	National University of Science and Technology	
	Military College of Engineering	
	Undergraduate FYP Report	

A Project Report Submitted in Partial Fulfilment of the Requirements for the Degree of

BE Civil Engineering

Project Title:

IN HOUSE WATER RECYCLING

Project Advisor:

Maj Dr NAEEM SHAHZAD

Syndicate Members:

ASC M. MOHSIN SHAFIQUE **(Syn leader)** NUST00000169099

ASC SYED SAAD HASAN NUST00000169108

ASC SYED HAMZA HASAN NUST00000169105

ASC OBAIDA BIN BURHAN NUST00000169116

SYNDICATE # 20

This is to certify that 8th semester part of the

BE Civil Engineering Project titled

IN HOUSE WATER RECYCLING

Submitted by

ASC M. MOHSIN SHAFIQUE **(Syn leader)**	NUST00000169099
ASC SYED SAAD HASAN	NUST00000169108
ASC SYED HAMZA HASAN	NUST00000169105
ASC OBAIDA BIN BURHAN	NUST00000169116

Has been accepted in partial fulfillment of the requirements for the Degree of BE Civil Engineering

_________________________ ___________________________

Dr Naeem Shahzad, Ph.D.
HoD Disaster Management Dept.
MCE, Risalpur
NUST, Islamabad

Dr. Irfan Abid, Ph.D.
HoD Water Resources Dept.
MCE, Risalpur
NUST, Islamabad

This page has been left blank intentionally

Table of Contents

List of Tables

List of Figures

List of Abbreviations

WHO	World Health Organization
PCRWR	Pakistan Council of Research in Water Recourses
NASA	National Aeronautics and Space Administration
NTU	Nephelometric Turbidity Unit
FTU	Formazin Turbidity Unit
ISF	Intermittent Sand Filter
SMBR	Submerged Membrane Bioreactor
GW	Grey Water
HRT	Hydraulic Retention Time
mg/l	milligram per liter
LPCD	Liters Per Capita per Day
COD	Chemical Oxygen Demand
BOD	Biochemical Oxygen Demand
TDS	Total Dissolved Solids
TSS	Total Suspended Solids
EC	Electrical Conductivity
UV	Ultraviolet
GAC	Granular Activated Carbon

ACKNOWLEDGEMENTS

Firstly, we would like to express our profound gratitude to ALLAH ALMIGHTY for giving us the strength, enablement and ability to complete this project and research to fulfill our degree requirements.

Our appreciation and sincere gratitude to our supervisor Dr. Naeem Shahzad, who has given us ideas, assistance and guidance throughout this research, who patiently taught us everything we need to know and guided us with his immense knowledge. We are profoundly grateful to Dr. Arshad Ali for his high experienced advice, his support and for helping us in our project. We are highly obliged, and indebted to our parents and institution for their support and facilitation in all the spheres. Sincere gratitude is extended to all those who aided us in our laboratory testing.

ABSTRACT

Water is a crucial component for the existence of all forms of lifecycles. The availability of fresh water for mankind consumption and for cultural and social needs is becoming scarcer rapidly. Water scarcity is hitting the globe along with Pakistan. Arid and semi-arid areas of the world are facing water scarcity issues. To overcome the alarming situation of water scarcity, grey water management is gaining importance in order to reuse it as alternative for fresh water for various purposes. This project deals with the recycling of greywater and its reuse as it is the best option to reduce water shortage in a sustainable manner. Main objective of this project is to design a sustainable and cost-efficient greywater recycling plant for a house, to treat greywater generated from a house and recommended to reuse it for the purposes of cleaning, garden watering and toilet flushing. This plant has designed with the main aim of solving water scarcity problem and increased water demand that is prevailing in Pakistan. The analysis of greywater, design procedure and economic analysis of greywater recycling plant is covered in this project along with the project benefits in accordance to national needs. The project will help to save the water cost significantly in areas like Karachi and Islamabad where water requirements are being met through private water bowsers.

Chapter 1

INTRODUCTION

1.1. General:

Water is one of the greatest blessing of Allah Almighty as it is the basic component for the survival of all the life forms and their activities and plays a very essential role. Notable sources of water supply are ground and surface water. But water resources have been facing crisis across the globe and these crises are growing at significant rate (Abu-Zeid,1998). The availability of fresh water for mankind consumption and for cultural and social needs is becoming scarcer rapidly as the industrialization and urbanization have retained massive amount of pressure on water, and in some countries rising population is the cause of water scarcity (Soomro *et al.*, 2011). Water scarcity is not only issue of Pakistan but a global issue. Arid and semi-arid areas of the world are facing water scarcity issues.

Therefore, in order to overcome the alarming situation of water scarcity, it's the supreme need to take a step forward and think about the solution of it. To reduce the stress of water scarcity, grey water management is gaining international gratitude in order to reuse it as alternative for fresh water for various purposes, irrigation is one of them (Ghaitidak and Yadav, 2013). Recycling of greywater and its reuse is a good possibility for water management strategy in a sustainable manner. To solve the problem of increased water demand, the networks of water recycling have been evolving all over the world since last few decades (Wilcox *et al.*, 2016).

In this report, we have designed a sustainable, eco-friendly and cost-efficient greywater recycling plant for a single house, to treat greywater generated from a house and recommend to reuse it for the purposes of garden watering, car & floor washing and toilet flushing. This plant has designed with a main aim of solving the water scarcity problem and increased water demand that is prevailing in Pakistan.

1.2. Background:

1.2.1. Worldwide Water Situation:

World Economic Forum has listed the water crisis as world's largest threat in its latest annual risk report. Steadily increasing demand of freshwater is severe warning to sustainability of human society (World Economic Forum, 2015; Mekonnen & Hoekstra, 2016). Rise in population, expansion in living standards, development of agriculture and change in consumption patterns are the foundations of rising water demands (Ercin & Hoekstra, 2014). Globally, water is enough and meeting the public demand but temporal and spatial variations of water availability and water demand are quite large. These variations show that some areas in the world face water scarcity every year. Essence of water scarcity is temporal and geographic mismatch between availability and demand of freshwater (Savenije, 2000).

About 50% population of developing countries is unable to get proper sanitation. According to UN (2012) report about 800 million people are living under severe effects of water scarcity. Report further says that in Africa and Asia, around 3 billion people would face severe consequences of water scarcity in 2025 (Food and Agriculture Organization of the UN, 2012; United Nations 2012). In order to overcome this situation, specifically in developing countries, improvement in grey-water management is required on urgent basis (Ghaitidak & Yadav, 2013).

