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A LOW-COST DRINKING WATER TREATMENT SYSTEM FOR SLUM DWELLERS OF DHAKA CITY, BANGLADESH AND A COMPARATIVE STUDY WITH COMMERCIALLY MANUFACTURED WATER FILTERS

By

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LIST OF ACRONYMS

Acronym	Description
DWASA	Dhaka Water Supply and Sewerage Authority
BBS	Bangladesh Bureau of Statistics
MLD	Million Liter per Day
ICDDRB	International Centre for Diarrheal Disease Research Bangladesh
BDHS	Bangladesh Demographic Health and Health Survey
NGO	Non-Government Organization
WHO	World Health Organization
DCC	Dhaka City Corporation
SWTP	Saidabad Water Treatment Plant
RUET	Rajshahi University of Engineering and Technology
BUET	Bangladesh University of Engineering and Technology
BTCL	Bangladesh Telecommunication Company Limited
USEPA	United States Environmental Protection Agency
NTU	Nephelometric Turbidity Units
BDT	Bangladeshi Taka (Currency)
UNICEF	United Nations Children's Fund
l/p/d	Liter Per Day
l/hr.	Liter Per Hour
l/hr./m^2	Liter Per Hour Per Square Meter

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A LOW-COST DRINKING WATER TREATMENT SYSTEM FOR SLUM DWELLERS OF DHAKA CITY, BANGLADESH AND A COMPARATIVE STUDY WITH COMMERCIALLY MANUFACTURED WATER FILTERS

Thesis Abstract- Idaho State University (Summer 2017)

Dhaka City, the capital of Bangladesh and one of the largest megacities of the world, is encountering an alarming decrease in the quantity and the quality of potable drinking water. Especially in the slum areas where mostly low-income people groups are living, the problem is more severe in comparison to the other residential and commercial areas of the city. In Dhaka City, approximately 4.5 million people live in the slum areas consisting of about 30% of the total city population. The slum dwellers are mostly economically disadvantages lacking in basic living necessities with items like shelter, food, education etc. In addition, many slum dwellers complain about the poor quality of drinking water supplied by Dhaka Water Supply and Sewerage Authority (DWASA), the main responsible authority for the water supply and sewerage of Dhaka city.

In this study, several samples of water supplied by Dhaka Water Supply and Sewerage Authority (DWASA) were collected from the Korail slum, one of the largest slums of the city. After testing the quality of samples, it has found that the water contains high concentration of E. coli and Turbidity which causes many water borne diseases among the slum dwellers.

To help solve the problem of poor drinking water quality, a clay water filter was proposed which is believed to be effective especially against E. coli, turbidity and suspended solids concentration of water. Also, this filter is economical and the raw materials are locally available hence the poor slum dwellers can afford it. Laboratory testing and analyses suggested that, the clay filter can remove up to 90.4% Log_{10} reduction of total E. coli concentration, 87% of turbidity concentration and 97.2% of suspended solids concentration of the raw water of Korail slum. To make a comparison, raw water samples of Korail slum also filtered by a commercially manufactured ceramic water filter and it removed up to 98.1% Log_{10} of E. coli concentration of water, 90.2% of turbidity concentration and 99% of suspended solids concentration. The study also suggested that the clay filter can treat up to 15 liters of water per day and 2 units of clay filter can easily meet the daily drinking water requirement of a 4-member family. For cleaning purpose, a metal scrubber used that showed a significant increase in the filtration rate of the filters. Performance projection has suggested that clay filter can run up to 225 days with regular plugging and able to meet the daily drinking water demand for a 4 members' family at least for 146 days. Laboratory analysis suggests that the continuous filtration exhibits a better filter life-time than non-continuous filtration. The clay filter designed for the study cost around $13 which is considerably less than the cost of commercially manufactured ceramic filter ($77). However, it is very much possible to reduces the unit price of the filter if it goes for the commercial manufacturing.

CHAPTER 1

INTRODUCTION

1.1 Background Information:

Bangladesh, after getting independence in 1971 has been facing rapid growth of its population. The population which was 67.63 million during 1971 is now 156.6 million and estimated at 243 million in 2050 (Bangladesh Bureau of Statistics, 2014); potentially making Bangladesh one of the most populous countries of the world. At present Bangladesh is the 8th most populous country of the world (CIA, World Factbook 2015). With the increase of population, the economic development is increasing faster as well. Now Bangladesh has the 57th largest economy of the world (International Monetary Fund, 2014). Most of the development is centralized in Dhaka, the capital city of Bangladesh and the 11th largest mega city of the world (World Urbanization Prospect 2014). As more and more people gather in this city from everywhere across the country, this makes it an economic, social and political hub of the country.

At present, Dhaka city has a population of 17 million in its 300-square kilometer area with a density of 30,748.8 people per square kilometer (Bangladesh Bureau of Statics, 2014). This large and diverse population creates many problems in the city like poverty, unemployment, crime etc. One of the most important perspective of this problem is the mushrooming of unlawful tenant settlement defined as slums. The poor people like to choose slums as their residence because of cheap and affordable living although the slum dwellers are getting almost zero service from government due to their illegal status. Slum dwellers experience a terrible water supply and sanitation service and hence many dwellers suffer and potentially die from diseases like diarrhea, cholera, arsenic etc. The environmental condition, especially the water pollution problems, arises from inadequate treatment of sewage, poor drainage and inappropriate disposal of solid waste are often terrible and worse than rural areas (Islam, N, et al., 1997).

According to some studies and field surveys conducted on the condition of the slum dwellers, slum environment causes them to become sick primarily due to the lacking of potable drinking water, proper waste disposal facilities and well defined hygienic knowledge such as sanitation practice and proper waste disposal. The poor quality of potable drinking water is extremely pivotal as many serious diseases are transported by water. Among the slum dwellers, the water borne disease rate is very high in comparison to people living in other areas of the city. The quality of water supplied to the slum dwellers is questionable and degraded as measured by various parameters like E. coli concentration, turbidity concentration etc. Also, there is a significant gap between the demand and supply of water provided by Dhaka Water Supply and Sewerage Authority (DWASA). Very unlikely the slum people has to pay higher than the relatively wealthier people of the city. In Dhaka city, slum people are usually boil the supply water before drinking but unfortunately the slum people find it difficult to afford boil the water due to cost and access.

In the above circumstance it's important to look over the scenario, investigate the problems and come up with a best possible solution. A low-cost and affordable drinking water treatment system that can be used by individual households or by a group can be a possible solution to overcome the water quality problem.

1.2 Objective:

The main objective of this study is to find an economic and affordable water treatment method for the slum dwellers of Dhaka city. The study will also focus on a comparative study of low cost water treatment method with the regular treatment methods like using expensive water filter, boiling the water etc. The study will focus on:

- Water supply and demand condition of the selected slum
- Existing water quality assessment
- Water borne disease rate among the slum dwellers
- Solid waste disposal facilities
- Develop an affordable treatment method for the slum dwellers.
- Performance evaluation of the treatment method
- Compare the efficiency of developed treatment method with regular treatment practice.

1.3 Scope of the Study:

The study is an effort to assess the existing water and sanitation crisis among the Dhaka city slums. The study will help to identify the present condition of slum people in terms of water quality, sanitation, waste disposal and water borne disease rate etc. Also it will help to assess the existing pipe network condition. The result of this study will better help to slum dwellers to earn the concern of the respective authorities. Considering the economic hardship of the dwellers, an economic and affordable water treatment system will help them have access to potable drinking water.

1.4 Research Methodology:

In order to carry out the objective of this study as described, a systematic methodology is developed and divided into following categories-

1.4.1 Selecting Best Fitted Slum for Study:

As Dhaka city has many slums it's important to find out the most suitable site/slum for the study. In this research, Korail Slum of Dhaka is selected for the study as it's one of the biggest and poorest slums of the city as well important for its location and existing condition. The place is suitable because of its poor condition and severe water crisis in comparison to the other slums of the city. The location of this slum also a major concern because the slum is located beside the Gulshan and Banani area which are highly developed and well organized in terms of facilities provided to residents. Bad housing and solid waste disposal facilities are also reasons for the selection.

1.4.2 Study Area Survey:

Surveying the study area is important in order to collect information and determine the present situation. In this study, surveying the study area is important mainly for checking the pipe condition, waste disposal facilities and existing water treatment facilities.

1.4.3 Collecting Sample:

An important part of the survey is collecting samples from study area. The samples are need to further study and the result describe the current condition. As one of the main focus of the study is to assess the water quality hence it's very important to collect the water sample and do the laboratory test.

1.4.4 Laboratory Analysis and Result:

Laboratory analysis would suggest the quality of the collected water based on which the filter/s would be developed. It's very important to consider the economic condition of the dwellers in order to get the solution as majority of the people are poor and beneath the average condition.

1.4.5 Develop the Water Filter/s:

Required water filters need to be developed based on the laboratory outcomes. Due to economic situation of the slum residents, the developed filter/s need to be economically viable.

1.4.6 Probable Outcomes:

The expected outcomes of the research are-

- Finding an economical and affordable water treatment method for the dwellers of Korail slum as well as the economically disadvantaged residents of Dhaka city.
- Test the existing water quality of that slum.
- Outline the existing water borne disease scenario of the area.
- Outline the existing piping system for supply water.
- Describe the water supply, sanitation and waste disposal facilities of that area.

CHAPTER 2

LITERATURE REVIEW

2.1 Background of Dhaka City:

Dhaka City has been developing rapidly as the capital city is the center of growth of the country. Industrial and infrastructure development of this city has result rapid urbanization and population increase as well as increasing poverty, unemployment and reducing open space. At present, many people in the city are striving to meet their basic needs like water, gas, electricity etc. Increasing population pressure makes the issue more vulnerable. Government now need to figure out the best possible and feasible solution to provide basic needs to its citizens. Figure 1 illustrates present insufficiency in water sector of the city. It is easily noticeable from the figure that water in Dhaka is not available all the year round and the quality of water is also questionable.

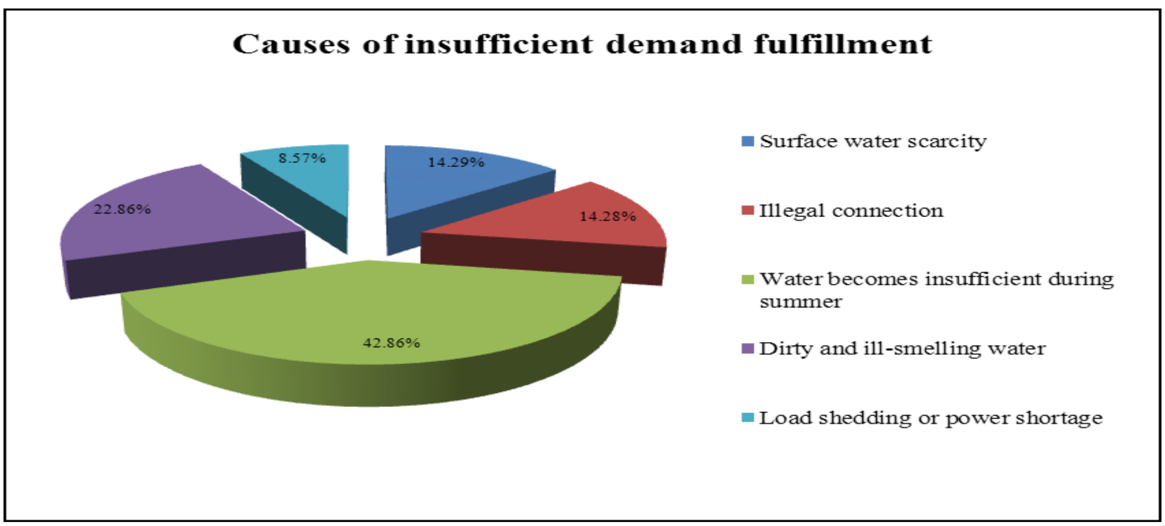

Figure 1. Causes of Insufficient Water supply (City Dwellers Point of View) (Unnayan Onneshan 2014)

2.2 Present Water Crisis of Dhaka:

Water supply of Dhaka city is mostly dependent on groundwater sources as more than 87% of total demand extracted from groundwater sources (Nahar et al., 2015). This huge extraction has caused a large decrease in groundwater table, with a 20 meters drop during last seven years at a rate of 2.81 meter per year (Unnayan Onneshan 2014). Present analysis forecasting that by 2050 the table will be lowered approximately 120 meters (Unnayan Onneshan 2014). In comparison to the groundwater depletion, the groundwater recharge rate is 1.33 (Unnayan Onneshan 2014) meter per year. Such findings imply that despite sufficient rainfall (1.87m/year) Dhaka city is experiencing a 1.48 meter per year of groundwater deficit (Unnayan Onneshan 2014). Moreover, the increasing rate of population, urbanization and industrialization has reduced the amount as well as the volume of surface water bodies surrounding by the city. Dhaka city is surrounded by four major rivers that could be a potential source of water but due to discharge of industrial waste and heavy pollution, surface water bodies are no longer useable. To meet the present water demand and reduce the pressure from groundwater source, DWASA, the water supply authority in Dhaka city has decided to collect the water from one of the largest rivers of Bangladesh, Jamuna. Although the distance is approximately 150km in order to get the quality surface water, DWASA decided to bring the water from that river. To do so they have to construct a pipe line from Jamuna River to Dhaka city.

Figure 2 shows the demand versus supply scenario of water. If the same thing will continue till 2050, Dhaka City will face a large gap of 704.3 MLD between total supply and consumption.

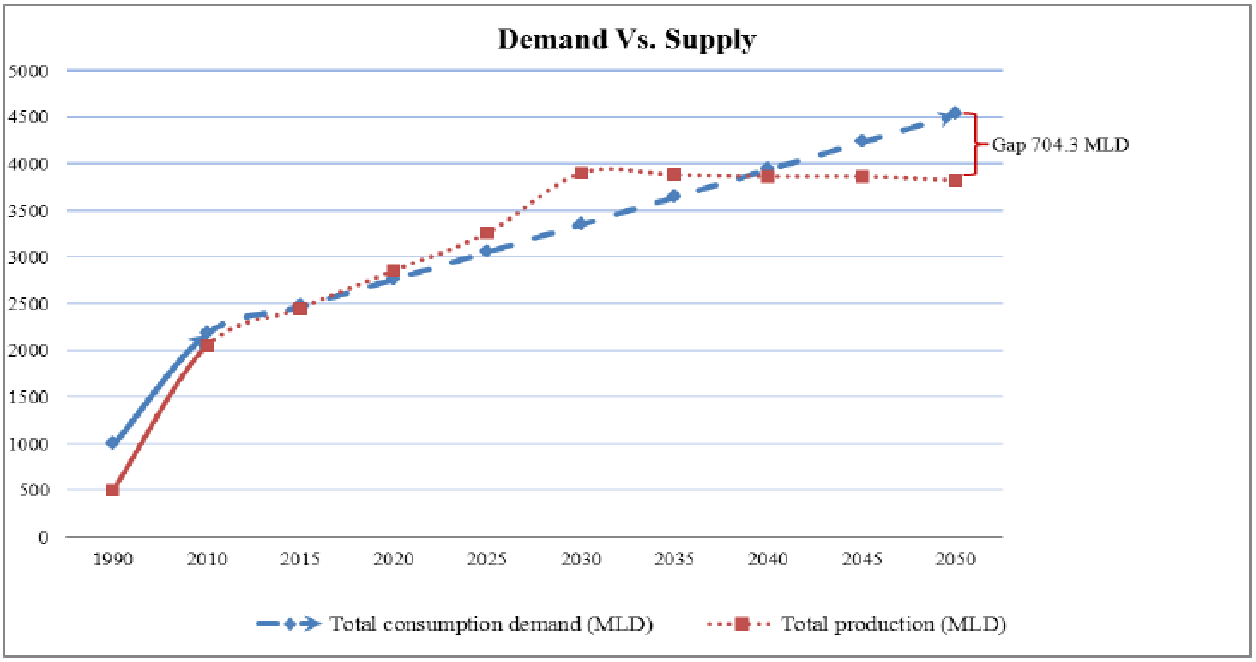

Figure 2. Demand vs. Supply Scenario (Considering 10% Production Loss) (Unnayan Onneshan, 2014)

2.3 Probable Future Water Crisis:

As Dhaka is the country's economic hub, more and more people are now moving to the city; and making the water supply condition more alarming. The present depletion rate of groundwater implies that if it continues, the groundwater resource will be depleted. One alternative could be collecting water from different sources apart from ground water. Sufficient treatment of surface water may be required to improve water quality. Unfortunately, most of the rivers of Dhaka are experiencing thermal waste because of industrial discharge which is eventually degrades the quality of water by reducing DO level, increase in toxins and destroying the aquatic lives of the river. Although Bangladesh is subjected to a heavy rainfall, water management is difficult as the rainwater mixes up with the polluted surface water and degrade the rainwater quality. Figure 3 shows a scenario of severe water pollution scenario of the Dhaka city:

Figure 3. River Pollution Scenario of the City (Dhaka Mirror, 2012)

At present, Dhaka City residents receive around 40 l/p/d of water in contrast to the demand of 150 l/p/d (Unnayan Onneshan 2014). The people of Dhaka city are limited in their daily activities by this little amount of water. Only 5.1 percent of total population of Dhaka city receives more than 60 l/p/d. On an average, 42.8 percent of the respondents receiving the 50 l/p/d and the rest (57.8 percent) are suffering from water scarcity despite piped connections (Unnayan Onneshan 2014).

2.4 Slums of Dhaka City:

Generally, a slum is defined as the settlement of housings with an infrequent growth in an unfavorable environment. In the slums, people are characterized as having inadequate housing and basic services. In the city of Dhaka, a remarkable number of people live in the slums and suffering from poor living standard. A majority of the slum dwellers lack basic human needs like energy, water, sanitation etc. Around 30% of Dhaka city population lives in the slums, making the scenario more critical (Hossain, 2014). In most of the city slums, high density living, continuous threat of eviction, inappropriate consumption of public resources, lack of basic services, unhygienic and polluted environment, great illiteracy rate, unemployment, under-employment, crime, drug addiction, social, moral and psychological degradation and poor health are very common which causes serious problem of the people living these slums. Figure 4 illustrates the slum population of Bangladesh as well as in its major cities. It's clearly indicates that Dhaka city has the highest amount of slum people compare to the other big cities of the country.

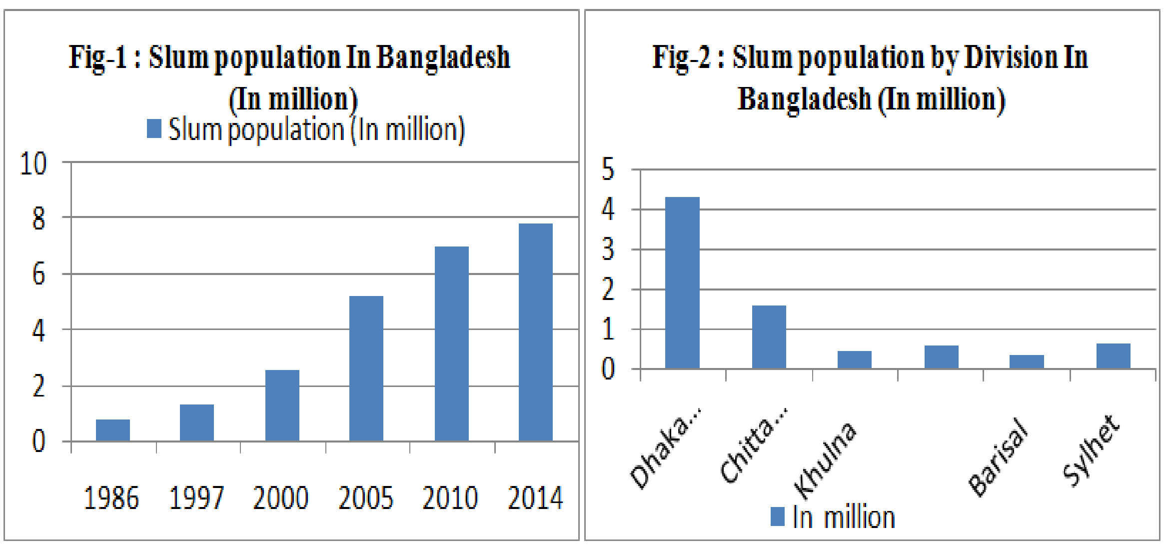

Figure 4. Slum Population of Bangladesh (Hossain, 2014)

2.4.1 Housing Condition:

As majority of the dwellers are poor and living below poverty line, the housing conditions of those slums are bad and unhygienic. People mostly use these houses to provide shelter from the natural elements. In terms of safety and protection, the houses are near unacceptable. Houses are mostly constructed of straw, leaves, gunny sacks, polythene paper, bamboo etc. Row upon row of linked tin sheds squeezed tightly together on top of poorly serviced land is hardly suitable for a healthy life standard. Most of the city's slums are in low lying areas which causes problems to the dwellers during the monsoon season as most of the slums flood during this time. Figure 5 shows the typical housing pattern of the slum areas of the city. As shown in the figure, housing in Korail slum is densely populated without having sufficient features for the dwellers.

