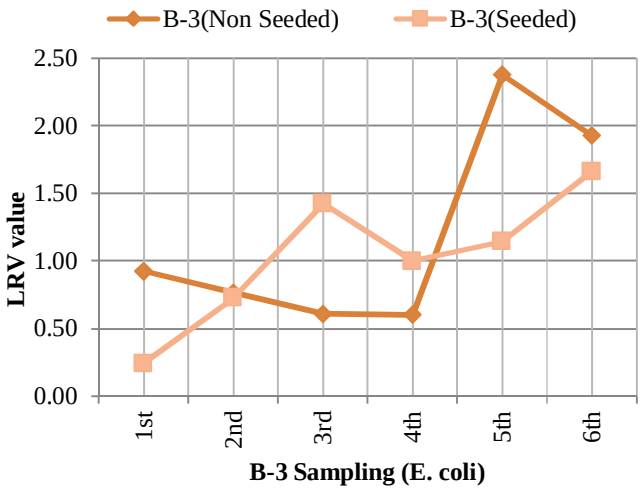
Figure 5.5b illustrates the effect of seeded waste water in LRV where all the filters showed variable performance in *E. coli* reduction than **Figure 5.5a** of unseeded waste water. The average LRV for B-1 was 1.24 (0.15-2.45), B-2 was 1.39 (0.47-3.20) and B-3 was 1.03 (0.24-1.66). At the beginning, B-1 showed *E. coli* removal efficiency with increasing LRV of 0.66 and 1.20 at 1st and 2nd sampling respectively and it increased up to 3rd sampling but started decreasing afterwards. This decreasing trend again started to increase after 5th sampling, which regained the maximum LRV (2.45) at last sampling. For B-2, filters with seeded waste water, initially started with increasing LRV value upto 3rd sampling. After that, it decreased in efficiency and again started increasing after 5th sampling and reached the maximum LRV (2.45). For B-3, with seeded waste water, the initial value of *E. coli* was LRV<1 (<90% reduction) but it started increasing and after 3rd sampling and it also started decreasing like other two filters. After 5th sampling, it increased up to maximum LRV of 1.03. Cleaning after 4th sampling didn't influence on 5th sampling for B-3 but eventually all the filters started improving after 5th sampling which may be continued upto last sampling. With seeded waste water, B-2 showed the maximum LRV (3.20) but the minimum LRV was shown by B-3 (1.66).

For B-1 and B-2, the suspended material and organic part may cause a problem to reach the highest efficiency and the maximum efficiency was observed before clogging. But cleaning had improved the performance after 4th sampling. So cleaning can be a good option to improve the performance when the device is clogged (Mellor *et al*., 2014).



a. *E. coli* LRV of B-1

b. *E. coli* LRV of B-2



c. *E. coli* LRV of B-3

Figure 5.6. Individual filter performance of *E. coli* LRV with seeded and unseeded waste water

The effect of seeded and non-seeded wastewater spiked with *E. coli* regarding *E. coli* removal of the filters of B-1, B-2 and B-3 respectively is illustrated in **Figure 5.6**. For B-1, (**Figure 5.6a)** the filter seeded with wastewater, the performance gradually

increased upto 3rd sampling, then decreased and again increased after 5th sampling. However, in case of non-seeded wastewater, performance increased sharply upto 2nd sampling with a maximum LRV of 5.43 and then the performance declined rapidly. For B-2 (**Figure 5.6b)**, the maximum LRV with seeded and unseeded wastewater were 3.20 and 2.82 respectively and the trends are very similar. For B-3 (**Figure 5.6c)** showed a bit different pattern in removal of *E. coli* with seeded and unseeded wastewater. The filter with no seeded wastewater, achieved its maximum efficiency of LRV 2.38 and with seeded wastewater, B-3 achieved its maximum LRV of 1.66 after periodic cleaning at 4th sampling. So both the cases, B-3 achieved the maximum efficiency after cleaning. From the test results, it is clear that the performance of the filter in removing *E. coli* for both seeded and non-seeded wastewater is not consistent.

Initially for 1st and 2nd sampling, the maximum feed water concentration of *E. coli* was below 300000 cfu/100 mL which was increased for the next four samplings to get high LRV value (Karim *et al*., 2016). It may have some effect on the overall removal efficiency. All three brands showed LRV >1 (> 90% reduction) in both the conditions. It signifies that all three brands were good in bacterial removal performance. Also the results from negative control show no secondary bacterial contamination was occurred during the experimental time.

The mean performance against *E. coli* (bacteria) with non-seeded waste water for B-1, B-2 and B-3 was LRV 2.15 (86.51% reduction), LRV 1.27 (87.35% reduction) and LRV 1.20 (86.62% reduction) respectively. The mean performance for B-1, B-2 and B-3 with seeded waste water was LRV 1.24 (79.42% reduction), 1.39 (83.26% reduction) and 1.03 (83.53%reduction) respectively. Among the performance, B-1 was the most effective in reducing *E. coli* (bacteria) followed by B-2 and B-3. In this study in laboratory controlled environment, the overall *E. coli* removal efficiency was very low. Some other CWF studies (Van Halem *et al*., 2007; Oyanedel-Craver and Smith, 2008; Brown and Sobsey, 2010; Clark and Elmore, 2011) also showed values near LRV 2. But using this same type of filters in control study in Cambodia (Brown *et al*., 2012) and field evaluation in Bangladesh (Karim *et al*., 2016), the removal efficiency for *E. coli* was found more than LRV5 and 1.78 respectively. This might be due to the lab cultured bacteria used in this study as spiking bacteria. Clark & Elmore (2011) showed that, bacteria used from natural source water, may be aggregated, attached to larger

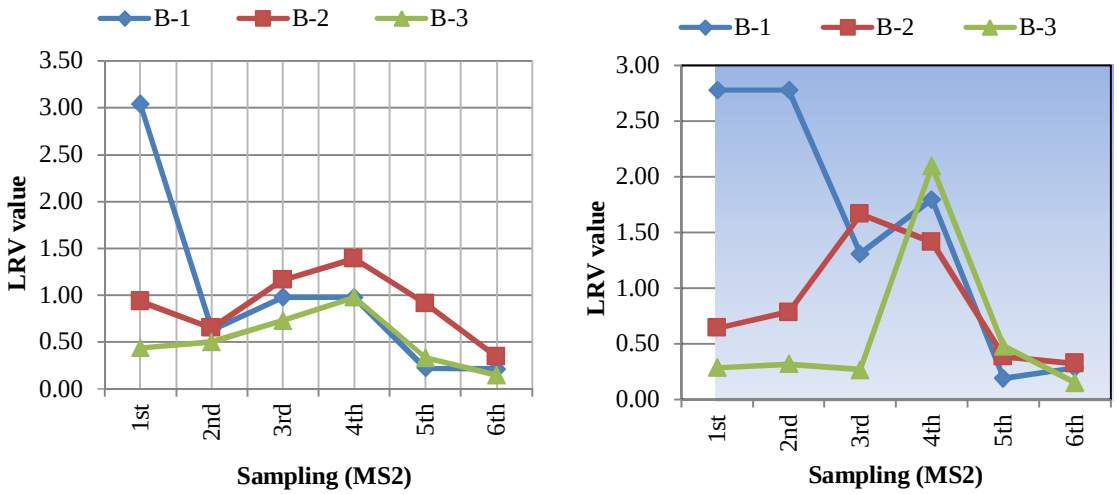
particles or encapsulated in flocks which can show more effectiveness. Another important fact was, the feed water, which was from ground water, was very good in quality and had low food nutrient for microbial survival, which could be a reason for low removal efficiency in this study (Salsali *et al*., 2011).

5.5. MS2 bacteriophage (Virus) Removal Performance

The MS2 bacteriophage removal efficiency for B-1, B-2 and B-3 filters in six sampling times with seeded and unseeded waste water in shown in **Table 5.3**. The results show that with no seeded waste water, the maximum (100%) reduction of B-1 was observed at 1st Sampling and minimum (35.6%) reduction was observed at 5th Sampling. For B-2, maximum (97.82 %) reduction was observed at 3rd Sampling and minimum (52.78 %) reduction was observed at 6th Sampling. B-3 has maximum (99.19%) reduction, observed at 4th Sampling and minimum (30%) reduction was observed at 6th Sampling. But Waste water addition showed different removal efficiency (**Table 5.3**) for the filters of the three brands. With waste water, the maximum reduction of B-1 was100% at 1st Sampling and minimum 38.71% reduction at 6th Sampling. For B-2, maximum reduction was 95.94% reduction at 4th Sampling and minimum was 54.55% reduction observed at 6th Sampling. B-3 has maximum of 89.47 % reduction observed at 4th Sampling and minimum was 28.57 % reduction at 6th Sampling.

Figure 5.7 illustrates the filter performance against MS2 bacteriophage for challenged water non seeded (**Figure 5.7a**) and seeded (**Figure 5.7b**) with wastewater in $\log_{10}$reduction value (LRV) for six sampling times. With unseeded waste water (**Figure 5.7a)**, the average LRV for B-1 was 1.52 (0.19-2.78), B-2 was 0.87 (0.33-1.66) and B-3 was 0.60 (0.15-2.09). B-1 showed good MS2 removal efficiency at the beginning with LRV 2.78 but with time, it decreased to LRV 1.80 at 4th sampling. Despite the reported periodic cleaning at 4th sampling, B-1 continued to fall down and never retrieved to the same efficiency. For B-2 filters with no seeded waste water, initially started with low LRV <1 (< 90% reduction) upto 2nd sampling. After that, it increased and reached at maximum efficiency (LRV 1.66) but started decreasing afterwards. After the cleaning at 4th sampling, it showed the decreasing LRV trend which may continue upto last sampling also. For B-3, with no seeded waste water,

initially the LRV value of MS2 was below 1 (< 90% reduction) upto 3rd sampling and on 4th sampling it increased up to maximum LRV 2.09. For B-3 also, the LRV decreasing trend started after 4th sampling and continued till the end.

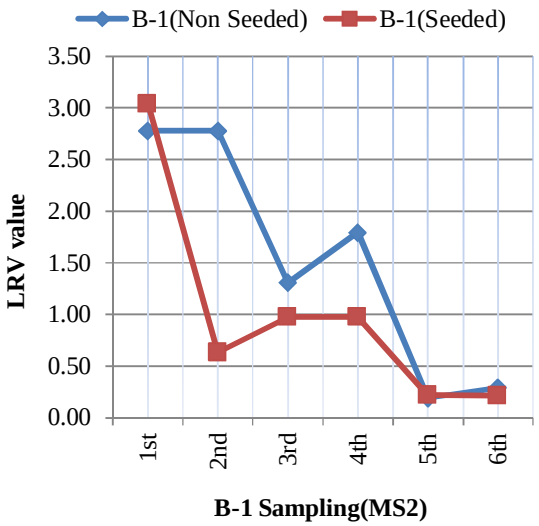


a. MS2 LRV in six sampling times (Seeded) **b. MS2 LRV in six sampling times (Non Seeded)**

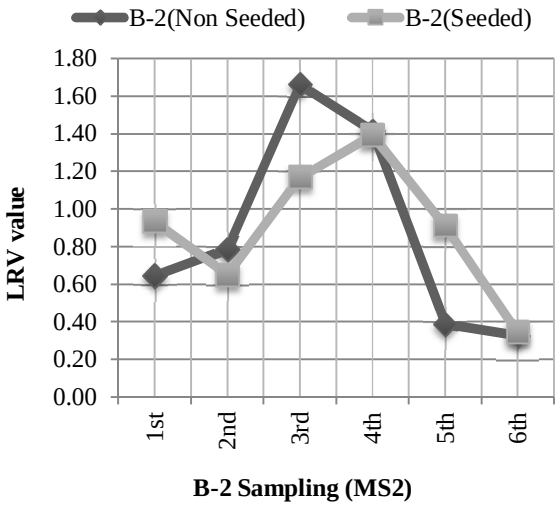
Figure 5.7. MS2 Log_{10} reduction value in six sampling times

The effect of seeded waste water with MS2 bacteriophage against all three types of filters was illustrated in **Figure 5.7b** in log_{10} reduction value (LRV). The average LRV for B-1 was 1.01 (0.21 - 3.04), B-2 was 0.90 (0.34 - 1.39) and B-3 was 0.52 (0.15-0.98). At the beginning, B-1 showed MS2 removal efficiency with the highest LRV of 3.04 but afterward it showed decreasing trend of removal and went down to LRV < 1. After that, value didn't increased more than LRV1.For B-2, filters with seeded waste water, showed more consistent performance than B-1. Though B-2 started LRV <1 but on 3rd sampling it increased and went to the maximum of LRV 1.39. Afterwards it showed continuous decreasing trend which didn't changed by periodic cleaning. For B-3, with seeded waste water, the initial value of MS2 was LRV <1 (< 90% reduction) but it started increasing and at 4th sampling the value increased to the maximum of LRV 0.98. Afterwards the decreasing trend didn't retrieve till the last sampling. The experimental results indicated that the performance of the filters in removing MS2 in LRV is not consistent.