As we all know that climate change has become a global issue. Saqib *et al*, (2018) mentioned in his research article that water scarcity and climate change are interrelated. He continued that reason behind long summers is due to excessive heat and average capacity of water is decreasing due to unnecessary use of water resources. Temperature and urbanization are also major threat to environment. Rising population and urbanization are putting pressure on water supply. Due to climate change, rainfall patterns get changed and becoming a reason of water scarcity (Saqib *et al.*, 2018).

1.2.2. Water Availability and Scarcity Conditions in Pakistan:

Water scarcity is hitting the globe along with Pakistan. Arid and semi-arid areas of the world are facing water scarcity issues. Many studies have been conducted to see the water quality status of Pakistan and found that water quality of Pakistan is deteriorating day-by-day (Daud *et al.,* 2017). Pakistan is located in the map of world surrounded by Afghanistan, India, Iran and China. Climate of our country is between parched (arid/dry) and semiarid conditions with average rainfalls varies in different parts of Pakistan (Daud *et al.,* 2017). Indus river is one of the main rivers of Pakistan that originates from Karakorum ranges to the Arabian Sea. Pakistan's economy is mostly dependent on agriculture and common crops are sugarcane, maize, wheat, cotton and rice. To meet the need of rising population, chemicals and fertilizers are added a better crop yield. Nature has blessed the Pakistan with plenty of surface water resources along with the ground water. But due to rapid growth in population it has been a huge stress on ground water resources (Soomro *et al.*, 2011).

Pakistan is already a water-stressed country, with around 1200 cubic meters per capita water availability in year 2000, a drop from 5,300 cubic meters in 1951 (Ahmed, 2007). The last survey which gave the results of 1038 cubic meters was conducted almost 11 years ago in 2008. Figure 1.1 represents the per capita water availability in Pakistan over different period of time. Study conducted by PCRWR revealed that the major cities of Pakistan will soon be under water crisis due to rapid depletion of ground water, causing a drought situation. Such crisis needs to be account for as soon as possible; otherwise, a large area of Pakistan's population will be facing severe deficiency of water. As a result, there is a need to take urgent actions and to manage water resources in a sustainable manner (Zhu *et al.*, 2016). Grey-water recycling is one of the main ways of preserving water resources in urban or arid areas.

A state experiences water insufficiency when water availability per capita is below 1000 m^3 and Pakistan almost touched this threshold of water scarcity in 2010 (Rijsberman, 2006). This will require major official modifications to manage the water resources and its usage. A recommended action is to quintessence on increasing total production of water. Otherwise, water availability will soon become major issue and restriction for agriculture.

Per Capita Water Availability

Year	Population (Million)	Per Capita Availability (m^3)
1951	34	5300
1961	46	3950
1971	65	2700
1981	84	2100
1991	115	1600
2000	148	1200
2013	207	850
2025	221	659

Source: Draft State of Environment Report 2005.

Figure 1.1: Per Capita Water Availability in Pakistan

(Source: Ahmed *et al*., 2007)

1.3. Greywater Recycling and its applications:

Our project deals especially with grey-water recycling at household level. Recycling of greywater and its reuse is exceptionally important to reduce the groundwater depletion and severe water crisis of Pakistan. Moreover, it will play vital role to manage water resources in a sustainable manner and help to preserve fresh natural groundwater for drinking purpose. Treated greywater can be reuse for following purposes:

- Irrigation
- Garden Watering
- Car Washing
- Floors Washing
- Toilet Flushing
- Fire Protection

Fresh water used for watering plants, car washing and toilet flushing accumulates a large quantity of water in an average house. If this fresh water is replaced by recycled greywater than it would contribute effectively in lowering the demand of fresh water and water shortage problems in Pakistan.

1.4. Grey Water:

Many researchers have given the various definitions of grey-water i.e. according to (WHO, 2006; Gross, 2008; Friedler & Hadari, 2006) waste-water that is coming from bath, laundry and kitchen is known as grey-water. Water from toilet fall under the heading of black water and is not a part of grey-water. According to Prillwitz & Farwell (1995), wastewater that does not include toilet waste and kitchen sinks is called grey-water. Friedler & Hadari (2006) has further categorized the grey-water. Water coming from tubs, showers and clothes washing machines is named as light grey-water. Grey-water that contains more contaminants from dishwashers, kitchen sinks and laundry are named as dark grey water (Birks and Hills, 2007).

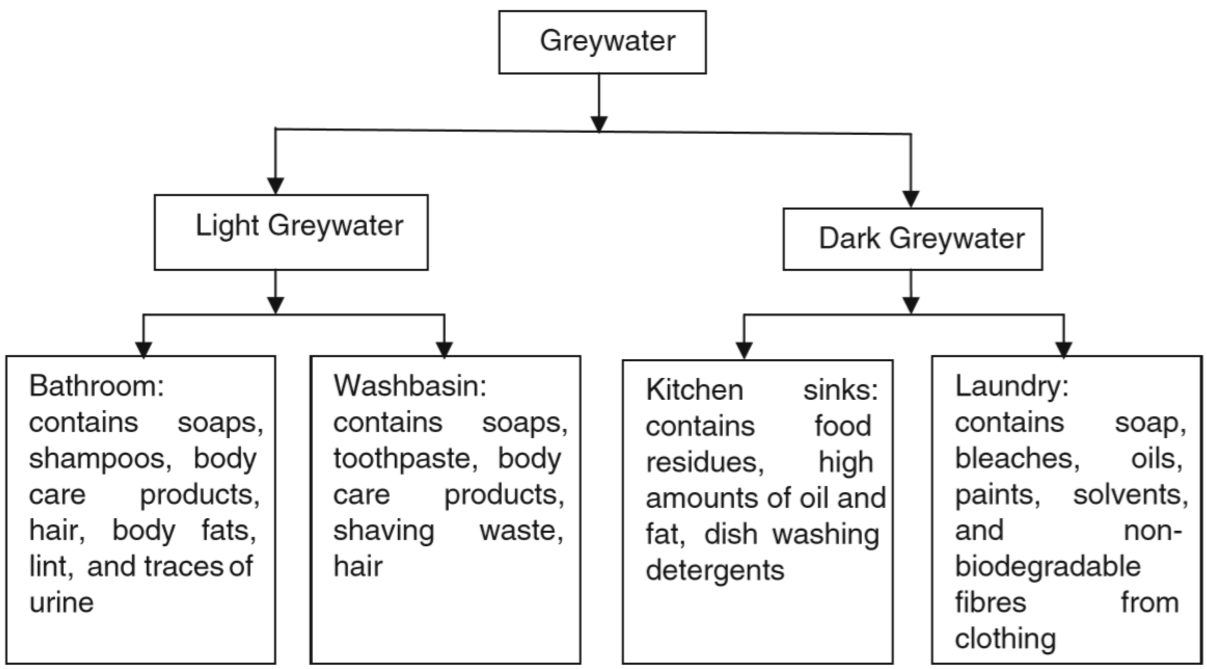


Figure 1.2: Types and Sources of Grey water

Source: (Ghaitidak and Yadav, 2013; Noah, 2002)

Typically, the greywater of bathroom and wash basins contains well amount of shampoos, soaps, toothpaste, shaving waste, hair etc. (Noah 2002). Greywater that originate from laundry contains bleaches, soap, washing powder and cloth fibers. Greywater generated from sink of kitchen constitute of dishwashing detergents, food residues, oil and fat (Ghaitidak and Yadav, 2013). Figure 1.2 also shows different constituents of light and grey water along with its source of origination.