Figure 5. Typical Housing Pattern of the Slum (Dhaka Tribune,2014)

2.4.2 Economic Condition:

The people living in the slums are mostly migrant people from the different parts of the country. They leave their home because of poverty or to change their economic conditions and thus come to city. Ultimately many can't change their economic condition and therefore they find shelter in the slums. The majority of the slum dwellers have no formal jobs to develop their livelihood. Males are often involved as semi-formal or informal jobs like rickshaw-puller, day laborer, street vendor, construction worker and small businessman. Many women work as maids-servant in domestic works, and garments worker in production works. Many women also work as day laborer at half of the wages of male laborers. As they are not efficient and productive on their works, employers who hired them, used to pay very little as their wages. Even children are working in order to contribute to their family. They generally work as scavengers, brick breaker laborers, vehicle conductors etc. In the poorest households with child workers, earnings from the children are significant, representing about one third of total household income. According to the Slum Census Report 2015, 40.98% of the slum population was employed where 65.53% was male and 11.91% was female while 59.02% people including children and student are unemployed with no specific job. The reported data claimed that the unemployment rate is very high among the slum population and the unemployed people usually engaged in begging.

Among the slum people, difference between earning and expenditure is huge. In a very expensive megacity like Dhaka, the earnings are very low in compare to the other people. According to the study, annual per capita income of slum dwellers is around TK.35000 ($455). Table 1 shows professions occupied by the slum dwellers and their annual average income which is less than the average per capita income of Bangladesh, $1314 (BBS, 2015).

Table 1:Annual Average Income of the Slum Dwellers of the City (Alamgir et al., 2009)

Livelihood Heads	Average Income (BDT.)	Average Income (USD.)
Petty Business	35500	460
Day Labor	38200	496
Rickshaw Pulling	38540	500
Small Job Service	45000	585
Others*	25400	330
Mean	36500	474
Others*= House wife, Maid Servant, Beggar etc.		

The reason behind their miseries is low income. A study of Bangladesh Bureau of Statistics shows that a 10ft*10ft room costs around TK.1000 ($13) per month in the slum. Also the slum dwellers have to pay another TK.1000 ($13) for electricity bill and TK.500 ($7) for water bill. A significant portion of their earnings are spent by paying bills and home rent. Moreover, they have pay for foods and other daily household chores. Still sometimes halfway through month they face shortage of money and are forced to borrow money from others or foods from shops, which just adds to their burden.

Because of the poor earnings, the assets belong to slum dwellers are negligible. According to the same study of Bangladesh Bureau of Statistics, the average market value of the assets of the slum dwellers is TK.7250 ($95). In most of the households there are a few low cost goods which are essential for urban living. In most of the households, there are low cost cooking utensils with an average value is TK.1035 ($14). Only a very few have some low cost furniture in their households. The percent of people who can afford their own television and radio/tape recorder in their households is very low. The slum residents do not owe any means of entertainment or better living standard. Studies show that the slum people usually buy second hand things at low cost and repair those things by themselves. Many of slum houses have sewing machines which also help them to save and earn some extra money.

2.4.3 Health Condition and Disease Rate:

The place where slum dwellers are living is not environmentally safe and cause several diseases among the dwellers, mostly to the children. Most of the slums of the city suffering by various water borne diseases such as diarrhea, dysentery, cholera and the rate is much higher than the national average. Children and women in slums frequently suffer from some form of malnutrition, such as- low birth weight, wasting, underweight, iodine deficiency and anemia. In the slums, mothers are unaware or excluded from the information of proper feeding practice to their children. This unawareness contributes very high infant and child mortality rate. According to a study conducted by the International Centre for Diarrhea Disease Research, Bangladesh (ICDDR, B) 90% of respondents "sometimes" experience hunger and only 10% said "never" and When slum dwellers were asked whether their family ate a balanced, nutritious diet, 94% responded in the negative. Another study from Bangladesh Demographic Health Survey (BDHS), 41% of children aged below 5 are suffering badly by underweight and 43.2% of those suffering from moderate or severe stunting. Disease rates among the slum dwellers are significantly high. Over 85% of the slum dwellers suffered by various diseases in recent times (< 6 Months). The common diseases are fever (39.5%), cough (7.8%), headache (6.4%), physical weakness (3.9%), high blood pressure (2.3 %) etc. The duration of sickness is 8-15 days. As most of the slum dwellers work on a daily wages basis, suffering period cause economic hardship among the dwellers. Maternal health services are not sufficient in the slum areas as many of the women seriously suffer or even face death during pregnancy or child birth. Due to the high cost of medical care, most of the slum women (65%) are compelled to receive health care from the NGO (Non-Government Organization) clinics or low- cost small medical centers. Unprofessionalism of the staffs, lack of privacy, religious barrier, long waiting time etc. are common shortfalls associated with these health care centers and NGO clinics. Around 60% of women give birth in houses where only around 25% of the deliveries are assisted by skilled attendants and rest of the 75% deliveries assisted by unskilled attendants, quack, and family members or even without any assistance. Among the children of the slum areas, around 92% of children are fully immunized against seven severe diseases which is a good sign for the children. But still many children are suffering by seasonal flu and water borne diseases. The health services that the slum population receives is lower than the services receives by other people of the country. Table 2 shows the main diseases amongst the slum dwellers. From the table it has identified that fever is the major disease to the slum residents.

Table 2: Disease Rate Amongst the Slum Dwellers (University of Dhaka, 2015)

Disease profile	No of people with disease	Percentage of households
Fever	1302	39.5
Gastric/Peptic ulcer	319	9.7
Cough	256	7.8
Headache	212	6.4
Diarrhea/loose motion	143	4.3
Physical weakness	129	3.9
High pressure	107	2.3
Pain in hand/leg/waist	91	2.8
Skin disease	77	2.3
Diabetes	67	2.0
Other diseases	591	18.8
Total	3294	100.0

2.4.4 Major Issues Related to Health Care:

In the slum areas of Dhaka city, there are several significant issues need to be solved in order to improve the health condition and disease rate among the dwellers. The major concerns are:

<u>Inadequate Sanitation and Hygiene Facilities:</u>

Among the slum dwellers, sanitation and hygiene practice is not up to standards mainly because of lack of awareness as well as insufficient physical facilities.

<u>Insufficient Infrastructure:</u>

The number of hygienic sanitation facilities is limited in the slum areas. As a result, people often use unhealthy sanitation systems like hanging latrines which is ultimately disposed in local water bodies that polluted the water. Open defecation is also very common in the slums creating additional health hazards that degrades water and air quality of adjoining areas.

Institutional Constraints of Hygiene Promotion:

To make the dwellers of the slums aware against the negative impact of unhygienic sanitation, educational institutions can play an enormous role. Hygiene education and social mobilization programs need to undertake in order boost up the awareness of the people. At present no such significant efforts been observed by the different institutions which leads the corresponding agencies become careless of their responsibilities and results because of proper coordination. Also sometimes there is a clear lack of sensitivity amongst majority of the agencies to serve the poor people of the slum areas. Proper institutional promotion can create the awareness to those poor people about their rights.

Waste Management and Disposal:

Production of waste is obvious in every community and thus disposal of waste. Very unlikely in the slum areas of Dhaka city disposal of waste and proper management of waste is absent. Dhaka City Corporation (DCC) already introduce state of the art technologies in order to dispose waste and solid waste produce by the inhabitants but the slum areas are excluded from this service. Majority of waste produced by the slum dwellers is never disposed and remain in to the slum. In order to improve the livelihood of the residents of the slum people, proper waste disposal system and waste management policy must have to be manipulated.

2.5 Water Supply and Sanitation System for the Slums:

To supply water amongst to the residents of the city, Dhaka Water Supply and Sewerage Authority (DWASA) is the only government authorized autonomous organization. Apart from supplying water, DWASA is responsible for several other issues like sewage disposal, storm water drainage etc. Apart from regular responsibilities DWASA facing several problems associated with water supply and sanitation to the city dwellers. Because of rapid ground water depletion, excessive pollution of surface water bodies, fast-growing urbanization, unplanned settlement, DWASA suffering a notable gap between the demand and supply of water. At present the daily demand of water is 150 l/P/d in contrast of that only 5.1% of dwellers received water of 60 l/p/d which means the gap between demand and supply is significantly high (Unnayan Onneshan 2014). Figure 6 shows the worse scenario of water supply among the slum residents of the city:

Figure 6. An Example of Water Supply Scenario in the Slums (UN University, 2014)

The main source of supply water is groundwater but due to rapid urbanization and concreting, groundwater table going down significantly.

Slum people who are already suffering by basic rights, badly neglecting by water supply mostly by potable drinking water supply. The gap between demand and supply is much higher than any other places of the city. Most of the slums are beyond the connection provided by DWASA and they have to rely on private organizations or other sources like standpipe. Despite little consumption, they have to pay more than middle-income or high- income group people. In Dhaka city, a poor household has to spend TK.500 ($6.5) per month for 30 l/p/d while a middle-income or high-income group family has to pay TK.400 ($5.2) per month for water supply of 45-50 l/p/d or more (Unnayan Onneshan 2014). Moreover, poor people have to buy additional water to maintain their daily chores. This extra expenditure makes problem on developing their livelihood.

Another major problem of supplied water is the quality as many study shown that the water supplied by DWASA significantly degraded by several water quality parameters given by World Health Organization (WHO). A recent study shows that 22.86% people of Dhaka city couldn’t drink water supplied by DWASA because of bad odor and heavily depends on bottled or jar water. Roughly 66% people used to boil water for drinking purpose while 50% of population use filter in order to get maximum safety (Hanchett, S, et al., 2003) The slum dwellers who do not have much money to buy expensive water filter to purify their water, depends on boiling water but due to excessive pressure on energy, these people merely get enough gas to boil water. As a result, they solely depend on drinking raw water and ultimately suffer by various types of diseases. Sometimes they buy water from private organization and sometimes using standpipes but these are not well enough to meet their requirement.

In slums where there is a DWASA connection, another problem is, political anomalies. Water distribution in the slums area in Dhaka City is informally governed by various groups such as political leaders, middle-men and middleman with the help of DWASA officials. Middle men are mainly those people having the control of a particular slum. Most of the time they are powered by political parties. Generally, slum dwellers needing water and those middle men arrange a supply connection for the dwellers taking some extra donation. Many middle men directly connected with DWASA officials help them to continue their illegal business. The role of middle men in the water supply system of the slums of Dhaka city are:

- Providing illegal water supply connection to the households with the help of DWASA officials.
- Illegal distribution of DWASA water by using reserve tanks.
- Providing water supply to the households and some religious institutions using unfair political power.

Despite paying monthly bill for water, slums dwellers pay extra TK.10000 to TK.15000 ($130-$200) for the illegal line provided by the middle men (Alamgir et al.,2009) Not surprisingly, they pay that amount of money to the middleman who helps them to afford such facility from DWASA. In case of any problems or difficulties, slum dwellers inform middle men rather contacting with the correspondence person of DWASA. Most of the slum dwellers are pleased about the service as at least they get water for their daily chores, although the method is illegal. There are few slums located very close to the headquarter of DWASA, but the adjacent slums are also deprived of water shortage as there are a few or no water pump or sources directly connected with the households of slum dwellers. Again the middle men who control the slums, establish some reserve tanks, toilets and shower rooms in a specific place of slums. Dwellers of those slums often use these facilities and pay the middle men. Almost 80% of slum dwellers who using such facilities are not satisfied with the distribution system and they revealed the amount they used to pay, much higher than the service they received.

Based on size and population density, DWASA now trying to supply water to couple of largest slums of the city. They established a main line and some lateral lines in order to supply water to the households of the slums. In those slums, water is supplied by DWASA twice a day, each for 10-15 minutes. Within this time frame people must collect water to meet the daily demand. Currently DWASA is trying to develop the distribution networks as well. The old corrugated still pipes are being replaced by PVC pipes in order to improve the quality of water. One slum of the city (Korail Slum) supplied by a PVC distribution system.

In terms of supply and demand, poor slum dwellers are still badly suffering, although DWASA is trying to improve their supply quantity and quality to the slum areas. Most of the slum dwellers still expressing their dissatisfaction because of poor quantity of supplied water. On average, daily supply to the slum area is 30 l/p/d (Nusrat et al., 2014). Slum people have to meet all of their drinking, shower, toilet and other household activities by this small amount of daily supply. A middle class family of Dhaka city consumes 10 and 7.5 times more water than a slum family and even they have to pay less than the slum people for water consumption bill.

Quality of supplied water is another major concern amongst the slum people. The water slum people received often violate the WHO drinking water parameter standard. At present less than 40% people of slums having the access of using potable drinking water and only 9% of total slum population having the access of managing solid waste produced by them (Biplob, P, et al., 2011) This results defecation of human and household waste directly to the open space, low-lying lands and water bodies and due to lack of sufficient water supply, people often drink dirty water suffered by various water borne diseases. Also the adjacent environment become polluted because of open defecation and cause significant degradation of air quality.

People who live in slums of the Dhaka city are clearly not satisfied with the quality of water provided by DWASA. Most of the dwellers said water is not drinkable because of bad odor. Around 40% slum people think the water is not safe to drink and having a poor quality. Dhaka city has only one water treatment facility for the whole city and according to their microbiology test, there is no such evidence of water quality degradation has found. So mostly the poor pipe connections are mainly responsible for the degradation of water quality. Still now, many areas of the city covered under the corrugated metal pipe networking systems. This metal pipes are an easy source of corrosion and thus degrade the quality of water. Moreover, unhealthy environment and livelihood, drinking unfiltered raw water make the scenario become more inferior. Amongst the slum dwellers, diseases like diarrhea, typhoid, fever, cholera are very common and people suffer by these diseases all the year round. Table 3 shows the major water supply sources of the slum residents of the city.

Table 3: Water Supply Sources Amongst the Slum Dwellers (University of Dhaka, 2015)

Characteristics		No. of HHs	Percentage (%)
Source of drinking water	Tube well	20	2.2
	supply water	353	39.2
	Electric motor/ pump water collected through tube well	416	46.2
	Filter water	38	4.2
	Others	73	8.1
	Total	900	100.0
Source of cooking water	Tubewell	14	1.6
	supply water	404	44.9
	Electric motor/ pump water collected through tube well	474	52.7
	Other	8	.9
	Total	900	100.0
Source of bathing water	Tube well	12	1.3
	supply water	400	44.4
	Electric motor/ pump water collected through tube well	476	52.9
	Other	12	1.3
	Total	900	100.0

2.6 Existing Water Treatment System of Dhaka City:

As a fast growing city, Dhaka facing some serious problem on the quality of water provided by DWASA. Rapidly growing population and industries add to the degradation of water quality mainly for drinking purpose. The major source of water in Dhaka city is ground water sources.

To reduce the excessive pressure on ground water source, DWASA now focusing on the surface water bodies to meet the demands. Dhaka could be a significant source of surface water as the city is surrounded by four major rivers. The water coming from these rivers could easily solve the water crisis of the city. But to severe population, water of all these four rivers need to be treated well before use. Although treating surface water is much expensive than the ground water, it could supply a remarkable portion of total water demand of Dhaka city.

To treat the water and provide water to the residents, DWASA operating one treatment plant near the city named “Saidabad Water Treatment Plant (SWTP)”. This is the only treatment plant for the city dwellers to provide fresh potable drinking water. The plant is able to supply 500,000 m^3 of water in everyday that approximately covers the 32% of total supplied in the city (Brac University, 2013).

Saidabad Water Treatment Plant usually treats the surface water collected from the rivers around the city. The Sitalakhya river is the main source of surface water of the treatment plant. Saidabad Water Treatment Plant is mainly a secondary treatment plant contributing prechlorination, coagulation, filtration, disinfection and pH correction etc. The treatment plant doing various physicochemical as well as bacteriological tests and in terms of these parameters, treated water of Saidabad Treatment Plant is safe to drink and domestic purposes. Other aesthetic properties of water like turbidity, color, taste, odor etc. are also under acceptable limit. Table 4 describes the quality of raw and treated water quality of the Saidabad Water Treatment Plant.

Table 4: Seasonal Variation of Physicochemical Parameters of Raw and Treated Water of Saidabad Water Treatment Plant (SWTP) (Alamgir et al., 2006)

Month*	pH	Turbidity (NTU)	Colour (TCU)	Conductivity (µS/cm)	TDS (mg/l)	Total alkalinity (mg/l as $CaCO_3$)	Total hardness (mg/ l as $CaCO_3$)	Fe (mg/l)	NH_3-N (mg/l)
January	7.39	4.7	14	380	195	173	145	0.12	3.67
February	7.39	7.2	31.3	430	220	225	177	0.13	6.24
March	7.46	8.3	21.5	500	254	230	170	0.18	7.06
April	7.42	5.4	18.6	420	225	225	165	0.16	3.08
May	7.19	11.2	10.18	250	126	120	189	0.20	1.09
June	6.87	49.4	10.0	130	65	70	50	0.70	1.28
July	6.95	51.54	12.0	120	61	60	60	0.80	0.39
August	7.20	53.23	09.0	130	63	50	55	0.85	0.33
September	7.22	61.53	10.0	130	65	60	65	0.80	0.40
October	7.06	31.52	18.5	135	67	60	65	0.40	0.41
November	7.13	15.29	23.0	202	101	100	108	0.30	0.21
December	7.42	7.30	18.0	326	163	156	145	0.11	1.25

*Monthly average values are presented. NTU = Nephelometric turbidity unit; TCU = True colour unit; TDS = Total dry solid; NH_3-N = Ammonia-nitrogen

Table 2. *Seasonal variation of physicochemical parameters of treated water of Saidabad Water Treatment Plant (SWTP) in the year 2004*

Month*	pH	Turbidity (NTU)	Colour (TCU)	Conductivity (µS/cm)	TDS (mg/l)	Total alkalinity (mg/l as $CaCO_3$)	Total hardness (mg/l as $CaCO_3$)	Fe (mg/l)	NH_3-N (mg/l)	Residual Cl (mg/l)	Total Cl (mg/l)
January	7.31	0.92	4	400	201	168	158	0.02	2.91	0.31	4.6
February	7.32	1.41	17	460	228	189	158	0.02	5.20	0.32	4.7
March	7.37	2.42	8.1	540	268	214	153	0.01	6.08	0.36	5.3
April	7.28	0.54	5.4	460	232	165	133	0.02	2.57	0.30	4.0
May	7.20	0.60	3.8	260	131	105	90	0.023	0.45	0.26	2.4
June	6.99	0.44	2.5	140	72	52	60	0.025	0.54	0.25	2.1
July	7.25	0.36	1.7	150	71	51	65	0.02	0.02	0.29	0.51
August	7.34	0.32	1.1	153	73	55	65	0.02	0.02	0.24	0.56
September	7.29	0.27	1.0	148	74	56	69	0.03	0.01	0.24	0.48
October	7.17	0.29	1.0	153	76	53	68	0.02	0.03	0.21	0.46
November	7.17	0.29	1.0	224	112	73	88	0.01	0.01	0.23	0.45
December	7.41	0.49	2.3	333	168	139	143	0.01	0.92	0.20	2.69

*Monthly average values are presented. NTU = Nephelometric turbidity unit; TCU = True colour unit; TDS = Total dry solid; NH_3-N = Ammonia-nitrogen; Cl = Chlorine

As mentioned before Saidabad Water Treatment plant is the sole treatment plant of the city and it can only provide 32% of total drinking water demand of Dhaka. Hence it is very important to extend the treatment facilities to meet the existing requirements of the city. To do so the government of Bangladesh has taken some actions to treat more water collected from the surface water bodies. Already, the Saidabad Water Treatment Plant extension project is approved, after completing this extension, there are plans to make new intake and pumping stations, raw water transmission mains, new sludge treatment plant and distribution primary mains. Apart from this extension project, DWASA also planning to build another treatment plant at Ghondopur, Dhaka which will be able provide 500 MLD of water using the water from the river Meghna. Also busing the water of Padma, another project is under approval which will be able to treats 900 MLD All of these projects are expecting to be finished by 2020 (Dhaka WASA, 2015).

