Low Cost Grey Water Treatment

And

Recycling System

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This is to certify that the thesis titled

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Supervisor: ______________________________

Head of Department: ______________________

Associate Dean: ___________________________

Dedication

We dedicate this endeavor to Almighty Allah

Our beloved families

&

Friends

Who were there with us whenever needed, encouraged and raised us when we were down and helped us making this immense task a success

Acknowledgement

First and foremost, we would like to express our sincere gratitude to Dr. Qazi (Associate Dean IESE), Dr. Zaheer (HOD Environmental Engineering IESE) and Madam Erum Aamir (Supervisor) for their inspiration, motivation, enthusiasm, support and immense knowledge.

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Most of all we are thankful to Almighty Allah, Who gave us the will, determination and strength to accomplish this task in this manner.

Never to forget, we offer our gratitude to our beloved parents and friends whose unconditional love and support guided us throughout, ultimately making this task a successful reality.

Sincerely,

Muhammad Talal Ali Khan

Shafaq Aftab

Talia Afzal

Wasim Abbas

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1. Introduction

Water is the most important and essential element to life on earth. Pure water is odorless, tasteless and clear liquid. The importance of water to mankind can be ascertained from the fact that it constitutes up to 50 to 90 % of the weight of living things. From agricultural to commercial sector, water is consumed by mankind to fulfill his day to day activities.

Biologically, water aids in the digestion and absorption of vital nutrients that help in proper smooth functioning of the human body. In addition to this, it also helps to maintain proper muscle tone, supplies oxygen to the cells and serves as a natural air conditioning system. Having a glance at the environment and its functioning, it can be ascertained easily that water plays an important role in helping preserve a balanced eco system.

The above mentioned information is sufficient in establishing the fact that water by far, is the most resource for mankind and sincere efforts are being made worldwide to conserve and efficiently use this resource. Yet there remain some negligent societies, including ours that continue to contaminate this precious resource,

Unfortunately, humans have proved to be inefficient water users. (The average hamburger takes 2,400 liters, or 630 gallons, of water to produce, and many water-intensive crops, such as cotton, are grown in arid regions.)

Water is a natural solvent. Before it reaches the consumer's tap, it comes into contact with many different materials, including organic and inorganic matter, chemicals, and other contaminants.

1.1 World Wide Water Distribution

Water is widely distributed on Earth as freshwater and salt water in the oceans. The earth is referred as blue planet, because when one sees it from the space, it gives the impression as blue which is due to reflection from the oceans. Large amount of the water on Earth is regarded as saline water. This includes water from oceans, sea, saline groundwater and amount to over 97% of the water on Earth. The remainder of the Earth's water constitutes the planet's fresh water resource. Classically, fresh water may be defined as water with a salinity of less than 1 percent that of the oceans. The ratio of salt water to fresh water on Earth is around 40 to 1. (USGS Water Science School) The planet's fresh water is very unevenly distributed. All fresh water was found in rivers and streams, today most fresh water exists in the form of ice, snow, groundwater and soil moisture, with only 0.3% in liquid form on the surface. Of the liquid surface fresh water, 87% is contained in lakes, 11% in swamps, and

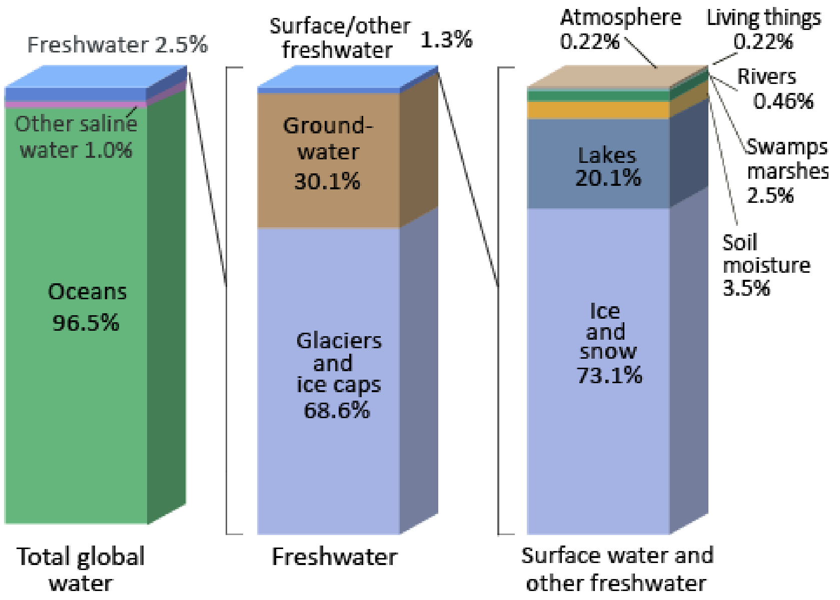


Figure 1 World Wide distribution of Water (Shiklomanov's, 1993)

only 2% in rivers. Small quantities of water also exist in the atmosphere and in living beings.

- The left bar shows that only 2.5% of all Earth's water is freshwater, which is what life needs to survive.
- The middle bar shows the breakdown on that 2.5% which is freshwater. Almost all of it is locked up in ice and in the ground. Only 1.3% of all freshwater (which was only 2.5% of all water) is surface water, which serves most of life's needs.
- The right side bar shows the breakdown of only the surface freshwater, which was only 1.3% of all freshwater. Most of surface freshwater is locked up in ice, and another 20% is in lakes. 0.46% of surface freshwater is in rivers. (Shiklomanov's, 1993)

1.2 Water Scarcity

According to United Nations (United, 2009), water scarcity is defined as:

> "Water scarcity is defined as the point at which the aggregate impact of all users impinges on the supply or quality of water under prevailing institutional arrangements to the extent that the demand by all sectors, including the environment, cannot be

satisfied fully. Water scarcity is a relative concept and can occur at any level of supply or demand. Scarcity may be a social construct (a product of affluence, expectations and customary behavior) or the consequence of altered supply patterns - stemming from climate change"

1.3 Causes

1.3.1 Pollution

Water pollution comes from many sources including pesticides and fertilizers that wash away from farms, untreated human wastewater, and industrial waste. Even groundwater is not safe from pollution, as many pollutants can leach into underground aquifers. Some effects are immediate, as when harmful bacteria from human waste contaminate water and make it unfit to drink or swim in. In other instances—such as toxic substances from industrial processes—it may take years to build up in the environment and food chain before their effects are fully recognized.

1.3.2 Agriculture

Agriculture uses 70% of the world's accessible freshwater, but some 60% of this is wasted due to leaky irrigation systems, inefficient application methods as well as the cultivation of crops that are too thirsty for the environment in which they are grown (World Wide Federation (WWF). This wasteful use of water is drying out rivers, lakes and underground aquifers. Many countries that produce large amounts of food—including India, China, Australia, Spain and the United States—have reached or are close to reaching their water resource limits. Added to these thirsty crops are the fact that agriculture also generates considerable freshwater pollution – both through fertilizers as well as pesticides – all of which affect both humans and other species.

1.3.3 Population growth

In the last 50 years, the human population has more than doubled. This rapid growth— with its accompanying economic development and industrialization—has transformed water ecosystems around the world and resulted in a massive loss of biodiversity. Today, 41% of the world's population lives in river basins that are under water stress (World Wide Federation (WWF). Concern about water availability grows as freshwater use continues at unsustainable levels. Furthermore, these new faces also need food, shelter, and clothing, thus resulting in additional pressure on freshwater through the production of commodities and energy.

1.4 Water Scarcity Facts

- Water scarcity already affects every continent. Around 1.2 billion people, or almost one-fifth of the world's population, live in areas of physical scarcity, and 500 million people are approaching this situation. Another 1.6 billion people, or almost one quarter of the world's population, face economic water shortage (where countries lack the necessary infrastructure to take water from rivers and aquifers) ((UNDP, 2006)
- Around **700 million** people in 43 countries suffer today from water scarcity (Water Scarcity (International Decade for action)).
- With the existing climate change scenario, almost **half the world's population** will be living in areas of high water stress by 2030, including between 75 million and 250 million people in Africa. In addition, water scarcity in some arid and semi-arid places will displace between 24 million and 700 million people (Coping with water scarcity. An action framework for agriculture and food security, 2012)
- A total of 2.7 billion find water scarce for at least one month of the year. Inadequate sanitation is also a problem for 2.4 billion people—they are exposed to diseases, such as cholera and typhoid fever, and other water-borne illnesses. Two million people, mostly children, die each year from diarrheal diseases alone ((World Wide Federation (WWF)).

- Water scarcity forces people to rely on unsafe sources of drinking water. It also means they cannot bathe or clean their clothes or homes properly. (WHO (Water Scarcity))
- Water scarcity underscores the need for better water management. Good water management also reduces breeding sites for such insects as mosquitoes that can transmit diseases and prevents the spread of water-borne infections such as schistosomiasis, a severe illness. (WHO (Water Scarcity))

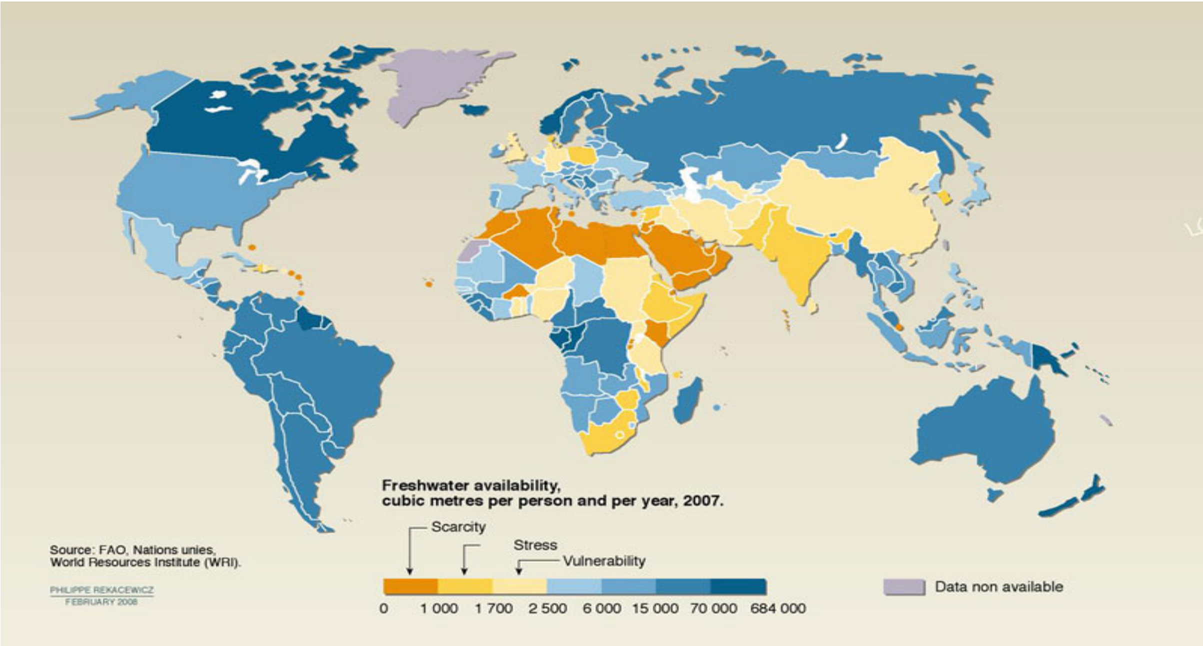


Figure 2 Water Scarcity Situations in the world

1.5 Situation in Pakistan

The current prevailing situation in Pakistan is distressful itself. For a country that is already plunged into the major glitches like corruption, terrorism and socio-economic instability; water scarcity is surely an unwelcome issue. Naturally due to government's lack of interest in this regard, the water scarcity problem is resulting in a greater demand of water. Various reasons like differences between the federal and provincial government, lack of machinery and lastly lack of technical knowhow, ultimately means that the construction of new reservoirs and completion of existing projects is always obstructed; hence leading to less water available.