1.4.1. Quantity of Grey Water:

The percentage of grey water in home wastewater is approximately varies from 50 to 80% of the total household wastewater (Li *et al.*, 2009). After the review of five research papers, results showed that around 26% of total grey-water is coming from washing machine and laundry. Figure 1.1 is showing distribution of grey water (Al-Mughalles *et al.*, (2012); Jamrah *et al.*, (2011); Ghaitidak and Yadav, (2013); Environment Agency (2008); Washington State Department of Health (2009)).

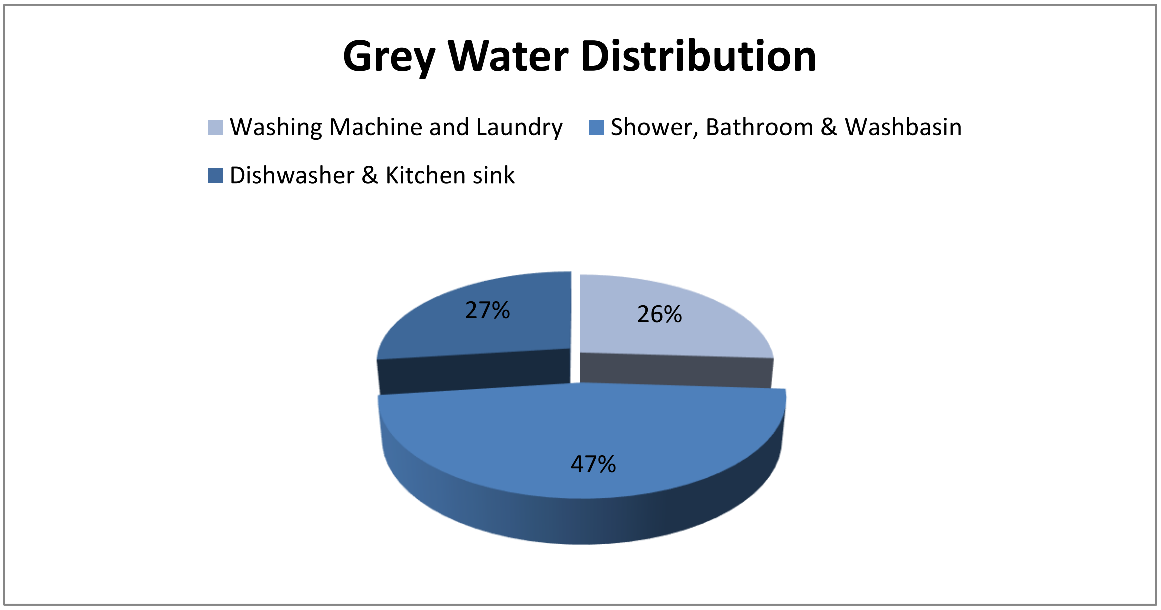


Figure 1.3: Distribution of grey water

Total wastewater generated from house constitutes almost 65% of the grey water and the grey water quantity also depends upon the total consumption of water in a house (Ghaitidak and Yadav, 2013). In case of installed vacuum toilets in home, the generation of grey water is up to 90% (otherwise 75%) of the total wastewater (Leal *et al.*, 2011).

The average value of greywater generated in a household level is 79 LPCD (Ukpong and Agunwamba, 2012). This is the average value from the data of 100 houses greywater generation in a week. Generally, greywater volume fluctuates from 90 to 120 liters per capita per day, depends upon the habits, water abundance, living standards and lifestyles (Li *et al.*, 2009). In Queensland, total of 95 LPCD greywater is generated from an average house (Ghaitidak and Yadav, 2013).

1.4.2. Quality of Grey Water:

The quality and characteristics of grey water varies a lot depending upon living habits, culture and variety of daily life products (soups, detergents etc.) used. However, typically biodegradability of greywater is generally good in terms of ratio of COD to $BOD_{5.}$ Physical pollutants and organics are higher in greywater generated from laundry and kitchen (Li *et al.*, 2009). Table 1.1 shows the range of different parameter of greywater generated from laundry, bathroom and kitchen.

Table 1.1: Characteristics of Greywater

Parameters	Greywater Source			
	Kitchen	Laundry	Bathroom	Mixed
pH	5.9 – 7.4	7.1 – 10	6.4 – 8.1	6.3 – 8.1
Turbidity (NTU)	298	50 – 444	44 – 375	29 – 375
EC (mS/m)	1.4 – 97	2.9 – 703	1.4 – 89	-
BOD (mg/l)	536 – 1460	48 – 472	50 – 300	47 – 466
COD (mg/l)	26 – 2050	231 – 2950	100 – 633	100 – 700
Chlorides (mg/l)	158 – 223	205 – 450	147 – 284	-
TDS (mg/l)	312 – 903	2,140 – 2,444	279 – 565	-
TSS (mg/l)	134 – 1300	68 – 465	7 – 505	25 – 183

Source: (Li *et al.*, 2009; Ghaitidak and Yadav, 2013)

Living habits and life styles of people living in different countries are different hence high variability has been seen in the characteristics of greywater (Eriksson *et al.*, 2002; Li *et al.*, 2009). Table 1.2 shows the characteristics of greywater observed in different countries.