Despite having several new treatment plants development, DWASA also focusing on potential rainwater harvesting and recharge the ground water depletion. It's also a sensible project of DWASA as Bangladesh receives heavy rainfall during monsoon and rainwater can play a vital role to groundwater recharge as well as to meet the demand of drinking water requirement. Although the project is called "risky" by DWASA think-tank because of the potential to contaminate the precious and clean groundwater. However, if potential cleaning and storage systems are developed, rainwater harvesting would become a major source of water for both drinking and domestic purposes, especially for slum dwellers who do not have the ability of buying water and can hoard the rainwater for their daily chores very easily.

2.7 Low Cost Water Treatment Technologies:

In the city of Dhaka, developing more water treatment systems is needed because of high demand for drinking water as well as the lack of existing treatment facilities setup for treating water. A significant portion of the city dwellers are living in slums and having a poor livelihood, concern must go for the developing low cost treatment systems so the poor people groups can easily access the fresh water for drinking and household purposes. Because of land shortage and high price of land in Dhaka, it is expensive to build new water treatment plants inside or around the city. However, it is very important to insure the access the fresh water amongst the people from every aspects of life. So to provide the full access of water to the poor people, development of low cost water treatment technology would be a potential solution. While developing new technologies, economic aspect would be the major consideration. The technology could be in house or community base so every single person will come under the shade of a treatment system. Community-wide water infrastructure is the best option, but until everyone has that, there are other, inexpensive clean water solutions. Considering the economic condition of the slum dwellers of the city, some effective as well as economical in house and community base water treatment systems are outline in the following sections:

2.7.1 Clay Filter:

Clay filters are an easy to develop filtration technique that can be built in house. Clay Filter can remove many significant disease causing microbes. The main components of this filter are sawdust, clay, plastic or ceramic bucket. In this filter, clay is mixed with sawdust and given a flower pot shape and fire it in kiln. Because of firing, sawdust burns and leaving small pores in the resulting ceramic through which water filters. This technique is very effective against many water borne diseases and thus used by many organizations around the world. Figure 7 shows the clay filters:

Figure 7. Clay Water Filter (Engineering for Change, 2012)

2.7.2 Bone Char Filtration:

This filter is especially effective against the heavy metals and other toxins like arsenic. Arsenic is a major problem in water of Bangladesh causing skin, bladder, kidney and lung cancer. Uranium is another harmful element found in the water and bone char filter is also effective against the uranium. Bone char. It made from crushed and charred cattle bones that are cheap and locally available. With the right design, filters can clean drinking water right in the home.

Figure 8. Bone Char Filter (Engineering for Change, 2012)

2.7.3 Slow sand Filtration:

Unlike previous two filtration systems, slow sand filter can be designed for a whole community. Slow sand filter is a combination of different parts like storage tank, aerator, pre-filters, disinfection stage, filtered water storage tank etc. The number of filters and filter types that are used in a slow sand filtration system will depend the quality of the source water and will be different for each community. Figure 9 shows the slow sand filtration system:

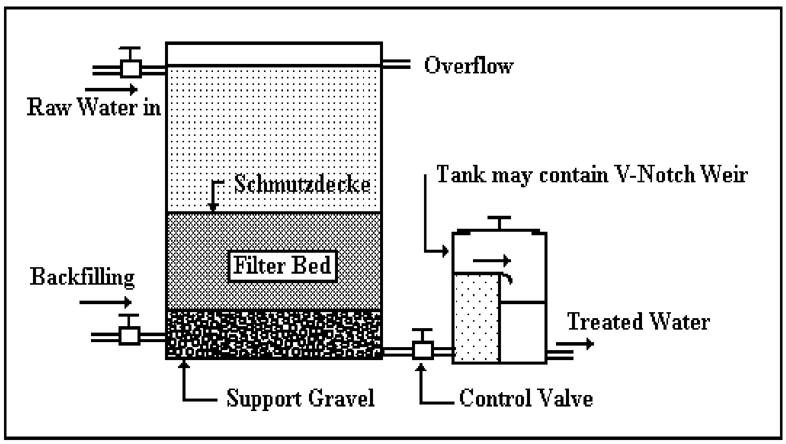

Figure 9. Slow Sand Filtration System (Engineering for Change, 2012)

2.7.4 Bamboo Charcoal:

This filter is a very good solution for especially poor income people and it is possible to makes it at home. The main constituents are charred bamboo, gravel etc. All materials are readily available, cheap, and environmentally sustainable. This system requires minimum maintenance which is another positive aspect so poor people can use it with a minimum maintenance cost. Considering economic aspect, this filtration system would be an affordable water treatment system with minimal maintenance and handling effort and cost. Figure 10 shows the filtration system using Bamboo Charcoal:

Figure 10. Bamboo Charcoal Filtration System (Engineering for Change, 2012)

2.7.5 Solar Sterilization:

The cheapest way to treat water when cost is more important than time and convenience. This is a simple method of leave a plastic bottle of water to the sunlight. The sunlight kills the microbes and other waterborne disease causing elements of the bottled water using UV radiation and heat. To accelerate the disinfection, some highly designed solar disinfection device are available on the market. The device contains a thermal indicator to let the drinkers know that water is safe to drink. Its black backing helps it absorb more sunlight. Another disinfection indicator uses to measure the exposure of sunlight and it gives signal when germs are dead. Figure 11 shows the Solar Sterilization method:

Figure 11. Water Purification Using Sunlight (Engineering for Change, 2012)

2.7.6 Solar Distillation:

A very effective water treatment system can even treat the muddy, salty or any other type of undrinkable water. The main treatment elements are evaporation and condensation. Specially to purify the salty water is the most unique aspect of this treatment technology over any other technologies describe in this section. A solar still can actually be a cheap and simple piece of shaped plastic or glass, or they can be more highly designed devices depends on the intensity of harmful elements and microbes to the water. Functionally the still allows sunlight through a clear panel onto the polluted water. Eventually the water heats and evaporate and finally condenses to the specific side of the panel. Later the water flows through a container specified to collect water. This system is effective and significantly kills the harmful pollutants from the water. Figure 12 shows Solar Distillation System:

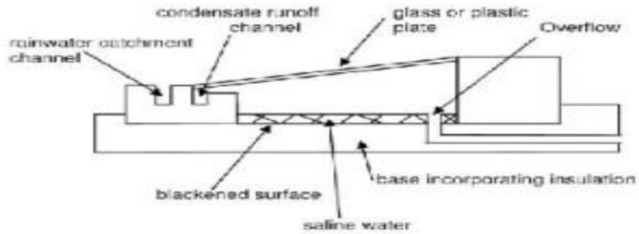

Figure 12. Solar Distillation System

2.7.7 Homemade Filter:

This is the easiest form of water treatment system though way effective to kill microbes and diseases causing pollutants from the water. A plastic bottle is again being the main part of that system. Other components of make this system are pebble, sand, piece of cloth and charcoal. The system consists of couple of layers of those components into a bottle once the bottom of the bottle cut downed. Then, the layers of the other components placed according to the figure. This filtration system is easy made and can even made by a household. For individual practice of treating water, this method is very convenient and fruitful as well. Figure 13 illustrates the system:

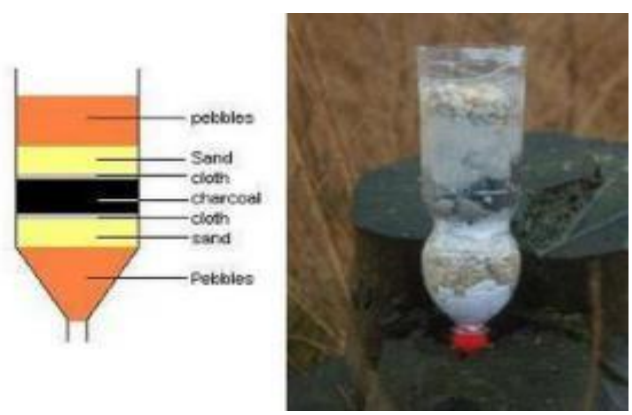

Figure 13. Emergency Homemade Filter (Engineering for Change, 2012)

2.7.8 Chlorination:

Like slow sand filter system, chlorination is another technology to treat water for the community base system and perhaps the most reliable and obvious solution of treating water. It is markedly effective against the diseases causing microbes and keep the water safe against many contaminants long after it added. Figure 14 shows the Chlorination system:

Figure 14. Chlorine Filtration System (Engineering for Change, 2012)

2.8 Water Filtration Using Clay Filter:

Previously, several methods of treating water were discussed based on availability of materials, expenses of those materials and the efficiency of the system. Analyzing economic perspective of the slum dwellers and overall conditions of the slum, the clay water filter has been proven as one of the most efficient systems of treating the water of Korail slum. Clay water filter is very effective against one of the most important pollutants of the water, E. coli. In the raw water sample of Korail slum, the E. coli concentration is above the drinking water standard. A clay filter may be an effective treatment system against the E. coli concentration of the water. Also in Bangladesh, raw materials of the clay filter are available, economical and more affordable for the residents. There is no extra space and money needed for setup and most importantly a clay filter can be used in individually, meaning any household can use this filter.

2.8.1 Potential Role of Clay Filter:

Clay is a quire common material and used for various purposes such as pottery, gardening etc. especially in the developing countries. people who live in the rural areas in developing countries are able to identify the importance of clays in their communities. Many non-governmental organizations are already working on establishing factories that produce ceramic water filters in the different parts in the world. The performance of clay water filter has been investigated and reported by many groups of researchers. Research shows that clay water filter is among the top five best treatment options for reducing turbidity and bacteria by more than 99% (Sobsey 2002; Sobsey et al., 2007). It is known that clay filter along with bio-sand filters, are the most sustainable technologies in the field of purification of drinking water in developing countries (Sobsey et al., 2008).

2.8.2 Filter Composition:

Common composition materials of the clay filter are clay, brick, saw dust, rice husk. Recent improvements have seen noble materials such as silver used as lining in the CWF's for further purification system (Sobsey et al., 2008). Filter performance is mostly depending on the proper composition of clay and combustible materials (saw dust, rice husk) as flow rate through the filter varies with the variation of the proportion of saw dust with clay. A 50:50 proportion of clay and burnout materials by their weight exhibits the maximum discharge followed by 30% and 20% composition of burn out materials and the slowest discharge rate was associated with the 5% proportion of burn out materials (C.C. Nnaji, et al.). Figure 15 illustrates the proportional importance of sawdust in filtration rate.

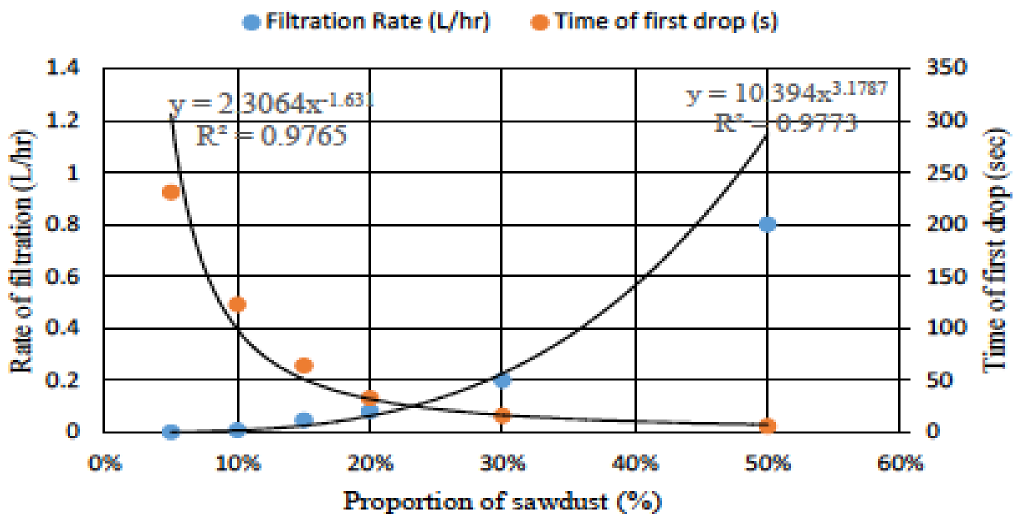

Figure 15. Sawdust Effect on Filtration Rate (C.C. Nnaji, et al.)

The mixture is then moistened with water and pressed into molds and pressed into the required shape. They are kept at room temperature to help green-wares lose water by drying them at room temperature. Once dried these green-wares are fired in a kiln to about 850°C. The sawdust is burnt off during the high temperature of firing, leaving behind the red colored clay filter with micro/nano pores in them. If the proportion of sawdust is changed in the mixture, the flow rate may also be affected because of the changes in geometry of the pores formed.

2.8.3. Filtration Procedure:

The main filtration mechanism of clay water filter is screening through the interconnected pores that contribute to flow rates are of dimensions smaller than the particles of the contaminants though one of the major disadvantages of this process is the possible clogging of the pores that eventually reduces the flow rate. Figure 16 shows the different types of pores can be present in the clay filter.

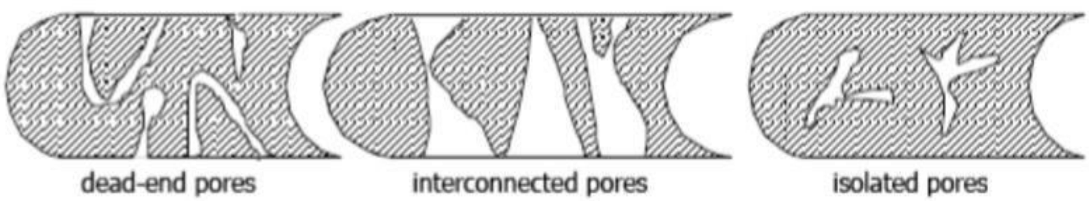

Figure 16. Types of Pores (Xialong, 2005)

Another form of filtration process is sedimentation where particulates due to larger densities than water slowly moves through the water-head and rest on the surface of the filter element. These particles are usually removed by a cleaning the filter.

2.8.4 Removal of Microbes:

Clay filters exhibits a very good removal rate against microbes such as E. Coli. The effectiveness of the ceramic water filter in microbe removal is mainly because of two reasons: screening and silver addition. In table 5, effectiveness in bacterial and viral removal for period 2000-2010 is given:

Table 5: Previous Literature on Bacterial and Viral Testing

References	Bacterial type	Reduction	
		%	LRV(log10)
Dies(2001)	Escherichia coli	>98	
Sagara(2000)	Escherichia coli		4.6
Lantagne(2001)	Cryptosporidium parvum		4.3
Roberts(2004), Duke et al (2006) & Hwang (2003)	Escherichia coli Diarrhoeal disease Total coliform	GM98 Mean 46 94-99.9	
Dies 2003	Escherichia coli	>98	
Coulbert(2005)	Escherichia coli	99.8	
Franz(2005)	Escherichia coli	92-100	
McAllister(2005)	Bacteria Viruses	99 20	
Clasen et al(2006) Halem (2006)	Escherichia coli Clostridium spores		3-6.8
Oyanedel-Craver &Smith (2008)	Escherichia coli Viruses	>97.8 <90	3.3-4.9
Brown &Sbsey(2010)	Escherichia coli MS2 Bacteriophages	Mean 99 90-99	2.1-2.9 1.2-4.1
USEPA(1987) &NSF(2003)	Bacteria Viruses Protozoa		6 4 3
Brazil ABNT NBR 14908	Escherichia coli Viruses		2

2.8.5 Removal of Turbidity:

Turbidity concentration of the water and the flow rate of the clay filter is inversely proportional. That means, higher the turbidity, lower the flow rate. This is due to the clogging of the pores by particles during filtration. Thus, it is important to clean the filter on a regular basis. Scrubbing could be a potential solution of cleaning the filter surface. Although scrubbing temporarily increased flow rates, ceramic water filters did not achieve their original flow rate and even with scrubbing, flow rates continually diminished However, some field investigations users have reported that filters provided enough water for additional uses and only 5% of filter disuse was attributed to unsatisfactory flow rates (Brown and Sobsey 2006).

2.9 Clay Water Filter Around the World:

As an economical and less expensive source of filtering water, clay is now using some African countries where potable water was a scarcity. In Kenya, two students from Pennsylvania State University, USA developed clay filter which was able to remove 98% of Bacteria from the water (Inhabitat, 2013). According to their experiment, the filter itself was able to remove 80% of bacteria and pathogens. Then, after coating the inside of clay filter with silver, it eliminated 98% of bacteria. They took help from an organization named Potters for Peace for designing the filter. According to another study conducted in Nigeria, clay water filter removes up to 99% of bacteria and pathogens from the water (Plappally et al., 2010).

In 2007, Cambodia arranged an experiment of using clay filter to its low income areas with a collaboration of UNICEF. The locally made clay water filter removed up to 97% of bacteria concentration from the water with a making cost of $7.50 (UNICEF, 2007). Table 6 shows the advantages of clay filter (which is states as Ceramic Filtration in the table) over other low-cost treatment methods.

Table 6: Comparison of Clay Water Filter with Other Filtration Methods (Safewaternow, 2016)

POU Water Filtration Technology	Initial Cost	Unit Cost (¢/L)	Economic Sustainability	Effective Against	% Diarrhea Reduction (95% CI)	Contribution to Local Economy	User Acceptability	Comments
Ceramic Filtration (CWF)	$10-$20	0.03-0.14	High	Bacteria; Protozoa; Parasites; Turbidity	46%	High	High	Low cost, effective, high acceptance
BioSand Filtration	$67	0.025 (1st year)	High	Bacteria; Viruses; Protozoa; Turbidity	47%	High	High	Effective, high acceptance
Chlorination	none	0.01-0.05	High	Bacteria; Viruses	37%	Moderate	Moderate	Portable - good for emergencies
Flocculation/ Chlorination (PuR)	Cloth, stirrer, 2 Buckets	1.00	Moderate	Bacteria; Viruses; Parasites; Metals; Turbidity	31%	Moderate	Moderate	Portable - good for emergencies
Solar Disinfection (SODIS)	Plastic bottles	Minimal	High	Bacteria; Viruses; Protozoa	31%	None	Low	Simple
Boiling	none	Cost of firewood	Moderate	Bacteria; Viruses; Protozoa		Low	Moderate	Simple

CHAPTER 3

WORKING METHODOLOGY

3.1 Selection of the Slum:

In Dhaka city, 30% of its total population lives in the slums (Hossain, 2014). Most of the slums are facing the same type of problems associated with water, sanitation, waste management etc. Amongst all of these slums, some specific slums are very identical in terms of their population, adjacent areas, standard of livelihood and the intensity of problems. For this study purpose, amongst all, the Korail slum was selected as the study area. This is one of the largest slum of the city having a population of around 200,000 (Biplob et al., 2011). Despite this large population, this slum is important because of its location as it’s located adjacent to the two very posh residential and commercial areas of the city. Figure 17 shows an aerial view of Korail slum. Also, the figure shows the Gulshan area located right after the Korail slum, one of the most expensive areas of the city.