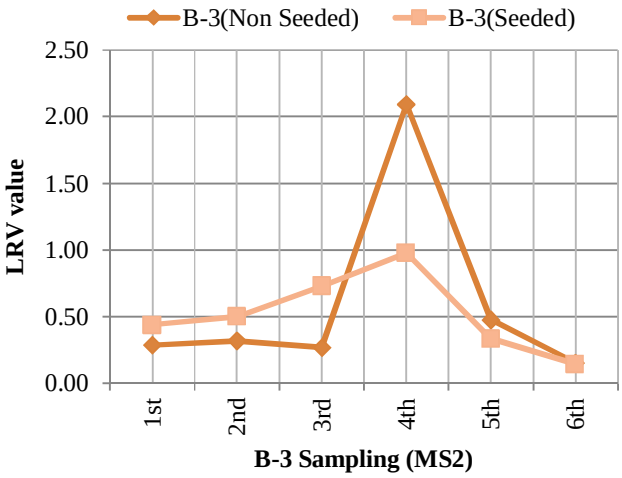
The effect of seeded and unseeded waste water spiked with MS2 bacteriophage for each individual brand of filters is illustrated in **Figure 5.8**. For B-1, the maximum efficiency with unseeded (LRV 3.04) and seeded (LRV 2.78) waste water was observed both at 1st sampling. After that, the decreasing trend of both the cases were inconsistent up to last sampling.



a. MS2 LRV of B-1



b. MS2 LRV of B-2



c. MS2 LRV of B-3

Figure 5.8. Individual filter performance of MS2 LRV with seeded and non-seeded waste water

For B-2, the trend was quite similar in performance for both the cases. The maximum efficiency for B-2 with seeded and unseeded waste water was LRV 1.66 and LRV 1.39 respectively and observed at 4^{th} and 3^{rd} sampling respectively. B-3 also showed a similar pattern in removal of MS2 and the maximum LRV (2.09) was achieved with unseeded wastewater, but with seeded waste water, none of the filters achieved removal efficiency LRV > 1 in the lifetime.

The effect of suspended material and organic part may cause a problem to reach the highest efficiency and the maximum efficiency was observed before cleaning. B-1 and B-2 showed more than LRV 1(> 90% removal efficiency) in both the conditions at least once in a lifetime but with seeded waste water, B-3 didn't achieve LRV 1. It was evident that, with waste water, the filters performance was reduced and it decreased (> 80% reduction) in later samplings. An important fact was, for both the cases against MS2 bacteriophage (virus) cleaning didn't improve the performance of the filters when removal trend was decreasing. It may be due to fact that the filters got exhausted which may need to change the body parts.

Initially for 1^{st} and 2^{nd} sampling, the maximum feed water concentration of MS2 was 300000 pfu/100 mL which was increased for the next four samplings to get high LRV value. It may have some effect on the overall removal efficiency in the earlier samplings. Also the results from negative control show no secondary viral contamination was occurred during the experimental time by the system. Also the results from negative control showed no secondary viral contamination was occurred during the experimental time by the system.

The mean performance against MS2 bacteriophage (virus) with no seeded waste water for B-1, B-2 and B-3 was LRV 1.52 (79.62% reduction), LRV 0.87 (77.78% reduction) and LRV 0.60 (57.13% reduction) respectively. The average performance for B-1, B-2 and B-3 with seeded waste water was LRV 1.01 (72.36 % reduction), 0.90 (82.89 % reduction) and 0.52 (64.10% reduction) respectively. In removal performance, B-1 was first, followed by B-2 and B-3. So in technological effectiveness, B-1 was most effective in reducing MS2 (virus). But B-2 showed more consistent removal performance against MS2 than B-1 and B-3. In this laboratory controlled environment, the overall MS2 removal efficiency was very low. This may be due to the size factor of virus (less than .1µm). In this size it is very difficult to inactivate the organism. But the

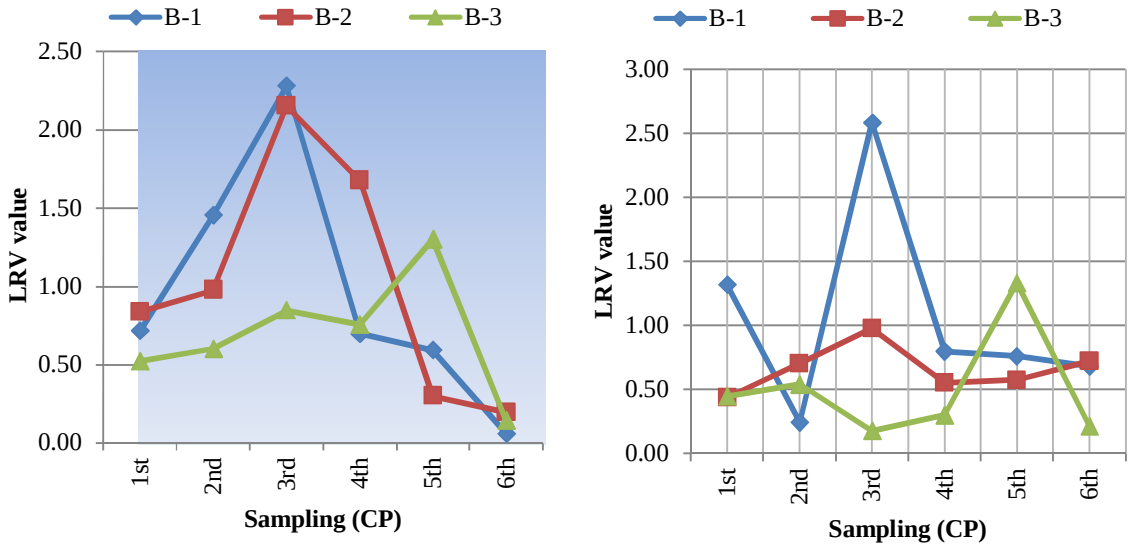
same type of filters were used in Cambodia (Brown *et al*., 2012) for control study where average removal of MS2 were much greater than this study(overall LRV range: 0.15-3.04 and mean:0.9) and in a range of LRV 1.6-2.6 for seeded waste water and LRV 2.7-3.4 for unseeded waste water. But other studies showed (Brown, 2007; Van Halem , 2006; Van Halem *et al*., 2007; Salsali *et al*., 2011; Brown *et al*., 2010; Bielefeldt *et al*., 2010; Van der Laan *et al*., 2014) a lower efficiency evidence in MS2 removal where LRV ranges from 0.21-2.6 depending on silver application or not. According to the hypothesis in Salsali *et al*. (2011), in natural waters the removal of MS2 bacteriophages is better but the laboratory cultured MS2 performance was yet unknown. Salsali *et al*. (2011) also stated that, in de-ionized water where the food nutrient is zero for microorganism, MS2 removal was quite low in terms $\log_{10}$reduction value, ranges from LRV 0.21-0.45. In this study the ground water was also very low in food nutrient for organism and good in physic-chemical quality which may also be a cause of low removal efficiency against MS2 bacteriophage.

5.6. *Clostridium perfringens* (Spore forming bacteria) Removal Performance

Table 5.3 shows the *C. perfringens* removal efficiency for B-1, B-2 and B-3 filters in six sampling times with seeded and unseeded waste water. The results showed that with non-seeded waste water, the maximum and minimum reduction of B-1 was 99.47% at 3rd Sampling and 12.8% at 6th Sampling respectively. For B-2, maximum and minimum reduction was observed 99.29% at 3rd Sampling and 36.36 % at 6th Sampling respectively. B-3 has maximum 95% reduction observed at 5th Sampling and minimum 28.42 % reduction at 6th Sampling. From the results (**Table 5.3**) of unseeded waste water, the maximum and minimum reduction of B-1 was observed 99.74% at 3rd Sampling and 43% at 2ndSampling respectively. For B-2, maximum and minimum reduction was observed 89.47% at 3rd Sampling and 63% at 1stSampling respectively whereas B-3 showed maximum 95.35 % at 5th Sampling and minimum 33.33 % reduction at 3rdSampling.

Figure 5.9 shows the effect of non-seeded **(Figure 5.9a)** and seeded **(Figure 5.9b)** waste water on three different filter brands against *C. perfringens* in $\log_{10}$ reduction value (LRV) respectively. With non-seeded waste water, the average LRV

for B-1 was 0.97 (0.06-2.28), B-2 was 1.02 (0.20-2.15) and B-3 was 1.20 (0.61-2.38). B-1 and B-2 showed almost similar performance in *C. perfringens* reduction. B-1 and B-2 showed maximum *C. perfringens* removal efficiency at the beginning with LRV 2.28 and 2.15 both at 3rd sampling respectively but with time, it reduced to LRV 0.70 and 1.68 at 4th sampling respectively. Despite the reported periodic cleaning at 4th sampling, the graph of B-1 and B-2 continued to fall down and never retrieved to the same efficiency. For B-3, with no seeded waste water, initially the value was LRV <1 (< 90% reduction) but it increased up to maximum LRV 1.30 after cleaning. For B-3, the reason to achieve the maximum efficiency after periodic cleaning is not clear. Also, the decreasing trend after 5th sampling signifies the wear out condition of the filter material. But B-3 was completely inconsistent in removal performance with unseeded waste water.

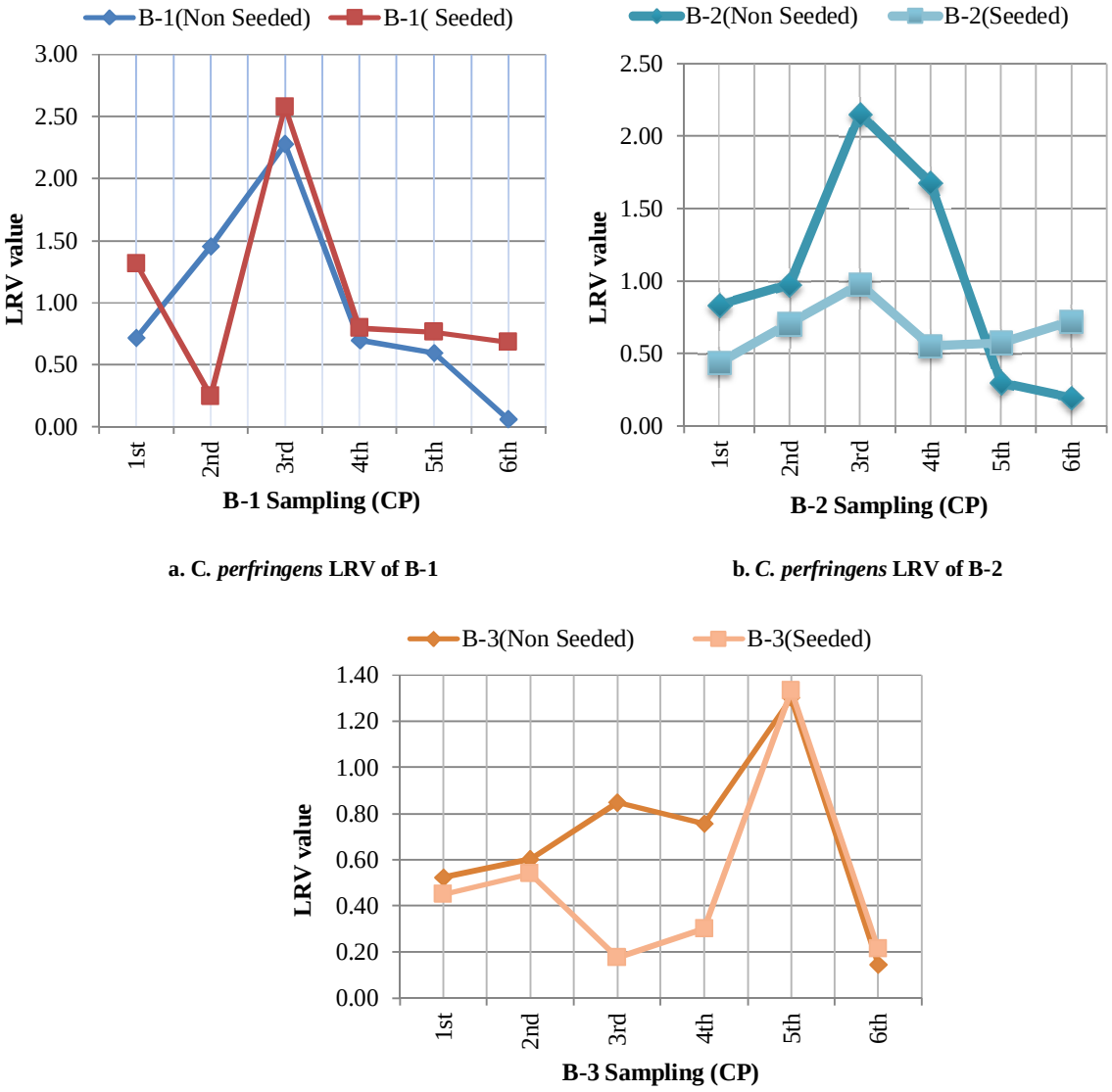


a. *C. perfringens* LRV in six sampling times (Non Seeded) **b. *C. perfringens* LRV in six sampling times (Seeded)**

Figure 5.9. *C. perfringens* LRV value in six sampling times

With seeded waste water (**Figure 5.9b)**, all the filters showed variable performance in *C. perfringens* reduction than unseeded waste water filters **(Figure 5.9 a)**. The average LRV for B-1 was 1.06 (0.24-2.58), B-2 was 0.66 (0.44-0.98) and B-3 was 0.50 (0.18-1.33). Primarily, B-1 showed *C. perfringens* removal efficiency with the highest LRV of 2.58 at 3rd sampling but the lowest LRV (0.24) was observed at 2nd sampling. After maximum efficiency at 3rd sampling, the graph of B-1 decreased and

the decreasing trend continued up to last sampling.B-2 filters with seeded waste water, showed more consistent performance than B-1. B-2 started with low efficiency and the maximum LRV (0.98) was LRV< 1 in the lifetime against *C. perfringens* reduction. The periodic cleaning in this case didn't improve the *C. perfringens* reduction potential. For B-3, with seeded waste water, the initial LRV value of *C. perfringens* was below 1 (<90% reduction) but it started increasing and at 5th sampling, value reached the maximum LRV 1.33.



a. C. *perfringens* LRV of B-1

b. *C. perfringens* LRV of B-2

c. C. *perfringens* LRV of B-3

Figure 5.10. Individual filter performance of *C. perfringens* LRV with seeded and non-seeded waste water

Figure 5.10 illustrates the effect of seeded and non-seeded waste water on three individual filter brands spiked with *C. perfringens*. B-1(**Figure 5.10a**) had the maximum LRV (2.58) for added waste water than the filter with no waste water (LRV 2.28). So for B-1, waste water effect was not too much influential in performance than unseeded filters. But B-1 with seeded waste water showed fluctuation in performance throughout the sampling time. For both the cases B-1 showed highest efficiency achieved before cleaning at 3rd sampling. For B-2 (**Figure 5.10b**), the trend was not similar in performance for both the cases against *C. perfringens.* The maximum LRV for B-2 with waste water was 2.18 and without waste water was 0.98. It means waste water did influence in performance of B-2. B-3 (**Figure 5.10c**) achieved the maximum LRV 1.33 for seeded waste water and LRV 1.30 for unseeded waste water which were similar in performance. For both the cases, B-3 achieved more than LRV 1once in a lifetime which means more than 90% removal against *C. perfringens.*

For *C. perfringens* in the 1st sampling, the maximum feed water concentration was 83 cfu/100 mL which was increased for the next samplings to get high LRV value. But the increase in *C. perfringens* count was not achieved significantly more than 5000cfu because of laboratory grown *C. perfringens.* All the three brands showed LRV > 1(> 90% removal efficiency) in both the conditions at least once in a lifetime except B-2 for seeded waste water case. It was evident that, with waste water, the filter's performance was decreasing than unseeded waste water. Also the results from negative control show no secondary spore contamination during the experimental time by the system.