Table 1.2: Characteristics of Greywater in different countries

Parameters	Pakistan [a]	Malaysia [b]	Germany [c]	UK [d]	USA [e]
pH	6.2	7	7.6	6.6 - 7.6	6.4
Turbidity (NTU)	-	-	29	26.5 - 164	31.1
EC (mS/m)	-	-	64.5	32.7	23
BOD (mg/l)	56	370	59	39 - 155	86
COD (mg/l)	146	630	109	96 - 587	-
TDS (mg/l)	102	-	-	-	171
TSS (mg/l)	150	130	-	37 - 153	17

(Sources: [a] Pathan *et al.* (2011), [b] Krishnan *et al.* (2008), [c] Merz *et al.* (2007), [d] Jefferson *et al.* (2004); Birks and Hills (2007); Pidou *et al.* (2008), [e] Jokerst *et al.* (2011))

1.5. Grey-water Treatment Methods:

To treat greywater for its reuse, wide range of technologies are available. No precise trend or scheme can be recognized amongst the categories of treatment used that different countries are using to recycle greywater. Different technologies have different removal efficiency for pollutants in greywater. However, a suitable blend of processes for greywater treatment can make it reusable which is both efficient and cost effective. For economic reasons, poorer counties are using low cost technologies that requires low maintenance cost. The classification of these technologies is based on treatment principle and as follow:

1. **Physical Technologies**
    - Sedimentation
    - Filtration
2. **Chemical Technologies**

- Coagulation and Flocculation
- Electric-coagulation
- Ion Exchange method

3. **Biological Technologies**
    - Membrane Bioreactor
    - Sequencing Batch Reactor
    - Trickling Filter
    - Activated Sludge Process
4. **Extensive Technologies**
    - Constructed Wetland
    - Reed Bed

For the treatment of greywater up to reuse standard, single technology may not be enough so scheme using combination of different technologies is being following. Selection of scheme and treatment processes depends upon reuse standards requirement. Economic and technical feasibility must be kept in mind while selecting suitable system for greywater recycling. Generally, the steps followed in treatment scheme is as follow:

1. **Pre-Treatment**
    a. Screening
    b. Neutralization
    c. Grit Chamber
    d. Skimming Tank
2. **Main Treatment**
    a. Coagulation and Flocculation
    b. Sedimentation
    c. Lime-Soda Softening
    d. Activated Sludge Process
    e. Trickling Filter
    f. Oxidation Pond
    g. Sand Filtration
    h. Membrane Bioreactor

i. Constructed Wetland

j. Reed Bed

k. Ion-Exchange

l. Anaerobic filtration

3. Post Treatment

a. Disinfection (UV, Chlorine)

On the basic of required performance of treatment unit, a scheme of different processes is selected for the treatment and cost factor also effect the selection of treatment technologies. Figure 1.4 and 1.5 shows the flow chart for the treatment of greywater.

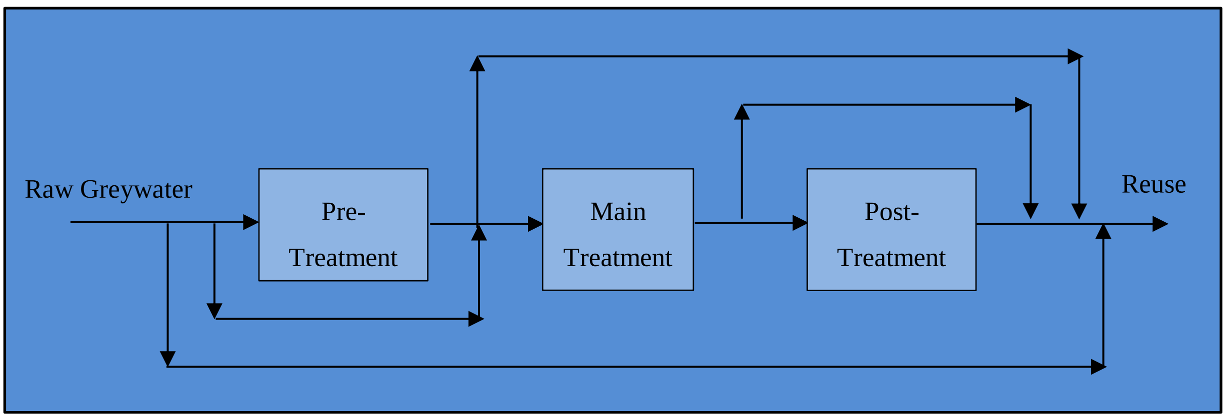


Figure 1.4: Flow chart for Greywater Treatment

Source: (Albalawneh and Chang, 2015)

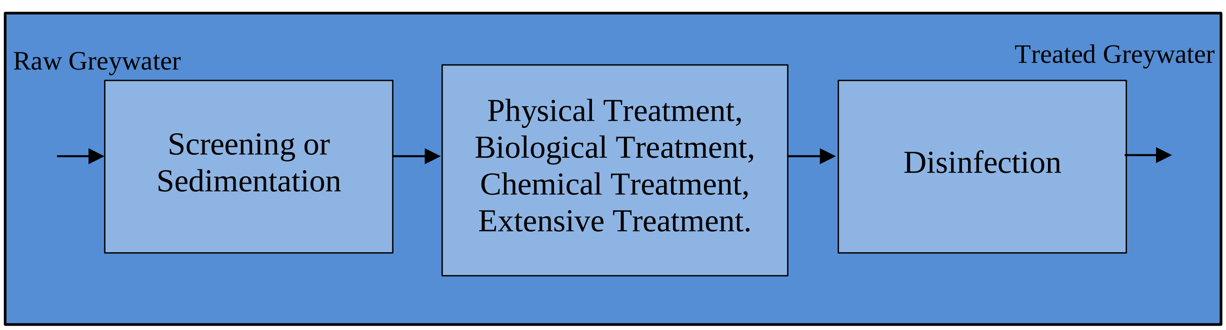


Figure 1.5: Flow Chart for Greywater Treatment

Source: (Oh *et al.*, 2018)

1.6. Problem Statement:

Improper management of water resources is the main cause of water scarcity. Pakistan is a water stressed country and due to rapid depletion of ground water; it may soon be under water crisis. According to recent studies, if a solution is not found in the near future it could lead Pakistan to a heavy water shortage and the results from crisis could lead to heinous and drastic effects which could affect all generations to come. Proper management of wastewater will not only fulfill the people's need of water but also remove the water scarcity issue.

The greatest challenge in the water resource management sector over few decades is the design and implementation of economic wastewater treatment that will permit reuse of treated grey water for selective residential and industrial purposes. Due to the ecological as well as scarcity conditions prevailing, this project could be a step towards all the solutions to our ongoing problems in the country in effective and sustainable manner. The success of this project could lead to a greywater recycling unit for each home and later could be taken to industrial level.

1.7. Aims and Objectives of this Project:

Objective: In House Water Recycling

The main aim of the project is to design a grey water recycling unit to treat the grey water at household level and make it reusable. Hence the main objectives of our present study are:

- To design a sustainable, eco-friendly, cost efficient and compact unit which can recycle the waste grey-water of a house, and make it reusable again for specific purposes.
- To reuse treated greywater for garden watering, car washing, house cleaning and toilet flushing. Therefore, to reduce the demand of fresh water and solve the issue of water crisis of Pakistan.

1.8. Relevance and Research Questions:

Current study has focus to find out and able to answer following relevant questions:

- Approximately how much greywater is generated by each person per day?
- Can sufficient percentage of water be recycled in local conditions?
- Will this system fail due to socio cultural issues?
- Will the recycling system be economical?
- What is the quality and characteristics of greywater before and after treatment?
- Is the filtration plant/scheme flexible to be installed at any time i.e. during or after construction?
- How frequently the maintenance of the filter will be required and will it be possible for lay man to clean the filters or will it require skilled personnel?