Agricultural sector is considered to be the backbone of our economy, accounting for 24% of national GDP, 48 % employment and 70 % of country's export. Obvious but important to state is the fact that agricultural sector thrives primarily on water. So, Due to rapid increase in population and reduction in storage capacities of Tarbela, Mangla and chasma, per capita availability is reduced to 1000 cubic meters, which is threshold value for water scarcity (Pakistan Institute of legislative development and, 2011)

Water shortage in the country has assumed alarming proportions following reduced flows in the western rivers from their sources in Indian-held Kashmir resulting in aggravating tension over sharing of available water among the provinces. (HAQ, 2011)

The combined impact of water shortage, pollution and deforestation, is calamitous for the country. Many wild animals, plants, aquatic species, birds and other forms of flora and fauna are affected and many of these may succumb to water scarcity and be annihilated. There have also been special sicknesses in the areas of Sindh where the water scarcity is the most severe. Many experts are attributing these sicknesses to the scarcity of water. These sicknesses include skin and eye diseases in the Kohistan area of Sindh and mental sickness in the Indus delta area. Also, as mentioned above, there has been a sharp increase in the suicide rate in Sindh. There are expert opinions that most of these cases are related to economic and social problems resulting from the scarcity of water. (Memon, 2002).

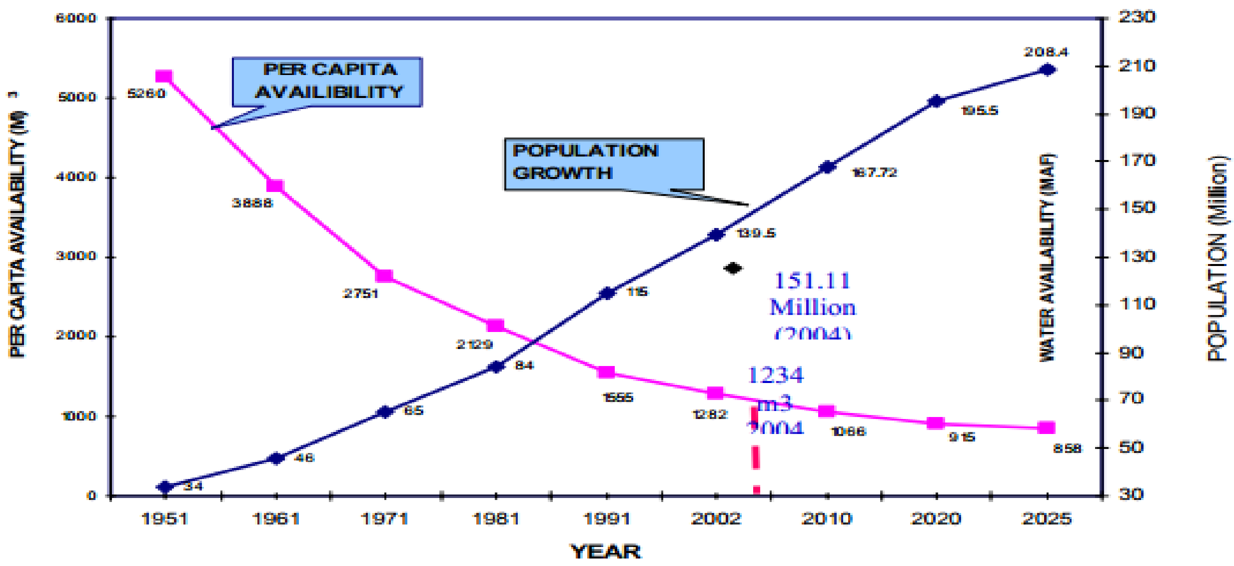


Figure 3 Water Availability Vs. Population Growth

Water shortage in Pakistan will surge up to 31% of people's needs by 2025 and this accentuates the need for some tangible steps that include water usage charges and building of storages, to cope with the problem. (Rana, 2013)

Agriculture is our chief sector and the water flowing in the channels to the crops is its blood line and if there is no or less water, then it's time to prepare to face economically as well as social problems. According to the estimates of federal government, the agriculture sector would suffer a loss of about Rs. 90 billion because of drought. Since agriculture has remained a major source of shouldering the already crippled economy, it has a vital role to play particularly in terms of food security and employment of the ever-burgeoning population of the country. It contributes around 35 % to the GNP and employs about 44% of labor force. It also contributes to 65% of export earnings (Water crisis in Pakistan, 2009).

So to sum up, the highlighted points towards the fact that water scarcity is not a myth, rather it's a harsh reality. As Environmental engineers, the responsibility of finding solutions for reducing demand on freshwater resources lies on our shoulders. The initiative was taken and it led us to the study of grey water area .Extensive research was incorporated in order to make such a treatment system which can be installed in the washrooms of our homes and educational institutions. This water after going through various purification procedures can be reused and if adopted on a bigger scale ,it is sure to help to supplement fresh water demand thus making freshwater more available to agriculture.

1.6 Grey Water

Grey water is generally defined as

"Waste water collected from indoor sources other than toilet, such as showers, bathtubs, hand basins and washing machines "

Some researchers include kitchen waste in grey water as well. For simplicity, we have not included kitchen waste in grey water as it is highly polluted with organic loading and contains oils as well.

Above facts shows that water scarcity is not a myth anymore and its happening. There is a need to find ways to reduce load on fresh water resources as they are only 1% (Eldessouky, 2006). Rainwater harvesting is the option to reduce load but this option is dependent on local climate and weather condition. Pakistan is a continental type of climate characterized by extreme variations of temperature, with such areas where annual rainfall may go up to 24 in (Recorded in Islamabad on 24 July 2001) and high temperature zones where temperature goes upto 50 C. In such a climate, rain water harvesting technique will be difficult to operate and unreliable in less rainfall areas. In such a situation, grey water can be one the technique to reduce loads on fresh water resources. Grey water is defined as

1.6.1 Domestic water consumption:

Water that comes to our home daily can be classified into four main types:

1. Toilet flushing
2. Drinking cooking
3. Household cleaning
4. Other household uses like car washing, gardening etc.

Among these four categories, there are at least two for which drinking water quality is not required and we can use treated grey water in these two types i.e. Toilet flushing and other households.

Following figure shows the usage of fresh water that come to our homes

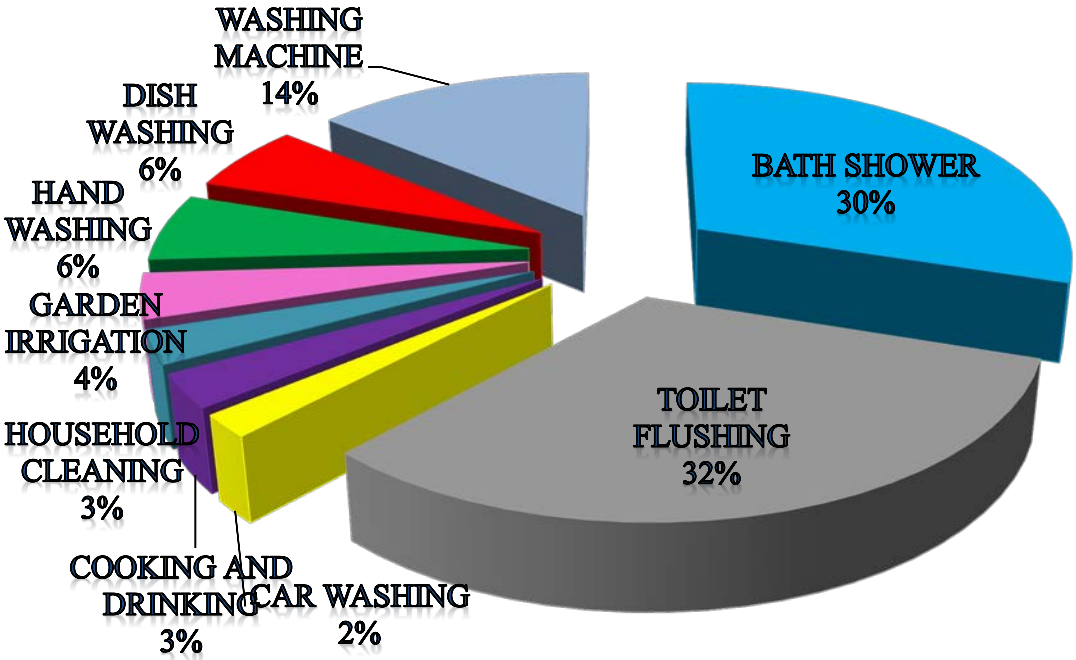


Figure 4 Daily Consumption of Fresh Water (Y. Chang)

The figure clearly shows that 40 % of activities don't require water of drinking quality and this can be replaced by treated grey water thus reducing the demand of fresh water.

According to (E. Ghisi, 2006)up to 35 % of water can be recycled using grey water instead of portable water in Brazil

1.7 Objective

The objective of the study is:

- To build a prototype of low cost and Sustainable Grey water treatment System
- To see its reuse applications in households.

2. Literature Review

2.1 Reuse of Greywater at Household Level

Authors: Barbara Imhof, Joele Muhlemann

A large compilation of data concerning physical and chemical characteristics of greywater was done by (Eriksson et al., 2002). Greywater shows substantial variations in composition; within a specific sample set, within an individual showering or bathing process and also between reported systems. The difference between these systems reflects variations in washing habits both in terms of product type and concentrations used. The composition of greywater also fluctuates with time because of the variations in water consumption in relation to the discharged amount of substances. An important effect has the chemical and biological degradation of the chemical compounds, within the transportation network and during storage. Chemical reactions can take place during storage and transportation of greywater, and thereby cause changes in the chemical composition of the water. Biological growth may lead to increased concentrations of microorganisms including faecal coliforms. This may also cause new organic and inorganic compounds to be produced as metabolites from partly degraded chemicals present in the greywater. The presence of nutrients such as phosphate, ammonium/ nitrate and organic matter will promote this microbial growth (Eriksson et al., 2002); (Ledin et al., 2001a). The quintessence is that a large number of chemical compounds and microorganisms can be present in the greywater. Temperature. Color, turbidity and total suspended solids are the physical parameters of greywater as discussed in this paper. Organisms possibly present in grey water are species of bacteria, protozoa, helminthes and viruses. If the greywater is reused for irrigation, parasitic protozoa and helminthes will not be a problem in relation to groundwater contamination due to their large size, which results in their removal by filtration as the water percolates under gravity (Eriksson et al., 2002). Bacteria and virus contamination of groundwater may, on the other hand, be a serious problem.

The storage of greywater is very inconsistently discussed; the references may even contradict each other. A summary of the opinions is given in the following chapter. The common point of all opinions is that greywater storage is difficult and the danger of pathogen growth present. The number of thermo tolerant coliforms increases strongly during the first days, which could imply that the number of pathogenic microorganisms increases, too. Another problem poses the depletion of oxygen during the degradation process which can lead to very bad smell. Most authors agree that it is better to avoid storage, but disinfecting of the greywater could also be a solution to the problem.