The average performance without waste water for B-1, B-2 and B-3 was LRV 0.97 (74.01% reduction), LRV 1.02 (76.41% reduction) and LRV 0.70 (72.78% reduction) respectively. The mean performance with seeded waste water for B-1 B-2 and B-3 was LRV 1.06 (80.64 % reduction), LRV 0.66 (76.58% reduction) and LRV 0.50 (58.59% reduction) respectively. So in comparison to brands and in technological effectiveness, B-1 was first, then B-2 and B-3.In this laboratory controlled environment, the overall *C. perfringens* removal efficiency was very low. There is not much literature available to support this phenomenon regarding low removal *Clostridium perfringens* removal for CWFs system evaluation. Other studies (Bhathena *et al*., 2014; Bielefeldt *et al.*, 2010) using different spore forming bacteria also showed low removal efficiency.

The same type of filters in Cambodia (Brown *et al*., 2012) evaluated the removal against *B. atrophaeus* spores having LRV range: 1.0-3.1 and mean: 1.3 for all brands with unseeded waste water and with seeded waste water, the overall LRV range: 0.76-2.4 and mean: 0.93 for all brands. It shows that, waste water has an effect on removal efficiency. This result was slightly greater than our study. Also another study in India (Bhathena *et al*., 2014) with spore removal efficiency using 3µm microspheres where all the brands showed low removal efficiency (less than LRV1) for both the cases with seeded and unseeded water. Brown *et al.* (2012) hypothesized some of the reasons for this low spore forming bacteria removal efficiency. It stated that, it was possible that because the spores are relatively hardy, they were unaffected by any biological activity or antimicrobial chemical agents (if any) in the filters. Because they are relatively hydrophobic, they may not have been amenable to removal and retention by electrostatic interaction with the filter media. Furthermore, retained spores could have possibly germinated, propagated, and then resporulated in the filter medium resulting in overall low net spore reductions by the filter system and may have contributed to the evident variable reduction over the course of testing. Another reason was in natural water, the removal of spore forming bacteria was better, as stated by Bielefeldt *et al*. (2010). The laboratory cultured *C. perfringens* performance is yet unknown. Also the quality of the default body parts of the filters can be a factor in long term evaluation performance.

5.7. Filters Complying WHO Recommended Performance Level

All the filters were evaluated for 23 weeks against three important pathogens *E. coli*, MS2 bacteriophage and *Clostridium perfringens* with two types of challenged water (unseeded waste water with spiking organism and seeded waste water with spiking organism). For all the organisms, two filters from each of the brands were observed. For each individual organism and from each brand, there were a total of 12 sampling points (six sampling points from seeded and unseeded cases). The results have been analyzed based on the WHO (WHO, 2011) recommended guideline value (GV) (**Table 2.7)**.

For **(Table 5.4)** bacteria (*E. coli*), most of the filters showed good removal efficiency. Out of 36 test samplings, 18 sampling results showed more than LRV 1 that

was > 90% removal efficiency. Among the filters, B-1 showed maximum removal efficiency against bacteria. Out of 12 sampling points, only 7 samples were LRV >1. Three points were LRV > 2 which signifies B-1 achieved "protective "target in terms of WHO GV. One result shows LRV > 4 which means B-1 achieved "highly protective" target once in the experimental period according to GV. Out of 12 sampling points for B-2, 5 results were LRV > 1. Two sampling points were LRV > 2 which also signifies B-2 achieved "protective" target twice in a study time against bacteria. For the case of B-3, 6 sampling results were LRV > 1 and only 1 sampling result shows "protective "target. This signifies, B-3 was also good in removal of bacteria but didn't comply that much of GV. None of the filters achieved the strict "highly protective "target against bacteria.

Table 5.4. Brands complying WHO guideline value (GV) for bacteria

***E. coli*(Bacteria)**			
	2 > LRV ≥ 1	**Protective (4 > LRV ≥ 2)**	**Highly Protective (≥ 4)**
B-1 (n=12)	3	3	1
B-2 (n=12)	2	3	0
B-3 (n=12)	5	1	0

Table 5.5. Brands complying WHO guideline value (GV) for virus

MS2 bacteriophage (Virus)			
	3 > LRV ≥ 1	**Protective (5 > LRV ≥ 3)**	**Highly Protective (≥ 5)**
B-1 (n=12)	4	1	0
B-2 (n=12)	4	0	0
B-3 (n=12)	1	0	0

Table 5.6. Brands complying WHO guideline value (GV) for protozoan group

***Clostridium perfringens* (Spore forming bacteria)**			
	2>LRV≥1	**Protective (4 > LRV ≥ 2)**	**Highly Protective (≥ 4)**
B-1 (n=12)	2	2	0
B-2 (n=12)	1	1	0
B-3 (n=12)	2	0	0

In case of virus (MS2 bacteriophage) removal (**Table 5.5)**, only 10 sampling results out of 36 samples were LRV > 1 from all brands. Among the filters, B-1 showed

maximum efficiency against virus. Out of 12 sampling results of B-1, 5 results were LRV > 1 and LRV < 3. Only one result was LRV > 3 which signifies B-1 achieved "protective "target in terms of WHO GV once in a study period. Out of 12 sampling results for B-2, 4 results were LRV > 1 and LRV < 3 but none of the points achieved WHO protective or highly protective target. For the case of B-3, only one sampling result was LRV > 1 and LRV < 3 and none of the filters achieved the WHO GV once in the experimental period.

For the case of spore forming bacteria (*Clostridium perfringens*) only 8 sampling results out of 36 points were LRV > 1 from all brands. Among the filters, B-1 again showed maximum efficiency against *C. perfringens*. Out of 12 sampling points, only 2 results were LRV > 1 and LRV < 2. And 2 results were LRV > 2 which signifies B-1 achieved "protective "target in terms of WHO GV twice in the study time against spore forming bacteria. Out of 12 sampling points for B-2, only 1 result was LRV > 1 and 1 was LRV > 2 as "protective" in terms of GV. For the case of B-3, only two sampling results were LRV > 1 but below the "protective" target of GV. None of the filters achieved WHO "highly protective" target.

Among all three brands, only B-1 achieved "Protective" target against bacteria, virus and spore forming bacteria but in a very limited number of cases (20% samples). So B-1 can be said as "protective" technology according to WHO GV with necessary epidemiological evidence of disease reduction (WHO, 2011) but it has to be consistent in microbiological performance. B-2 also achieved "protective" target against bacteria and spore forming bacteria but only 11% samples showed such performance. B-2 cannot be classified as "interim" technology only if it can show consistent improvement of microbial performance added with credible epidemiological evidence indicates that use of such devices results in reductions in waterborne disease. The data achieved for B-3 showed that it only achieved once the "protective" target against bacteria but cannot be "protective" against virus and spore forming bacteria. But Brown *et al*. (2012) mentions that only B-3 achieved WHO recommended "protective" level of performance in Cambodia. It is not clear that whether the B-3 used in this study and the B-3 in Brown *et al*. (2012) study were same in manufacturing. However in this study, B-3showed good removal efficiency and can be said a good treatment device against indicator organisms but did not achieve WHO recommended targets. Also some other

studies comments on CWF technologies as “protective” against bacteria (Mohamed *et al*., 2016; Bhathena *et al*., 2014) but those technologies were different in terms of manufacturing and filtration system than this study.

5.8. Physic-Chemical Outcome

Several physic-chemical parameters like pH, color, turbidity and EC were examined of the feed and filtered water during the experiment period. **Table 5.7** shows the physic-chemical data of the water obtained from this control experiment.

The feed water was ground water which is a good source of minerals and low organic content. But the added wastewater can contribute some organic content and colloidal substance for which the physic-chemical parameters can vary. For B-1, the mean pH value of the feed and filtered water was 7.51 and 7.84, respectively. It was observed that the mean pH of the filtered was has increased, probably due to alkalinity of mineral of filters. This also observed for the case of B-2 (mean pH =7.74 for feed water and 8.06 for filtered water) and B-3 (mean pH=7.6 for feed water and 7.94 for filtered water). In case of color, the initial concentration of color in feed water was more than 100 pt-co. color unit. Less removal of color was observed by the filters (mean values of color in filtered water were 103, 97 and 94.25 pt-co. color unit for B-1, B-2 and B-3 respectively. Electric conductivity was found in the range of 580-610 µS/cm in the feed water and the mean values show that, B-1 and B-3, reduced electric conductivity by 15-30 µS/cm in the filtered water. Turbidity was initially found < 5 NTU in the feed water for most of the filters. The test results showed that all the filters mostly reduced turbidity and it was 20.17%, 23.83% and 14.50% reduction for B-1, B-2 and B-3, respectively. Less removal of turbidity was observed in this study, as the feed water turbidity was very low. The seeded waste water didn’t increase too much turbidity concentration. Another study in Cambodia (Brown *et al*., 2012) shows low turbidity concentration (< 5 NTU) using the lab experimented seeded waste water which is analogous with this study. For drinking water, turbidity less than 5NTU is not a big concern (WHO, 2011b), as the recommended level of turbidity is 5 NTU according to WHO GV (WHO, 2011). The turbidity removal more than 70-80% was observed during the field study using similar filters (Chapter 4).

The significant reduction of turbidity and color was not possible using water having turbidity less than 5 NTU. A separate week long experiment was carried out having water with high initial turbidity and color by the filters. Two filters from each brand, one spiked with wastewater and another without wastewater, natural clay was added to increase the turbidity and color of the feed water. **Table 5.8** shows the results of the weeklong experiment of turbidity and color reduction performance study. For B-1, the mean turbidity concentration was 57.84 NTU and 1.34 NTU and color concentration was 403.29 and 40.14 pt-co. color unit for feed and filtered water respectively. The mean turbidity and color reduction was 98% and 90% respectively. For B-2, the mean turbidity concentration was 51.57 NTU and 0.57 NTU and color concentration was 348.86 and 26.71 pt-co. color unit for feed and filtered water respectively. For a week time, the mean turbidity and color reduction for B-2 was 99% and 92% respectively. For B-3, the mean turbidity concentration was 55.70 NTU and 1.38 NTU and color concentration was 416.71 and 42.29 pt-co. color unit for feed and filtered water respectively. For a week time, the mean turbidity and color reduction was 98% and 89% respectively. All the filters showed almost similar turbidity reduction (around 98%) potential which was more than the value obtained during the field study (Chapter 4). Also color reduction was similar (90%) for all the cases.

Table 5.7. Physico-chemical data of six sampling times

		Physico - Chemical parameters								Turbidity Reduction (%)
		pH		Color(Pt-co)		EC(µs/cm)		Turbidity(NTU)		
	Sampling	1	2	1	2	1	2	1	2	
B-1	1st	7.19-7.74	7.37-8.22	1-26.5	2.5-32.5	577-590	575-654	0.39-1.55	0.54-2.5	-
	2nd	7.59-7.97	8.03-8.26	130-140	125-135	581-589	531-585	0.21-0.73	0.12-0.35	41
	3rd	7.05-7.7	7.47-8	115-155	110-141	575-612	516-599	0.31-0.48	0.2-0.43	28
	4th	7.11-7.99	7.65-8	115-155	112-160	590-612	570-620	0.37-0.48	0.21-0.43	27
	5th	7.05-7.85	6.85-8.2	120-148	110-135	545-601	570-615	0.3-0.57	0.27-0.41	24
	6th	7.05-7.76	7.25-8	0	0	563-595	513-594	0.25-0.89	0.22-0.75	32
Mean value		**7.51**	**7.84**	**108**	**103**	**587**	**581**	**0.55**	**0.46**	**20.17**
B-2	Sampling	1	2	1	2	1	2	1	2	
	1st	7.29-8.06	8.22-8.69	1-26.5	1.0-21	567-594	730-889	0.73-3.76	0.39-1.82	24
	2nd	7.5-7.72	8-8.26	90-112	95-115	565-593	560-585	0.25-0.43	0.16-0.31	26
	3rd	7.29-8.13	7.72-8.07	92-131	90-125	592-666	579-642	0.15-0.45	0.1-0.39	27
	4th	7.25-8.1	7.35-8	90-165	85-130	589-642	575-620	0.2-0.47	0.15-0.36	12
	5th	7.1-7.85	7.25-8.15	115-137	100-130	555-610	584-625	0.15-0.4	0.1-0.31	24
	6th	7.24-8.3	7.7-8.45	0	0	543-595	531-580	0.2-3.65	0.17-1.7	30
Mean value		**7.74**	**8.06**	**106**	**97**	**605**	**631**	**0.69**	**0.48**	**23.83**
B-3	Sampling	1	2	1	2	1	2	1	2	
	1st	7.33-7.9	7.51-8.06	2-24.5	1-21.5	573-589	593-641	0.55-1.75	0.55-2.74	-
	2nd	7.52-8.2	8.01-8.5	103-135	100-140	574-591	564-582	0.19-0.27	0.1-0.22	26
	3rd	7.39-7.76	7.83-8.14	95-131	91-121	592-644	575-626	0.18-0.35	0.15-0.32	11
	4th	7.3-8	7.56-8.65	95-145	75-122	593-645	575-625	0.18-0.45	0.12-0.33	26
	5th	7.1-7.95	7.3-8.1	125-147	115-132	550-610	565-612	0.25-0.47	0.21-0.35	24
	6th	7.1-7.93	7.53-8.1	0	0	554-595	543-582	0.026-1.36	0.17-0.87	36
Mean value		**7.6**	**7.94**	**101**	**94.25**	**599**	**596**	**0.44**	**0.43**	**14.50**
1= Feed water Range **2= Filtered water Range**										