1.9. Significance of the Project:

The greatest contest in the water resource management sector over few decades is the design and implementation of low-cost wastewater treatment that will permit reuse of treated grey water for selective residential and industrial purposes. Also recycling of grey-water at household level will help the authorities to handle waste-water as very small amount of water will be collected by water authorities of Pakistan. Significances of this project are:

- Due to the scarcity conditions prevailing, this project could be a step towards all the solutions to our ongoing problems in the country related water crisis.
- This project will reduce the overall demand for water in the country because clean water which is being used for outdoor chores will be replaced by this recycled grey water. So, this project will play vital role to manage water resources in a sustainable manner.

Other advantages of this project are:

- The reduced demand will also help to replenish the ground water table which is depleting day by day because most people are using borehole water at domestic level.
- The recycling plant will be made available at a rate which will be economical for an average owner of the house.

- The success of this project could lead to a grey water recycling unit for each home for a sustainable future.
- This project will reduce fresh water demand and make water available for the water scarce regions of the country.
- Volume of the wastewater will be reduced and the handling of waste water will be made easier for the authorities.

1.10. Areas of Application:

Our project is directly related and beneficial in accordance to current national need of Pakistan due to water shortage problem in country. Applications of our project are as follow:

- The grey-water recycling plant will be installed at household level in affordable price.

- A person produces between 90-120 LPD of grey-water, which will be recycled and use for all outdoor purposes; irrigation, washing cars or cleaning floors etc.

- The recycled grey water will be very useful for irrigation and gardening as the grey water nutrient like phosphorous and nitrogen provide an excellent food source for the plants.

- The recycled grey-water can freely be used for house cleaning purposes. Moreover, the water used for flushing can also be replaced by recycled grey water.

1.11. Flow chart for Research Methodology:

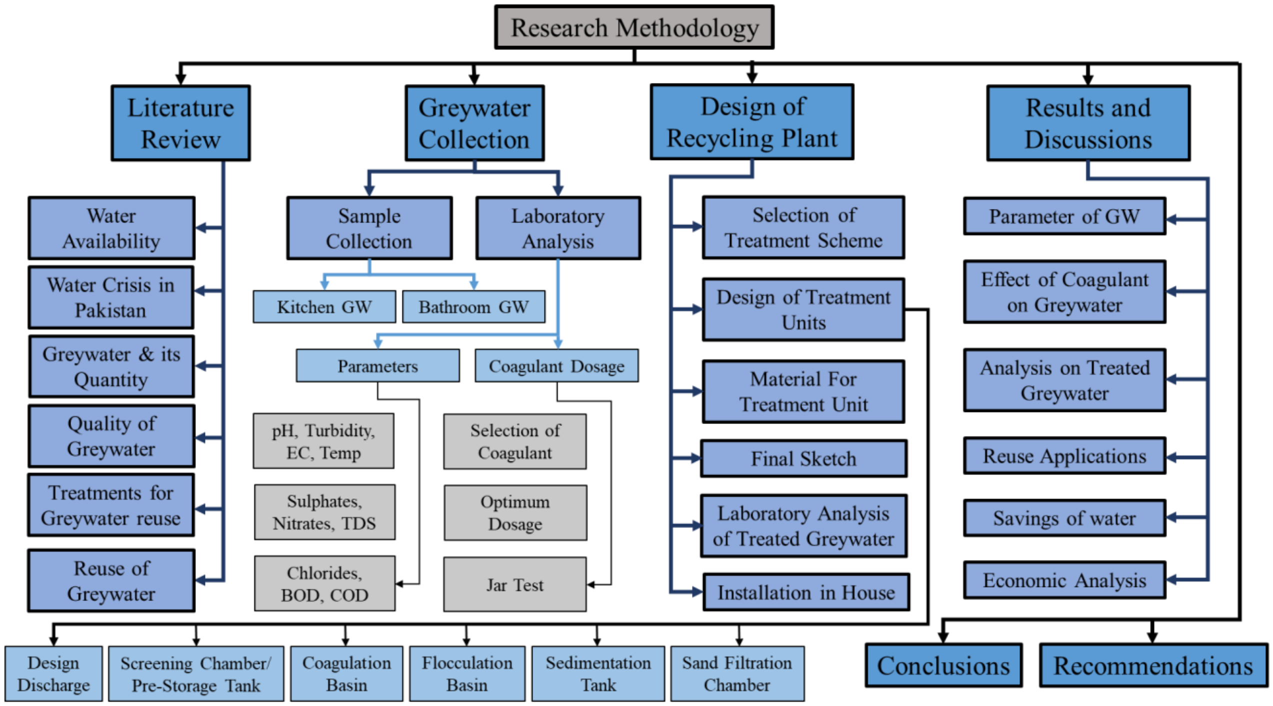


Figure 1.6: Flowchart for Research Methodology

Chapter 2

LITERATURE REVIEW

2.1. Worldwide Water Availability and Scarcity:

Water is a crucial component for the existence of all forms of lifecycles. Abu-Zeid (1998) did a research on water resources and he mentioned that from last five decades, water resources have been facing crisis across the globe and these crises are growing at significant rate. The availability of fresh water for mankind consumption and for cultural and social needs is becoming scarcer rapidly. Kumar *et al.,* (2019) claimed that rapid industrialization and urbanization has amplified the demand of water in every field of life, mainly in industrial and agricultural sector. Due to increased demand of water, water scarcity has become a worldwide issue. According to Kumar *et al.,* (2019), for the sustainable future, the efficiency and supply in usage of water bears considerable importance.

According to Liu *et al.,* (2017), the scarcity of water has developed a major limitation to social and economic progress and a hazard to living in growing parts of the biosphere. du Plessis (2017) said that the one of the most broadly distributed substances around the surface of world is water and is vital for human health, growth and development as well as for the working of ecosystems. Water is recognized internationally as basic human right and subsequently, in order to meet its requirements, it has to be efficiently and effectively managed.

2.2. Water Availability and Scarcity Conditions in Pakistan:

Rahut *et al.*, (2016) mentioned in his article that Pakistan is facing water shortage and will face a severe scarcity of water in agriculture and domestic sector. According to the empirical analysis, less productivity of crops and lower household income is mainly due to the scarcity of water that farmers are currently facing. For maintaining high yield of crops and poverty reduction in Pakistan, healthy investment is required from both private and public sector in irrigation water management.