Depending on the economic aspects and required effluent quality, greywater undergoes different degrees of treatment before being reused or disposed. There are usually three degrees of treatment defined (Morel, 2002). 3 treatment steps are involved; firstly settling chamber, second stage organic decomposition and the last step is the advanced cleaning of wastewater

Many different reuse options exist for treated greywater:

- Residential reuse (flushing toilets, hand washing, cleaning, gardening)
- Irrigation of agricultural areas
- Industry (wash-down, cooling water, makeup water)
- Discharge into nearby streams, lakes or other water body

2.2 A Future for Grey Water Recycling

Authors: Ken Sutherland

Among the most challenging environmental problems worldwide, water shortage holds the top rank leading to severe economic problems, particularly in developing nations. The main cause of this shortage is the excessive and unchecked consumption of raw water, population growth and lack of rainfall in many areas of the world. The Millennium Development Goal for water was to reduce the proportion of the people without access to safe drinking water. Though incentives have been made to overcome these, yet, a more widened approach is required.

An alternative source is needed to minimize the wastage of water; one of them could be the conversion of salt and brackish water (the water having more salinity than the fresh water) into fresh water and the other being the conversion of waste water produced by human habitation. Most of the water intake to domestic and commercial establishments results in the form of waste water, which generally goes to the municipal sewer. Around 30-40% of this is generated by toilet flushing, referred to as black water and the one generated from kitchen, washing, bathing, laundry etc. is referred to as grey water. The re-use and reprocessing of the latter is encouraged nowadays because it requires less intense treatment and can contribute to the prevention of excessive use of fresh water.

Grey water should be collected separately from black water and should be sent through an independent sewerage system for processing coupled with the right degree of local treatment for it to be re-used. Some of the domestic uses of the recycled grey water will be garden and indoor plant watering, toilet flushing, car washing, dish washing and clothes washing etc.

Practically, the process used for grey water treatment should be less expensive than the cost of buying in fresh mains water and should be acceptable to the house owner in terms of easy maintenance and occupying least possible space. The most suitable in cost terms would be a deep sand filter, with automatic reverse flow washing. For removal of pathogens, use of membranes with pre filters is advised and an MBR can be used for the removal of dissolved impurities. Depending on the degree of treatment, the resultant water should still be contained in use, such as irrigating by underground pipes rather than on surface spraying due to the chance of spread of pathogens.

The major problems in implementing a grey water treatment system can be the human acceptance of using recycled water this way and the overall installation costs and additional costs of this system in residential properties. The recycling should be done in a way so as to avoid the building up within the water use and treatment system of long lasting impurities. A final finishing filter in the treatment plant is an essential component of the plant. Diversion of the kitchen effluents containing oils or grease away from grey water collection should be practiced and change of some components of dishwasher or clothes washing programs to reduce load on a treatment plant. Matching of grey water supply and use is also important.

For a fact, the companies most concerned with this system are the small organizations; the large equipment suppliers are not much interested and the filtration industry is not giving a serious thought to the use of grey water as a resource. This should not be the case considering the current status of water need and the increasing waste water quantities.

2.3 Design of a modified low cost treatment system for the recycling and reuse of laundry waste water

Authors: Jamil Ahmad, Hisham EL-Dessouky

Treated water is a careful and costly process through which clean water reaches our home daily. Water is a viable resource and it should not be wasted. About 1 % of water is used for drinking purpose rest of water is used for washing machines, toilets, showers and lawns. There is a need to find ways to conserve water in order to fight either water shortages in semi and arid regions and in highly populated areas. Wash water used in laundry contains higher chemical concentrations such as sodium, phosphorous, boron, surfactants, ammonia and nitrogen. It is high in suspended solids, turbidity and oxygen demand. All this makes discharge of this water as a threat to public health Reduce recycle and reuse is a part of cleaner production which concentrates on reduction at source rather than end of pipe approach. Brovoll et al (2002) investigates that in most countries, recycling have risen sharply over the past 15 years. There is very less information in literature about low cost treatment system for laundry waste water.

For the designed purpose, process of washing in the laundry house of petroleum refinery was observed and data was collected for 24 hours basis. Water for the laundry house is supplied from the refinery main water reservoir and is stored in the existing water supply tank, which serves as primary storage tank. From this tank water is distributed and used inside of the laundry house. Another tank was placed on ground for easy access. Dirty clothes including staff uniforms from the refinery and the local hospitals contaminated with dirt, oil and suspended particles were collected. Water is taken from primary and secondary tanks. Clothes were sent to kiln where water taken from primary and secondary storage was heated at high temperature and soap and detergents are added. The dirty clothes were then sent to first rinsing tank where soap solution was made to remove heavy contamination. Second rinse was also given to remove dust and other material from the clothes. Bleaching was done at the end. After washing the clothes, water is discharged through a final drain. The process was discharging 1.80m3 to the nearby drain that was a loss to the refinery. Alsoas the cost of water increases with the passage of time, this loss becomes intolerable.

The waste water were analyzed in the refinery quality control laboratory (QCL) and compared with the tap water for priority physical and chemical parameters to find out the level of contamination. A small size sand and gravel filter was made in a refinery workshop having three layers i.e. gravel and sand, in a stainless steel hopper. Waste water was passed through it and treated water were analyzed. Physical and chemical parameters like pH, Turbidity, TSS, TDS, COD, BOD and total hardness were tested. Results were shown in the table below:

S.no	***Tests***	***Waste Water***	***Filtered Water***	***Tap Water***
1	pH	8.02	7.71	7.5
2	Temperature (◦C)	30	28	30
3	TSS (ppm)	380	40	3.5
4	TDS(ppm)	540	380	250
5	BOD(ppm)	42	40	3
6	COD (ppm)	310	310	55
7	Turbidity (NTU)	10.27	0.4	0
8	TH (ppm)	240	150	262
9	Iron contents (ppm)	0.4	6	0

Table 1 Results

The data reveals that water is alkaline in nature. Due to soap and detergents, TSS and TDS were also very high and this was responsible for higher COD and BOD. TSS, pH and turbidity can be decreased by sedimentation and filtration. TDS and TH are normally brought to low level with RO or elector dialysis while COD and BOD can be reduced with aeration. Top management was not willing to allow use of expensive methods. The data has shown that sedimentation and filtration improved the quality of waste water to be used for the first rinse of clothes.

The total cost of the treatment system includes the cost of pipe length with fittings, pump and motor, strainer, excavation, RCC construction, treated water storage tank, steel used and the operating cost due to electricity. PVC pipe is used to transport the waste water from the laundry house to the treatment plant while stainless steel pipe was used for the transport of the treated water to the treated water tank. The designed laundry waste water treatment system using sedimentation and filtration was able to give a diluted solution of soap and detergent, which is suitable for first rinse of the dirty clothes. An appropriate disinfectant complying with the used detergent should be added to achieve proper disinfection of the hospital textiles. The total cost of the system is the sum of total capital cost and total operating cost and is calculated as US$ 1443. The calculated payback period was 1 year it was considered as very low and favorable.

3. Materials and Methods

The proposed experimental procedure consisted of the following steps:

1) Synthetic Grey Water Preparation
2) Characteristics of Synthetic Grey Water
3) Physical Treatment of Real and Synthetic Grey Water
4) Disinfection of Filtered Water
5) Proposed Equipment Design
6) Prototype Designing and Testing
7) Materials and Equipment

Each step is explained in detail in the following section

3.1 Synthetic Grey Water Preparation

3.1.1 Initial Experiments

For initial experimentation, grey water samples from Institute of Environmental Sciences and Engineering (IESE) boys and staff washrooms were collected by placing buckets under the sinks.

The soapy water samples were then tested in the laboratory for different parameters like turbidity, temperature, pH, COD, alkalinity, hardness, TDS and TSS. The results were carefully listed. These was repeated a couple of times so as to get a know-how of the generalized properties of grey water.

The properties were found to be varying each time. This sample water was used to run the proposed treatment procedure around 7 to 8 times. The operating conditions, treatment procedure, equipment and materials were kept consistent during each experiment. To get consistent results, it was figured out that a synthetic grey water sample should be made to better assess properties of grey water and to treat it accordingly.

3.1.2 Synthetic Grey Water Preparation

3.1.2.1Requirements for Synthetic Grey Water Formulation

i. It should be similar to actual grey water in composition.
ii. It should provide a matrix that permits the survival of pathogens and micro-organisms.
iii. It should contain compounds in detectable concentrations which would be having harmful environmental impacts in actual grey water.
iv. It should be reproducible and should provide consistent quality between batches and between users.

3.1.2.2 Preparation

It consisted of the following steps:

i. Initially, those products were selected which were expected to be found in average households, which included personal care products, detergents and additional laboratory chemicals for achieving the concentration ranges of various parameters as required.
ii. All ingredients (except the clay and secondary effluent) were weighed and mixed with 500 mL warm water in a blender at low speed for one minute. The quantities given in the table below are for 100 L of grey water.
iii. The feed tank was filled with a mixture of the required amount of tap water and the concentrated ingredients prepared previously.
iv. A submersible pump was installed in the feed tank to mix the grey water overnight.
v. Mixing the grey water overnight caused a decrease in the pH into the correct range (Table 2) and also the temperature of the grey water into the desired range of 25-35°C.
vi. The pump outlet in the feed tank was modified so as to direct it towards the feed tank walls to reduce entrainment of air and foaming in the feed tank.

Ingredient	Amount in 100L	Product Used
Moisturizers	1	Dove
Toothpaste	3.25	Colgate Maximum Cavity Protection
Deodorant	1	Axe
Na_2SO_4	3.5	Analytical grade
$NaHCO_3$	2.5	Analytical grade
Na_2PO_4	3.9	Analytical grade
Clay	5	Industrial grade
Vegetable Oil	0.7	Seasons' Canola
Shampoo/hand wash	72	Palmolive
Laundry	15	Omo High Performance
Boric Acid	0.14	Industrial grade
Lactic Acid	2.8	Analytical grade
Secondary Effluent	2 L	From Treatment Plant

Table 2 Synthetic Grey Water Ingredients (Clare Diaper, 2008)

3.2 Characteristics of Synthetic Grey Water

After complete settling, the grey water sample was tested for pH, turbidity, conductivity, chemical oxygen demand (COD), alkalinity, hardness, total dissolved solids (TDS), total suspended solids (TSS) and microbial count. The properties are shown as follows:

Parameter	**Value/Range**
Suspended Solids (mg/L)	60-80
BOD (mg/L)	130-180
Temperature (^{0}C)	25-35
pH	6.5-8.0
Turbidity (NTU)	50-70
Conductivity (uS/cm)	300-400
COD (mg/L)	250-400
TOC (mg/L)	50-150
Total Coliforms (cfu/100ml)	10^3-10^4
E. Coli (cfu/100ml)	10^2-10^3

Table 3 Characteristics of Sythetic Grey Water

Figure 5 Synthetic Grey Water

Suspended Solids, Turbidity, Temperature, pH, Conductivity, COD and Total Coliforms were the main properties of synthetic grey water which caught attention.

After the synthetic sample was made, all the above mentioned tests were performed on it on regular basis through concerned laboratory apparatus and with the help of technical laboratory staff. This was done to design a proper treatment process that shows reproducible results and to minimize any form of error or variance in the results due to changing characteristics of the sample.

3.3Physical Treatment of Grey Water

3.3.1 Sedimentation

Sedimentation is the removal of suspended particles that are heavier than water by gravitational settling. The density of mineral particles is usually between 2000 to 3000 kg/m3 and can easily settle out by gravity while organic particles have densities ranging from 1010 to 1100 kg/m3 (TANGKI, 2012)and take a long time to settle by gravity. Generally, coagulants are used to destabilize particle to form larger and settable solids.