Figure 17. Aerial View of Korail Slum (Wikimapia, 2014)

The dwellers of that slum are extremely poor and are often suffering many diseases, mostly water borne diseases like diarrhea, cholera, and dysentery etc. because of the lack of clean water supply. Although the slum is within the water supply coverage area of DWASA, disease rate is significantly higher because of the quality of supplied water. A variety of family sizes were observed in this slum, some big with 8-10 members while some of with 3-4 members. Hygiene practice and sanitation is mostly absent in this slum and many of people, especially children use open defecation. There is no proper solid waste management system in the slum thus the dwellers use open space to dispose the solid wastes from their household activities and personal use. Dwellers are poor income people and mainly occupied in the professions like day labor, office peon, street hawker, carpenters, boatman etc. The majority of income is spent on housing and food so they hardly have enough money to fulfill the other household activities. Table 7 indicates the details information about Korail slum including its population, water quality and sanitation facilities.

Table 7: Details Information of Korail Slum (Biplob et al., 2011)

Location	Korail Slum, Gulshan, Dhaka
permanency	49 years
Area	85 Acres
Number of Household	25,000
Population	200,000
Water Facility	2 Water Points for Collection
Sanitation facility	350 Water sealed latrines, 250 bucket latrines, 540 hanging latrines
Drainage Facility	Discontinuous Drainage
Solid Waste Management	Open Defecation

3.2 Background Information of Selected Site:

Korail slum began at 1961 on a designated government area. Land was allocated for the telecom department, however because it sat unused, eventually it was grabbed by some local people with political power (Shiree-DSK, 2012). In 1990, 90 acres from the original land was given to the water department board, violating the laws. Individuals, who had the ownership of the land, took legal action against this allocation with the telecom board reclaiming that 90 acres of land from water department. On that stage, there are three parties who are stakeholders of today's Korail slum- telecom board, water board and private landowners. After 1990, unused pieces of land were gradually captured by different telecom board officials, political godfathers and city ward commissioners. Those people started renting land to house low income groups of the city and eventually because of high demands of low rate housing, inhabitants slowly expanded to create

Korail slum as it is today. Nowadays, many people of the slum are squatters on illegally government land.

3.3 Present Condition of the Slum:

According to a study conducted by the students of Rajshahi University of Engineering and Technology (RUET), the present condition of the Korail slum in terms of different aspects are:

3.3.1 Land Owner:

Amongst the all dwellers, 7% of residents has own land, although their acquisition was illegal. 11% of residents states that the owner of the slum is BTCL, 30% people said that the actual owner is DCC and 52% of people said Government of Bangladesh (GoB) is the actual owner of this slum. The land ownership breakdown shows in Figure 18:

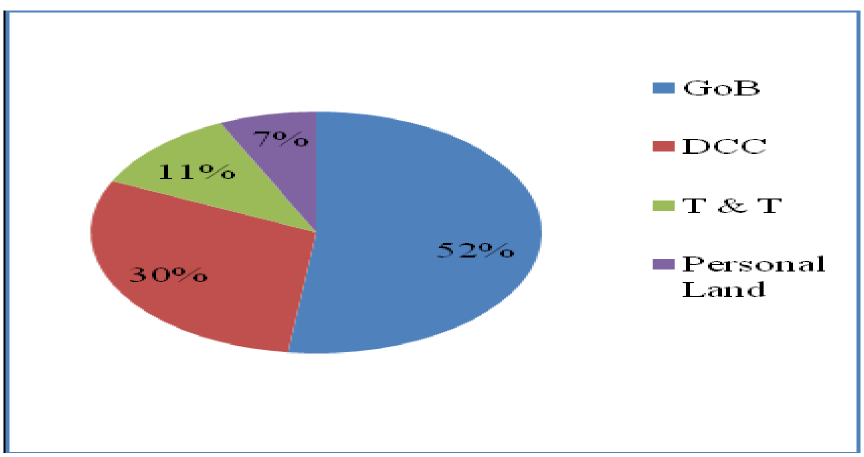

Figure 18. Actual Slum Owners (Biplob et al., 2011)

3.3.2 Occupation of the People:

According to the questionnaire, 4% responded said that they work in the industry as a worker. 17% of responded said they were occupied as a street hawker. Majority of responded (47%) are rickshaw pullers. For monthly income, 49% responded said their monthly income is around TK.3000-TK.5000 ($39-$65) and rest of the 51% people said about the range of monthly income in between TK.5000-TK.8000 ($65-$110). The amount they mentioned is extremely less than the average income of the dwellers of the city. Their income hardly affords the all the basic demands of them (Biplob et al., 2011)

3.3.3 Water Supply:

Korail slum is under the coverage of DWASA, thus DWASA supplies water to the slum. Though the supplied amount is not quite sufficient and dwellers depend on other supply sources like NGOs and purchasing water from different organizations. DWASA supplies water around 3-4 hours a day and residents have to complete their all daily chores using and storing it for a day. However, DWASA only supplies 57% of total water demand. The remainder of the 43% of people generally use shallow tube-wells or sometimes they purchase water from other organizations to meet their daily chores.

3.3.4 Availability of Water:

The water supplied by DWASA is not satisfying for the residents in terms of quality or quantity. Amongst the dwellers, 79% responded were not satisfied by the availability of water and they barely have sufficient water to do their household activities. Only 21% responses were satisfied with the availability of water supplied (Biplob et al., 2011)

3.3.5 Defecation Practice:

The Korail slum is experiencing a worsening condition of sanitation and defecation practices, like other slums in Dhaka city. 54% of the people use hanging latrines. The main shortfall of this type of latrine is these latrines are mostly above the water bodies like rivers, canals etc. and excreta goes directly to the water bodies and degrades the quality of surface water source. Unfortunately, many people of the slum are using these polluted surface waters for their house hold activities. 29% and 17% people are using Pit and Bucket latrines respectively. Most of the latrines are unhygienic and are a significant source of spreading diseases. No proper hygienic latrines such as water sealed latrine exists in the slum area, hence there are no sanitary devices. The slum doesn't have any separate sanitation blocks for male and female. Figure 19 shows the disposal method of human waste.

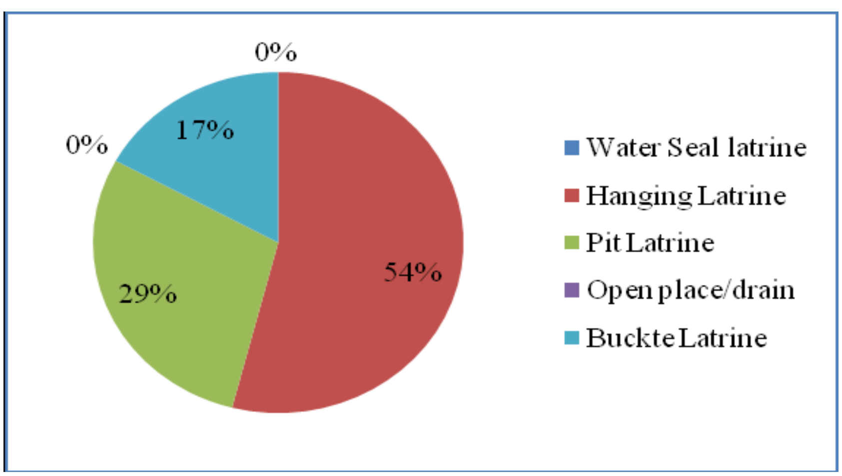

Figure 19. Mode of Defecation (Biplob et al., 2011)

3.3.6: Solid Waste Management:

The management of solid waste inside the slum area is also lacking. Most of the dwellers dispose of their solid waste in the open space due to the lack of solid waste disposal sites. Solid wastes include food waste, paper, rubbish, ashes and residues, special wastes such as street sweeping, roadside litter and abandoned vehicles are discharge inside the slum into the open air causing significant degradation of environment as well as health of the dwellers. Almost 99% respondents are not satisfied for the solid waste management in Korail slum area while only 1% people is satisfied for the solid waste management in that area. In the slum area, some people earn extra money by selling compost. Waste is occasionally collected from the door to door system and disposed of at the communal bins of DCC. Adjacent to the telecom board office, solid wastes are collected by bins and the trucks waiting outside at the main road to collect the waste from the bins. Some wastes are also put into the garbage bins of DCC. Figure 20 shows the solid waste problem in the slum.

Figure 20. Present Condition of Solid Waste Inside the Slum (Biplob et al., 2011)

3.3.7 Disease Rate Investigation:

The rate of diseases, especially water borne diseases in the Korail slum is much higher than the average of the city. Because of environmental pollution and pollution of adjacent water and air, disease rate amongst the dwellers is significantly greater. The most common diseases amongst the dwellers are diarrhea, dysentery and cholera and the rate is 50%, 24% and 26% respectively. Maximum medical expenditure is associated with these three diseases with an average recovery period of 10 days.

3.4 Field Visit:

A field survey was conducted in the Korail slum in order to collect the water samples, provide a visual observation of the pipe network and to observe the existing environmental conditions and the lives of the slum dwellers. The survey team led by Mr. Ashequr Rahman also talked to the slum dwellers to get the information regarding water supply, sanitation, existing water treatment systems, defecation procedure etc. Slum residents discussed about the overall scenario and the way of living and their socio-economic condition of life. The survey team collected several samples of water from the slum. For the first batch of laboratory analysis, the survey team collected five water samples from the slum. Four samples were collected from the same water discharge point but different time period of the day. The last sample collected was the boiled water just to see the difference between raw water and boiled water. For the second batch of laboratory analysis, 30 liters of raw water was collected again from the same discharge point but this time the sample was collected at one time. In Korail slum, water is treated and supplied by the central water treatment system of Saidabad. In the Korail slum, very few people can afford expensive water filters to treat the water, so the people of the slum use boiling as their only way to treat the water. But the fuel cost is difficult with their income. However, many still try and to boil the raw water. The consequence of drinking raw water effects their health and disease is very common amongst the dwellers of the slum.

To compare the quality of water of the Korail slum, the survey team also collected another sample of water from a residential area of Dhaka city, Dhanmondi. Dhanmondi is one of the affluent residential areas of the city also connected to the DWASA main and Saidabad treatment plant. Figure 21 shows the existing water supply and piping system of Korail slum.

Figure 21. Existing Water Supply System of Korail Slum

3.5 Water Quality of the Slum:

To test the slum water quality comparing to the quality of water in the other residential areas, several tests were completed. By the field inspection, 5 different samples of water collected from the household of the slum including a boiled water sample. Four samples were collected directly from the same water supply source (Pipe) at different times of the day. Also. Another raw water sample of Dhanmondi area was collected. This area is one of the affluent residential areas of the city. This sample was collected and tested for comparison purposes. All samples were taken to the lab of Bangladesh University of Engineering and Technology (BUET), the biggest engineering institution of the country. After the first sampling, it has found that raw water of Korail slum is highly concentrated by the E. Coli and turbidity. Other pollutant parameters such as PH, BOD, Hardness, Ammonia etc. were in the safe zone. Because of the high concentration, only E. coli and turbidity test was conducted for other 3 samples and every time E. Coli and turbidity concentrations were found significantly higher than the Bangladesh Drinking Water Standard and WHO standard. Boiled water of Korail slum also could not satisfies the E. Coli standard. Raw water sample of the Dhanmondi residential area satisfies for turbidity concentration but failed to satisfies E. coli concentration. The results of the water testing were not unexpected. Unlike the water of Korail slum, water sample of Dhanmondi residential is much better than the water quality of Korail slum in every perspective. All parameters except E. coli concentration of the water satisfies both local as well as WHO standard for drinking water. The raw water of Korail slum detected several deviations on two of the important water parameters-turbidity and E. coli concentration. Both parameters are above the local and WHO drinking standards so in this study, treatment systems for both E. coli and turbidity has highlighted mostly. Table 8 shows the result of water quality in terms of different pollutant parameters.

Table 8: Water Quality Data

Parameters	**Raw Water of Korail Slum**	**Boiled Water of Korail Slum**	**Raw Water of Dhanmondi Area**	**Bangladesh Drinking Water Standard**	**WHO Standard for drinking Water**
BOD (PPM)	3.8	3.2	2.6	2.5-6.5	3-5
PH	6.5	6.81	6.6	6.5-8.5	6.5-8.5
E. coli (CFU)	100, 52, 58,55 (per 100 ml)	5/100 ml (tested 100 CFU sample)	28/100 ml	0	0
Turbidity (NTU)	15.82, 12.25, 12.0, 11.58	3.1	1.2	10	5.0
Hardness (mg/L)	109	102	197	200-500	500
Ammonia as NH_3-N (mg/L)	.42	.29	.39	.50	1.5

3.6 Preparation of making Clay Filter:

While making the clay filter, a manual provided by Massachusetts Institute of Technology (MIT) was followed. The main components of clay filter are dry clay, water, burned brick, rice husk, silver and sawdust. Silver is a very good absorbent of pathogens. All the materials are readily available and economical in Bangladesh. Materials are mixed with a ratio provided by the MIT manual book. Table 9 describes the recipe of preparing the clay filter.

Table 9: Main Recipes of Clay Water Filter (MIT, 2010)

Filter Quantity	**Dry Clay (kg)**	**Rice Husk (kg)**	**Dry Saw Dust (kg)**	**Burned Brick (Kg)**	**Total (kg)**
1	5.5	1.0	2.0	.50	10

The filter wall is porous allowing water to percolate through the porous surface of the filter. Once the all materials are mixed, it was formed into a flower pot shape and dried and fired. Without drying before the firing, the filter will undergo a significant change of volume in the firing kiln which will cause cracking in the filter surface. The drying process continues for up to 48 hours and sunlight is used as the natural dryer. While drying, the filter needs to be rotate in 90 degrees clockwise about its vertical axis for the uniform drying by the sun. Once the filter is dry enough to touch so its shape remains unchanged, firing process starts. For firing, filter needs to be placed in to a sealed kiln where the filter heated around 4 hours with an average temperature of 550° Celsius. However, in a different study of Dies (2003), the temperature was mentioned as 850^0 Celsius. For this study, the filter was burn with a temperature of 550° Celsius. The filter was made by a local potter. Figure 22 shows the filter made for this study.

Figure 22. Clay Water Filter Designed for the Study

3.6.1 Filtration system:

Filtration method of clay filter follows gravity flow. Filtration system requires nothing but pouring the water in to the filter. The filter automatically filtrates the untreated water and percolates the water to the water bucket placed underneath the filter. Pore of the clay filter retains the bacteria and pathogens. Pore size of the filter usually less than 0.2 micron which is less than the usual size of bacteria and pathogens 0.50-2.0 micron (microbiology info, 2015).

3.6.2 Processing of Water samples before Filtration:

Collected raw water samples did not go through any specific sterilization procedure prior testing. For bacteria concentration, 250ml of sample for each testing was separated for testing. The sample was separated by a container described in EPA method given by the BUET. The container was sterilized by itself so there was no need for any further sterilization. Sample containers were positioned such that the mouth of the container was pointed away from the sample point. After removal of the water from the container, a small portion of the sample should be discarded for the testing. After the filtration, the samples were immediately taken to the environmental lab of BUET. Prior moving to BUET lab, no further preservation or refrigeration was taken. For turbidity testing, raw water samples were collected by plastic bottle. Prior collecting the samples, bottles were thoroughly cleaned and rinsed to avoid any additional contamination. No preservation takes place before and after filtration. After filtration, the samples were taken to BUET lab along with other samples.

3.7 Water Filtration by Sand Stone Turbidity Filter:

A sand-stone turbidity filter is especially effective for removing turbidity in water. Turbidity is a major problem in drinking water, the higher the concentration of turbidity present in the drinking water, higher the risk of developing a disease called Gastrointestinal Disease which is especially problematic for the immunocompromised people. The main reasons behind the turbidity concentration of water are:

- Phytoplankton
- Sediments from Erosion
- Waste Discharge
- Algae Growth
- Urban Runoff

In the city of Dhaka, because of rapid industrialization, open disposal of waste has been an alarming issue along with runoff of polluted industrial discharge. Careless disposals of hospital wastes, personal care products and open defecation also make the scenario worse. As a consequence, water gets polluted and turbid. Also because of poor maintenance of supply networking systems, using old steel pipes can cause the water pollution. According to the field survey conducted by the research group, it has confirmed that in Korail slum area, most of the piping systems consist of old galvanized iron pipe with visible appearance of rusting.

3.7.1 Preparing Sand-Stone Turbidity Filter:

The clay filter is mainly effective against the E. coli concentration in drinking water. But in the water samples collected and tested from the Korail slum, has also a high concentration of turbidity. To remove the turbidity concentration from drinking water, sand stone filter was proposed in this study alongside with clay filter. Same as clay filter, making sand stone filter is not also a difficult task. It requires all local materials which are cheap and readily available. The main components of sand stone filter are-

- Gravel
- Sand
- Charcoal
- A piece of cloth

The procedure of making this filter is easy and doesn’t take a lot of time and money. Most importantly, it requires no technical knowledge to handle the filter. Figure 23 illustrates the sand-stone turbidity filtration system:

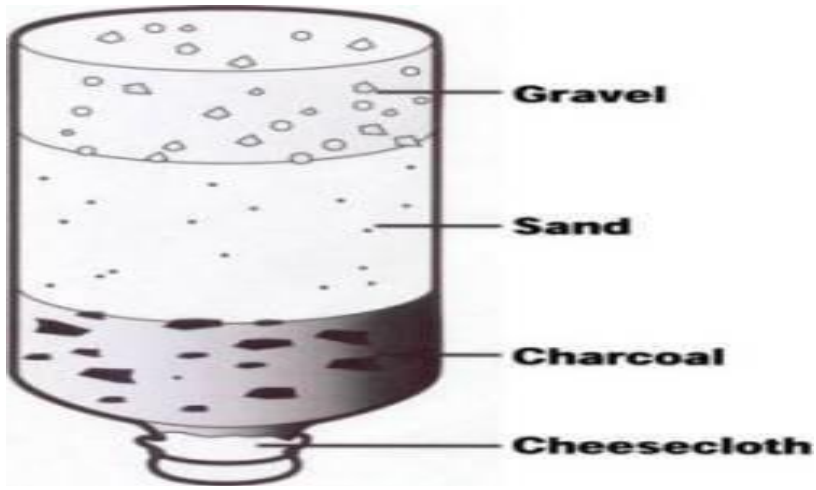

Figure 23. Sand-Stone Turbidity Filter

Each part of the filter works differently to remove cloudiness of water. The gravel layer catches large pieces of debris such as twigs, leaves and bugs. Next, the sand layer catches smaller particles such as dirt and grit and makes the water cleaner. Last layer of the filter is activated charcoal layer which catches the bacteria and some other chemicals and makes the water clean and purified. Activated charcoal is recommended because it has oxygen added back to it. Because of that, charcoal become more porous and better at filtering impurities than regular charcoal. Activated carbon works by adsorption system. But in this study, regular charcoal was used instead of activated charcoal because activated charcoal is not always available to the slum residents hence it was important to justify the efficiency of regular charcoal. All the components in the water binds chemically to the carbon of the charcoal. Meanwhile water passes through the charcoal with less impurities in it.

The sand-stone filter designed for this research followed the original methodology of making this filter. At the top surface gravel have placed, second layer consists by sand

and third layer consists by the charcoal. Finally, at the bottom part, a white piece of cloth was placed in order to remove any visible dirt. Figure 24 shows the filtration for the study using sand-stone filter:

Figure 24. Filtration in Sand-Stone Turbidity Filter

3.7.2 Measuring Turbidity Concentration of Portneuf River Water:

To compare the efficiency of turbidity filter made at Bangladesh, another turbidity filter was made at USA following the same design criteria. This turbidity filter was used to reduce the turbidity of Portneuf river, Idaho, USA. Three samples of river water were collected from the river in three different times of the day. At first, the turbidity value of raw water samples collected from the Portneuf river were measured. Later the raw water samples were filtered by the turbidity meter. Finally, turbidity value of filtered water was measured again by the turbidity meter in order find the difference and removal efficiency of turbidity filter.