Table 5.8. Separate turbidity and color experiment for a weeklong period

		Physic - Chemical parameters				Turbidity Reduction (%)	Color Reduction (%)
		Turbidity(NTU)		Color (Pt-Co)			
B-1	Sampling	1	2	1	2		
	1st day	64.9	2.05	419	48	97%	89%
	2nd day	60.3	0.98	440	31	98%	93%
	3rd day	35	0.53	294	35	98%	88%
	4th day	59.6	1.2	430	32	98%	93%
	5th day	57.3	2.35	410	42	96%	90%
	6th day	62.5	0.62	395	45	99%	89%
	7th day	65.3	1.65	435	48	97%	89%
Mean value		**57.84**	**1.34**	**403.29**	**40.14**	**98%**	**90%**
B-2	Sampling	1	2	1	2		
	1st day	58.3	0.63	329	29	99%	91%
	2nd day	55.2	0.65	383	24	99%	94%
	3rd day	38.9	0.36	299	21	99%	93%
	4th day	52.3	0.23	350	29	100%	92%
	5th day	49.3	0.56	362	35	99%	90%
	6th day	56.2	0.84	339	26	99%	92%
	7th day	50.8	0.75	380	23	99%	94%
Mean value		**51.57**	**0.57**	**348.86**	**26.71**	**99%**	**92%**
B-3	Sampling	1	2	1	2		
	1st day	60.9	3.38	433	55	94%	87%
	2nd day	55.6	0.32	488	5	99%	99%
	3rd day	37.8	0.59	206	32	98%	84%
	4th day	60.6	2.25	455	52	96%	89%
	5th day	62.3	0.65	430	49	99%	89%
	6th day	53.5	0.15	425	53	100%	88%
	7th day	59.2	2.3	480	50	96%	90%
Mean value		**55.70**	**1.38**	**416.71**	**42.29**	**98%**	**89%**

1= Feed water Range
2= Filtered water Range

CHAPTER 6: CONCLUSION AND RECOMMENDATION

6.1. General

This chapter includes the summary of the research findings based on discussions in **Chapter 4 and Chapter 5**. Moreover, recommendations and guideline for future work related to this investigation are also proposed in this chapter.

6.2. Conclusion Based on Field Evaluation

The major conclusion on the field evaluation are as follows:

1. The available water supply options (PSF, RWH, pond water) in the studied coastal rural areas are highly contaminated by various microorganisms and not suitable for drinking without in-house treatment.

2. The health risk associated with the source waters in the coastal areas are more than WHO recommended level of 1.0 µDALY/person.yr. The upper and lower bound of the total disease burden estimates is much higher than the reference level. For PSF and pond water, the estimated mean disease burden exceeds the maximum reference level. But RWHs, the lower bound of total health is found to be lower than the recommended level and exceeds at other two estimations. Viral disease dominates the total health burden at lower estimation, whereas, bacterial disease dominates at upper estimation which summarizes that, bacteria is mostly responsible for most of disease events.

3. From field performance, the CWFs reduced TC, FC and *E. coli* concentrations than source water significantly ($p < 0.05$) in all monitoring cycles. The average reductions of *E. coli* were 2.2 $\log_{10}$ reduction in four monitoring cycles and TC and

FC was significant removed ($p < 0.05$) in filtered water in all monitoring cycles. For *E. coli,* CWF showed WHO recommended protective target against bacteria (log_{10} reduction > 2) in three monitoring cycles which signifies the effectiveness of CWF against bacteria. In household condition, the number of filtered water samples satisfying WHO recommended guideline of zero *E. coli*/100 mL also increased significantly. WHO recommended protective target was shown against pond water samples but not against PSF and RWH water samples due to low microbial level.

4. A significant reduction of microbial level by the filters was observed but the removal performance of the CWFs were found inconsistent. The field turbidity level was found very low (< 5NTU) which can be easily removed. Fluctuation in performance over time was also observed due to the change of water sources and quality, changes of use conditions, hygienic practices of the users and others. Thus, intervention at the household level by the filters alone cannot ensure complete microbial safety of water and addition of a secondary disinfection such as chlorination may be necessary for complete microbial safety of water.

5. CWFs have significant potential in reducing the microbial health burden associated with the coastal water supply options. Against pond, PSF and RWH, CWF showed median health burden reduction > 90% with reference to baseline condition. This signifies the improvement of water quality from source water condition. But median health risks for filtered water do not meet the WHO recommended level.

6.3. Conclusion Based on Laboratory Controlled Environment

The major findings on laboratory controlled experiment are listed below:

6. Results from control experiment showed that, the brands have variable performance among them against different pathogens. Good quality filter material and proper maintenance of the filters can eventually increase the performance in due time.

7. The continuous laboratory monitoring of flow rate illustrates that, CWF is not that efficient in producing sufficient amount of water for a standard household of 1.5-3.5 liters/hour.

8. With high turbidity and color level, CWF can improve the quality of water in a variety of concentration. All the filters have shown decreased performance with time and in later stage of life, the body parts need to be replaced if necessary. Periodic cleaning can be a good option to increase the microbiological and physico-chemical performance of the filters when the filters were seen clogged or the filtration rate is reduced.

9. The study showed that, source water was groundwater which is of low nutrient source for pathogenic multiplication and thereby the overall microbial removal potential was very low in terms of other studies where the source water is surface water or other nutrient rich water. Also the field study showed more consistent reduction potential against bacteria where the source water was whether surface water or rain water.

10. All Ceramic Water Filters (CWF) filters from the three brands improved the microbial water quality with high initial concentration and $\log_{10}$ reduction (LRV) ranging from 0.3-5.4 $\log_{10}$ reduction for *E. coli* (bacteria), 0.15- 3 $\log_{10}$ reduction for MS2 bacteriophage (virus) and 0.06 - 2.5 $\log_{10}$ reduction for *Clostridium perfringens* (spore forming bacteria). The control study result in reducing *E. coli* was found close with field study.

11. The recommended level of WHO for three types of organisms only allows B-1 the "protective" technology against all three pathogens (in 20% samples). B-2 has been seen as an "interim" technology (in 11% samples) and B-3 showed good reduction potential but only showed protectiveness against bacteria once in the study time.

12. Manufacturer claims regarding pathogenic reduction was not achieved from the study because B-1 and B-3 claimed that it can keep water free from bacteria and

amoeba (protozoa). But this study showed that the water is in some cases completely free from bacteria but not from spore forming bacteria.

13. Influence of sterile waste water have shown low microbial removal potential of CWFs against all three kinds of organisms.

14. The field and lab study concludes that, CWF can improve the water by reducing the microbiological organisms but inconsistently meet the WHO recommended level of performance.

6.4. Recommendation for Further Study

The performance of Ceramic Water Filter (CWF) is dependent on various structural parameters which need to be evaluated to get more in-depth performance issues. As assembled from different sources, the filter material quality has to be examined which is a big issue of performance. The relationship between material quality and microbiological performance need to be evaluated and need to know the improvement aspects. Source water quality is another influencing factor on the efficacy of the technology.

A commonly expressed concern about CWFs is that uncharacterized “mineral stone” media may leach unsafe levels of chemical contaminants into product water (personal communication, M. Sampson, A. Shantz, RDIC; B. McLaughlin and P. Lennon, PATH). Some CWF manufacturers claim that mineral stones contain exotic materials such as germanium which may have diverse effects as preventing cancer or increasing sex drive. So these concerns have to be verified in favor of public health. Also the data that has been produced here from the controlled study and the field study cannot be oversimplified and used for all circumstances especially for all types of source water. In different source water, maintenance, storage and handling condition, the performance of the same technology may vary.

The manufacturer’s claim has been seen in most cases as false marketing claims which have to be controlled using law enforcement. The advertising of true information for water treatment technologies is of great importance because, in most cases, users cannot

verify the device's performance with manufacturer's claim. Also the lack of standards or regulatory oversight on manufacturing and commercially selling of treatment devices in Bangladesh is an impediment to protect consumer right. In doing so, this microbiological performance data that the studies have produced will be helpful to understand the performance potential of such devices. Also it is a necessary first step in a broader assessment of these uncharacterized devices which may play role in providing safe drinking water.

This study finding suggests that CWFs do not consistently meet the WHO minimum performance recommendations and thus these devices would need more development. More evidence based studies under laboratory and households' usage conditions are recommended to verify the filter performance for vulnerable population with unreliable water supply. If these technologies can be more examined, evaluated with lots of epidemiological data in relation with disease events and can be authenticated by experts as safe treatment technology with necessary improvements and regulations, than nationwide scaling up by subsidies and strategies can be a good alternative as household water treatment system (HWTS) to provide safe drinking water as advised by international community and standards.

6.3. Limitations of the study

The studied filters had been chosen based on market price and maximum demand among different users. Most of these filters were imported and assembled locally. Some manufacturer brings different parts of the filter from different countries. Thus the quality of filter material is unknown.

In WHO (2011) guideline, the minimum water to be filtered by any HWT technology in laboratory verification is 20 liters. But the studied filters did not have the same filtration rate. So for proper management, all the CWFs were allowed to filter individually and thus uniform filtration volume was not possible to maintain. This phenomenon may influenced the filtration performance.

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APPENDIX A: FIELD BASED DATA

Table A 1. List of households for distributed filters in surveyed area

Sl. No.	ID	Name and Address	Source Water
1	D1	Taposh Bishwash, Chalna Bazaar, Pouroshova Pukur Par., Mobile: 01911684925	Pond
2	D2	Pronob Bishwash, Chalna Bazaar, Pouroshova Pukur Par., Mobile: 01714632946	Pond
3	D3	Gouri Bishwash, Chalna Bazaar, Pouroshova Pukur Par. 01757496340	Pond
4	D4	Lolita Goldar, Chalna Bazaar, Pouroshova Pukur Par. 01717283164	Pond
5	D5	Jahangir Saheb, Chalna Bazaar, Launch Ghat. 01939112843	P.S.F.
6	D6	Md. Rafiqul Islam, Chalna Bazaar, Pouroshova. 01739966889	P.S.F.
7	D7	Horidas Roy, Boro Kholisha, Chalna. 01942290688	Pond
8	D8	Mridul Roy, Boro Kholisha, Chalna. 01928166760	RWHS
9	D9	Nikhil Ronjon Roy, Boro Kholisha, Chalna. 01916589137, 01710557001	Pond
10	D10	Chompa Mondol, Boro Kholisha, Chalna.	Pond
11	D11	Bijli Roy, Boro Kholisha, Chalna. 01777891636	Pond
12	D12	Thakurdas Bawali, Mejo Kholisha	Pond
13	D13	Dolonchapa Bawali, Mejo Kholisha. 01922016051	Pond
14	D14	Sheela Boiragi, Chalna Pouroshova, Dacope. 01914255962	RWHS

15	D15	Gopal Chandra Boiragi, Chalna Bazaar, Dacope, K.C. School Khaler Par., 01721760833	RWHS
16	D16	Shufola Rani Boiragi, Chalna Pouroshova, Dacope. 01949210352	RWHS
17	D17	Shova Rani Mondol, Chalna Bazaar, K.C. School 01925676071	RWHS
18	D18	Biplob Mondol, Chalna Pouroshova, Dacope. 01820518655	RWHS
19	D19	Reba Boiragi, Chalna Bazaar, K.C. School. 01737286852	RWHS
20	D20	Lipika Rani Boiragi, Chalna Pouroshova, Dacope. 01727012836	RWHS
21	D21	Rita Rani Chakrabarti, Chalna Bazaar, K.C. School. 01911087822	RWHS
22	D22	Konika Boiragi, Chalna Bazaar, Beside Robi Tower 01745647813	RWHS
23	D23	Rintu Bishwash, Chalna Bazaar, Beside Robi Tower. 01813860160	RWHS
24	D24	Ebadul Islam, Kamarkhola, Uttorpara. 01913047232	P.S.F.
25	D25	Md. Humayun Kabir, Kamarkhola, Uttorpara. 01916138438	P.S.F.
26	D26	Md. Emdadul Gazi, Kamarkhola, Uttorpara. 01820633270	P.S.F.
27	D27	Jhorna Begum, Kamarkhola, Uttorpara. 01742531117	P.S.F.
28	D28	Md. Sirazul Islam (Dhali), Kamarkhola, Uttorpara.	P.S.F.
29	D29	Parvin Begum, Kamarkhola, Uttorpara.	P.S.F.
30	D30	Md. Rouf Sardar, Laxmikhola, end of old pitch road.	P.S.F.
31	D31	Provati Mondol, Laxmikhola, end of old pitch road. 01935660541	P.S.F.