Suspended material may be particles, such as clay or silts, originally present in the source water. Suspended material or floc is created from material in the water and the chemical used in treatment processes. It is accomplished by decreasing the velocity of the water being treated to a point below which the particles will no longer remain in suspension. When the velocity no longer supports the transport of the particles, gravity will remove them from the flow (Minnesota Rural Water Association Manual)

3.3.2 Filtration

Filtration involves the flow of water through a granular bed, of sand or another suitable media, at a low speed. The media retains most solid matter and permits the water to pass. Filtration process is usually repeated to ensure adequate removal of unwanted particles in the water (Ontario, 2010). This kind of slow filtration over a granular bed is generally known as slow sand filtration. The separation is not complete, and it will depend on the pore size and the thickness of the medium as well as the mechanisms that occur during filtration

A multimedia filter was made for treatment of grey water. Depth of each layer is given below

Layers	Thickness
Gravel	4”
Sand	3”
Activated Carbon	3”

Table 4 Filter Construction along Media Thickness

The filter is a laboratory scale filter which was constructed students of Environmental Engineers. It consists of three layers; gravel, Sand, Activated Carbon. It has the capacity to reduce the COD, hardness, turbidity and various other factors in grey water by a considerable amount.

3.3.2.1 Media Size Determination

Sieve	Opening (mm)	Mass retained on the sieve (g)	Cumulative Mass Retained (g)	% Finer
4	4.75	0	0	100
10	2	6	6	98.8
16	1.18	13	19	96.2
30	0.6	58	77	84.6
60	0.25	261	338	32.4
100	0.15	109	447	10.6
200	0.075	45	492	1.6
Pan		8	500	0

Table 5 Determination of Sand Particle Size

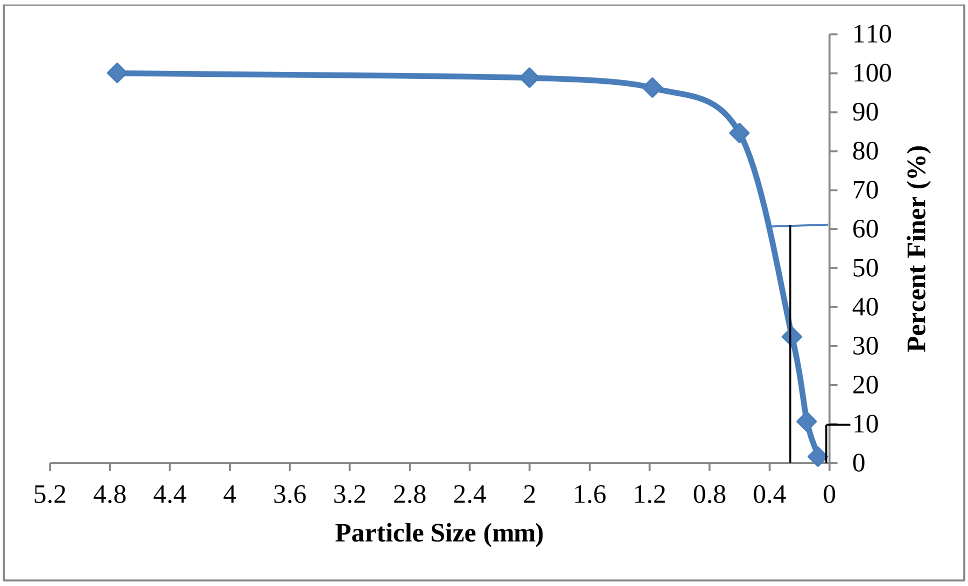


Figure 6 Particle Size Distribution Curve of Sand

Co-efficient of Uniformity = $C_u = D_{60}/D_{10} = 0.4/0.2 = 2$

Sieve	Openings (mm)	Mass Retained on the sieve (g)	Cumulative mass retained on the sieve (g)	% Finer
4	4.75	0	0	100
10	2	395	395	21
16	1.18	104	499	0.2
30	0.6	1	500	0
60	0.25	0	0	0
100	0.15	0	0	0
200	0.075	0	0	0
Pan		0	0	0

Table 6 Determination of Activated Carbon Particle Size

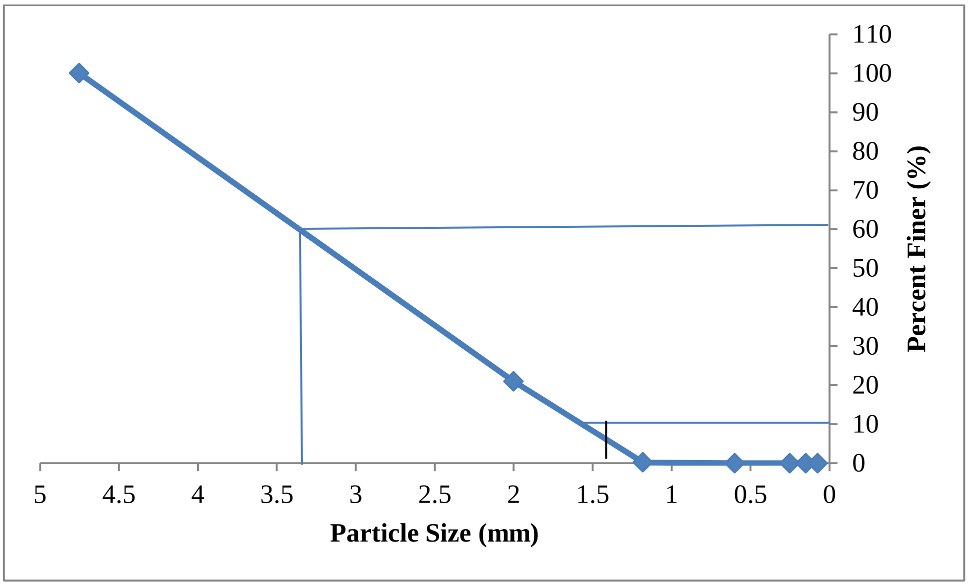


Figure 7 Particle Size Distribution Curve of Activated Carbon

Co-efficient of Uniformity = $C_u = D_{60}/D_{10} = 3.35/1.6 = 2.094$

Before the experimental procedure was started, a new filter was made using the above mentioned media. The filter media was overflowed with clean tap water to release any sort of air trapped in the media.

The settled water was then passed through the filtration assemble. This step was done manually. The filtrate was then tested for all the already mentioned tests.

3.4 Disinfection of Filtered Water

3.4.1 Selection of Disinfectant

Filtration was followed by disinfection. Before that, it was to be made sure that such a disinfectant was to be chosen which satisfied the following criteria.

i. Readily available in the market
ii. Easy-to-use for the consumers in a residential compound
iii. No adverse health effects
iv. Yields negative result when tested for the presence of Coliform contamination
v. Gives consistent results regarding the presence of Coliform contamination
vi. Cost effective/Economical
vii. Contains an effective concentration of chlorine in the water for 24 hours after the disinfection to ensure the absence of Coliform contamination

3.4.2 Disinfection using Clorox Solution

An optimum concentration of Clorox solution had to be determined that resulted in zero Coliform and at the same time had no damaging effects on consumers' health.

Following steps were performed to determine an optimum Clorox solution concentration (for the filtered water) in the designed equipment.

i. 100 ml filtrate (water filtered through the filter) was taken in 10 separate flasks.
ii. Clorox solution was added in varying concentrations to the filtrate to the flasks.
iii. Each flask was stirred with a glass rod manually for 5 seconds on an approximate with the provision of a detention time of 15min.
iv. Spread plating was then carried out for the detection of presence of Coliform contamination.

3.5 Proposed Equipment Design

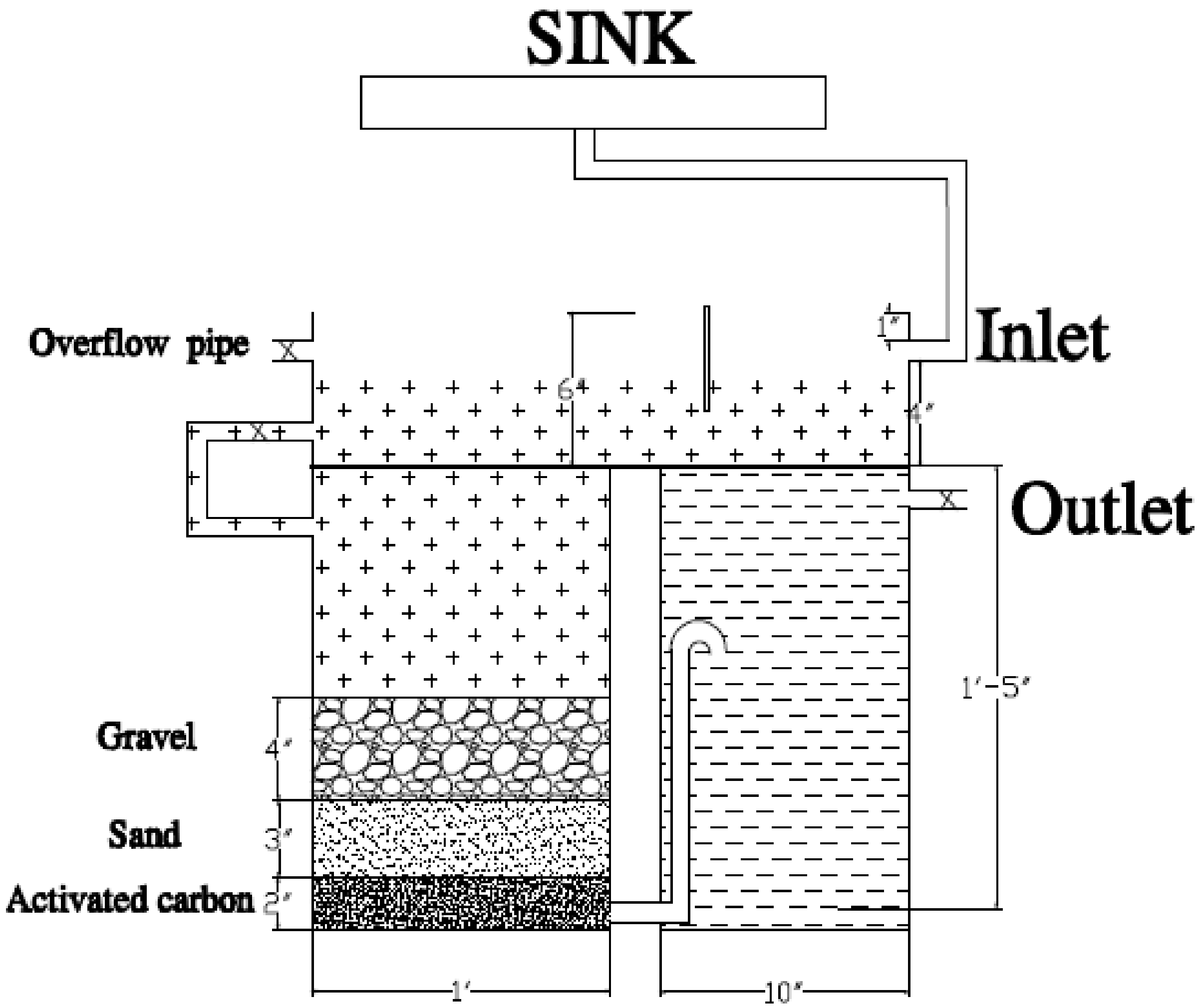


Figure 8: Schematic Diagram

Figure 9: Proposed Treatment System

The prototype has been made from Acrylic sheet. A sheet of 8 mm was used in making prototype. The top most chamber is the Sedimentation/Collection chamber, the second is the Filtration chamber and the last is the storage/ Disinfection Chamber. The dimensions of each compartment are given in the following table:

Dimensions (inches)	1st Chamber	2nd Chamber	3rd Chamber
Length	24 “	12”	10”
Width	12”	12”	12”
Height	6”	18”	18”

Table 7 Dimensions of Prototype

3.6 Prototype Designing and Testing

3.6.1 Sedimentation/Collection Chamber

The grey water sample from the sink will be collected in the sedimentation/collection chamber. In this chamber, the particles will settle down. The lighter particles will remain suspended in the sample. To provide settling, the velocity of the water being treated will be decreased to a point below which the particles will no longer remain in suspension. These particles will ultimately start settling in the sedimentation chamber.