3.8 Water Filtration by Ceramic Filter:

In order to get a comparison with clay filter, a ceramic water filter was also used in the research. Ceramic water filters are used mainly for removing pathogenic bacteria which is similar to the clay water filter. Ceramic water filters are effective treatment system against bacteria and other microbial pathogen. It can be also treated water with silver. The main purpose of adding silver is to kill bacteria and prevent the growth of mold and algae in the filter body. Ceramic filtration does not remove chemical contaminants per se. However, some manufacturers (especially of ceramic candle filters) incorporate a high-performance activated carbon core inside the ceramic filter cartridge that reduces organic & metallic contaminants. The active carbon absorbs compounds such as chlorine. Filters with active carbon need to be replaced periodically because the carbon becomes clogged with foreign material. [Ceramic Water Filter. (n.d.). In Wikipedia. Retrieved February, 2009, from https://en.wikipedia.org/wiki/**Ceramic_water_filter**]. Figure 25 shows the filtration procedure using ceramic water filter:

Figure 25. Filtration Using Ceramic Filter

3.9 Laboratory Testing of Filtered Water:

After filtering the raw and boiled water samples collected from Korail slum and Dhanmondi area by clay filter, ceramic filter and sand-stone filter, all the collected samples of the water brought to the environmental engineering laboratory of Bangladesh University of Engineering and Technology (BUET) where testing for E. coli concentration and turbidity was completed. To do the testing, BUET authority maintained the USEPA testing method for both E. coli and turbidity (USEPA 1103.1; SM 9221 F for E. coli) (USEPA 180.1 Rev 2; SM 2130 B for Turbidity).

3.9.1 USEPA 1103.1 Method for E. Coli Testing:

Method 1103. 1 is provide by USEPA to measure E. coli concentration in water. In this method, E. coli colony is measure by Membrane Filtration (MF) technique. The MF method provides a direct count of bacteria in water based on the development of colonies on the surface of the membrane filter, a water sample is filtered through the membrane which retains the bacteria. After filtration, the membrane is placed on a selective and differential medium, mTEC, incubated at 35°C ± 0.5°C for 2 ± 0.5 hours to resuscitate injured or stressed bacteria, and then incubated at 44.5°C ± 0.2°C for 22 ± 2 hours. Following incubation, the filter is transferred to a filter pad saturated with urea substrate. After 15 minutes, yellow, yellow-green, or yellow-brown colonies are counted with the aid of a fluorescent lamp and a magnifying lens (Method 1103.1: Escherichia coli in Water by Membrane Filtration Using membrane-Thermotolerant Escherichia coli Agar) (mTEC, March 2010). Figure 26 shows colony production E. coli:

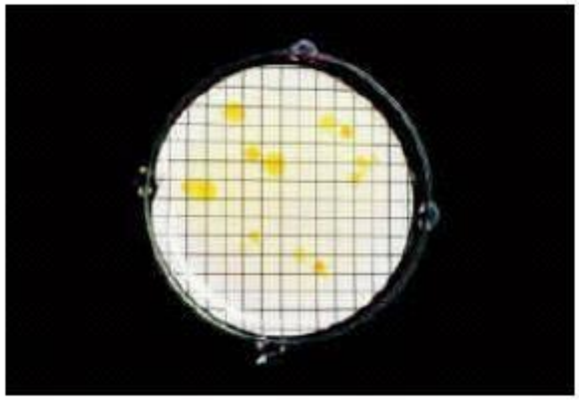

Figure 26. Colony Production of E. Coli in Mtec Agar (USEPA, 2015)

After the sample testing, calculation of E. coli colony concentration in the water sample is calculated by-

E. coli/ 100 ml = No. of E. Coli Colonies/ Volume of sample Filtered (ml) *100

The results are reported as the E. coli CFU per 100 ml of sample.

3.9.2 USEPA 180.1 Method for Turbidity Testing:

This is the method provided by USEPA for measuring turbidity of water. The applicable range of this testing manual is 0-40 Nephelometric turbidity units (NTU). The method is based upon a comparison of the intensity of light scattered by the sample under defined conditions with the intensity of light scattered by a standard reference suspension. The higher the intensity of scattered light, the higher the turbidity. A primary standard suspension is used to calibrate the instrument. A secondary standard suspension is used as a daily calibration check and is monitored periodically for deterioration using one of the primary standards. Formazin polymer is used as a primary turbidity suspension for water because it is more reproducible than other types of standards previously used for turbidity analysis. A commercially available polymer primary standard is also approved for use for the National Interim Primary Drinking Water Regulations. This standard is identified as AMCO-AEPA-1, available from Advanced Polymer Systems. After the sample testing, the report results as Table 10:

Table 10: Report Results of Testing (USEPA, 2015)

NTU	Record to Nearest
0.0-1.0	0.05
1.0-10.0	0.10
10.0-40.0	1.0
40.0-100.0	5.0
100-400	10.0

3.10 First Batch of Laboratory Analysis:

In the first batch of testing, clay and ceramic filters were used to remove E. coli from the raw water of Korail slum. Four different raw water samples were collected from the same water discharge point of Korail slum at the different times of the day. Sand-stone filter was used to remove turbidity of the water. For this study, two different sand-stone turbidity filters built, one in Bangladesh and another one in U.S. Both filters made by the same conception and used to see the consistency of the filter performance. Sand-stone filter which made is U.S., used to remove the turbidity of Portneuf river, Pocatello. Figure 27 shows the steps of 1st week laboratory testing.

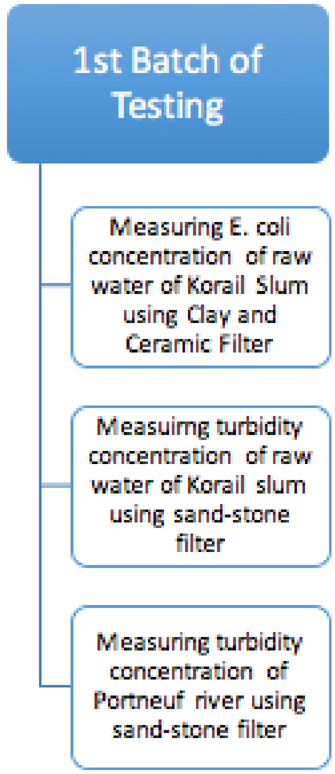

Figure 27. Details of First Batch Laboratory Testing

3.11 Second Batch of Laboratory Testing:

The first batch of testing gives an idea about the efficiency of clay filter for removing E. coli from the water and sand-stone filter to remove turbidity. A comparison was also drawn between clay and ceramic filter in terms of E. coli removal. In the second batch of laboratory testing, clay filter solely used for removing both E. coli and turbidity of the water. For comparison, ceramic filter was also used as well to remove both pollutants. An additional pollutant parameter: suspended solids was added to the second batch of study. A flow rate analysis of both filters was also completed. The purpose of analyzing flow rate is to check the hydraulic efficiency of the filters and how they change with the continuous use. It is expected that continuous use of the filters will eventually plug the filters. In this study, 75% reduction of the original flow rate was determined as the plug-in period. At the same time, it was also observed how both filters work with respect to time. After plugging, an efficient cleaning material is suggested to clean the clay filter. For the flow rate per unit filter area, an equal hydraulic head of 5-inches was used for both filters. For volumetric flow rate analysis, 10 liters' sample of raw water of Korail slum was used. The surface area of clay filter was calculated 0.021m^2 and the surface area of ceramic filter was calculated 0.066 m^2. The filtration was conducted for an hour in daily basis. Figure 28 shows the details of second batch of laboratory testing:

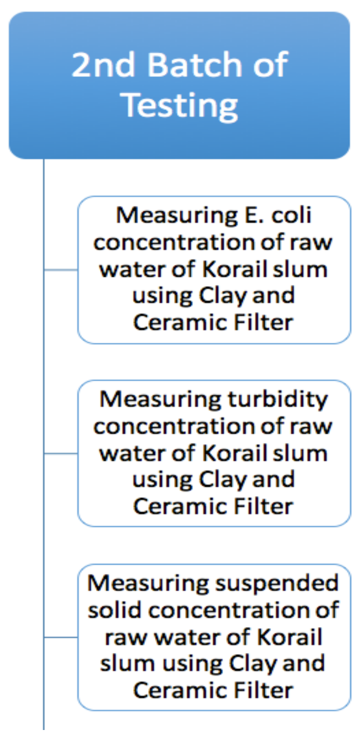

Figure 28. Details of Second Batch Laboratory Testing

Now, to evaluate the filters performance and to see the trend of flow rate, the analysis continued for 21 hours, 1 hour in each day that means the analysis continued for 21 days. Another major purpose of this break down is to monitor how often the clay filter need to plug-up. The breakdown of laboratory analysis shows in the Figure 29.

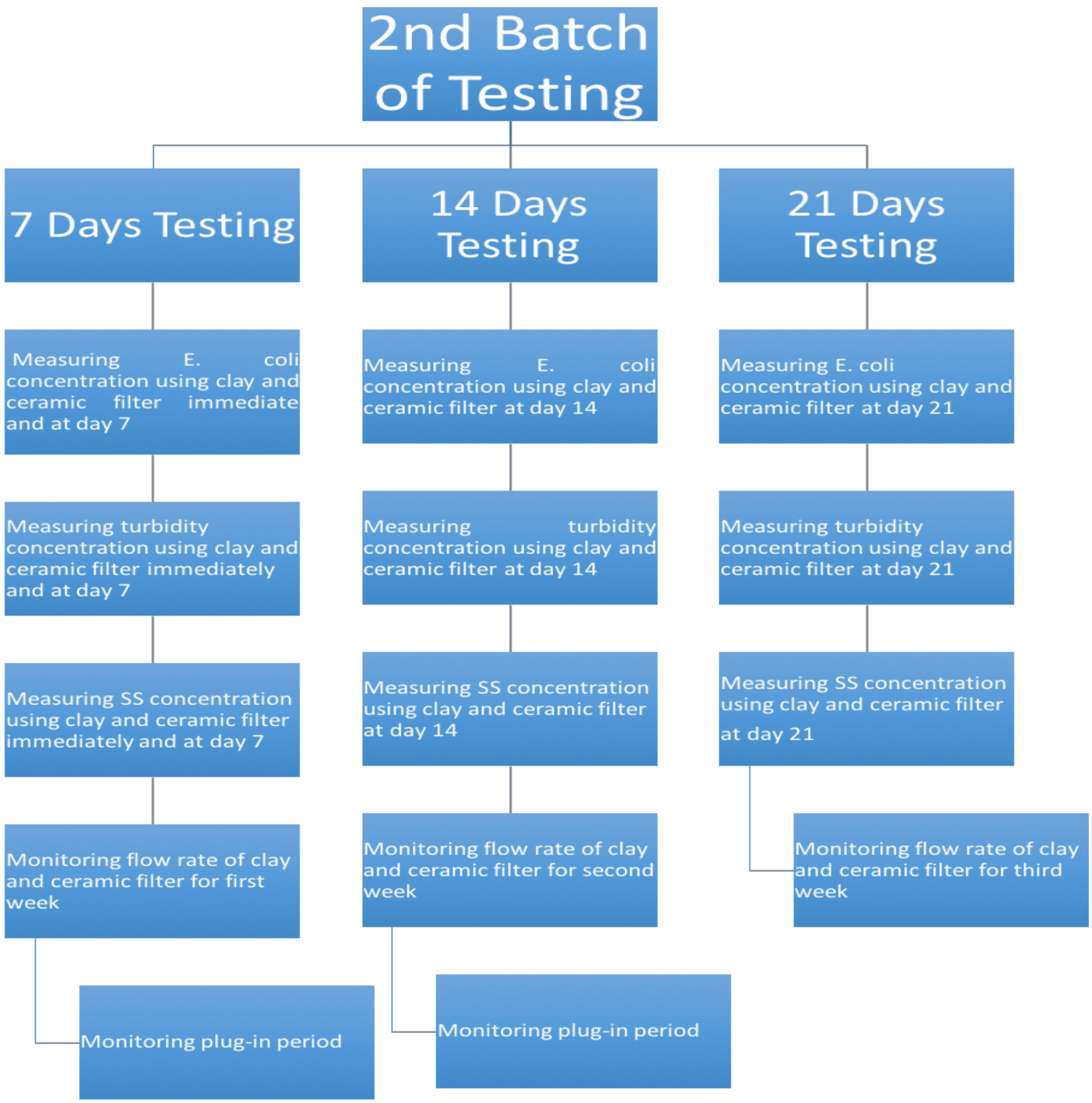

Figure 29. Breakdown of Second Batch Testing

3.12 Additional Testing:

In the second batch of laboratory reaction, the filtration was conducted for 1 hour per day. So, all the calculation and analyses was based on that filtration. To analyze the filters performance for the continuous filtration, additional testing was conducted. In this section, both filters were used for the 72 hours of continuous filtration testing. Another purpose of this analysis was to monitor the difference between continuous and non-continuous filtration. While testing, same hydraulic head that was used for the second batch of the laboratory analysis was maintained for the consistency. Also, plug in period was fixed 75% just as the previous analysis. Because of the time constraint, removal efficiency testing of the filters was not conducted.

CHAPTER 4

RESULT AND DISCUSSION

In this chapter, details of laboratory tasting and outcomes are discussed including the performance evaluation of clay filter and comparison between both filters. Also, efficiency of the sand-stone filter to remove turbidity is assessed.

4.1First Batch of Laboratory Testing:

In the first batch of testing, the clay and the ceramic filters are used for removing E. coli concentration of water. Table 11 shows the filters' performance for removing E. coli concentration.

Table 11: Filters' Performance for Removing E. Coli

Sample	E. coli Conc. of Raw water (CFU/100 ml)	E. coli Conc. After Clay Filtration (CFU/100ml)	Log_{10} Reduction (%)	E. coli Conc. After Ceramic Filtration (CFU/100ml)	Log_{10} Reduction (%)
1	100	22	78	15	85
2	52	5	90.4	1	98.1
3	58	8	86.2	5	91.4
4	55	8	85.5 **Average=85.02** **STDEV= 5.16**	2	96.4 **Average=92.72** **STDEV= 5.88**

For the turbidity testing, sand-stone filter was used and the performance shows in Table 12.

Table 12: Filters' Performance for Removing Turbidity

Sample	Turbidity (Raw Water: Korail slum) NTU	Turbidity (Filtered Water: Korail slum) NTU	% Removal	Turbidity (Raw Water: Portneuf River) NTU	Turbidity (Filtered Water: Portneuf River) NTU	% Removal
1	15.82	2.08	87	34.85	3.80	89.1
2	12.25	2.05	83.2	40.50	5.26	87
3	12.05	2.28	81.1	32.75	3.93	88
4	11.58	2.15	81.4	38.60	4.63	88
			Average=83.175			**Average=88.025**
			STDEV= 2.7			**STDEV= 0.86**

4.2 Second Batch of Laboratory Testing:

In the second batch of testing, the clay filter was used along with the ceramic filter. Table 13 shows the E. coli removal performance for the both filters.

Table 13: E. Coli Removal Performance

Sample	E. coli Conc. of Raw water (CFU/100 ml)	E. coli Conc. After Clay Filtration (CFU/100ml)	Log_{10} Reduction	E. coli Conc. After Ceramic Filtration (CFU/100ml)	Log_{10} Reduction
Immediate	74	10	86.5	6	92
7 hours		13	82.4	6	92
14 hours		17	77	9	87.8
21 hours (After Plug-up)		11	85	8	89
			Average=82.725		**Average=90.2**
			STDEV=4.2		**STDEV=2.1**

Also, for turbidity testing, clay and ceramic filter was used and result shows in the Table 14.

Table 14: Turbidity Removal Performance

Sample	Turbidity Conc. of Raw water (NTU)	Turbidity Conc. After Clay Filtration (NTU)	% Removal	Turbidity Conc. After Ceramic Filtration (NTU)	% Removal
Immediate	10.2	1.4	86.3	1.0	90.2
7 hours		2.1	79.4	1.3	87.2
14 hours		2.6	74.5	1.5	85.3
21 hours (After Plug-in)		1.6	84.3 **Average=81.125** **STDEV=4.3**	1.1	89.4 **Average=88.025** **STDEV=1.4**

Table 15 shows the details of SS removal performance of both filters.

Table 15: Suspended Solids Removal Performance

Sample	SS Conc. of Raw water (mg/l)	SS Conc. After Clay Filtration (mg/l)	% Removal	SS Conc. After Ceramic Filtration (mg/l)	% Removal
Immediate	1.8	0.05	97.2	0.02	99
7 hours		0.08	95.6	0.02	99
14 hours		0.20	89	0.05	97.2
21 hours (After Plug-in)		0.07	96 **Average=94.4** **STDEV=3.7**	0.03	98.3 **Average=98.37** **STDEV=0.85**

Filtration rate was monitored for both filters. Both volumetric flow rate and flow rate per unit area of the filter surface was monitored. Table 16 shows the filtration rate analyses of the clay filter.

Table 16: Filtration Rate Analyses for Clay Filter

Hour	Filtration Rate/Unit Area (lt./hr./m^2)	% Decrease	Volumetric Flow Rate (lt./hr.)	% Decrease
1	36.19		0.76	
2	36.19	0	0.76	0
3	35.24	2.63	0.74	2.6
4	35.24	2.63	0.74	2.6
5	35.24	2.63	0.74	2.6
6	32.86	9.20	0.69	9.2
7	32.86	9.20	0.69	9.2
8	31.90	11.85	0.67	11.8
9	31.90	11.85	0.67	11.8
10	30.48	15.78	0.64	15.8
11	30.48	15.78	0.64	15.8
12	30.48	15.78	0.64	15.8
13	28.57	21.05	0.60	21.1
14	27.62	23.68(Plugged-up)	0.58	23.7 (Plugged-up)
15	33.81	6.58	0.71	6.6
16	33.81	6.58	0.71	6.6
17	33.81	6.58	0.71	6.6
18	32.86	9.20	0.69	9.2
19	32.86	9.20	0.69	9.2
20	32.86	9.20	0.69	9.2
21	31.90	11.85	0.67	11.8

Table 17 shows the filtration rate analyses of the ceramic filter.

Table 17: Filtration Rate Analyses for Ceramic Filter

Hour	Filtration Rate/Unit Area (lt./hr./m^2)	% Decrease	Volumetric Flow Rate (lt./hr.)	% Decrease
1	16.21		1.07	
2	16.21	0	1.07	0
3	16.21	0	1.07	0
4	16.21	0	1.07	0
5	15.00	7.46	0.99	7.5
6	15.00	7.46	0.99	7.5
7	15.00	7.46	0.99	7.5
8	13.94	14.00	0.92	14
9	13.94	14.00	0.92	14
10	13.94	14.00	0.92	14
11	13.94	14.00	0.92	14
12	13.94	14.00	0.92	14
13	13.94	14.00	0.92	14
14	12.88	20.54 (Plugged-up)	0.85	20.6 (Plugged-up)
15	15.00	7.46	0.99	7.5
16	15.00	7.46	0.99	7.5
17	15.00	7.46	0.99	7.5
18	15.00	7.46	0.99	7.5
19	15.00	7.46	0.99	7.5
20	13.94	14.00	0.92	14
21	13.94	14.00	0.92	14

4.3 Additional Testing:

Table 18 shows the filtration rate analyses of the clay filter.