Pakistan has received a natural gift from Allah Almighty in terms of surface and ground water resources. Regrettably, rapid growth of population, inappropriate consumption, industrialization and other anthropogenic activities cause the reduction in quantity and quality of available water. Daud *et al.,* (2017) mentioned that the 5600 cubic meters per capita of water was available in Pakistan when its name was being came into world's map. Unfortunately, in 2010, water availability per capita was 1038 cubic meters, a decreased of over 400 percent in six decades and it will keep on decreasing in near future at alarming rate.

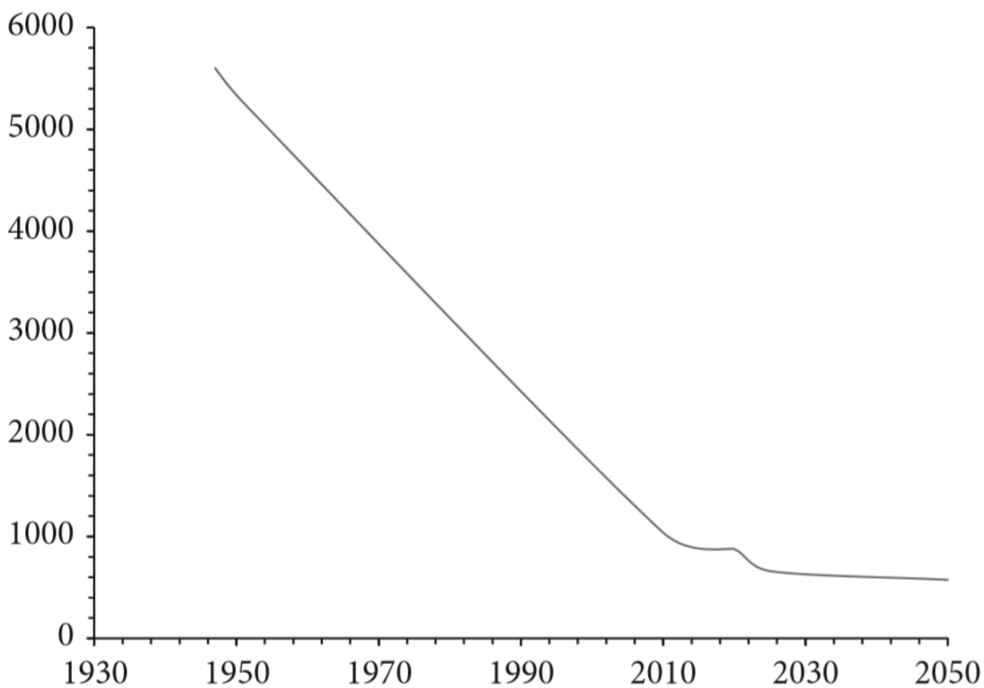


Figure 2.1: Water Availability in Pakistan, m^3 per capita

(Source: Daud, 2017)

According to Daud *et al.,* (2017), Punjab has finest water supply scheme as compared to other provinces. 7% of the people living in rural areas of Punjab depends on rivers and ground water sources (bore holes, wells) for water supply. The ratio of utilizing water from dug wells and other unprotected sources in rural areas of Sindh, Baluchistan and KPK is almost 24%, 72% and 46% respectively, shown in figure 2.2.

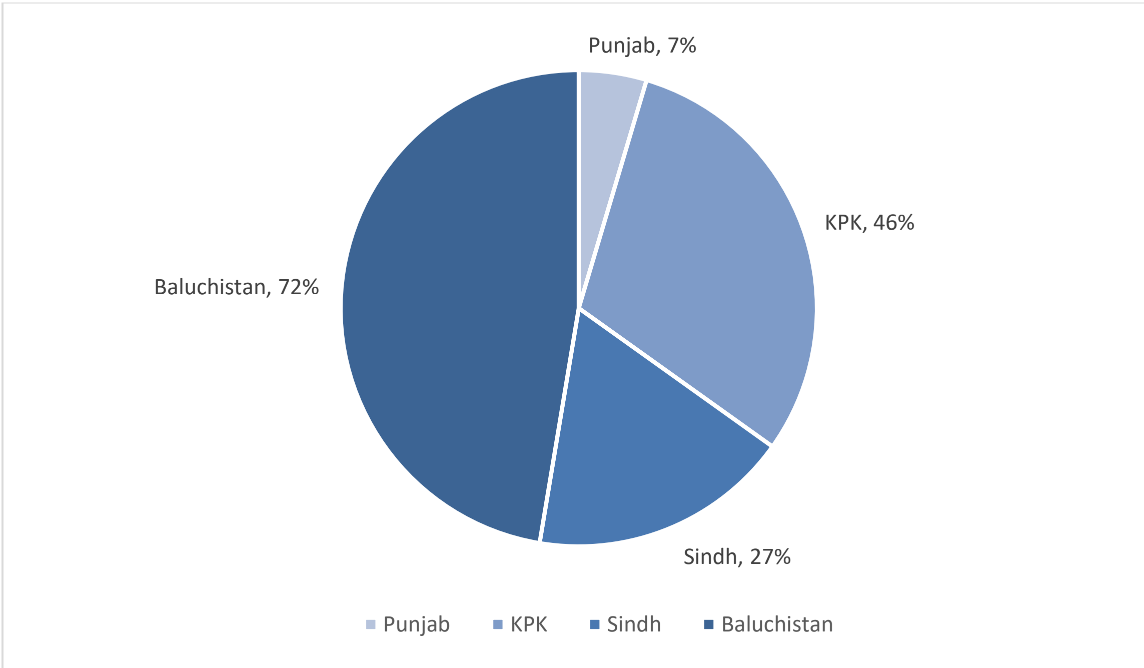


Figure 2.2: Dependence Percentage of Water Supply in Pakistan

Source: (Daud, 2017).

Due to increase in population and increased demand of water, Pakistan will shortly fall under the list of water scare countries. Study conducted by PCRWR exposed that the major cities of Pakistan will soon be underneath water crisis due to quick depletion of groundwater, triggering a drought-like condition. There is a need to account for such crisis as soon as poosible; otherwise, a large area of Pakistan's population, will be facing severe shortage of water. As a result, there is a need to take urgent actions and to manage water resources in a sustainable manner (Zhu *et al.*, 2016).

Ahmed *et al.*, (2007) mentioned that the economy of Pakistan largely depends on agricultural sector. Major input in the production of agriculture sector is water availability and its effective use. Water demand is increasing hastily, but the opportunities for growth of water resources are fading day by day. As a result, there is immediate need of water conservation strategies and water resources management plan keeping in view of future water requirements.

According to Rijsberman (2006), shortly, water will become a major limitation for agriculture sector and principally in Africa and Asia. A state experiences water insufficiency when water availability per capita is below 1000 m^3 and Pakistan almost touched this threshold in 2010. This will require major official modifications to manage the water resources and its usage. A recommended action is to quintessence on increasing total production of water.