Figure 10 Sedimentation/ Collection Tank

3.6.2 Filtration Chamber

The settled water was then allowed to flow into the filtration chamber, where the water was passing through the filtration assembly. The filtration assembly and the respective heights have been stated in the table (top to bottom);

The Filtration Chamber Construction

Filtration Media	Thickness of layer
Gravel	4 “
Sand	3”
Activated Carbon	3”

Table 8 Filtration Chamber Construction

Figure 11 Filtration Assembly

3.6.3 Clear Filtrate/ Disinfection Chamber

The filtered water was then allowed to flow into the clear filtrate where disinfectant is added. To achieve good disinfection, proper head was given to create a certain degree of turbulence (mixing) and suitable time (detention time) for the disinfectant to mix with the filtered water. The pipe having a diameter of 0.5" allowed the water to flow when the level of water was at least up to 22 liter mark. Enough detention time was ensured for the mixing of the disinfectant with the water.

Figure 12 Disinfection Chamber

3.6.4 Cost and Maintenance of the Equipment

Although the proposed prototype was made using Acrylic sheet, still, they can be replaced by any plastic or less cheap containers. While the cost of the prototype is Rs. 12000, the replaced equipment like a plastic will cost not more thanRs. 5000. When considering maintenance and operation, it can operate for a two month without the need for backwashing and if required, it is quite simple and can be easily done by any person well aware of the equipment. The media, having prominently varying sizes and colors can be taken out on a piece of a clean cloth or a chart paper, separated and then washed with clean water. It can finally be put back according to the marked color instruction on the chamber.

3.7 Materials and Equipment

This section enlists all the materials and equipment's used during the overall experimental procedure.

3.7.1 Materials

- Grey Water
- Tap Water and Distilled Water
- Clorox disinfectant (5.25 % Hypochlorite)
- Chemicals used in various tests like COD, Alkalinity, Hardness, and Total Suspended Solids etc.

Device/ Equipment	Company
Turbidity Meter	HACH
pH Meter	HACH
Weighing Balance	Shimadzu
Colony Counter	SUNTEX
Oven	LabTeck
Laminar Flow Hood	ESCO
Portable Autoclave	Dioxins
Incubator	----------

Table 9 Equipment Used in Project

3.8 Sampling:

3.8.1 Grab Samples

There are two types of samples based upon their method of collection:

1. Grab samples
2. Composite samples.

The choice of method depends upon the analysis that is required on the sample. A grab sample, also known as a catch sample, consists of a single sample taken at a specific time. This is the sampling technique mostly used for labs.

Composite sampling is the one in which all of the material is collected at once and can only represent the conditions at a particular time (Ogbonnaya). It can be taken manually by using a pump or scoop or by dipping the container directly into the water to be sampled. Certain tests require the use of grab samples and need to be analyzed immediately upon collection. These tests include pH, temperature, dissolved oxygen, chlorine residual and fecal coliform.

3.8.1.1 Need of a Grab Sample:

- To collect a grab sample for tests that usually require composite samples (unusual discharge occurs in which an operator must determine if appropriate action needs to be taken immediately).
- When there is an intermittent discharge as in industrial monitoring situations.

- Analysis of specific types of unstable parameters such as pH, dissolved oxygen, chlorine residual, nitrites and temperature
- To represent some well-mixed surface waters, but rarely, wastewater streams for water quality evaluation.

3.8.1.2 Limitations (Code of Federal Regulations):

- A grab sample takes just a snapshot of the characteristics of the water at a specific point and time, so it may not be completely representative of the entire flow.
- Grab samples are preferred for some tests like pH, dissolved oxygen, and total residual chlorine which change very rapidly in water once the sample is removed from the flow
- Grab samples must be collected carefully to make them as representative as possible of the water as a whole. They should be taken at a time of day when the plant is operating near its average daily flow rate.
- If grab samples are used to determine plant efficiency by collecting a raw water sample and a treated water sample, then the collection of the effluent should be delayed long enough after collection of the influent sample to allow for the raw water to pass completely through the treatment process.
- Mixing two or more grab samples may not result in a result which averages the characteristics of the samples. Chemical reactions can take place in mixed samples which alter pH and chlorine residual values.

3.8.2 The Prototype:

Grab samples are most appropriate to small plants with low flows and limited staffs which cannot perform continual sampling and have limited time. The prototype design described above is also a small scale plant installed inside homes, so grab sampling was selected instead of composite sample. Due to limited time, composite sampling would have been too hefty.

4. Results and Discussion

In this chapter results of the previously mentioned experiments carried out at various stages will be discussed. In The following listing, different stages are shown for which results have been discussed in the subsequent section;

1. Characteristics of original greywater
2. Characteristics of filtered water
3. Discussion of results

In order to check the consistency of the proposed experimental procedure, it was performed for 30 days. However, the results of the 3 averaged experimental runs are discussed.

4.1 Characteristics of original Greywater

Samples of grey water were collected and analyzed for physical and chemical parameters to check the quality of grey water and subsequently use the results for the design of the treatment system. Following parameters were analyzed during the experimentation.

4.1.1 pH

The alkaline nature of greywater was revealed by the Continuous observation of the data collected. Following graph shows the trend of pH during the whole testing period.

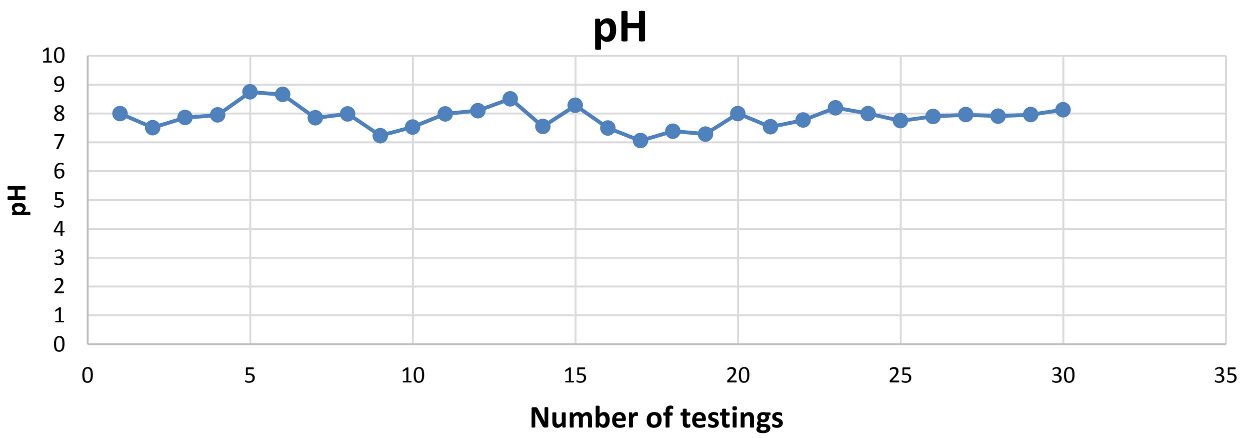


Figure 13 pH Trend

4.1.2 Turbidity, TSS and TDS

This gives information about the particles and colloids that could clog the installations and pores. Grey water sampled from three washrooms was highly turbid. Measured TSS, TDS and turbidity support this result.

Turbidity (NTU)	13.4	13.5	12.7
TSS(mg/lit)	4.4	5.2	7.5
TDS(mg/lit)	339	324	321

Table 10: Three averaged values for Turbidity, TSS, and TDS over the testing period