Table 18: Filtration Rate Analyses for the Clay Filter

Hour	Filtration Rate/Unit Area (lt./hr./m^2)	% Decrease	Volumetric Flow Rate (lt./hr.)	% Decrease
1	30.95		0.65	
2	30.95	0	0.65	0
3	30.95	0	0.65	0
4	30.95	0	0.65	0
5	30.95	0	0.65	0
6	30.95	0	0.65	0
7	30.95	0	0.65	0
8	30.95	0	0.65	0
9	30.95	0	0.65	0
10	30.95	0	0.65	0
11	30.95	0	0.65	0
12	30.00	3.07	0.63	3.08
13	30.00	3.07	0.63	3.08
14	30.00	3.07	0.63	3.08
15	30.00	3.07	0.63	3.08
16	30.00	3.07	0.63	3.08
17	30.00	3.07	0.63	3.08
18	30.00	3.07	0.63	3.08
19	30.00	3.07	0.63	3.08
20	27.62	10.76	0.58	10.77
21	27.62	10.76	0.58	10.77
22	27.62	10.76	0.58	10.77
23	27.62	10.76	0.58	10.77
24	27.62	10.76	0.58	10.77
25	27.62	10.76	0.58	10.77
26	27.62	10.76	0.58	10.77
27	27.62	10.76	0.58	10.77
28	27.62	10.76	0.58	10.77
29	27.62	10.76	0.58	10.77
30	27.62	10.76	0.58	10.77
31	26.19	15.38	0.55	15.38
32	26.19	15.38	0.55	15.38
33	26.19	15.38	0.55	15.38
34	26.19	15.38	0.55	15.38
35	26.19	15.38	0.55	15.38

36	26.19	15.38	0.55	15.38
37	26.19	15.38	0.55	15.38
38	25.71	16.93	0.54	16.92
39	25.71	16.93	0.54	16.92
40	25.71	16.93	0.54	16.92
41	25.71	16.93	0.54	16.92
42	25.71	16.93	0.54	16.92
43	24.76	20	0.52	20
44	24.76	20	0.52	20
45	24.76	20	0.52	20
46	24.76	20	0.52	20
47	24.76	20	0.52	20
48	24.76	20	0.52	20
49	24.76	20	0.52	20
50	23.33	24.62	0.49	24.61
51	29.52	4.62	0.62	4.61
52	29.52	4.62	0.62	4.61
53	29.52	4.62	0.62	4.61
54	29.52	4.62	0.62	4.61
55	29.52	4.62	0.62	4.61
56	29.52	4.62	0.62	4.61
57	29.52	4.62	0.62	4.61
58	29.52	4.62	0.62	4.61
59	29.52	4.62	0.62	4.61
60	29.52	4.62	0.62	4.61
61	29.52	4.62	0.62	4.61
62	29.52	4.62	0.62	4.61
63	29.52	4.62	0.62	4.61
64	29.52	4.62	0.62	4.61
65	29.52	4.62	0.62	4.61
66	29.52	4.62	0.62	4.61
67	29.52	4.62	0.62	4.61
68	29.52	4.62	0.60	4.61
69	28.57	7.69	0.60	7.69
70	28.57	7.69	0.60	7.69
71	28.57	7.69	0.60	7.69
72	28.57	7.69	0.60	7.69

Table 19 shows the flow rate analyses of the ceramic filter.

Table 19: Filtration Rate Analyses for the Ceramic Filter

Hour	Filtration Rate/Unit Area (lt./hr./m^2)	% Decrease	Volumetric Flow Rate (lt./hr.)	% Decrease
1	15.45		1.02	
2	15.45	0	1.02	0
3	15.45	0	1.02	0
4	15.45	0	1.02	0
5	15.45	0	1.02	0
6	15.45	0	1.02	0
7	15.45	0	1.02	0
8	15.45	0	1.02	0
9	15.45	0	1.02	0
10	15.45	0	1.02	0
11	15.45	0	1.02	0
12	15.45	0	1.02	0
13	15.45	0	1.02	0
14	15.45	0	1.02	0
15	15.45	0	1.02	0
16	15.45	0	1.02	0
17	15.45	0	1.02	0
18	15.45	0	1.02	0
19	15.45	0	1.02	0
20	15.45	0	1.02	0
21	15.45	0	1.02	0
22	15.45	0	1.02	0
23	15.45	0	1.02	0
24	15.45	0	1.02	0
25	15.45	0	1.02	0
26	15.15	1.94	1.00	1.96
27	15.15	1.94	1.00	1.96
28	15.15	1.94	1.00	1.96
29	15.15	1.94	1.00	1.96
30	15.15	1.94	1.00	1.96
31	15.15	1.94	1.00	1.96
32	15.15	1.94	1.00	1.96
33	15.15	1.94	1.00	1.96
34	15.15	1.94	1.00	1.96
35	15.15	1.94	1.00	1.96
36	15.15	1.94	1.00	1.96
37	15.15	1.94	1.00	1.96
38	15.15	1.94	1.00	1.96

39	15.15	1.94	1.00	1.96
40	15.15	1.94	1.00	1.96
41	15.15	1.94	1.00	1.96
42	15.15	1.94	0.96	5.88
43	14.55	5.82	0.96	5.88
44	14.55	5.82	0.96	5.88
45	14.55	5.82	0.96	5.88
46	14.55	5.82	0.96	5.88
47	14.55	5.82	0.96	5.88
48	14.55	5.82	0.96	5.88
49	14.55	5.82	0.96	5.88
50	14.55	5.82	0.96	5.88
51	14.55	5.82	0.96	5.88
52	14.55	5.82	0.96	5.88
53	14.55	5.82	0.96	5.88
54	14.55	5.82	0.96	5.88
55	14.55	5.82	0.96	5.88
56	14.39	6.86	0.95	6.86
57	14.39	6.86	0.95	6.86
58	14.39	6.86	0.95	6.86
59	14.39	6.86	0.95	6.86
60	14.39	6.86	0.95	6.86
61	14.39	6.86	0.95	6.86
62	14.39	6.86	0.95	6.86
63	14.39	6.86	0.95	6.86
64	14.39	6.86	0.95	6.86
65	14.09	8.80	0.93	8.82
66	14.09	8.80	0.93	8.82
67	14.09	8.80	0.93	8.82
68	14.09	8.80	0.93	8.82
69	14.09	8.80	0.93	8.82
70	14.09	8.80	0.93	8.82
71	14.09	8.80	0.93	8.82
72	14.09	8.80	0.93	8.82

4.4 Performance Evaluation of the Filters:

In this section, filters' performance in terms of filtration rate was investigated. Both filtration rate per unit area of the filters and the volumetric filtration rate were investigated. Also, an extrapolation of the filters' performance was conducted.

In total performance evaluation study, three different fits (Linear, Exponential and 2nd Order Polynomial) were used to extract all the possible outcomes.

Figure 30 shows the analysis of flow rate per unit area of the filters using linear fit.

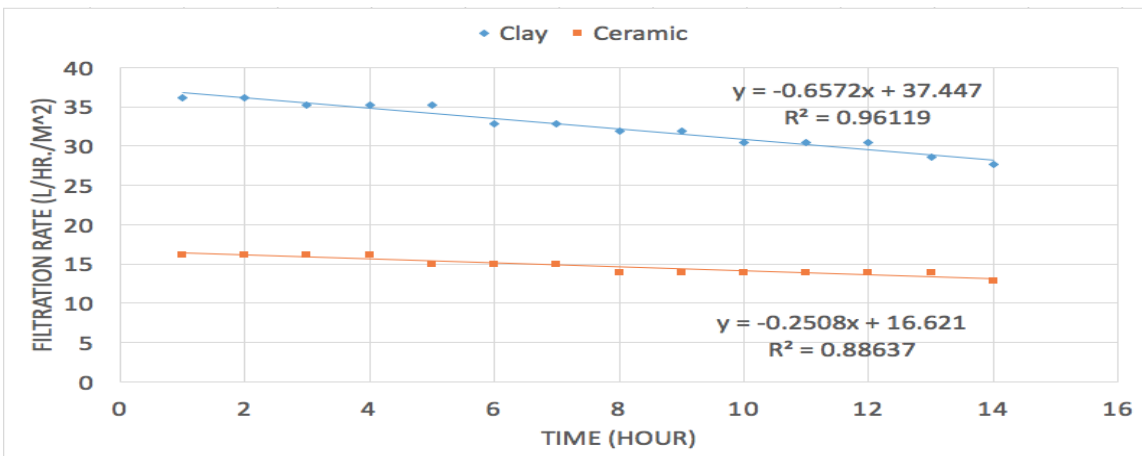

Figure 30. Analysis of Flow Rate Per Unit Area (Linear Fit)

Figure 31 shows the analysis of flow rate per unit area of the filters using exponential fit.

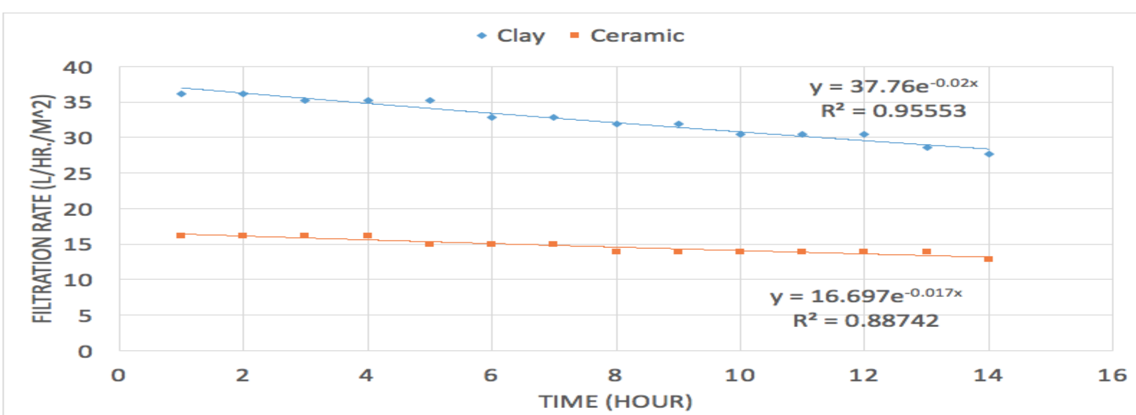

Figure 31. Analysis of Flow Rate Per Unit Area (Exponential Fit)

Figure 32 shows the analysis of flow rate per unit area of the filters using 2nd order polynomial fit.

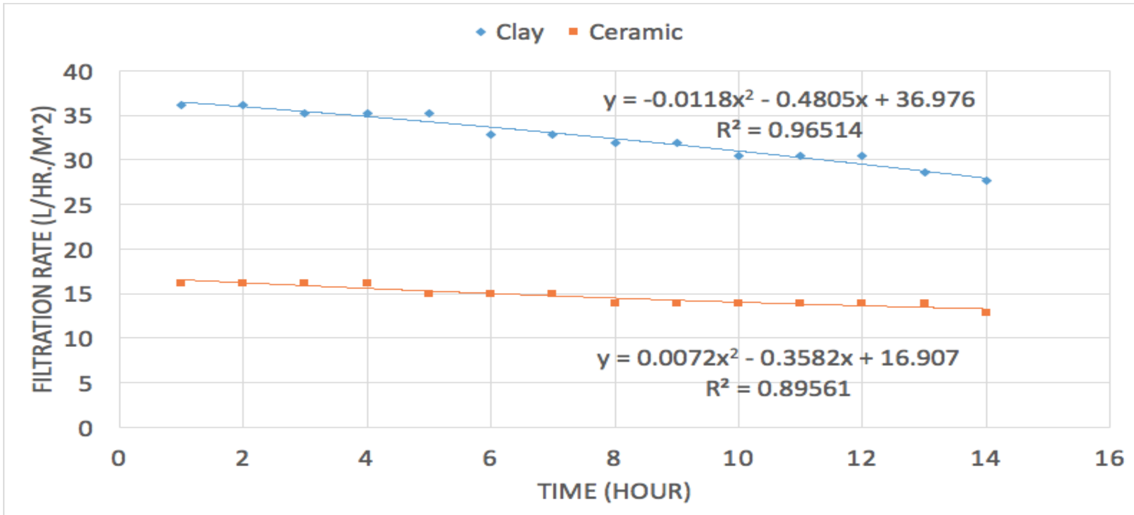

Figure 32. Analysis of Flow Rate Per Unit Area (2nd Order Polynomial Fit)

Figure 33 shows the volumetric flow rate analysis of the filters using linear fit.

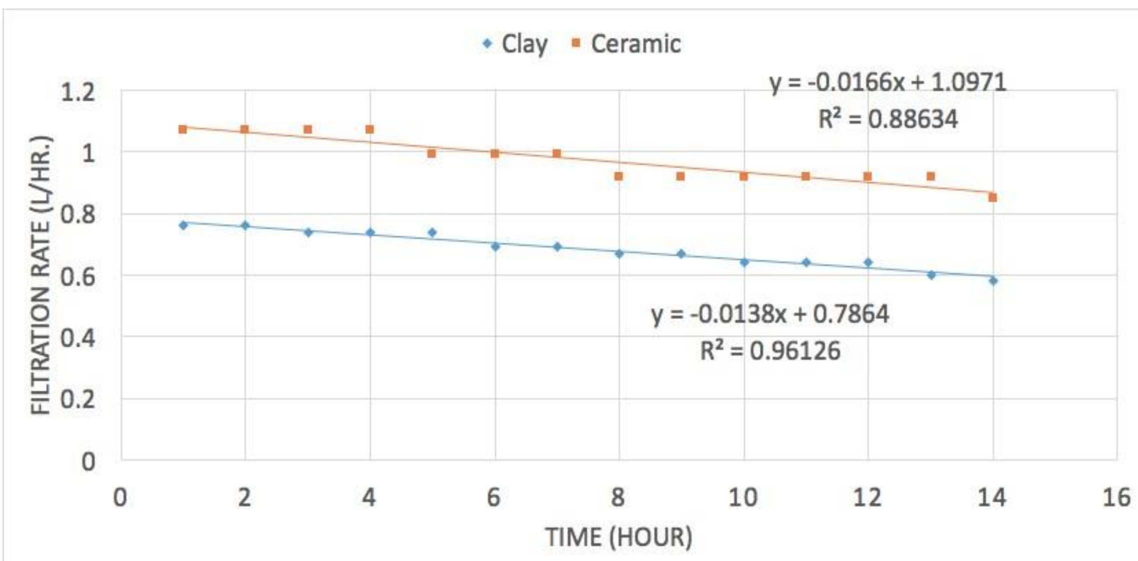

Figure 33. Analysis of Volumetric Flow Rate (Linear Fit)

Figure 34 shows the volumetric flow rate analysis of the filters using exponential fit.

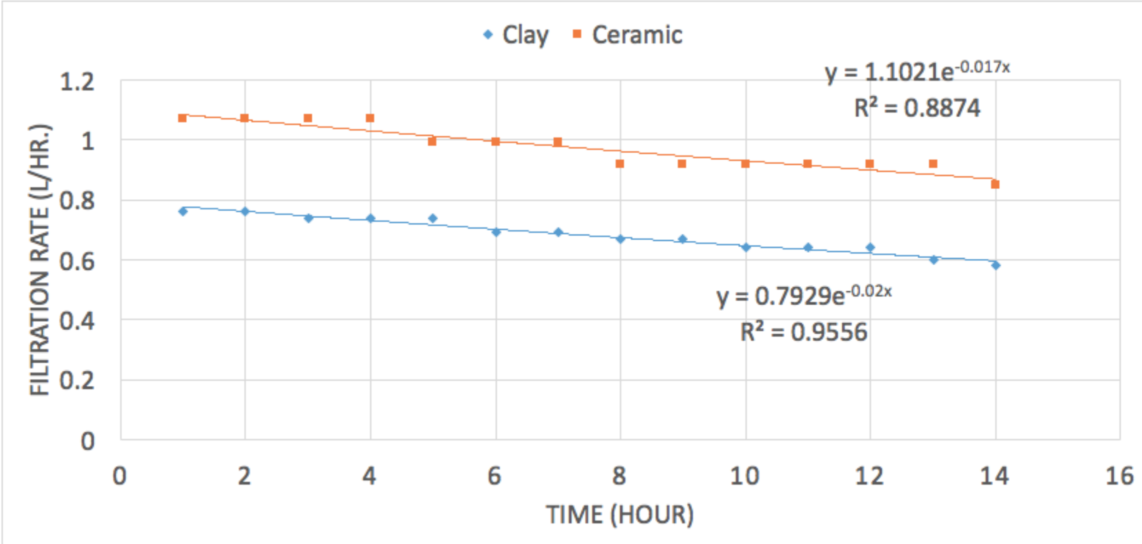

Figure 34. Analysis of Volumetric Flow Rate (Exponential Fit)

Figure 35 shows the volumetric flow rate analysis of the filters using 2nd order polynomial fit.

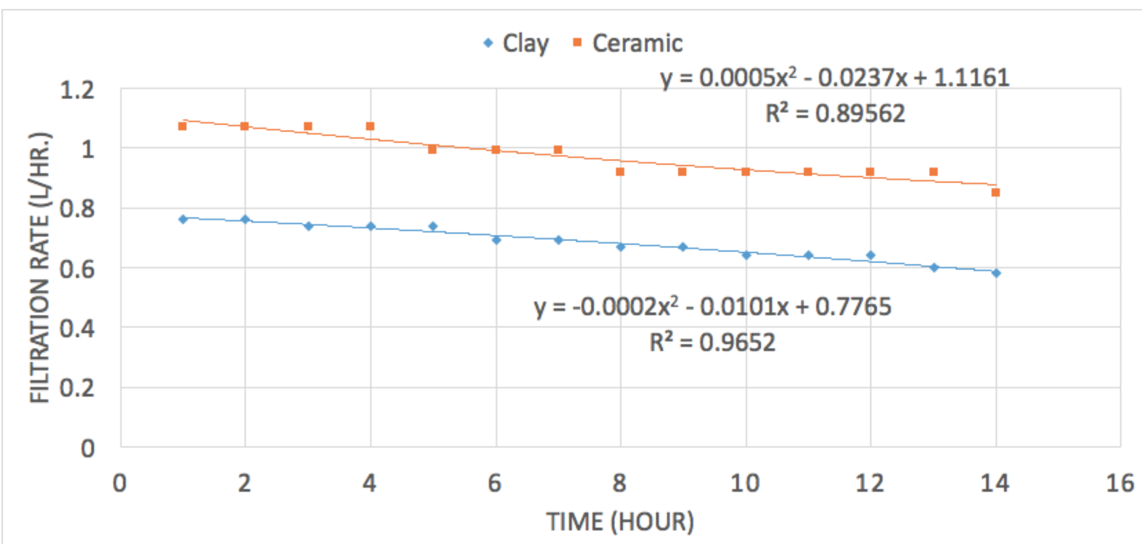

Figure 35. Analysis of Volumetric Flow Rate (2nd Order Polynomial Fit)

Now, Figure 36 shows an extrapolation of the filtration rate of the both filters with respect to time. Extrapolation shows the approximate time period of filters sustainability. Linear fit was used for this plot.

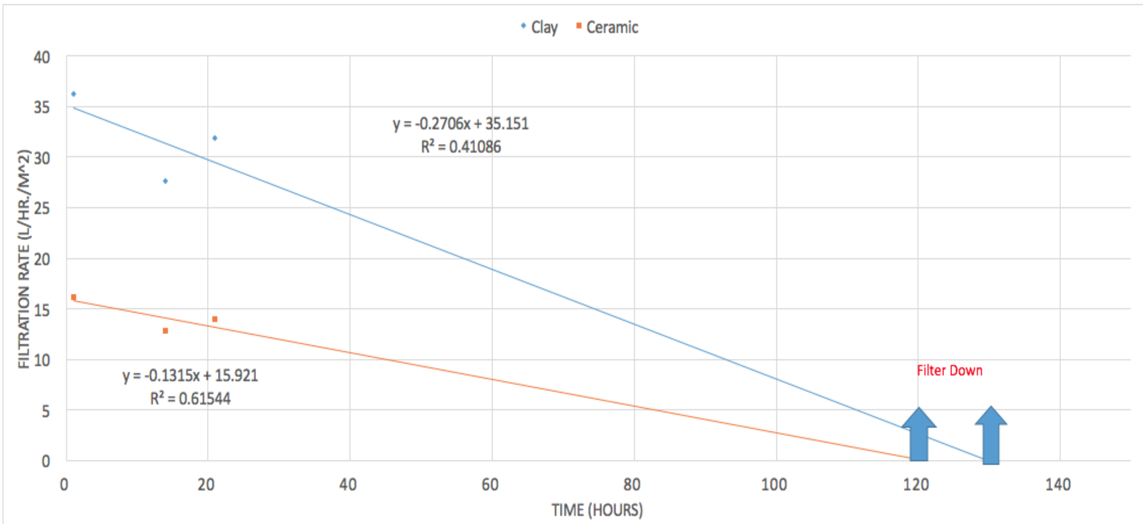

Figure 36. Flow Rate Projection of Filters with Respect to Time and Plugging (Linear Fit)

Figure 37 shows the flow rate projection of filters with respect to time with plugging with an exponential fit.