Kugelman (2018) conducted a study on water scarcity and projected that Pakistan might be water scarce country by 2025. The PCRWR and UN have claimed it in recent years. In the meantime, groundwater is depleting at frightening rate. According to the World-Wide Fund in Pakistan, the groundwater table has dropped to below 130 ft in Lahore. NASA report revealed that the Indus basin aquifer is the 2nd most stressed aquifer across the globe. In few areas, the Indus has reduced to a pond, fetching sadness to agriculturalists and a farming sector that governs the economy of country. Drought-like circumstances are prevalent in Baluchistan.

Therefore, in order to overcome this alarming situation, it's the supreme need to take a step forward and think about the solution of it. Reuse of waste water (after treatment) and less use of fresh water (except for specific purposes) is a good possibility for water management strategy in a sustainable manner. Ghaitidak and Yadav, (2013) claimed in his article that, to reduce the stress of water scarcity, grey water management is gaining international gratitude in order to reuse it as alternative for fresh water for various purposes, irrigation is one of them.

To fight against the water scarcity issues, the networks of water recycling have been evolving all over the world since last few decades. Wilcox *et al.,* (2016) said that suitable strategies are required for the advancement of technologies for water reuse to solve the problem of increased water demand.

2.3. Grey water Recycling and its Applications:

According to Wichmann *et al.,* (2009), grey water is the type of wastewater (urban) that includes wastewater from bathroom sinks, showers, laundry, kitchen sinks and dishwashers, but doesn't include water from toilets i.e. black water (Strenstrom and Ottoson, 2003; Eriksson, 2002; World Health Organization 2006).

Eriksson *et al.,* (2002) did a research on greywater reuse and mentioned that due to increasing demand of fresh water and the shortage of water availability in both developing and developed countries, the idea for the reuse of grey water is gaining international importance and for many purposes e.g. irrigation and toilet flushing etc., recycled grey water can be used as best alterative in place of fresh water as it will reduce the demand of fresh water and ultimately its best solution for prevailing water scarcity conditions in many developing counties including Pakistan. Ghaitidak and Yadav, (2013) claimed that the reuse of greywater after recycling effects the total water supply that is available for daily household use in a best way positively.

Jefferson *et al.,* (2000) did a research on greywater recycling at domestic level. He mentioned that a number of technologies are available to recycle greywater ranges from advanced treatment systems for reuse on larger scale to a simple single unit system to reuse it in a house. In different cities of UK, variety of techniques are used to recycle greywater. Different treatments include sand filtration, natural filtration, simple filtration, membrane bioreactor and chlorine disinfection. After comparing different techniques available for recycling, research concluded that the water recycled by the process of membrane bioreactor meet applicable quality standards but it is very costly. Advanced filtration can recycle grey water up to acceptable standards.

For the reuse of greywater in irrigation, Ukpong and Agunwamba, (2012) conducted a study and designed the sand filtration system that recycles greywater up to the standards of water required for irrigation. First step was to determine the discharge of water. For this purpose, he collected the samples from hundred houses and the average greywater discharge per capita was 79 liters/day. To design the filter, laboratory tests were conducted to check the parameters of greywater and compared against water standards for irrigation. Keeping in mind the difference of parameters, slow sand filter was designed for given discharge as shown in figure 2.3. Due to the tangible nature, filter efficiency was very high. Effectiveness of the sand filter depends upon the depth and its surface area. This method of greywater recycling would prove beneficial for developing countries to overcome its water scarcity issue and play an effective role in water resources management in a sustainable manner.

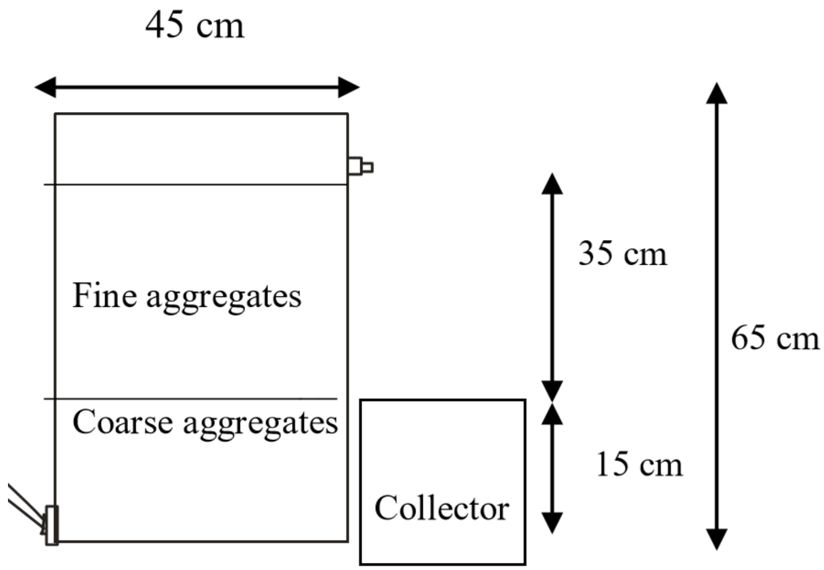


Figure 2.3: Sand Filter for Greywater Recycling

Source: (Ukpong and Agunwamba, 2012)

Greywater is a large source of water with low biological/organic content. The idea of recycling greywater is considered as feasible and its contribution towards sustainable management of water resources cannot be denied. Pidou *et al.*, (2007) did a research on greywater recycling and discussed the treatment options available in his article along with the applications of greywater after recycling. In a house, greywater could be used for toilet flushing and watering the plants reducing the overall demand of fresh water for other activities. If we look in larger scale, recycled greywater could be used for landscape irrigation, fire protection and construction purposes. Sand filters and simple treatment can only achieve the limited greywater treatment economically whereas membranes are good to remove solids but not much efficient. On the other hand, good greywater treatment can be achieved by biological and other extensive treatments. Hence combination of different types of treatment is always a good option to recycle greywater economically in order to guarantee effective treatment.