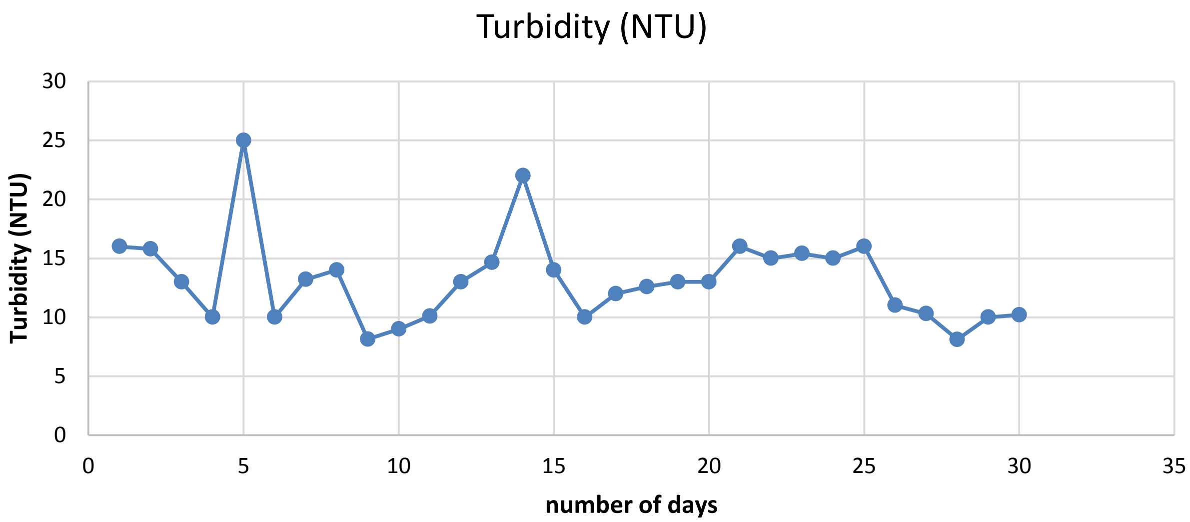


Figure 14 Turbidity Range of Original Sample

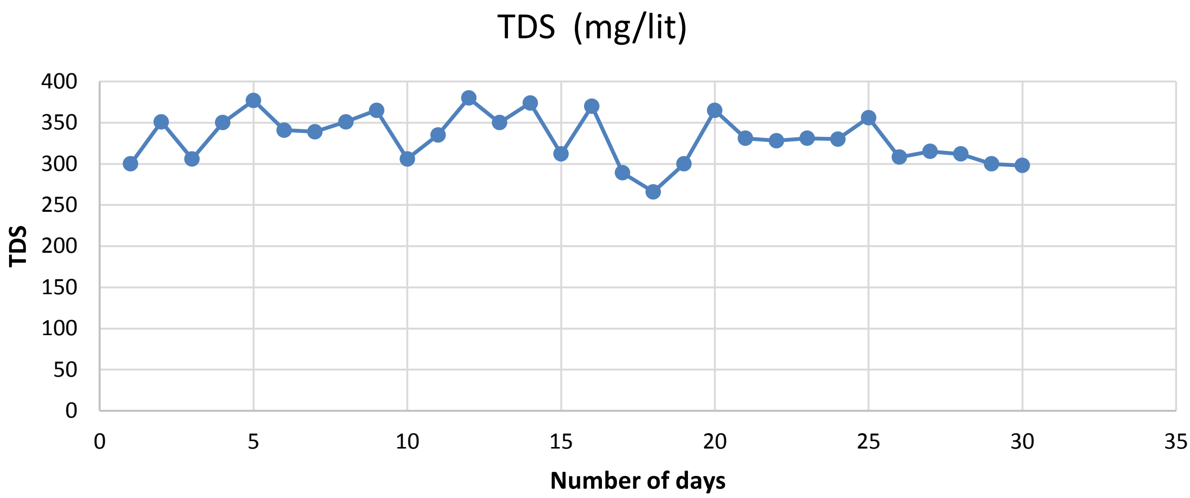


Figure 15 TDS Range of Original Sample

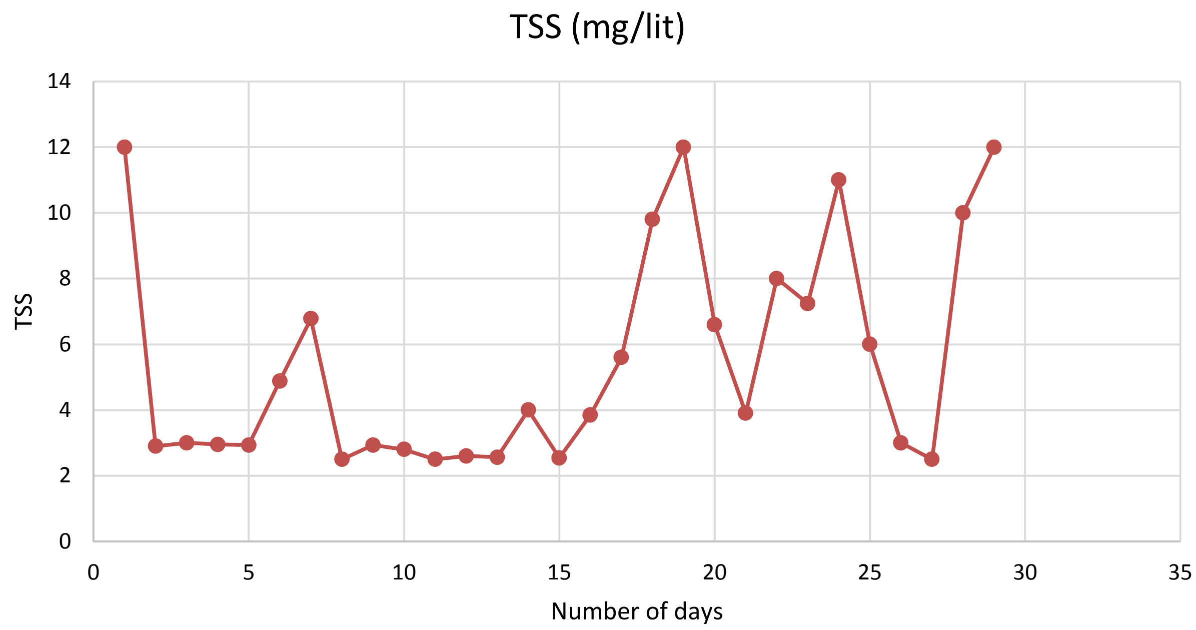


Figure 16 TSS Range of Original Sample

4.1.3 Chemical Oxygen Demand (COD)

The content of chemical oxygen demand (COD) indicates the risk of oxygen depletion. This is due to the degradation of organic matter during transport and storing and possibility of production of sulfides producing bad odor. (Ledin et al., 2001a). Most of the COD derives from household chemicals like soaps and laundry detergents, so that the COD in greywater is expected to be at same level as the residential waste water (Eriksson et al., 2002). Following COD results were obtained after thorough experimentation of the greywater.

COD of untreated water ranged in between 250 to 600 mg/lit.

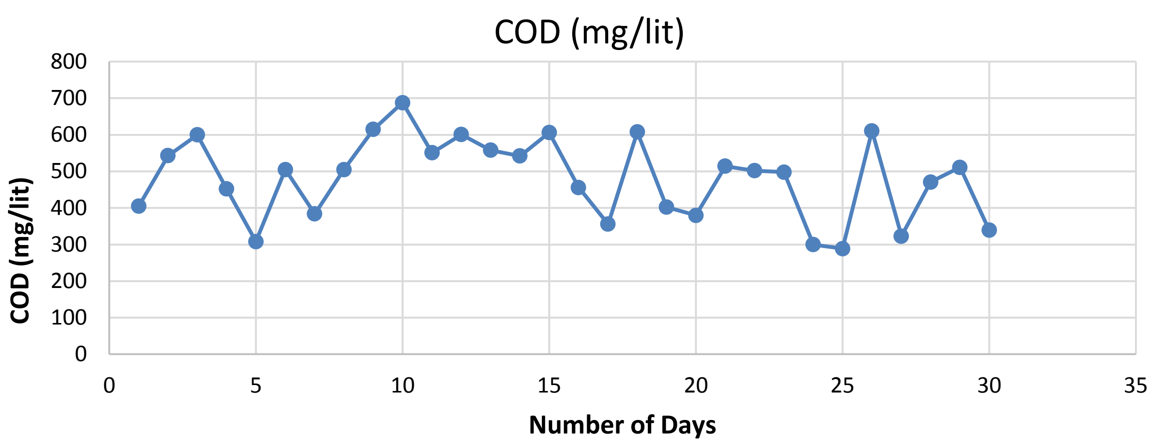


Figure 17 COD range of Original Sample

4.1.4 Alkalinity

Tendency of the water to neutralize acids is called alkalinity. Greywater, having a pH of greater than 7, indeed reveals that it would be having higher alkalinity (EPA). Presence of carbonates, bicarbonates and hydroxides result in higher alkalinity because they help in lowering H+ ions thus decreasing the acidity of water. Carbonates and bicarbonates are present in soaps and detergents. Following graph shows the trend of alkalinity in the untreated Greywater.

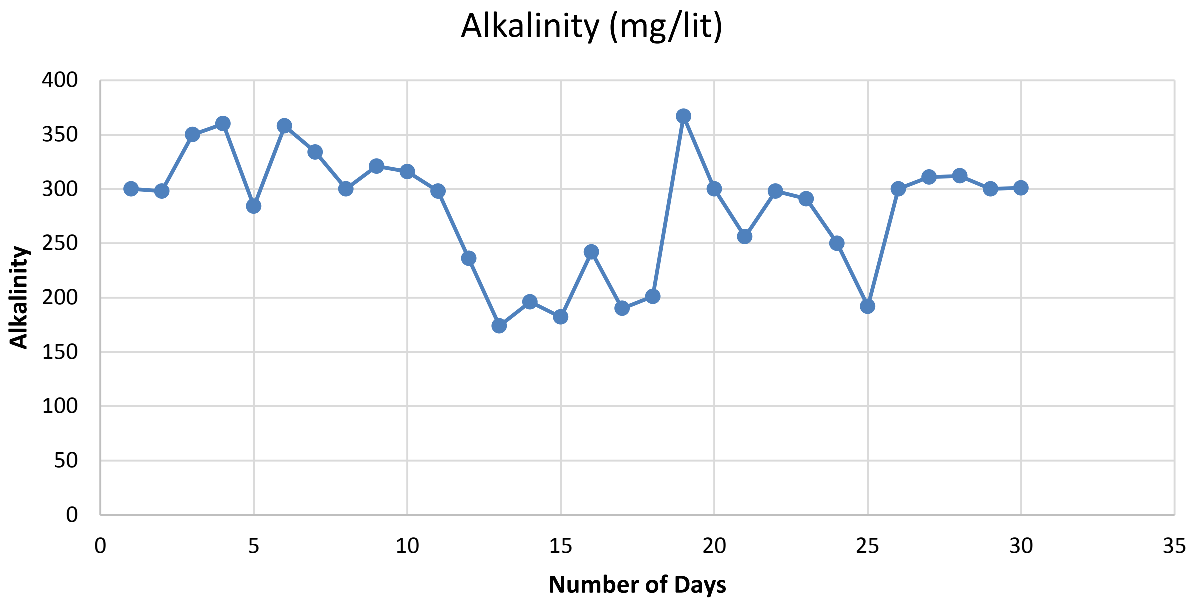


Figure 18 Alkalinity of sample Grey water

4.1.5 Hardness

Scientists define hardness as the capacity of water to precipitate soaps (Wurts). This hardening of water is primarily due to the presence of two ions namely, the divalent calcium and magnesium cations. However , it should be noted that "Hard water "is a relative term and the water having high hardness values tends to cause scaling of pipes and malfunctioning of the various systems. Hardness of greywater was measured for a period of 3 days and the data obtained is shown below.

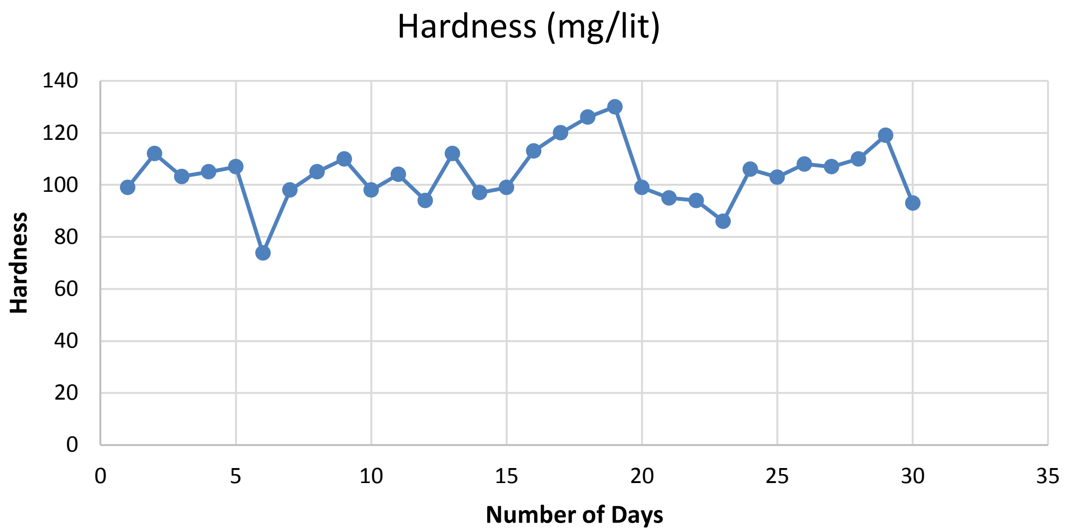


Figure 19 Variations in Hardness of sampled Greywater

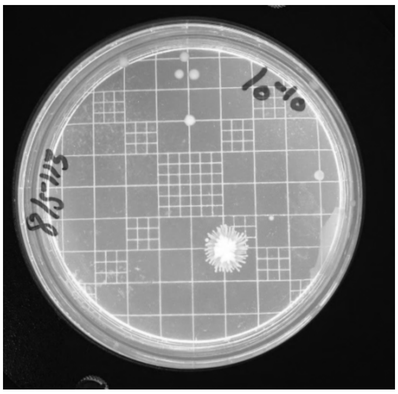
4.1.6 Coliform Count

Various samples of were tested in order to obtain the total coliform count. Following table shows the results obtained*.

Experimental Runs	Total Coliform Count
First Run	$10^{-7.7}$
Second Run	10^{-9}
Third Run	10^{-6}

Table 11: Three averaged results for the Coliform count of Grey water over the testing period

*(For the ease of understanding only 3 averaged results are shown here)



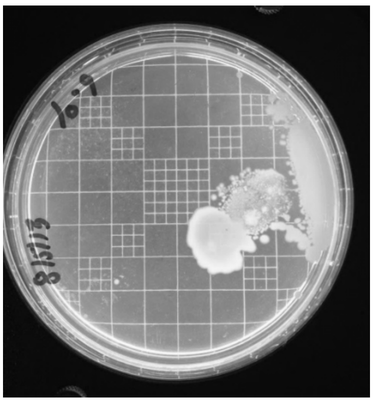


Figure 20 Coliform Count before The treatment process

4.2 Characteristics of filtered water

Greywater was treated using the proposed treatment system and same characteristics were observed for the treated/filtered water as discussed in the previous section. These results are discussed below.