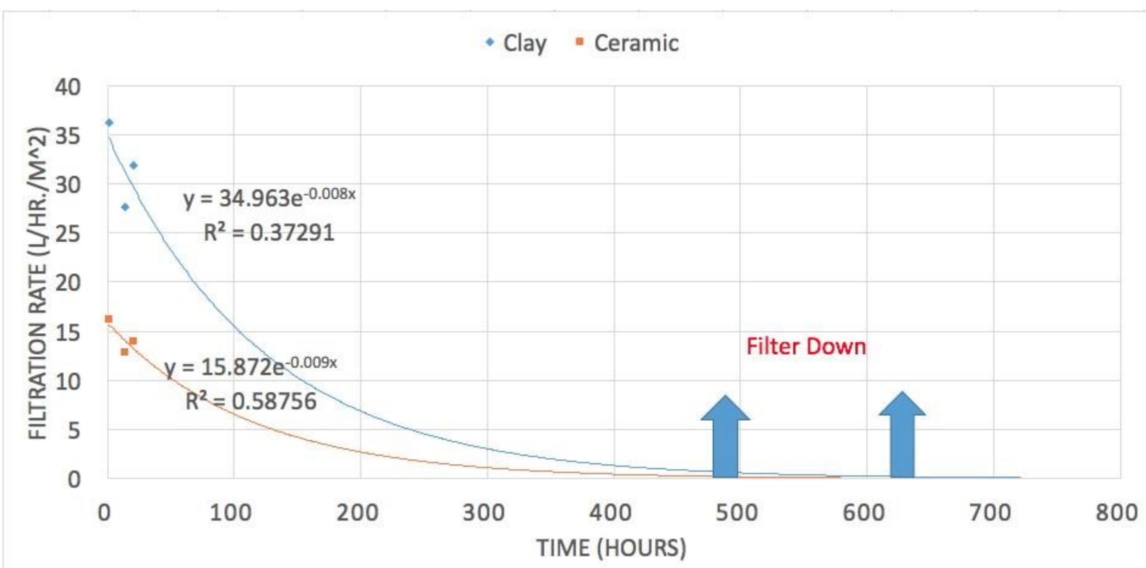

Figure 37. Flow Rate Projection of Filters with respect to Time with Plugging (Exponential Fit)

Figure 38 shows the flow rate projection of filters with respect to time with plugging with a 2nd order polynomial fit.

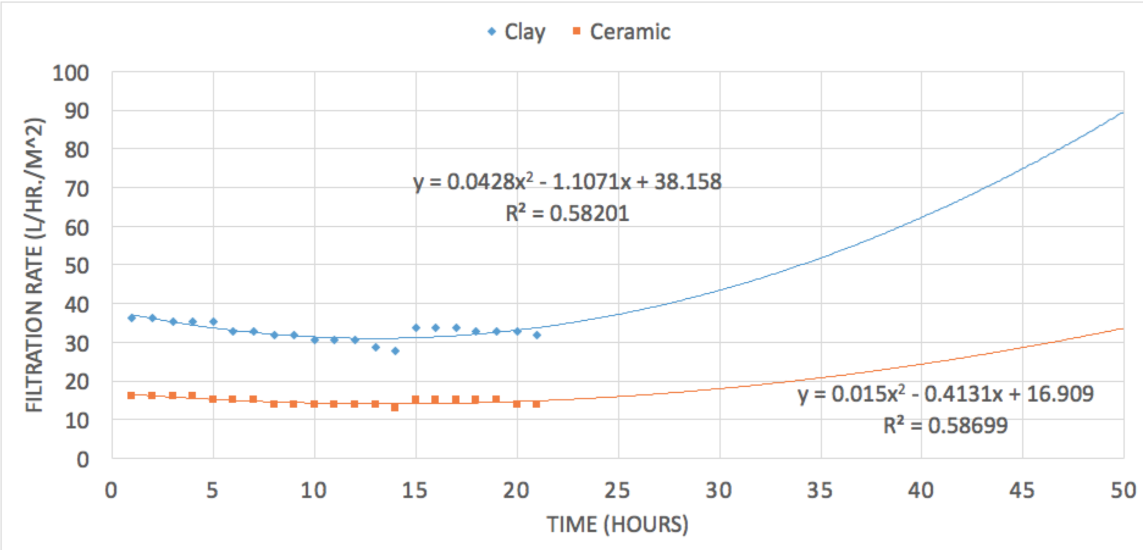

Figure 38. Flow Rate Projection of Filters with Respect to Time with Plugging (2nd Order Polynomial Fit)

Figure 39 shows the flow rate projection of the filters with respect to time and without plugging using a linear fit.

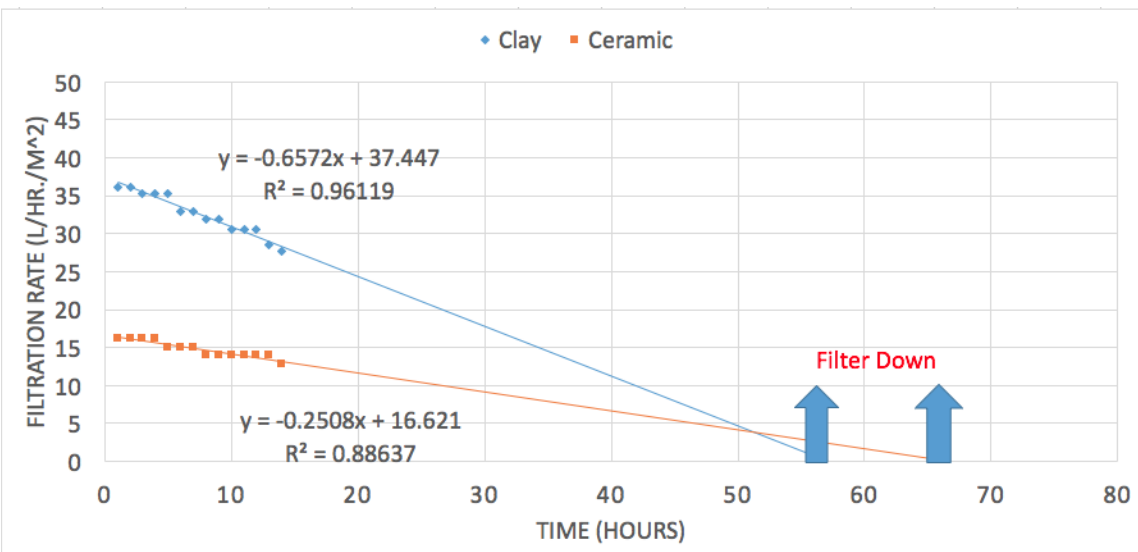

Figure 39. Flow Rate Projection of Filters with respect to Time Without Plugging (Linear Fit)

Figure 40 shows the flow rate projection of the filters with respect to time and without plugging using an exponential fit.

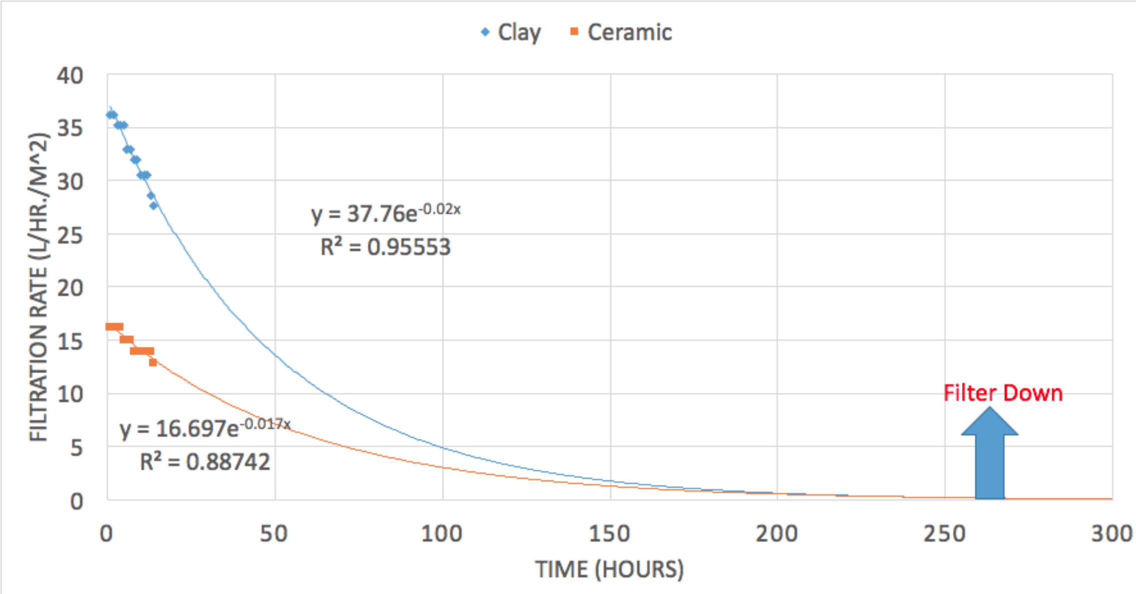

Figure 40. Flow Rate Projection of the Filters with Respect to Time Without Plugging (Exponential Fit)

Figure 41 shows the flow rate projection of the filters with respect to time and without plugging using an 2nd order polynomial fit.

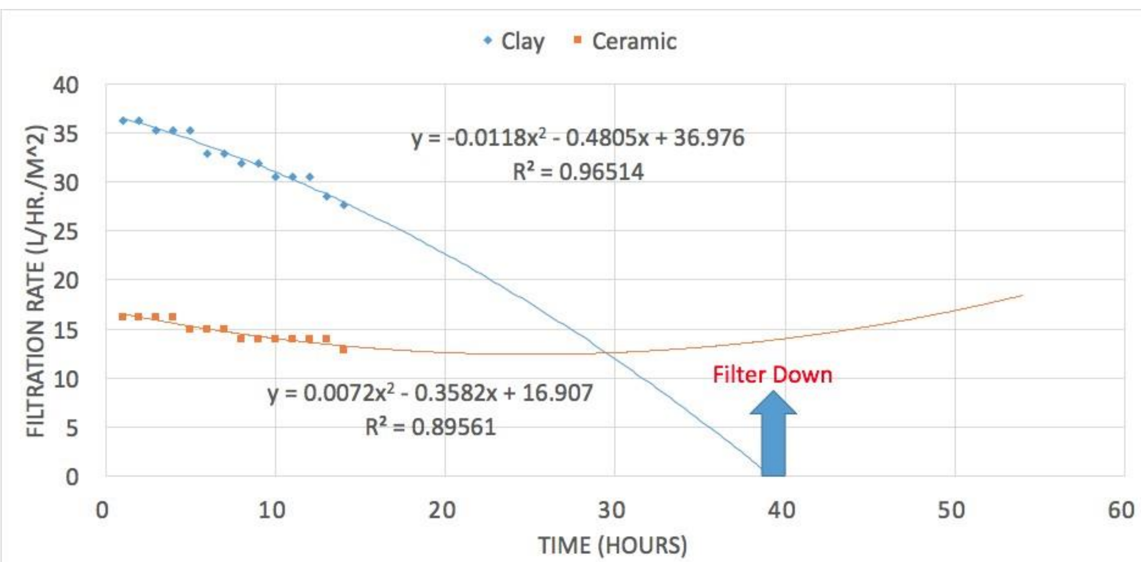

Figure 41. Flow Rate Projection of the Filter with Respect to Time Without Plugging (2nd Order Polynomial Fit)

4.5 Performance Evaluation Based on Additional Testing:

This section analyze the sustainability of the clay filter based on the 72 hours continuous testing. Table 18 shows that the filtration rate of the clay filter dropped close to 25% (24.62%) at the 50th hour of the testing. So, after 50th hour, the filter cleaned by a metal scrubber and the testing continued for 72 hours. However, table 19 shows that the filtration rate of the ceramic filter did not drop to 25% after the testing so flow rate projection of the ceramic filter with plugging did not include in to the analysis. Figure 42 shows the performance projection of the clay filter with plugging using linear fit.

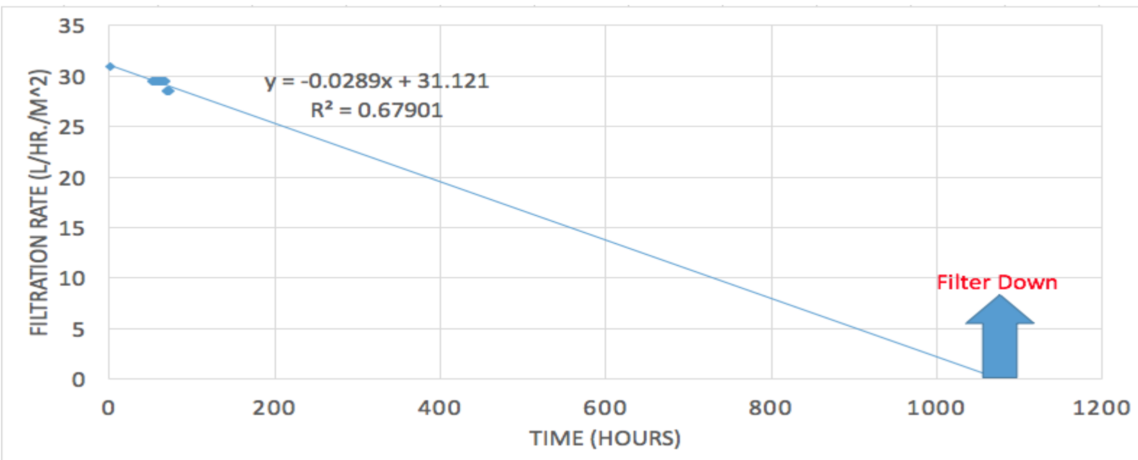

Figure 42. Flow Rate Projection of the Clay Filter in Additional Testing with Plugging (Linear Fit)

Figure 43 shows the performance projection of the clay filter with plugging using exponential fit.

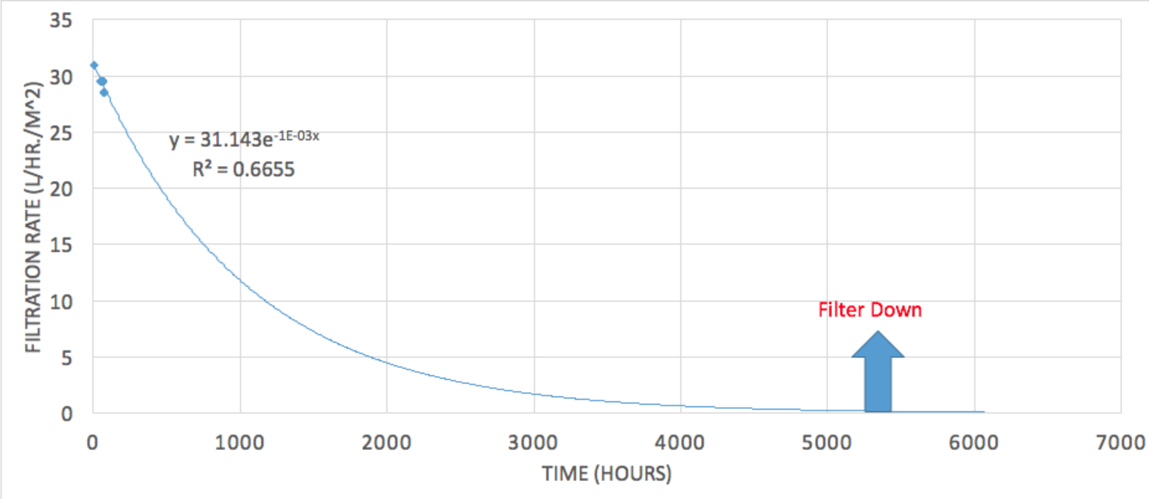

Figure 43. Flow Rate Projection of the Clay Filter in Additional Testing with Plugging (Exponential Fit)

Figure 44 shows the performance projection of the clay filter with plugging using 2nd order polynomial fit.

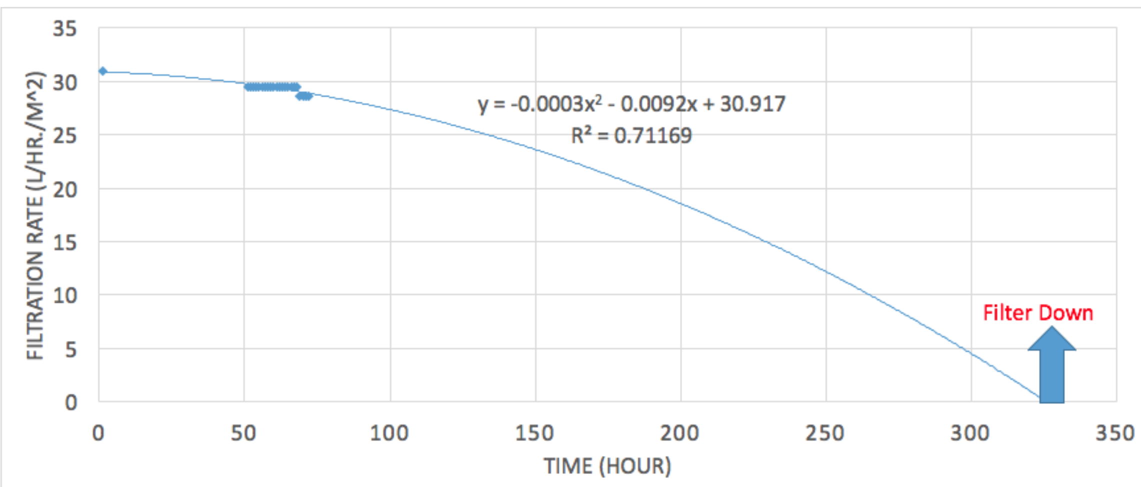

Figure 44. Flow Rate Projection of the Clay Filter in Additional Testing with Plugging (2nd Order Polynomial Fit)

Filtration rate projection without plugging includes both clay and ceramic filter. Figure 45 shows the projection using a linear fit.