32	D33	Provati Gayn, Laxmikhola, end of old pitch road. 01944235562	P.S.F.
33	D34	Krishnapad Mondol Advocate, Ukilpara, Chalna. 01913045152	RWHS
34	D35	Lotika Bishwash, Pouroshova Upazilla Quarter, Chalna Bazaar., Mobile: 01713909030	P.S.F.
35	D36	Gayitri Sarkar, Mejo Kholisha.01947270855	Pond
36	D37	Pagli Dashi, Mejo Kholisha.01944327450	Pond
37	D38	Nasim Mollah, Khona Molla Bari, Dacope. 01918061429	RWHS
38	M1	Raoshan Ara,South Chadpai Pond, 01914510905	South Chadpai Pond
39	M2	Moslema Begum, South Chadpai Pond, 01195334904	South Chadpai Pond
40	M3	Noab Ali Haoladar, South Chdpai Pond Bank, 01190728417	South Chadpai Pond
41	M4	Chadpai Nesar Shah Maddomik School, Chadpai, 01917371093	RWHS
42	M5	Md. Joynal Abedin, Chadpai Nesar Shah Maddomik School, 01917371093	RWHS
43	M6	Jannatul Dola , South Chadpai Pond Area, 01925328304	South Chadpai Pond
44	M7	Shofita Dhali, Chaprar Mor, 01767788742	Joykha Pond
45	M8	Shrimoti Dhali , Chaprar Mor, 01917863143	Joykha Pond
46	M9	Sheikh Nazim Uddin, Sundarban Hachari, Chapra, 01719660840	RWHS
47	M10	Comela Begum, Chadpai Gasir Mor, 01934033097	Fulpukur Pond
48	M11	Anjuara, Chadpai Gasir Mor, 01735020955	Fulpukur Pond
49	M12	Hasnahena, Keoratola, 01718973404	
50	M13	Jahid, Keoratola, 01923948663	RWHS
51	M14	Shahadat Hossain Mintu, Signal Tower, 01932694115	RWHS
52	M15	Tara Begum, Gussogram , Kanainagar, 01920285336, 01728906046	Gussogram Pond
53	M16	Shalomi Sordar, South Kanaimari,	South Kanaimari Pond

		01770384924 (Tonmoy Sordar)	
54	M18	Shefalikanat, Chilabajar, 01921351231	RWHS
55	M19	Pobitra Pande, Chilabajar, 01925434968	RWHS
56	M20	Sufia Begum, Keoratola, 01766113379	RWHS
57	M21	Meherun, Joykha Village, 01932693428	Fulpukur
58	M22	Abdul Aziz Musolli, Fulpukur Pond Bank, 01933563397	Fulpukur PSF
59	M23	Fosiar Rahman Jardar, Fulpukur Pond Bank, 01932437841	Fulpukur PSF
60	M24	Rahima begum, Fulpukur Pond Bank, 01929523281	Fulpukur PSF
61	M25	Md Jahangir Sheikh, Mithakhali, 01710109531	Mithakhali Pond
62	M26	Sheikh Muraduzzaman, Mithakhali, 01919130440	Mithakhali Pond
63	M27	Pronoti Mondol, Damerkhanda Pukur Par, 01935210312	Damerkhanda Pukur
64	M28	Arun Ray, Damerkhanda Pukur Par, 01717248874	Damerrkhanda Pukur
65	M29	Bokul , Datter Math, Dai Dighi Pukur Par, 01965054124	Dai Dighi
66	M30	Dolony, Datter Math, 01944832600	Dai Dighi
67	M31	Ruhul Amin Talukder,Bashtola, Sundarban Union, 01765916611	Talukdar Bari PSF
68	M32	Khulsum Begum, Bashtola, Sundarban Union, 01765916611	Talukdar Bari PSF
69	M33	Ishak, Keoratola, 01914051203	RWH
70	M34	Urmila basar, Keyabunia, chillabajar, 01961154143	RWH
71	M35	Adhir Chandra Bain, Keyabunia, Chillabajar,01920343172	RWH

APPENDIX B: CONTROL EXPERIMENTAL DATA

Table B.1. Filtration cycle of B-1

Filter Name		B-1 (Passing-liter)					
Date	**Week**	**J-1**	**J-2**	**J-3**	**J-4**	**J-5**	**J-6**
1st Sampling		0	0	0	0	0	0
5/4/16-9/4/16	1st	42	64	57	47	42	52
19/4/16-22/4/16	2nd	44	56	39	48	39	45
23/4/16-30/4/16	3rd	39	44	36	38	23	26
1/5/16-5/5/16	4th	32	30	31	31	29	30
9/5/16-13/5/16	5th	40	39	38	37	36	38
16/5/16-20/5/16	6th	24	24	24	23	24	23
25/5/16-31/5/16	7th	31	33	32	33	33	33
2nd Sampling		**252**	**290**	**257**	**257**	**226**	**247**
Percentage (%)		**19%**	**21%**	**19%**	**19%**	**18%**	**19%**
1/6/16-5/6/16	8th	54	53	53	50	52	54
6/6/16-10/6/16	9th	43	40	43	42	43	43
11/6/16-17/6/16	10th	56	55	56	56	56	55
18/6/16-23/6/16	11th	61	61	60	60	61	61
25/6/16-30/6/16	12th	43	42	43	42	41	41
3rd Sampling		**509**	**541**	**512**	**507**	**479**	**501**
Percentage (%)		**47%**	**49%**	**48%**	**48%**	**46%**	**47%**
12/7/16-15/7/16	13th	48	47	47	46	48	48
17/7/16-22/7/16	14th	81	80	81	79	81	81
23/7/16-29/7/16	15th	73	73	72	72	71	73
1/8/16-5/8/16	16th	43	42	43	42	43	41
4th Sampling		**754**	**783**	**755**	**746**	**722**	**744**
Percentage (%)		**70%**	**71%**	**70%**	**70%**	**69%**	**70%**
8/8/16-12/8/16	17th	45	42	44	43	43	45
16/8/16-19/8/16	18th	35	34	35	35	35	34
22/8/16-31/8/16	19th	64	64	63	63	64	64
5th Sampling		**898**	**923**	**897**	**887**	**864**	**887**
Percentage (%)		**83%**	**84%**	**83%**	**83%**	**83%**	**83%**
1/9/16-8/9/16	20th	39	39	38	37	39	39
20/9/16-30/9/16	21st	63	63	62	62	61	61
3/10/16-11/10/16	22nd	51	51	50	50	50	51
13/10/16-18/10/16	23rd	28	27	28	28	27	27
6th Sampling and Total		**1079**	**1103**	**1075**	**1064**	**1041**	**1065**
Percentage (%)		**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

Table B.2. Filtration cycle of B-2

Filter Name		B-2(Passing-liter)					
Date	**Week**	**M-1**	**M-2**	**M-3**	**M-4**	**M-5**	**M-6**
1st Sampling		**0**	**0**	**0**	**0**	**0**	**0**
5/4/16-9/4/16	1st	85	79	55	64	52	57
19/4/16-22/4/16	2nd	87	64	55	73	61	48
23/4/16-30/4/16	3rd	72	58	45	58	51	44
1/5/16-5/5/16	4th	51	46	40	47	42	43
9/5/16-13/5/16	5th	59	57	49	53	55	50
16/5/16-20/5/16	6th	33	33	33	33	33	32
25/5/16-31/5/16	7th	44	44	42	43	44	44
2nd Sampling		**431**	**381**	**319**	**371**	**338**	**318**
Percentage(%)		**27%**	**25%**	**22%**	**25%**	**23%**	**22%**
1/6/16-5/6/16	8th	79	74	70	74	81	74
6/6/16-10/6/16	9th	61	60	61	60	60	61
11/6/16-17/6/16	10th	65	65	66	66	65	65
18/6/16-23/6/16	11th	94	94	93	92	90	94
25/6/16-30/6/16	12th	65	65	63	63	62	65
3rd Sampling		**795**	**739**	**672**	**726**	**696**	**677**
Percentage(%)		**50%**	**49%**	**46%**	**48%**	**47%**	**46%**
12/7/16-15/7/16	13th	72	69	70	72	72	71
17/7/16-22/7/16	14th	107	106	107	105	104	107
23/7/16-29/7/16	15th	105	104	105	103	105	105
1/8/16-5/8/16	16th	59	60	61	62	61	61
4th Sampling		**1138**	**1078**	**1015**	**1068**	**1038**	**1021**
Percentage(%)		**72%**	**71%**	**70%**	**71%**	**70%**	**70%**
8/8/16-12/8/16	17th	62	63	62	64	62	62
16/8/16-19/8/16	18th	52	50	50	52	52	52
22/8/16-31/8/16	19th	87	86	86	85	87	87
5th Sampling		**1339**	**1277**	**1213**	**1269**	**1239**	**1222**
Percentage(%)		**85%**	**84%**	**84%**	**84%**	**84%**	**83%**
1/9/16-8/9/16	20th	54	53	51	51	50	54
20/9/16-30/9/16	21st	83	82	81	83	82	83
3/10/16-11/10/16	22nd	67	67	65	66	65	67
13/10/16-18/10/16	23rd	40	41	41	40	40	40
6th Sampling and Total		**1583**	**1520**	**1451**	**1509**	**1476**	**1466**
Percentage (%)		**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

Table B. 3. Filtration cycle of B-3

Filter Name		B-3 (Passing-liter)					
Date	**Week**	**N-1**	**N-2**	**N-3**	**N-4**	**N-5**	**N-6**
1st Sampling		0	0	0	0	0	0
5/4/16-9/4/16	1st	87	74	74	81	80	69
19/4/16-22/4/16	2nd	77	76	74	76	72	70
23/4/16-30/4/16	3rd	66	60	57	59	52	44
1/5/16-5/5/16	4th	55	54	52	53	53	45
9/5/16-13/5/16	5th	66	59	57	57	57	53
16/5/16-20/5/16	6th	33	33	33	33	33	33
25/5/16-31/5/16	7th	44	43	44	44	42	44
2nd Sampling		**428**	**399**	**391**	**403**	**389**	**358**
Percentage(%)		**26%**	**24%**	**24%**	**25%**	**24%**	**23%**
1/6/16-5/6/16	8th	84	84	83	81	84	83
6/6/16-10/6/16	9th	65	63	65	65	65	65
11/6/16-17/6/16	10th	88	88	86	85	88	88
18/6/16-23/6/16	11th	97	97	96	95	97	96
25/6/16-30/6/16	12th	65	65	63	63	64	64
3rd Sampling		**827**	**796**	**784**	**792**	**787**	**754**
Percentage(%)		**50%**	**49%**	**48%**	**49%**	**48%**	**47%**
12/7/16-15/7/16	13th	77	77	76	77	77	76
17/7/16-22/7/16	14th	119	119	118	119	118	119
23/7/16-29/7/16	15th	116	115	114	116	116	116
1/8/16-5/8/16	16th	64	63	65	65	64	64
4th Sampling		**1203**	**1170**	**1157**	**1169**	**1162**	**1129**
Percentage(%)		**72%**	**72%**	**72%**	**72%**	**72%**	**71%**
8/8/16-12/8/16	17th	64	64	63	63	65	65
16/8/16-19/8/16	18th	53	53	52	52	51	51
22/8/16-31/8/16	19th	88	88	87	87	88	88
5th Sampling		**1408**	**1375**	**1359**	**1371**	**1366**	**1333**
Percentage(%)		**84%**	**84%**	**84%**	**84%**	**84%**	**84%**
1/9/16-8/9/16	20th	54	54	53	53	54	54
20/9/16-30/9/16	21st	86	85	86	85	84	83
3/10/16-11/10/16	22nd	77	76	76	76	75	77
13/10/16-18/10/16	23rd	44	42	43	44	44	43
6th Sampling and Total		**1669**	**1632**	**1617**	**1629**	**1623**	**1590**
Percentage(%)		**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

Table B. 4. Average and Cumulative filtration of different filters

	Average Filtration (liters)			Cumulative Filtration (liters)		
Weeks	**B-1**	**B-2**	**B-3**	**B-1**	**B-2**	**B-3**
1st	51	65	78	51	65	78
2nd	45	65	74	96	130	152
3rd	34	55	56	130	185	208
4th	31	45	52	161	230	260
5th	38	54	58	199	283	318
6th	24	33	33	222	316	351
7th	33	44	44	255	360	395
8th	53	75	83	308	435	478
9th	42	61	65	350	496	543
10th	56	65	87	406	561	630
11th	61	93	96	466	654	726
12th	42	64	64	508	718	790
13th	47	71	77	556	789	867
14th	81	106	119	636	895	985
15th	72	105	116	708	999	1101
16th	42	61	64	751	1060	1165
17th	44	63	64	794	1122	1229
18th	35	51	52	829	1174	1281
19th	64	86	88	893	1260	1369
20th	39	52	54	931	1312	1422
21st	62	82	85	993	1394	1507
22nd	51	66	76	1044	1461	1583
23rd	28	40	43	1071	1501	1627
Averaged	**47**	**65**	**71**			

Table B. 5. Typical flow rates of different B-1 filters

B-1										
Filter ID	**Hours**							**Total filtered Volume (liter)**	**Total filtration Time (hours)**	**Flow rate (liter/hour)**
	1st	**2nd**	**3rd**	**4th**	**5th**	**6th**	**7th**			
J-1 (NW)	3.25	0.25	1.25	0.5	0.75	0.5	0.5	7	7	1.00
J-2(WW)	3	1.5	1.25	0.5	0.5	0.5	0.25	7.5	7	1.07
J-3(NW)	2	1	0.75	0.5	0.75	0.25	0.75	6	7	0.86
J-4(WW)	4.2	1.8	1	0.25	0.75	0	0	8	5	1.60
J-5(NW)	1.75	0.25	0.5	0.5	0.25	0.25	0.5	4	7	0.57
J-6(WW)	2.5	1.25	1	0.75	0.5	0.5	0.5	4	7	0.57
NW = No Wastewater ; WW = With Wastewater									**Average =**	**0.95**

Table B. 6. Typical flow rates of different B-2 filters

B-2										
Filter ID	**Hours**							**Total filtered Volume (liter)**	**Total filtration Time (hours)**	**Flow rate (liter/hour)**
	1st	**2nd**	**3rd**	**4th**	**5th**	**6th**	**7th**			
M-1(NW)	1	1	0.75	0.5	0.75	0.5	0.25	4.75	7	0.68
M-2(WW)	1	0.75	1	0.5	0.5	0.5	0.25	4.5	7	0.64
M-3(NW)	3.5	1.75	1.75	0.5	0	0.5	0.25	8	7	1.14
M-4(WW)	1.25	1	0.75	0.75	0.5	0.5	0.25	5	7	0.71
M-5(NW)	0.75	0.75	0.5	1	0.25	0.5	0.25	4	7	0.57
M-6(WW)	0.25	0.15	0.35	0.25	0.25	0.5	0.5	3	7	0.43
NW = No Wastewater ; WW = With Wastewater									**Average =**	**0.70**