4.2.1 pH

After treating the alkaline greywater with the treatment system, it was observed that the filtered water became neutral i.e. its average pH became 7 (got reduced from 8). Trends in the pH during the whole testing period are shown in the graph

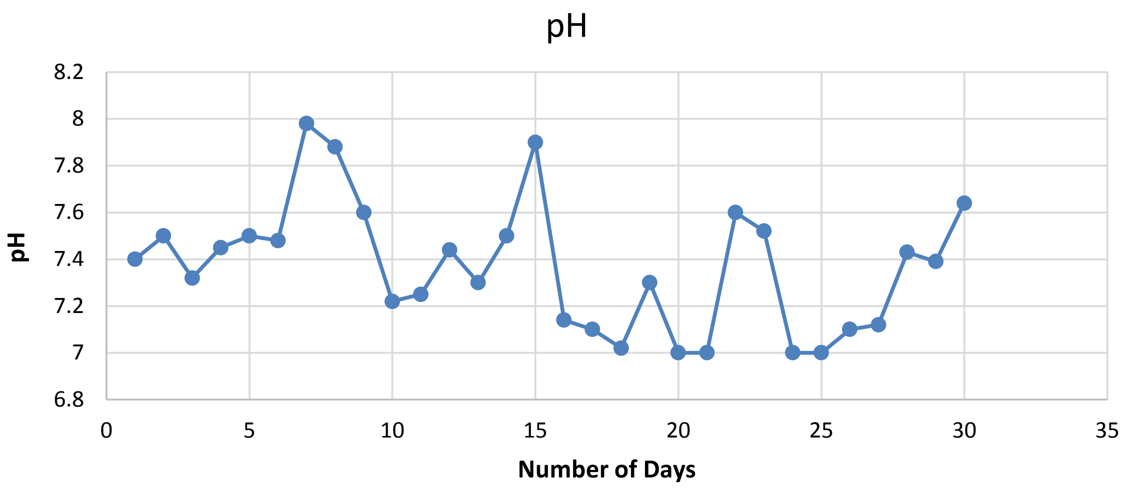


Figure 21 Reduction in pH of water after filtration

4.2.2 Turbidity, TSS and TDS

After passing the water through the treatment system, the turbidity of water reduced by a factor of 80%, TSS by 65% and TDS by 40%. Following table shows the averaged values of these three parameters.

Turbidity (NTU)	2.3	1.8	1.4
TSS(mg/lit)	1.6	2	0.85
TDS(mg/lit)	276	264	211

Table 12: Three averaged results for turbidity, TSS and TDS for the treated water

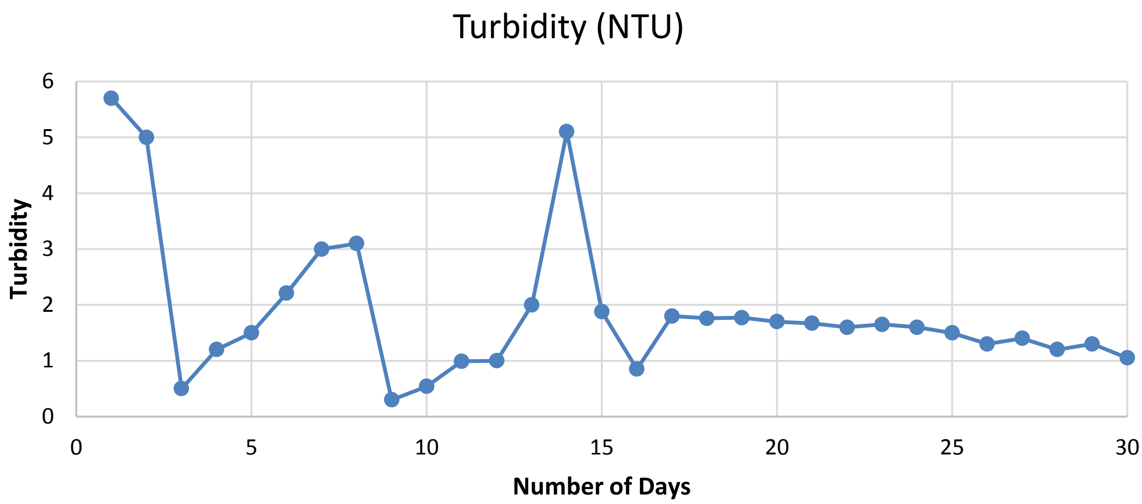


Figure 22 Reduction in turbidity after treatment process

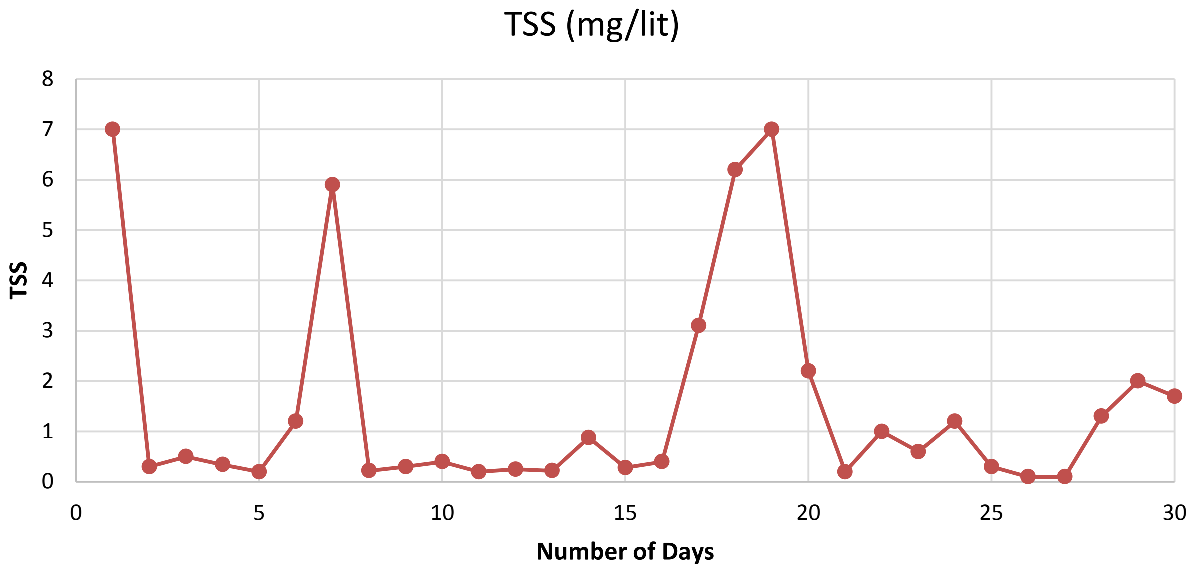


Figure 23 Reduction in TSS after treatment process

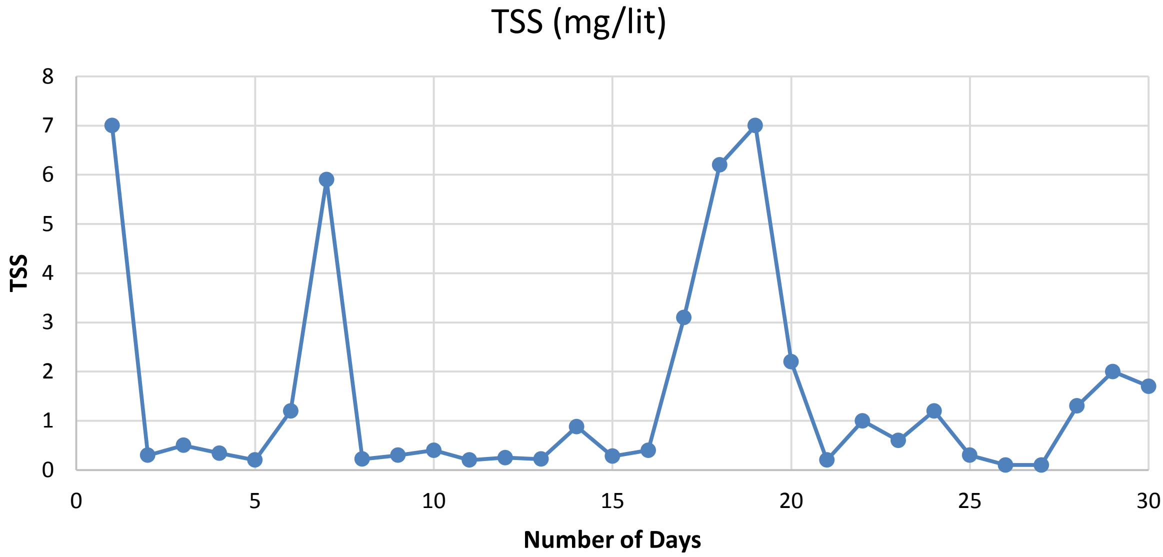


Figure 24 Reduction in TSS after treatment process

4.2.3 Chemical Oxygen Demand (COD)

The treatment system reduced the COD of to a minimum range lying between 60 and 150 mg/lit. Removal efficiency came out to be 90%. Following is the graph showing the results of COD taken for 30 days.

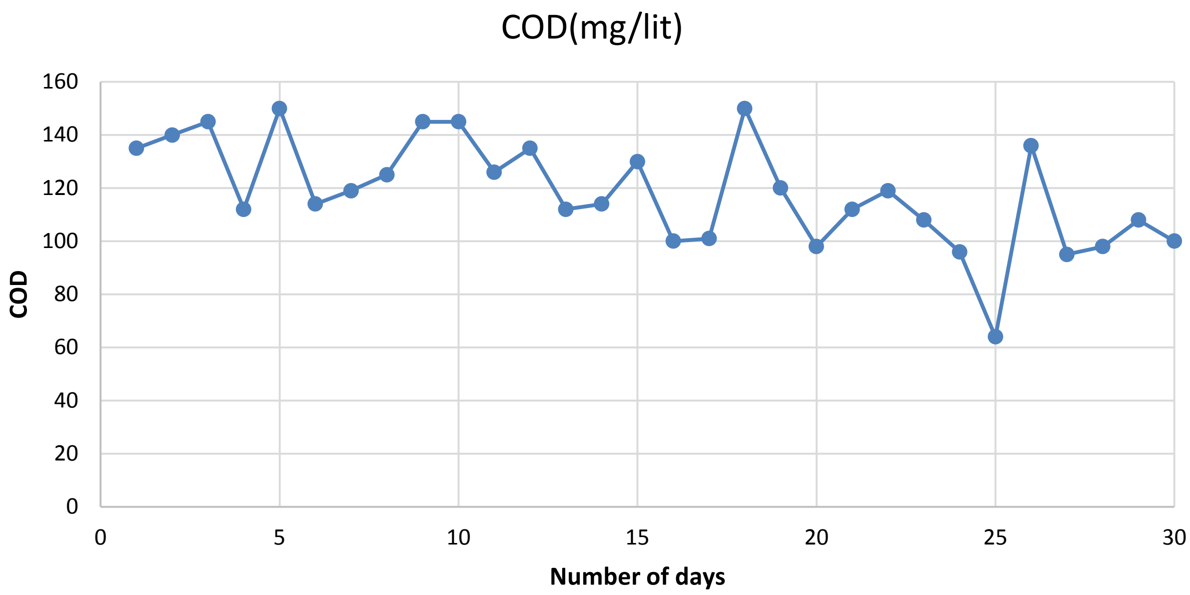


Figure 25 Trends in reduction of COD of greywater after the proposed treatment

4.2.4 Alkalinity

The treated water showed 50% less alkalinity upon analysis .as the pH decreased after the filtration process, it led to a reduction in the alkalinity of the water. Results of filtered water in terms of alkalinity are shown.