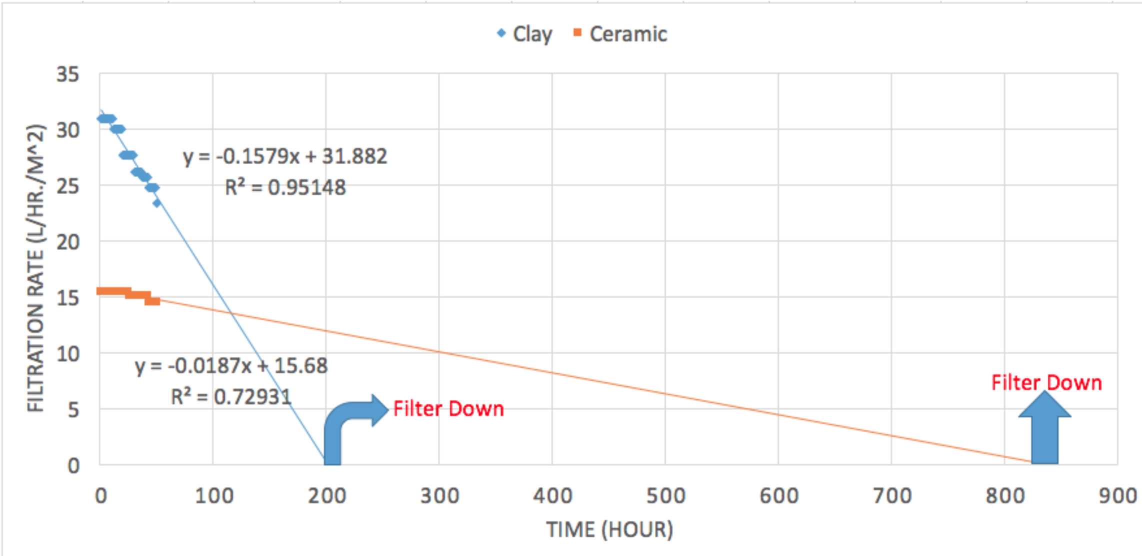

Figure 45. Flow Rate Projection of the Clay Filter in Additional Testing without Plugging (Linear Fit)

Figure 46 shows the projection using exponential fit.

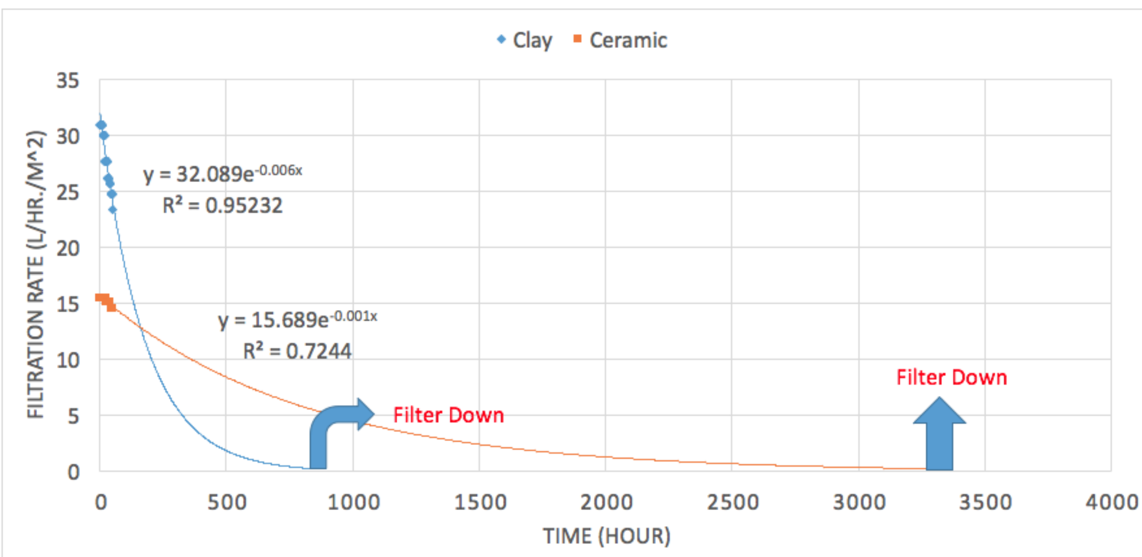

Figure 46. Flow Rate Projection of the Clay Filter in Additional Testing without Plugging (Exponential Fit)

Figure 47 shows the projection using polynomial fit.

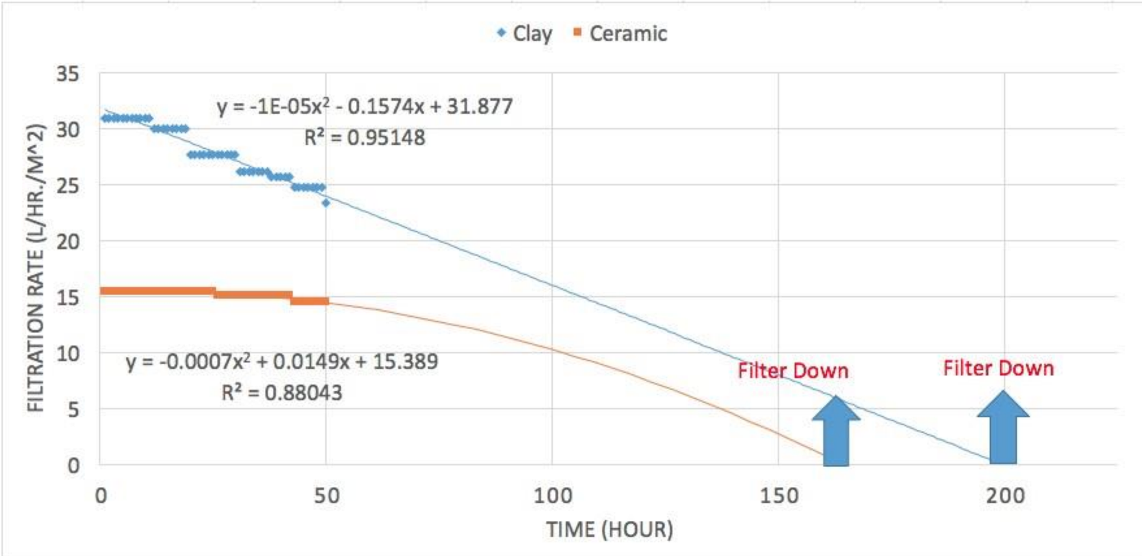

Figure 47. Flow Rate Projection of the Clay Filter in Additional Testing without Plugging (2nd Order Polynomial Fit)

Figure 48 shows the difference between continuous and non-continuous filtration in terms of their percent decrease.

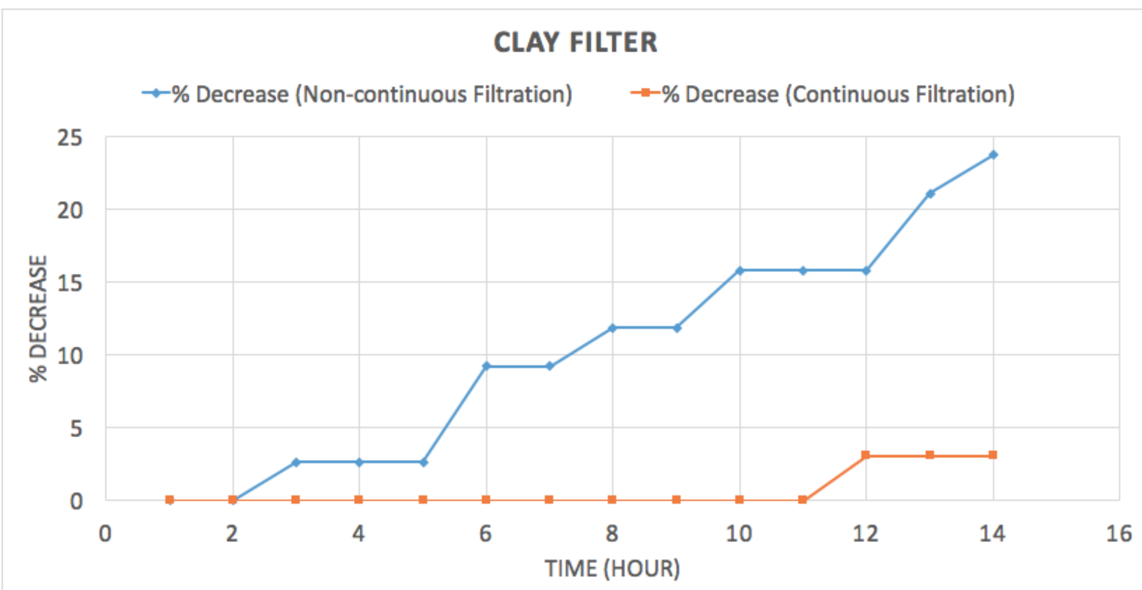

Figure 48. Difference Between Continuous and Non-Continuous Filtration

4.6 Drinking Water Demand:

As per WHO recommendation, the daily drinking water demand for an individual is 7.5 liters. So, for a 4-members' family, total daily demand of drinking water is 30 liters. Now, as per volumetric flow rate analysis of this study, if a clay filter can run continuously for 24 hours, it will be able to treat 15.09 liters of water. So, 2 units of clay filter can easily meet the daily drinking water demand for a 4-members' family by treating 30.18 liters of water per day. Although, flow rate drops with the passage of time, but regular cleaning of the clay filter exhibits a raise of its rate.

4.7 Discussion:

Analysis of the data indicates that clay water filter is capable of removing various pollutants from the water. However, in compare to some previous studies of E. coli removal, the rate is still a bit less. For turbidity and suspended solids concentration analysis, the reduction rate is decent. In all sampling, sand-stone filter, clay filter and also ceramic filter successfully dropped the turbidity concentration below 5 NTU. Smaller surface area of clay filter exhibits a higher flow rate per unit area of the filter in comparison to the ceramic filter. However, while considering the volumetric flow rate, the ceramic filter works better than the clay filter because of the smaller pore of the clay filter to percolate water. Data analysis illustrates that; if the clay filter used one hour a day, it needs to be cleaned in every two weeks as the flow rate drops around 75% of its original flow rate and if the filter runs for 21 hours a day, it has to be cleaned in 14th hour because of the same reason. Continuous filtration testing suggested that the clay needs to plug in after 50^{th} hour. Cleaning of filters exhibits a raise of filtration rate for both filters so as a cleaning material, metal scrubber can be used. Interestingly, flow rate projection of both filters indicates that, after cleaning the filters, clay filter rebound closer to the original flow. However, the ceramic filter is able to go without cleaning for a longer period of time.

In this study, the total laboratory analyses divided in to two separate batches. In the first batch of laboratory analyses, the clay filter was suggested for the E. coli removal and the sand-stone filter was suggested for the turbidity removal. To compare the E. coli removal using the clay filter, a ceramic filter was also used and average Log_{10} reduction of E. coli was found 85.025% for clay filtration and 92.725% for ceramic filtration. For turbidity removal test, two different sand-stone filters were made, one in Bangladesh and another one is in U.S. using the same methodology. Two filters were made to analyze the consistency between both filters and laboratory analyses suggested that sand-stone filter made in U.S. exhibits a better average removal efficiency of 88.025% in compare to the filter made in Bangladesh with an average removal efficiency of 83.175%. Sand-stone filter that made in U.S. used to remove the turbidity concentration of Portneuf river. Four different water samples were collected from both Korail slum and Portneuf river for the analysis.

In the second batch of testing, only the clay filter was suggested for removing the pollutants. As an additional pollutant parameter, suspended solids concentration was added in this batch of testing. Ceramic filter was used as well for the comparison. This testing continued for 21 hours and after 14 hours, both filters were cleaned by the metal scrubber. Also, filtration rates were monitored for up to 21 hours for the both filters. In this batch, the ceramic filter again exhibits a better removal rate for all three pollutant parameters, however, the removal rates of the clay filter were also convincing.

For the filtration rate, filtration rate per unit area of filter surface and volumetric flow rate testing was conducted for the both filters. As the objective was to clean the filters when the flow rates drop to 75% of its original flow rate, so, at 14^{th} hour, the clay filter was cleaned as the flow rates dropped close to 75% of the original flow rates. Although, the filtration rates for the ceramic filter did not drop to the 75% after 14^{th} hour, but the ceramic filter also cleaned along with the clay filter to maintain the consistency. Cleaning of both filters significantly raised the filtration rates. Both filters recovered around 93% of their original flow rates after cleaning.

For projecting the filtration rate and the filters sustainability, three different fits were used to get the best out of them. The projection was conducted considering with and without plugging. Linear, Exponential and 2^{nd} Order Polynomial fit was applied to analyze the trend of the filtration rate. Analyzing figure 36, 37 and 38 suggesting that the clay filter can sustain 40 days with a regular bi-weekly plugging if the filter uses one-hour a day. Analyzing the figures suggesting that, exponential fit exhibits a higher sustainability for the both filters. 2^{nd} order polynomial fit exhibits an unrealistic result that showing the filtration rates would never drop to zero which is not practical in real. For all three fits, coefficient of determination (R^2) values were ranged between 0.18-0.59 indicated that the model poorly explains the variability of the data around its mean.

Analyzing the plots of filtration rate projection without plugging indicates that the clay filter can sustain up to 11 days. Again, the exponential fit exhibits the highest sustainability for the both filters. The 2^{nd} order polynomial fit for the ceramic filter exhibits the same trend as previous fit. This time the coefficient of determination values ranged between 0.96-0.88 indicates better fits.

To compare the continuous filtration with non-continuous filtration, an additional testing was also conducted where both clay and ceramic filters went for a continuous filtration process for 72 hours. The main objective of this testing is to find out the efficiency of the clay for continuous usage. As, in the previous testing, filtration rate was monitored for 1 hour per day basis, another major purpose of this study is to determine the sustainability of the continuous filtration. Also, continuous filtration is more realistic in the context of the slum residents of Dhaka city. As per continuous filtration, clay filter exhibits a plug in period at 50^{th} hour that means after 50^{th} hour, the filtration rate dropped around 25% of its original flow rate and cleaning, it regained 95.4% of its original flow rate. On the other hand, the ceramic filter did not need to plug in as its flow rate did not drop to 25% in between testing. Performance projection indicates that the clay filter can last around 225 days with a regular cleaning (Figure 43). As, the ceramic filter did not plugged-up, so no projection was conducted for the ceramic filter with plugging. Without plugging, the clay filter can last around 34 days whereas the ceramic filter last around 138 days (Figure 46).

An important aspect of projecting the sustainability of the filters in terms of their filtration rate is to ensure the maximum utilization of the filters by the slum residents. The slum residents certainly do not wait till the filtration rate drop to zero as their main intention is to meet the daily drinking water demand using the filters. As the WHO recommended demand for the drinking water is 7.5 liters per capita per day, it is important to filtrate at least minimal amount of water in daily basis using the filters.

Since, the exponential fit exhibits the highest filter life-time, analysis of exponential fit with plugging indicates that, if the clay filter can run continuously including a regular plugging, it will be able to meet the daily drinking water demand of a 4 members' family up to1 146 days.

Comparing both continuous and non-continuous filtration analysis, it is feasible to say that the continuous filtration gives an overall better performance than the non-continuous filtration. In non-continuous filtration, filtration rate drops very quickly in compare to the continuous filtration. As a result, filter often needs to clean. Also, non-continuous filtration reduces the life-time of the filters. On the other hand, continuous filtration extends the life-time of the filters and ensures the continuous cleaning process. That is why based on this study, it is highly recommended to use the filter in continuous basis. As per this study, assumption is, the clay filter needs to plug in every after 50th hour. However, with time being, drop of filtration rate may occur early thus the filter will have to clean more often as well.

CHAPTER 5

CONCLUSION AND FUTURE CONSIDERATION

5.1 Conclusion:

As per the established objectives, the main purpose of this study is to develop a low-cost drinking water treatment method for the low-income people group of Dhaka city. To develop the treatment method, this study focused on several issues important for the consideration. Existing water crisis of the Dhaka city especially in the slum areas where mostly low-income people are living is one of the important prospects of the study. At present, Dhaka City residents receive around 40 l/p/d of water in contrast to the demand of 150 l/p/d. This water crisis situation is even worse in the slum areas where around 30% of total population of the city resides. Slum residents receive 30 l/p/d of water where the average rate is 40 l/p/d. But very unlikely, In Dhaka city, a poor household has to spend TK.500 ($6.5) per month for 30 l/p/d while a middle-income or high-income group family has to pay TK.400 ($5.2) per month for water supply of 45-50 l/p/d or more. So, to solve the crisis of potable drinking water among the slum residents and to analyze the existing condition, Korail slum of the Dhaka city was selected as the study area as it is one of the largest slums of the city with a population of 200,000. Although this slum is covered by the DWASA supply chain, only 57% of the total demand of the slum provides by DWASA. Also, 79% people expressed their dissatisfaction regarding the quality and the availability of the supply water. Dwellers of the Korail slum is suffering some water borne diseases like Diarrhea, Dysentery, and cholera mostly because of drinking contaminated water. Considering all these aspects, several samples of water from the

Korail slum were collected and tested for common water parameter such as E. Coli, turbidity, BOD, PH, hardness etc. Among all of the pollutant parameters, the concentration of E. Coli and turbidity found very high in the water. So, the treatment method was developed based on removing E. Coli, turbidity and an additional parameter: suspended solids.

This study developed a clay filter as a potential mitigation measure for removing the pollutants from the water. Laboratory analyses showed that clay filter can remove up to 90% Log_{10} concentration of E. coli, 86% of turbidity concentration and 97% of suspended solids concentration of the water of Korail slum. The comparative study showed that the removal rate of clay filter is slightly lower than a commercially manufactured ceramic water filter. The highest removal rate of ceramic filter for E. coli was obtained around 98% of Log_{10} reduction. For turbidity and suspended solids, the rate was around 90% and 99% respectively. Also, both volumetric flow rate and flow rate per unit of filter area were analyzed for the both filters. For filtration rate per unit area, clay filter showed a higher rate than the ceramic filter because of its small surface area. However, for volumetric flow rate, ceramic filter delivered higher flow rate. To observe the consistency of flow rate and to check the plug-in period, continuous and non-continuous filtration analysis was conducted and 75% reduction of the original flow rate was considered for the plug-in period. Comparing both analyses it was found that the continuous filtration exhibits a better filtration and performance projection for the both filters. In continuous filtration, at 50^{th} hour, the flow rate dropped close to 75% thus the clay filter cleaned by the scrubber to recover its flow rate. To observed the efficiency of scrubbing, filtration continued to monitor how the filter performed after plug-in and it has observed that, after plug-in, the filter recovered 95.4% of its original flow rate. To assure the consistency, the ceramic filter also cleaned along with clay filter. Volumetric flow rate analysis suggests that, if the clay filter continuously runs for 24 hours a day with a, it will be able to treat 15.09 liters of water.

Overall, it is very much possible to establish clay filter as a potential method of treating drinking water among the low-income people of the Dhaka city. Cheap production cost, availability of raw materials can make this filter a viable option to the low income people group. When a good quality water filter costs around BDT. 6000 ($App. $77) with a complicated operation and maintenance requirements, a clay filter can provide the similar services only by BDT. 1000 (App. $13). The difference is very significant and the amount is also very much affordable for low-income people group of the slum. If commercial manufacturing of the clay filter starts, the price may reduce and will become much more convenient for the slum people. Also, the concept of clay water filter in Bangladesh is still not very well known. The method of making clay filter is easy and does not require any technical knowledge. Pottery is a common and very traditional occupation in Bangladesh and many poor people are living on this profession. It is possible to occupy these people group into the commercial manufacturing of the clay filter which also may become helpful to them in terms of their economic condition. In many different parts of the world, clay water filter has been using as a water purifier with a considerable removal efficiency. So, commercial manufacturing of this filter can create a new dimension in the water purification techniques in Bangladesh, especially to the slum residents who can't capable of affording expensive water filters.

5.2 Future Consideration:

Although it has proven that clay water filter can remove a significant portion of pollutants like E. Coli, turbidity, and suspended solids concentration of the drinking water with a considerable efficiency rate, it could not achieve 100% removal efficiency for E. coli reduction. According to World Health Organization (WHO) and US Environmental Protection Agency (USEPA), there should be zero concentration of E. coli presence in the drinking water because of its severe effects on human health. In this regard, clay filter could not properly have matched with the criteria. Probably the main reason behind its low E. coli removal rate in compare to the previous studies is not doing the characterization of clay material. Organic clay may host several microbial concentrations by itself thus reduce the removal efficiency of the filter. So, before start working on clay material, it is important to characterize it as inorganic clay. The clay filter designed for this research was made by an amateur potter so quality control issue was not maintained in a professional way. However, the study shows that, the clay filter is able to reduce the harmful pollutants from the raw water samples of Korail slum and if clay materials characterize properly and quality assurance maintain during its design and handling, it is possible to increase not only its removal efficiency but also the filtration rate.

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