Table B. 7. Typical flow rates of different B-3 filters

B-3										
Filter ID	**Hours**							**Total filtered Volume (liter)**	**Total filtration Time (hours)**	**Flow rate (liter/hour)**
	1st	**2nd**	**3rd**	**4th**	**5th**	**6th**	**7th**			
N-1(NW)	4	1.75	1.25	1.25	0.75	0.75	0.25	10	7	1.43
N-2(WW)	2	1.25	1	1	1	0.75	0.5	7.5	7	1.07
N-3(NW)	2	2	1.5	1.5	1	0.75	0.25	9	7	1.29
N-4(WW)	1.75	1.25	1.25	1.25	1	0.75	0.5	7.75	7	1.11
N-5(NW)	2	1	1	0.5	0.75	0.75	0.5	6.5	7	0.93
N-6(WW)	1	0.5	0.5	0.5	0.25	0.25	0.25	3.25	7	0.46
NW = No Wastewater ; WW = With Wastewater									**Average =**	**1.05**

Table B. 8. Microbiological result of *E. coli* in 1st sampling

Date	Sampling	Sl	Filter ID	Composition	Count (cfu/100mL)	LRV VALUE	% Reduction
05.04.2016	1st	1	J-1.1	T.W+ Organism	64400	3.96	99.99
		2	J-1.2	T.W+ Organism	7		
		3	M-1.1	T.W+ Organism	5000	0.94	88.60
		4	M-1.2	T.W+ Organism	570		
		5	N-1.1	T.W+ Organism	4000	0.93	88.13
		6	N-1.2	T.W + Organism	475		
		7	J-2.1	T.W + W.W + Organism	11000	0.66	77.97
		8	J-2.2	T.W + W.W + Organism	2423		
		9	M-2.1	T.W + W.W + Organism	3000	0.47	65.80
		10	M-2.2	T.W + W.W + Organism	1026		
		11	N-2.1	T.W + W.W + Organism	2000	0.24	43.00
		12	N-2.2	T.W + W.W + Organism	1140		
		13	J-7.1	T.W	0	N.C	N.C
		14	J-7.2	T.W	0		
		15	J-8.1	T.W + W.W	0	N.C	N.C
		16	J-8.2	T.W + W.W	0		
N.C= Negative Control; J=B-1 , M=B-2, N=B-3; T.W= Tap water, W.W= Waste water							

Table B. 9. Microbiological result of *E. coli* in 2nd sampling

Date	Sampling	Sl	Filter ID	Composition	Count (cfu/100mL)	LRV VALUE	% Reduction
01.06.2016	2nd	1	J-1.1	T.W+ Organism	270000	5.43	100.00
		2	J-1.2	T.W+ Organism	1		
		3	M-1.1	T.W+ Organism	1520	0.73	81.38
		4	M-1.2	T.W+ Organism	283		
		5	N-1.1	T.W+ Organism	1140	0.76	82.81
		6	N-1.2	T.W + Organism	196		
		7	J-2.1	T.W + W.W + Organism	288000	1.20	93.75
		8	J-2.2	T.W + W.W + Organism	18000		
		9	M-2.1	T.W + W.W + Organism	1615	0.63	76.47
		10	M-2.2	T.W + W.W + Organism	380		
		11	N-2.1	T.W + W.W + Organism	1520	0.73	81.25
		12	N-2.2	T.W + W.W + Organism	285		
		13	J-7.1	T.W	0	N.C	N.C
		14	J-7.2	T.W	0		
		15	J-8.1	T.W + W.W	0	N.C	N.C
		16	J-8.2	T.W + W.W	0		
N.C= Negative Control; J=B-1 , M=B-2, N=B-3; T.W= Tap water, W.W= Waste water							

Table B. 10. Microbiological result of *E. coli* in 3rdsampling

Date	Sampling	Sl	Filter ID	Composition	Count (cfu/100mL)	LRV VALUE	% Reduction
27.06.2016	3rd	1	J-1.1	T.W+ Organism	138000	1.24	94.20
		2	J-1.2	T.W+ Organism	8000		
		3	M-1.1	T.W+ Organism	187000	2.82	99.85
		4	M-1.2	T.W+ Organism	285		
		5	N-1.1	T.W+ Organism	264000	0.61	75.38
		6	N-1.2	T.W + Organism	65000		
		7	J-2.1	T.W + W.W + Organism	243000	2.39	99.59
		8	J-2.2	T.W + W.W + Organism	1000		
		9	M-2.1	T.W + W.W + Organism	300000	3.20	99.94
		10	M-2.2	T.W + W.W + Organism	190		
		11	N-2.1	T.W + W.W + Organism	240000	1.43	96.25
		12	N-2.2	T.W + W.W + Organism	9000		
		13	J-7.1	T.W	0	N.C	N.C
		14	J-7.2	T.W	0		
		15	J-8.1	T.W + W.W	0	N.C	N.C
		16	J-8.2	T.W + W.W	0		
N.C= Negative Control; J=B-1 , M=B-2, N=B-3; T.W= Tap water, W.W= Waste water							

Table B. 11. Microbiological result of *E. coli* in 4th sampling

Date	Sampling	Sl	Filter ID	Composition	Count (cfu/100mL)	LRV VALUE	% Reduction
02.08.2016	4th	1	J-1.1	T.W+ Organism	300000	0.31	50.67
		2	J-1.2	T.W+ Organism	148000		
		3	M-1.1	T.W+ Organism	140000	0.45	64.29
		4	M-1.2	T.W+ Organism	50000		
		5	N-1.1	T.W+ Organism	120000	0.60	75.00
		6	N-1.2	T.W + Organism	30000		
		7	J-2.1	T.W + W.W + Organism	298000	0.62	75.84
		8	J-2.2	T.W + W.W + Organism	72000		
		9	M-2.1	T.W + W.W + Organism	980000	0.96	88.98
		10	M-2.2	T.W + W.W + Organism	108000		
		11	N-2.1	T.W + W.W + Organism	680000	1.00	90.00
		12	N-2.2	T.W + W.W + Organism	68000		
		13	J-7.1	T.W	0	N.C	N.C
		14	J-7.2	T.W	0		
		15	J-8.1	T.W + W.W	0	N.C	N.C
		16	J-8.2	T.W + W.W	0		
N.C= Negative Control; J=B-1 , M=B-2, N=B-3; T.W= Tap water, W.W= Waste water							

Table B. 12. Microbiological result of *E. coli* in 5th sampling

Date	Sampling	Sl	Filter ID	Composition	Count (cfu/100mL)	LRV VALUE	% Reduction
30.08.2016	5th	1	J-1.1	T.W+ Organism	632000	0.69	79.75
		2	J-1.2	T.W+ Organism	128000		
		3	M-1.1	T.W+ Organism	408000	1.16	93.14
		4	M-1.2	T.W+ Organism	28000		
		5	N-1.1	T.W+ Organism	95000	2.38	33.33
		6	N-1.2	T.W + Organism	400		
		7	J-2.1	T.W + W.W + Organism	888000	0.15	29.73
		8	J-2.2	T.W + W.W + Organism	624000		
		9	M-2.1	T.W + W.W + Organism	152000	0.61	68.42
		10	M-2.2	T.W + W.W + Organism	48000		
		11	N-2.1	T.W + W.W + Organism	102000	1.15	26.17
		12	N-2.2	T.W + W.W + Organism	7300		
		13	J-7.1	T.W	0	N.C	N.C
		14	J-7.2	T.W	0		
		15	J-8.1	T.W + W.W	0	N.C	N.C
		16	J-8.2	T.W + W.W	0		
N.C= Negative Control; J=B-1 , M=B-2, N=B-3; T.W= Tap water, W.W= Waste water							

Table B. 13. Microbiological result of *E. coli* in 6th sampling

Date	Sampling	Sl	Filter ID	Composition	Count (cfu/100mL)	LRV VALUE	% Reduction
23.10.2016	6th	1	J-1.1	T.W+ Organism	66500	1.25	94.44
		2	J-1.2	T.W+ Organism	3700		
		3	M-1.1	T.W+ Organism	57000	1.50	83.58
		4	M-1.2	T.W+ Organism	1800		
		5	N-1.1	T.W+ Organism	76000	1.93	98.82
		6	N-1.2	T.W + Organism	900		
		7	J-2.1	T.W + W.W + Organism	760000	2.45	99.64
		8	J-2.2	T.W + W.W + Organism	2700		
		9	M-2.1	T.W + W.W + Organism	855000	2.45	99.96
		10	M-2.2	T.W + W.W + Organism	300		
		11	N-2.1	T.W + W.W + Organism	665000	1	90.00
		12	N-2.2	T.W + W.W + Organism	14500		
		13	J-7.1	T.W	0	N.C	N.C
		14	J-7.2	T.W	0		
		15	J-8.1	T.W + W.W	0	N.C	N.C
		16	J-8.2	T.W + W.W	0		
N.C= Negative Control; J=B-1 , M=B-2, N=B-3; T.W= Tap water, W.W= Waste water							

Table B. 14. Microbiological result of *Clostridium perfringens* in 1st sampling

Date	Sampling	Sl	Filter ID	Composition	Count (cfu/100mL)	LRV VALUE	% Reduction
05.04.2016	1st	1	J-3.1	T.W+ Organism	26	0.72	80.77
		2	J-3.2	T.W+ Organism	5		
		3	M-3.1	T.W+ Organism	48	0.84	85.42
		4	M-3.2	T.W+ Organism	7		
		5	N-3.1	T.W+ Organism	10	0.52	70.00
		6	N-3.2	T.W + Organism	3		
		7	J-4.1	T.W + W.W + Organism	83	1.32	95.18
		8	J-4.2	T.W + W.W + Organism	4		
		9	M-4.1	T.W + W.W + Organism	41	0.44	63.41
		10	M-4.2	T.W + W.W + Organism	15		
		11	N-4.1	T.W + W.W + Organism	31	0.45	64.52
		12	N-4.2	T.W + W.W + Organism	11		
		13	M-7.1	T.W	0	N.C	N.C
		14	M-7.2	T.W	0		
		15	M-8.1	T.W + W.W	0	N.C	N.C
		16	M-8.2	T.W + W.W	0		
N.C= Negative Control; J=B-1 , M=B-2, N=B-3; T.W= Tap water, W.W= Waste water							

Table B. 15. Microbiological result of *Clostridium perfringens* in 2nd sampling

Date	Sampling	Sl	Filter ID	Composition	Count (cfu/100mL)	LRV VALUE	% Reduction
01.06.2016	2nd	1	J-3.1	T.W+ Organism	570	1.45	96.49
		2	J-3.2	T.W+ Organism	20		
		3	M-3.1	T.W+ Organism	95	0.98	89.47
		4	M-3.2	T.W+ Organism	10		
		5	N-3.1	T.W+ Organism	32	0.60	75.00
		6	N-3.2	T.W + Organism	8		
		7	J-4.1	T.W + W.W + Organism	1000	0.24	43.00
		8	J-4.2	T.W + W.W + Organism	570		
		9	M-4.1	T.W + W.W + Organism	760	0.70	80.26
		10	M-4.2	T.W + W.W + Organism	150		
		11	N-4.1	T.W + W.W + Organism	3000	0.54	71.17
		12	N-4.2	T.W + W.W + Organism	865		
		13	M-7.1	T.W	0	N.C	N.C
		14	M-7.2	T.W	0		
		15	M-8.1	T.W + W.W	0	N.C	N.C
		16	M-8.2	T.W + W.W	0		
N.C= Negative Control; J=B-1 , M=B-2, N=B-3; T.W= Tap water, W.W= Waste water							

Table B. 16. Microbiological result of *Clostridium perfringens* in 3rd sampling

Date	Sampling	Sl	Filter ID	Composition	Count (cfu/100mL)	LRV VALUE	% Reduction
27.06.2016	3rd	1	J-3.1	T.W+ Organism	190	2.28	99.47
		2	J-3.2	T.W+ Organism	1		
		3	M-3.1	T.W+ Organism	285	2.15	99.30
		4	M-3.2	T.W+ Organism	2		
		5	N-3.1	T.W+ Organism	190	0.85	85.79
		6	N-3.2	T.W + Organism	27		
		7	J-4.1	T.W + W.W + Organism	380	2.58	99.74
		8	J-4.2	T.W + W.W + Organism	1		
		9	M-4.1	T.W + W.W + Organism	190	0.98	89.47
		10	M-4.2	T.W + W.W + Organism	20		
		11	N-4.1	T.W + W.W + Organism	285	0.18	33.33
		12	N-4.2	T.W + W.W + Organism	190		
		13	M-7.1	T.W	0	N.C	N.C
		14	M-7.2	T.W	0		
		15	M-8.1	T.W + W.W	0	N.C	N.C
		16	M-8.2	T.W + W.W	0		
N.C= Negative Control; J=B-1 , M=B-2, N=B-3; T.W= Tap water, W.W= Waste water							

Table B. 17. Microbiological result of *Clostridium perfringens* in 4th sampling

Date	Sampling	Sl	Filter ID	Composition	Count (cfu/100mL)	LRV VALUE	% Reduction
02.08.2016	4th	1	J-3.1	T.W+ Organism	1900	0.70	80.00
		2	J-3.2	T.W+ Organism	380		
		3	M-3.1	T.W+ Organism	950	1.68	97.89
		4	M-3.2	T.W+ Organism	20		
		5	N-3.1	T.W+ Organism	2850	0.76	82.46
		6	N-3.2	T.W + Organism	500		
		7	J-4.1	T.W + W.W + Organism	4750	0.80	84.00
		8	J-4.2	T.W + W.W + Organism	760		
		9	M-4.1	T.W + W.W + Organism	2850	0.55	71.93
		10	M-4.2	T.W + W.W + Organism	800		
		11	N-4.1	T.W + W.W + Organism	3800	0.30	50.00
		12	N-4.2	T.W + W.W + Organism	1900		
		13	M-7.1	T.W	0	N.C	N.C
		14	M-7.2	T.W	0		
		15	M-8.1	T.W + W.W	0	N.C	N.C
		16	M-8.2	T.W + W.W	0		
N.C= Negative Control; J=B-1 , M=B-2, N=B-3; T.W= Tap water, W.W= Waste water							