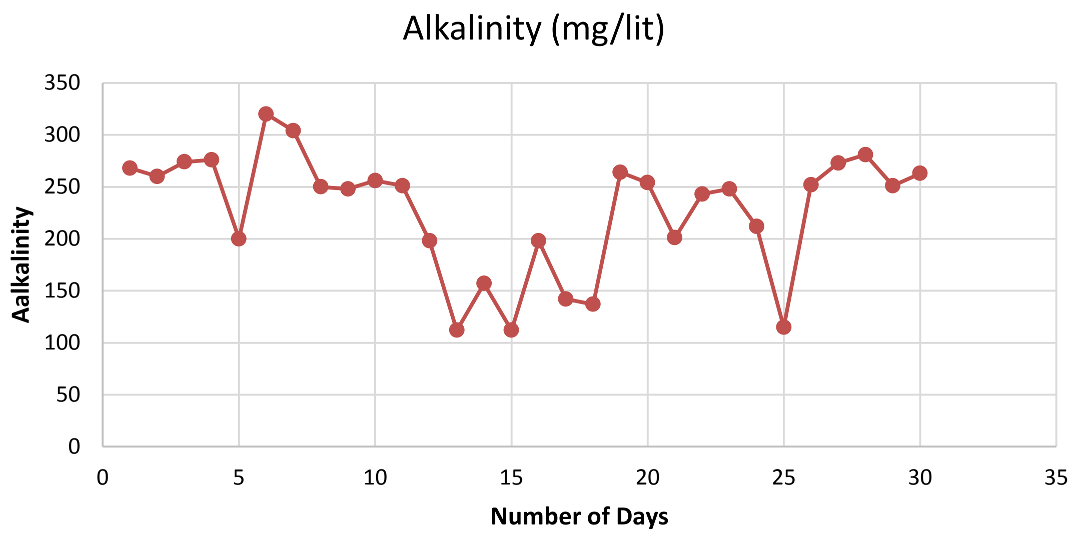


Figure 26 Reduction in Alkalinity after the treatment

4.2.5 Hardness

The proposed treatment system was successful in removing about 40% of hardness from the original sample. Upon further investigations , the ascertained range of hardness of the treated water came out to be 50 to 80 mg/lit which wasn't that high and easily fell in the acceptable limits . Rest of the values are depicted with the aid of the diagram below

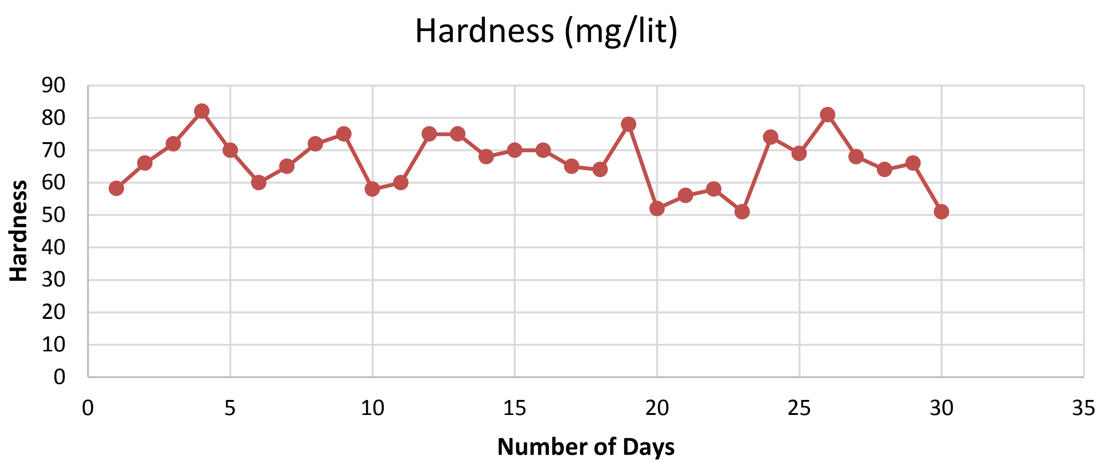


Figure 27 Reduction in Hardness after the treatment

4.2.6 Coliform count (with and without disinfection)

Treated water effluent was tested for the coliform count before and after the disinfection chamber. For every round of test, before disinfection the coliform count came out to be between 10^{-2} and 10^{-4}. Whereas after the disinfection; treated water showed zero coliform count which was the required achievement.

Experimental Runs	Total Coliform Count
First Run	Too numerous to count
Second Run	Too numerous to count
Third Run	Too numerous to count

Table 13: Results for coliform count for treated water without disinfection

Experimental Runs	Total Coliform Count
First Run	Zero
Second Run	Zero
Third Run	Zero

Table 14: Results for coliform count for treated water with disinfection

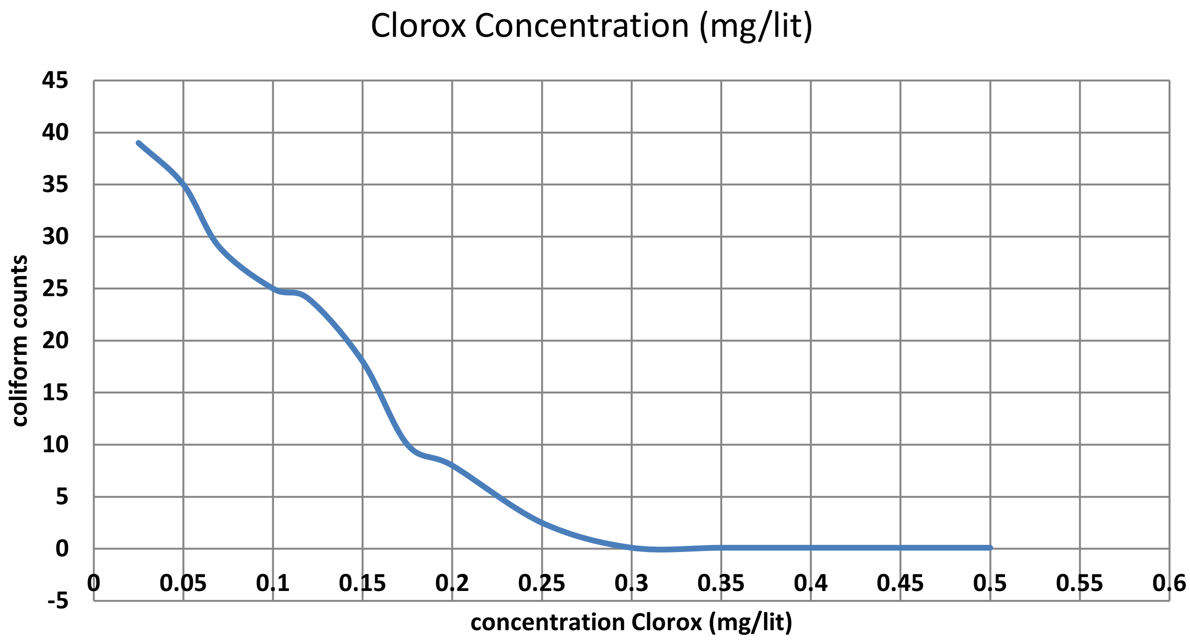


Figure 28: The observed trend of decrease in coliform count with increasing conct. of Clorox

The figure below shows the decreasing trend of coliform counts with the increasing concentration of Clorox.

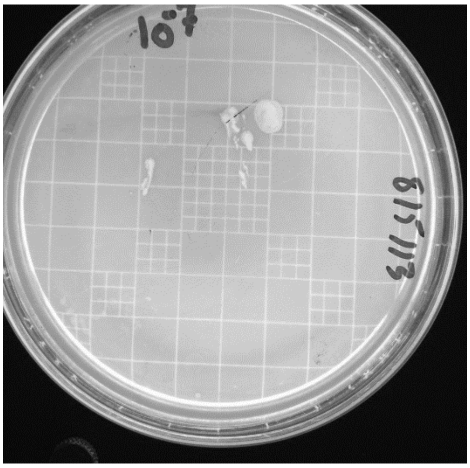


Figure 29: Coliform count after treatment and before Disinfection

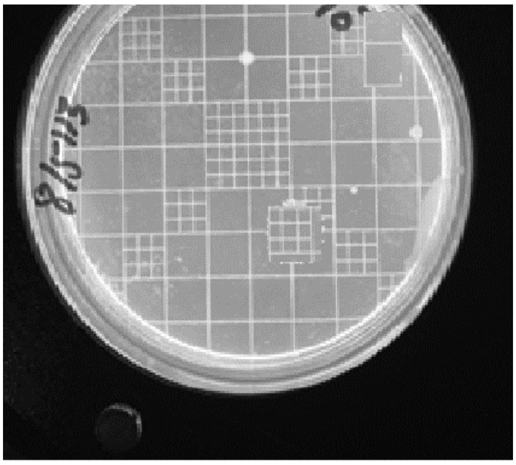


Figure 30: Coliform count after disinfection

4.3 Discussion of results

Studies on various characteristics of influent and effluent water were conducted. Comparison on the basis of these studies led to the following results about the removal efficiencies. The filtration rate measured through the filter was 1litres/min.

Parameters	Sample Water	Filtrate	Efficiency (%)
Turbidity (NTU)	9 and 16	0.3-4	97
TSS (mg/lit)	2.5-6.8	0.2-2.2	92
COD (mg/lit)	400-600	60-120	85
Electrical conductivity (µS)	900-2000	500-800	60
Alkalinity (mg/lit)	300-400	200-250	40
Hardness (mg/lit)	73-112	50-80	30
TDS (mg/lit)	306-380	220-329	30

Table 15: Removal Efficiencies

4.3.1 Filtrate Rate
The filtration rate was measured to be 1litres/min.

4.3.2 Clorox
In terms of volume of water: 22 liters of water needs 3 ml of Clorox

4.3.3 Residual chlorine
The disinfected samples of filtered water were tested and analyzed for the residual chlorine after 24 hours by the iodometric method. However, its concentration was found to be undetectable.

4.3.4 Testing for coliforms
The disinfected water was tested for coliform counts after a period of 24 hours and it was found to be zero.

5. Conclusion

The conclusions drawn from the before mentioned experimental study is reported as under:

1. The filter system was designed , constructed , fabricated and operated successfully
2. The system is reliable, cost effective and can be made mobile after further modification
3. It was found very economical in suburban areas where there is no direct supply of water
4. The water quality with reference to turbidity, COD and coliforms, provided by the system coheres with National Environmental Quality Standards, Pakistan (Environment, 2000)
5. The prototype costs for Rs.10, 000 which was mainly the cost of glass used for the purpose of presenting, it can be replaced with plastic which reduces the cost for almost 50% i.e. PRs 4000 to 5000.

6. Recommendations

The system can be improved by expanding the research and incorporating the following considerations:

1. The proposed system is "One Sink System", for more economical use it can be constructed on large scale for a whole residence with separate pipe line systems for water recycling.
2. This system can be incorporated in large buildings and hotels having connected sink systems as "Satellite Treatment Chambers"
3. Glass body of the prototype can be replaced with the plastic one for cost benefits and easy handling
4. Further studies should be conducted for the disinfecting agents, Alkalinity, EC and hardness of treated water.
5. More studies are needed for the use of treated water for irrigation purposes, which is a whole new perspective

List of Tables

List of Figures

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