Table B. 18. Microbiological result of *Clostridium perfringens* in 5th sampling

Date	Sampling	Sl	Filter ID	Composition	Count (cfu/100mL)	LRV VALUE	% Reduction
30.08.2016	5th	1	J-3.1	T.W+ Organism	1020	0.59	74.51
		2	J-3.2	T.W+ Organism	260		
		3	M-3.1	T.W+ Organism	1580	0.30	50.00
		4	M-3.2	T.W+ Organism	790		
		5	N-3.1	T.W+ Organism	1800	1.30	95.00
		6	N-3.2	T.W + Organism	90		
		7	J-4.1	T.W + W.W + Organism	1040	0.76	82.69
		8	J-4.2	T.W + W.W + Organism	180		
		9	M-4.1	T.W + W.W + Organism	2590	0.57	73.36
		10	M-4.2	T.W + W.W + Organism	690		
		11	N-4.1	T.W + W.W + Organism	860	1.33	95.35
		12	N-4.2	T.W + W.W + Organism	40		
		13	M-7.1	T.W	0	N.C	N.C
		14	M-7.2	T.W	0		
		15	M-8.1	T.W + W.W	0	N.C	N.C
		16	M-8.2	T.W + W.W	0		
N.C= Negative Control; J=B-1 , M=B-2, N=B-3; T.W= Tap water, W.W= Waste water							

Table B. 19. Microbiological result of *Clostridium perfringens* in 6th sampling

Date	Sampling	Sl	Filter ID	Composition	Count (cfu/100mL)	LRV VALUE	% Reduction
23.10.2016	6th	1	J-3.1	T.W+ Organism	860	0.06	12.79
		2	J-3.2	T.W+ Organism	750		
		3	M-3.1	T.W+ Organism	5225	0.20	36.36
		4	M-3.2	T.W+ Organism	3325		
		5	N-3.1	T.W+ Organism	1900	0.15	28.42
		6	N-3.2	T.W + Organism	1360		
		7	J-4.1	T.W + W.W + Organism	1925	0.68	79.22
		8	J-4.2	T.W + W.W + Organism	400		
		9	M-4.1	T.W + W.W + Organism	2375	0.72	81.05
		10	M-4.2	T.W + W.W + Organism	450		
		11	N-4.1	T.W + W.W + Organism	1425	0.21	38.95
		12	N-4.2	T.W + W.W + Organism	870		
		13	M-7.1	T.W	0	N.C	N.C
		14	M-7.2	T.W	0		
		15	M-8.1	T.W + W.W	0	N.C	N.C
		16	M-8.2	T.W + W.W	0		
N.C= Negative Control; J=B-1 , M=B-2, N=B-3; T.W= Tap water, W.W= Waste water							

Table B. 20. Microbiological result of MS2 bacteriophage in 1st sampling

Date	Sampling	Sl	Filter ID	Composition	Count (pfu/100mL)	LRV VALUE	% Reduction
05.04.2016	1st	1	J-5.1	T.W+ Organism	600	2.78	100.00
		2	J-5.2	T.W+ Organism	0		
		3	M-5.1	T.W+ Organism	133200	0.64	77.25
		4	M-5.2	T.W+ Organism	30300		
		5	N-5.1	T.W+ Organism	101600	0.29	48.33
		6	N-5.2	T.W + Organism	52500		
		7	J-6.1	T.W + W.W + Organism	1100	3.04	100.00
		8	J-6.2	T.W + W.W + Organism	0		
		9	M-6.1	T.W + W.W + Organism	89200	0.93	88.34
		10	M-6.2	T.W + W.W + Organism	10400		
		11	N-6.1	T.W + W.W + Organism	68000	0.44	63.53
		12	N-6.2	T.W + W.W + Organism	24800		
		13	N-7.1	T.W	0	N.C	N.C
		14	N-7.2	T.W	0		
		15	N-8.1	T.W + W.W	0	N.C	N.C
		16	N-8.2	T.W + W.W	0		
N.C= Negative Control; J=B-1 , M=B-2, N=B-3; T.W= Tap water, W.W= Waste water							

Table B. 21. Microbiological result of MS2 bacteriophage in 2nd sampling

Date	Sampling	Sl	Filter ID	Composition	Count (pfu/100mL)	LRV VALUE	% Reduction
01.06.2016	2nd	1	J-5.1	T.W+ Organism	600	2.78	100.00
		2	J-5.2	T.W+ Organism	0		
		3	M-5.1	T.W+ Organism	76000	0.79	83.68
		4	M-5.2	T.W+ Organism	12400		
		5	N-5.1	T.W+ Organism	95200	0.32	52.10
		6	N-5.2	T.W + Organism	45600		
		7	J-6.1	T.W + W.W + Organism	104800	0.63	76.72
		8	J-6.2	T.W + W.W + Organism	24400		
		9	M-6.1	T.W + W.W + Organism	300000	0.65	77.60
		10	M-6.2	T.W + W.W + Organism	67200		
		11	N-6.1	T.W + W.W + Organism	114000	0.50	68.42
		12	N-6.2	T.W + W.W + Organism	36000		
		13	N-7.1	T.W	0	N.C	N.C
		14	N-7.2	T.W	0		
		15	N-8.1	T.W + W.W	0	N.C	N.C
		16	N-8.2	T.W + W.W	0		
N.C= Negative Control; J=B-1 , M=B-2, N=B-3; T.W= Tap water, W.W= Waste water							

Table B. 22. Microbiological result of MS2 bacteriophage in 3rd sampling

Date	Sampling	Sl	Filter ID	Composition	Count (pfu/100mL)	LRV VALUE	% Reduction
27.06.2016	3rd	1	J-5.1	T.W+ Organism	102000	1.31	95.10
		2	J-5.2	T.W+ Organism	5000		
		3	M-5.1	T.W+ Organism	92000	1.66	97.83
		4	M-5.2	T.W+ Organism	2000		
		5	N-5.1	T.W+ Organism	108000	0.27	46.30
		6	N-5.2	T.W + Organism	58000		
		7	J-6.1	T.W + W.W + Organism	152000	0.98	89.47
		8	J-6.2	T.W + W.W + Organism	16000		
		9	M-6.1	T.W + W.W + Organism	132000	1.17	93.18
		10	M-6.2	T.W + W.W + Organism	9000		
		11	N-6.1	T.W + W.W + Organism	84000	0.73	80.95
		12	N-6.2	T.W + W.W + Organism	16000		
		13	N-7.1	T.W	0	N.C	N.C
		14	N-7.2	T.W	0		
		15	N-8.1	T.W + W.W	0	N.C	N.C
		16	N-8.2	T.W + W.W	0		
N.C= Negative Control; J=B-1 , M=B-2, N=B-3; T.W= Tap water, W.W= Waste water							

Table B. 23. Microbiological result of MS2 bacteriophage in 4th sampling

Date	Sampling	Sl	Filter ID	Composition	Count (pfu/100mL)	LRV VALUE	% Reduction
02.08.2016	4th	1	J-5.1	T.W+ Organism	124800	1.80	98.40
		2	J-5.2	T.W+ Organism	2000		
		3	M-5.1	T.W+ Organism	104000	1.41	96.15
		4	M-5.2	T.W+ Organism	4000		
		5	N-5.1	T.W+ Organism	448000	2.09	99.20
		6	N-5.2	T.W + Organism	3600		
		7	J-6.1	T.W + W.W + Organism	288000	0.98	89.44
		8	J-6.2	T.W + W.W + Organism	30400		
		9	M-6.1	T.W + W.W + Organism	512000	1.39	95.94
		10	M-6.2	T.W + W.W + Organism	20800		
		11	N-6.1	T.W + W.W + Organism	304000	0.98	89.47
		12	N-6.2	T.W + W.W + Organism	32000		
		13	N-7.1	T.W	0	N.C	N.C
		14	N-7.2	T.W	0		
		15	N-8.1	T.W + W.W	0	N.C	N.C
		16	N-8.2	T.W + W.W	0		
N.C= Negative Control; J=B-1 , M=B-2, N=B-3; T.W= Tap water, W.W= Waste water							

Table B. 24. Microbiological result of MS2 bacteriophage in 5th sampling

Date	Sampling	Sl	Filter ID	Composition	Count (pfu/100mL)	LRV VALUE	% Reduction
30.08.2016	5th	1	J-5.1	T.W+ Organism	368000	0.19	35.65
		2	J-5.2	T.W+ Organism	236800		
		3	M-5.1	T.W+ Organism	284800	0.39	58.99
		4	M-5.2	T.W+ Organism	116800		
		5	N-5.1	T.W+ Organism	251200	0.48	66.88
		6	N-5.2	T.W + Organism	83200		
		7	J-6.1	T.W + W.W + Organism	313600	0.22	39.8
		8	J-6.2	T.W + W.W + Organism	188800		
		9	M-6.1	T.W + W.W + Organism	280000	0.91	87.71
		10	M-6.2	T.W + W.W + Organism	34400		
		11	N-6.1	T.W + W.W + Organism	304000	0.33	53.68
		12	N-6.2	T.W + W.W + Organism	140800		
		13	N-7.1	T.W	0	N.C	N.C
		14	N-7.2	T.W	0		
		15	N-8.1	T.W + W.W	0	N.C	N.C
		16	N-8.2	T.W + W.W	0		
N.C= Negative Control; J=B-1 , M=B-2, N=B-3; T.W= Tap water, W.W= Waste water							

Table B. 25. Microbiological result of MS2 bacteriophage in 6th sampling

Date	Sampling	Sl	Filter ID	Composition	Count (pfu/100mL)	LRV VALUE	% Reduction
23.10.2016	6th	1	J-5.1	T.W+ Organism	280000	0.29	48.57
		2	J-5.2	T.W+ Organism	144000		
		3	M-5.1	T.W+ Organism	576000	0.33	52.78
		4	M-5.2	T.W+ Organism	272000		
		5	N-5.1	T.W+ Organism	400000	0.15	30
		6	N-5.2	T.W + Organism	280000		
		7	J-6.1	T.W + W.W + Organism	248000	0.21	38.71
		8	J-6.2	T.W + W.W + Organism	152000		
		9	M-6.1	T.W + W.W + Organism	352000	0.34	54.55
		10	M-6.2	T.W + W.W + Organism	160000		
		11	N-6.1	T.W + W.W + Organism	168000	0.15	28.57
		12	N-6.2	T.W + W.W + Organism	120000		
		13	N-7.1	T.W	0	N.C	N.C
		14	N-7.2	T.W	0		
		15	N-8.1	T.W + W.W	0	N.C	N.C
		16	N-8.2	T.W + W.W	0		
N.C= Negative Control; J=B-1 , M=B-2, N=B-3; T.W= Tap water, W.W= Waste water							

Table B.26. Physic-chemical results for B-1 in 1st sampling

	pH	EC(µs/cm)	TURBIDITY(NTU)	COLOR(pt-co)
J-1-1	7.36	583	1.24	10
J-1-2	7.88	575	2.5	4.5
J-2-1	7.33	582	1.55	5.5
J-2-2	7.63	592	0.72	2.5
J-3-1	7.74	577	0.89	2
J-3-2	7.86	579	0.9	3.5
J-4-1	7.39	582	1.28	3.5
J-4-2	7.88	595	0.54	19
J-5-1	7.28	590	1.3	4.5
J-5-2	8.22	600	0.97	6.5
J-6-1	7.34	589	1.14	13
J-6-2	7.8	606	2.27	3
J-7-1	7.2	586	0.39	1
J-7-2	7.37	605	1.1	5
J-8-1	7.19	588	0.88	26.5
J-8-2	7.52	654	0.91	32.5

Table B.27. Physic-chemical results for B-2 in 1st sampling

		pH	EC(µs/cm)	TURBIDITY(NTU)	COLOR(pt-co)
M-1	M-1-1	7.47	589	3.76	4
	M-1-2	8.22	846	1.52	5
M-2	M-2-1	7.45	586	1.12	1
	M-2-2	8.59	828	1.04	1
M-3	M-3-1	7.51	584	1.34	4
	M-3-2	8.4	744	0.61	2
M-4	M-4-1	7.7	586	0.75	2
	M-4-2	8.41	764	0.7	8.5
M-5	M-5-1	8.06	567	1.05	13.5
	M-5-2	8.56	743	0.77	13.5
M-6	M-6-1	7.29	594	2.08	26.5
	M-6-2	8.41	730	1.82	19
M-7	M-7-1	7.48	579	1.01	5.5
	M-7-2	8.48	860	1.26	21
M-8	M-8-1	7.4	587	0.73	1
	M-8-2	8.69	889	0.39	5.5

Table B. 28. Physic-chemical results for B-3 in 1st sampling

		pH	EC(µs/cm)	TURBIDITY(NTU)	COLOR(pt-co)
N-1	N-1-1	7.45	581	1.02	7.5
	N-1-2	7.65	593	2.74	2
N-2	N-2-1	7.34	581	1.61	2.5
	N-2-2	7.72	603	1.9	1
N-3	N-3-1	7.46	580	0.55	10
	N-3-2	7.86	608	0.71	4.5
N-4	N-4-1	7.35	589	0.71	15.5
	N-4-2	8	595	0.73	1
N-5	N-5-1	7.76	573	0.75	3.5
	N-5-2	7.59	606	0.63	3.5
N-6	N-6-1	7.9	580	1.02	16
	N-6-2	8.06	635	0.55	4
N-7	N-7-1	7.33	587	0.63	2
	N-7-2	7.51	641	1.27	9.5
N-8	N-8-1	7.41	582	1.75	24.5
	N-8-2	7.92	615	2.18	21.5

Table B. 29. Physic-chemical results for B-1 in 2nd sampling

		pH	EC(µs/cm)	TURBIDITY(NTU)	COLOR(pt-co)
J-1	J-1-1	7.63	586	0.45	135
	J-1-2	8.07	573	0.15	131
J-2	J-2-1	7.59	587	0.41	136
	J-2-2	8.22	585	0.25	128
J-3	J-3-1	7.77	585	0.73	130
	J-3-2	8.03	546	0.13	130
J-4	J-4-1	7.66	586	0.21	135
	J-4-2	8.26	536	0.12	130
J-5	J-5-1	7.96	589	0.35	140
	J-5-2	8.08	556	0.2	135
J-6	J-6-1	7.89	589	0.43	131
	J-6-2	8.05	531	0.35	125
J-7	J-7-1	7.6	589	0.45	140
	J-7-2	8.18	565	0.3	130
J-8	J-8-1	7.97	581	0.41	135
	J-8-2	8.16	573	0.21	130

Table B. 30. Physic-chemical results for B-2 in 2nd sampling

		pH	EC(µs/cm)	TURBIDITY(NTU)	COLOR(pt-co)
M-1	M-1-1	7.58	587	0.43	110
	M-1-2	8.02	582	0.3	115
M-2	M-2-1	7.55	586	0.35	95
	M-2-2	8	577	0.29	97
M-3	M-3-1	7.54	586	0.39	103
	M-3-2	8.21	581	0.28	100
M-4	M-4-1	7.57	585	0.32	104
	M-4-2	8.07	575	0.21	105
M-5	M-5-1	7.5	593	0.25	112
	M-5-2	8.03	581	0.16	100
M-6	M-6-1	7.72	591	0.36	105
	M-6-2	8.21	585	0.26	110
M-7	M-7-1	7.62	565	0.33	90
	M-7-2	8.25	560	0.31	95
M-8	M-8-1	7.7	577	0.38	93
	M-8-2	8.26	570	0.28	101

Table B. 31. Physic-chemical results for B-3 in 2nd sampling

		pH	EC(µs/cm)	TURBIDITY(NTU)	COLOR(pt-co)
N-1	N-1-1	7.52	587	0.25	105
	N-1-2	8.03	581	0.2	110
N-2	N-2-1	7.7	585	0.21	115
	N-2-2	8.1	580	0.14	112
N-3	N-3-1	7.77	585	0.23	103
	N-3-2	8.06	579	0.17	100
N-4	N-4-1	7.53	585	0.26	114
	N-4-2	8.25	582	0.21	120
N-5	N-5-1	7.63	591	0.27	130
	N-5-2	8.36	575	0.22	131
N-6	N-6-1	8.2	577	0.21	135
	N-6-2	8.5	565	0.18	140
N-7	N-7-1	8.11	574	0.19	114
	N-7-2	8.2	564	0.15	110
N-8	N-8-1	7.96	579	0.21	117
	N-8-2	8.01	571	0.1	112

Table B. 32. Physic-chemical results for B-1 in 3rd sampling

		pH	EC(µs/cm)	TURBIDITY(NTU)	COLOR(pt-co)
J-1	J-1-1	7.05	588	0.45	135
	J-1-2	7.47	566	0.3	125
J-2	J-2-1	7.7	589	0.35	120
	J-2-2	7.99	580	0.25	115
J-3	J-3-1	7.23	599	0.31	145
	J-3-2	7.95	585	0.24	130
J-4	J-4-1	7.66	580	0.35	155
	J-4-2	8	516	0.2	141
J-5	J-5-1	7.59	575	0.41	145
	J-5-2	7.95	598	0.37	132
J-6	J-6-1	7.69	612	0.45	131
	J-6-2	7.75	587	0.26	125
J-7	J-7-1	7.2	585	0.47	130
	J-7-2	8	575	0.32	118
J-8	J-8-1	7.2	601	0.48	115
	J-8-2	7.9	599	0.43	110

Table B. 33. Physic-chemical results for B-2 in 3rd sampling

		pH	EC(µs/cm)	TURBIDITY(NTU)	COLOR(pt-co)
M-1	M-1-1	7.34	617	0.45	111
	M-1-2	7.99	597	0.31	110
M-2	M-2-1	8.13	609	0.2	115
	M-2-2	8.07	601	0.11	112
M-3	M-3-1	7.69	625	0.35	92
	M-3-2	8.05	601	0.28	95
M-4	M-4-1	7.67	622	0.43	100
	M-4-2	8	597	0.39	97
M-5	M-5-1	7.29	666	0.36	115
	M-5-2	7.72	642	0.28	112
M-6	M-6-1	7.38	631	0.3	131
	M-6-2	7.99	617	0.25	125
M-7	M-7-1	7.79	592	0.23	95
	M-7-2	7.94	581	0.14	90
M-8	M-8-1	7.6	598	0.15	95
	M-8-2	7.98	579	0.1	91

Table B. 34. Physic-chemical results for B-3 in 3rd sampling

		pH	EC(µs/cm)	TURBIDITY(NTU)	COLOR(pt-co)
N-1	N-1-1	7.47	620	0.2	110
	N-1-2	7.95	602	0.18	105
N-2	N-2-1	7.56	620	0.22	117
	N-2-2	8	602	0.15	115
N-3	N-3-1	7.61	624	0.27	125
	N-3-2	7.83	611	0.23	120
N-4	N-4-1	7.68	613	0.28	131
	N-4-2	7.85	608	0.21	121
N-5	N-5-1	7.48	644	0.18	114
	N-5-2	7.86	616	0.15	112
N-6	N-6-1	7.39	632	0.2	110
	N-6-2	7.86	626	0.17	105
N-7	N-7-1	7.76	592	0.23	95
	N-7-2	8.07	577	0.31	91
N-8	N-8-1	7.69	593	0.35	125
	N-8-2	8.14	575	0.32	121

Table B. 35. Physic-chemical results for B-1 in 4th sampling

		pH	EC(µs/cm)	TURBIDITY(NTU)	COLOR(pt-co)
J-1	J-1-1	7.25	598	0.47	140
	J-1-2	7.65	570	0.31	123
J-2	J-2-1	7.81	592	0.37	127
	J-2-2	7.98	590	0.21	112
J-3	J-3-1	7.99	612	0.37	115
	J-3-2	7.98	585	0.24	154
J-4	J-4-1	7.67	590	0.4	132
	J-4-2	8	617	0.34	160
J-5	J-5-1	7.64	612	0.41	155
	J-5-2	7.97	620	0.34	140
J-6	J-6-1	7.67	590	0.47	134
	J-6-2	7.77	581	0.27	134
J-7	J-7-1	7.1	595	0.47	127
	J-7-2	7.99	580	0.37	120
J-8	J-8-1	7.75	601	0.48	117
	J-8-2	7.98	585	0.43	112

Table B. 36. Physic-chemical results for B-2 in 4th sampling

		pH	EC(µs/cm)	TURBIDITY(NTU)	COLOR(pt-co)
M-1	M-1-1	7.37	616	0.47	115
	M-1-2	7.99	597	0.35	112
M-2	M-2-1	8.1	610	0.37	95
	M-2-2	8	600	0.27	93
M-3	M-3-1	7.65	601	0.42	100
	M-3-2	7.9	595	0.36	98
M-4	M-4-1	7.65	630	0.36	116
	M-4-2	8	610	0.27	110
M-5	M-5-1	7.29	642	0.2	165
	M-5-2	7.85	620	0.31	125
M-6	M-6-1	7.38	635	0.29	137
	M-6-2	7.8	615	0.34	130
M-7	M-7-1	7.75	589	0.31	90
	M-7-2	7.99	575	0.15	85
M-8	M-8-1	7.25	590	0.25	120
	M-8-2	7.35	580	0.19	115

Table B. 37. Physic-chemical results for B-3 in 4th sampling

		pH	EC(µs/cm)	TURBIDITY(NTU)	COLOR(pt-co)
N-1	N-1-1	7.35	620	0.2	115
	N-1-2	7.56	610	0.15	107
N-2	N-2-1	8	612	0.25	120
	N-2-2	8.65	601	0.17	118
N-3	N-3-1	7.65	625	0.41	131
	N-3-2	7.95	615	0.31	115
N-4	N-4-1	7.45	631	0.45	145
	N-4-2	7.65	618	0.3	125
N-5	N-5-1	7.45	645	0.18	118
	N-5-2	7.64	625	0.12	110
N-6	N-6-1	7.3	631	0.21	115
	N-6-2	7.59	612	0.16	100
N-7	N-7-1	7.95	595	0.27	95
	N-7-2	8.1	575	0.21	75
N-8	N-8-1	7.65	593	0.37	135
	N-8-2	8.15	575	0.33	120

Table B. 38. Physic-chemical results for B-1 in 5th sampling

		pH	EC(µs/cm)	TURBIDITY(NTU)	COLOR(pt-co)
J-1	J-1-1	7.05	570	0.57	145
	J-1-2	7.25	595	0.41	130
J-2	J-2-1	7.85	545	0.47	127
	J-2-2	7.95	585	0.32	110
J-3	J-3-1	7.55	568	0.35	148
	J-3-2	7.85	570	0.3	135
J-4	J-4-1	7.2	585	0.36	142
	J-4-2	8.2	601	0.29	130
J-5	J-5-1	7.15	600	0.45	132
	J-5-2	7.35	612	0.34	128
J-6	J-6-1	7.65	590	0.55	120
	J-6-2	6.85	601	0.32	110
J-7	J-7-1	7.35	601	0.47	128
	J-7-2	7.7	615	0.35	115
J-8	J-8-1	7.3	585	0.3	124
	J-8-2	7.75	595	0.27	118

Table B. 39. Physic-chemical results for B-2 in 5th sampling

		pH	EC(µs/cm)	TURBIDITY(NTU)	COLOR(pt-co)
M-1	M-1-1	7.35	555	0.21	117
	M-1-2	7.85	595	0.16	115
M-2	M-2-1	7.35	601	0.3	125
	M-2-2	7.95	585	0.23	115
M-3	M-3-1	7.25	584	0.35	130
	M-3-2	7.7	592	0.21	117
M-4	M-4-1	7.85	575	0.4	135
	M-4-2	8.15	584	0.3	128
M-5	M-5-1	7.34	598	0.35	135
	M-5-2	7.74	601	0.31	128
M-6	M-6-1	7.15	610	0.32	115
	M-6-2	7.25	620	0.27	100
M-7	M-7-1	7.1	575	0.15	125
	M-7-2	7.3	585	0.1	117
M-8	M-8-1	7.4	610	0.27	137
	M-8-2	7.75	625	0.21	130

Table B. 40. Physic-chemical results for B-3 in 5th sampling

		pH	EC(µs/cm)	TURBIDITY(NTU)	COLOR(pt-co)
N-1	N-1-1	7.15	570	0.25	125
	N-1-2	7.3	585	0.21	115
N-2	N-2-1	7.95	575	0.3	135
	N-2-2	8.1	590	0.25	130
N-3	N-3-1	7.5	595	0.35	131
	N-3-2	7.75	601	0.24	127
N-4	N-4-1	7.15	610	0.47	135
	N-4-2	7.35	612	0.35	127
N-5	N-5-1	7.85	601	0.35	130
	N-5-2	0.795	612	0.28	124
N-6	N-6-1	7.1	550	0.41	147
	N-6-2	7.5	565	0.3	132
N-7	N-7-1	7.21	575	0.45	135
	N-7-2	7.6	585	0.35	130
N-8	N-8-1	7.65	590	0.41	141
	N-8-2	7.98	610	0.28	128

Table B. 41. Physic-chemical results for B-1 in 6th sampling

		pH	EC(µs/cm)	TURBIDITY(NTU)
J-1	J-1-1	7.63	593	0.43
	J-1-2	7.95	584	0.022
J-2	J-2-1	7.43	595	0.35
	J-2-2	7.54	585	0.23
J-3	J-3-1	7.76	563	0.25
	J-3-2	8	513	0.18
J-4	J-4-1	7.73	566	0.43
	J-4-2	7.94	554	0.33
J-5	J-5-1	7.64	583	0.89
	J-5-2	7.83	594	0.73
J-6	J-6-1	7.55	583	0.35
	J-6-2	7.63	582	0.23
J-7	J-7-1	7.05	573	0.83
	J-7-2	7.25	543	0.75
J-8	J-8-1	7.39	584	0.63
	J-8-2	7.93	555	0.55

Table B. 42. Physic-chemical results for B-2 in 6th sampling

		pH	EC(µs/cm)	TURBIDITY(NTU)
M-1	M-1-1	7.24	550	0.65
	M-1-2	7.7	545	0.52
M-2	M-2-1	7.75	575	0.75
	M-2-2	7.98	565	0.45
M-3	M-3-1	7.87	595	0.2
	M-3-2	7.77	580	0.17
M-4	M-4-1	7.67	590	0.35
	M-4-2	7.95	560	0.25
M-5	M-5-1	7.5	575	3.65
	M-5-2	8	545	1.7
M-6	M-6-1	7.45	543	1.36
	M-6-2	8	531	0.97
M-7	M-7-1	7.88	565	1.36
	M-7-2	8.1	553	1
M-8	M-8-1	8.3	563	0.3
	M-8-2	8.45	544	0.21

Table B. 43. Physic-chemical results for B-3 in 6th sampling

		pH	EC(µs/cm)	TURBIDITY(NTU)
N-1	N-1-1	7.52	554	0.31
	N-1-2	7.93	545	0.21
N-2	N-2-1	7.63	588	0.36
	N-2-2	7.84	573	0.24
N-3	N-3-1	7.93	595	0.026
	N-3-2	8	582	0.17
N-4	N-4-1	7.1	593	0.27
	N-4-2	7.85	575	0.19
N-5	N-5-1	7.67	563	0.41
	N-5-2	7.84	553	0.27
N-6	N-6-1	7.54	563	0.45
	N-6-2	7.53	543	0.35
N-7	N-7-1	7.85	577	0.48
	N-7-2	8	566	0.18
N-8	N-8-1	7.63	593	1.36
	N-8-2	8.1	575	0.87