Different schemes for greywater recycling were found in many countries across the globe. Pidou *et al.*, (2007) mentioned different technologies and schemes of greywater recycling along with the name of countries that are recycling greywater for reuse. In UK, Spain and Australia, a combine scheme of simple technologies was used to treat greywater and reuse it in toilet flushing and watering garden (shown in table 2.1). Simple technologies include screening, cartridge filter, filtration, disinfection, trench and sedimentation. In Slovenia, a blend of chemical technologies (scheme: sand filter, coagulation/ion exchange and granular activated carbon) to achieve a good treatment of greywater as pilot scale system (shown in table 2.2). Extensive treatments include vertical and horizontal reed bed, constructed wetland, aqua cell and ponds are used in different schemes along with sand filters and sedimentation to recycle greywater in UK, USA, Costa Rica, Germany Nepal, Switzerland, Germany, Italy and Sweden (shown in table 2.5). Biological technologies are also common in various counties like Japan, Korea Germany and UK for the treatment of greywater. Variety of biological processes include batch reactor, MBR (membrane bioreactor), rotating biological reactor, anaerobic filters, biofilm and chlorination/UV disinfection are used for recycling greywater (shown in table 2.4). Membrane filtration and sand filters fall in the category of physical treatment technologies (shown in table 2.3). Greywater treated by using UF membranes (ultra-filtration) can achieve more effective treatment i.e. 100% removal of suspended solids and turbidity. The treated greywater can be reuse mainly for irrigation purposes and toilet flushing and it's a sustainable step towards the water resource management in both developed and developing countries. No precise trend or scheme can be recognized amongst the categories of treatment used that different countries are using to recycle greywater. For economic reasons, poorer counties are using low cost technologies that requires low maintenance cost.

Table 2.1: Treatment Scheme for Greywater Recycling using Simple Technologies

Simple Technologies		
Country	**Building type + Reuse Application**	**Treatment Scheme**
Spain	Hotel+ Toilet flushing	Screening + Sedimentation + Disinfection
UK	House + Toilet flushing	Disinfection + Filtration
USA	House + Toilet flushing and irrigation	Cartridge filter
Australia	House + Garden watering	Trench + Sedimentation

Source: (Pidou *et al.*, 2007)

Table 2.2: Treatment Scheme for Greywater Recycling using Chemical Technologies

Chemical Technologies		
Country	**Building type + Reuse Application**	**Treatment Scheme**
Slovenia	Pilot scale	Coagulation + Sand filtration + GAC
UK	Bench scale	Photo voltaic (TiO_2/UV) oxidation
Taiwan	Pilot scale	Electro-coagulation process + Disinfection

Source: (Pidou *et al.*, 2007)

Table 2.3: Treatment Scheme for Greywater Recycling using Physical Technologies

Physical Technologies		
Country	**Building type + Reuse Application**	**Treatment Scheme**
Slovenia	Pilot scale	RO & UF membrane
Japan	House + Garden watering	Soil filtration
Oman	Mosque + Landscaping Irrigation	Filtration + GAC + Sand filtration + Disinfection
Canada	Apartments + Toilet flushing	Screening Chamber + Sedimentation tank + Multi-media filtration + Ozonation

Source: (Pidou *et al.*, 2007)

Table 2.4: Treatment Scheme for Greywater Recycling using Biological Technologies

Biological Technologies		
Country	**Building type + Reuse Application**	**Treatment Scheme**
Japan	House	Anaerobic filtration + Submerged biofilter + Sedimentation tank + Disinfection
China	Pilot scale	Screening Chamber + Membrane bioreactor
Jordan	House + Irrigation	Sedimentation tank + Anaerobic filtration
Australia	House + Garden watering, Laundry & Toilet flushing	Screening + UV Disinfection + Biofilm

Source: (Pidou *et al.*, 2007)

Table 2.5: Treatment Scheme for Greywater Recycling using Extensive Technologies

Extensive Technologies		
Country	**Building type + Reuse Application**	**Treatment Scheme**
Israel	House + Irrigation	Sedimentation tank + constructed wetland
USA	House + Irrigation and Toilet flushing	Aquacell + Sand filtration + Copper dosing + Disinfection
Nepal	House +, Garden watering, Cleaning and Toilet flushing	Sedimentation tank + Reed bed Filtration
Sweden	Village + Irrigation	Sedimentation tank + Reed bed + Sand filtration

Source: (Pidou *et al.*, 2007)

In China, Zhu *et al.,* (2018), did a research and described the necessity and feasibility of on-site reuse of water after treatment. As water crisis is increasing tremendously, the reuse of urban waste water is relatively poor and its promotion bears noteworthy potential in a country like China. Grey water is considered as low-polluter and a stable source of wastewater and therefore on-site recycling is preferred for reuse in toilet flushing. Grey water produced from bathing activity is least polluted whereas main pollutant sources of greywater are kitchen and laundry. Filtration and sedimentation are considered as post or pre-treatment units for greywater recycling. Treatment involves chemical coagulation, filtration and disinfection can treat greywater up to the acceptable limits for its reuse in landscape irrigation, toilet flushing, vehicle washing and industrial systems. Though it is not considered as advanced treatment but its considerably acceptable for human exposure. Advanced treatment includes reverse osmosis, activated carbon, oxidation processes and treatment by soil aquifer and significantly higher cost. For reuse of grey water in toilet flushing, the combination of physical filtration with aerobic biological processes is the most feasible and economical treatment for on-site recycling of greywater.

In developing countries, the reuse of urban wastewater is well-thought-out plan for irrigation use and to improve the amount of water available in the country for irrigation. Ochoa *et al.,* (2019) used geotextile filters followed by sand filtration system (ISF) for the treatment of greywater and concluded that for the greywater treatment, it is efficient and feasible system. Geotextile filter were used as pre-treatment for the removal of chemical oxygen demand and suspended solids. Another benefit of geotextile is the enhancement of initial life span of ISFs.

Al-Jayyousi (2003) claimed that greywater reuse plays a vital role in sustainable management of water in dry regions. For the sustainable reuse, it is necessary that treated grey water should meet and fulfill technical feasibility, aesthetics, hygienic safety and economic feasibility. Before reaching anaerobic state, greywater should be treated and reuse immediately. United States of America, Australia and Japan are leading the list of countries with highest reuse of greywater. Besides this, UK, Sweden, Germany and Canada are involved actively in greywater research and its applications. Simple 2-stage system, disinfection along with coarse filtration, is commonly used for greywater recycling and reuse in United Kingdom. Al-Jayyousi (2003) conducted his research in Jordan to assess to potential of greywater reuse towards sustainable management of water resources. In spite of massive investment in the sector of water resources, a considerable amount of water is deficient in Jordan. Hence to reduce the demand of fresh water of irrigation use, greywater bears significant importance to reuse it for irrigation purpose in a sustainable way.

On-site greywater treatment and reuse is one of the sustainable ways to reduce the demand of water as water scarcity conditions are increasing tremendously across the globe. Fountoulakis *et al.,* (2016) conduced a research to check the efficiency of membrane bioreactor for the greywater recycling of a single house and reuse it for toilet flushing (shown in figure 2.4). Approximately 77% COD and 92% TSS removal was achieved using SMBR. Significant amount of TSS, COD and surfactants are found in greywater of a house. Therefore, SMBR plays an effective role in the reduction of these parameters and make greywater reusable for indoor (toilet flushing) and outdoor (irrigation) purposes.

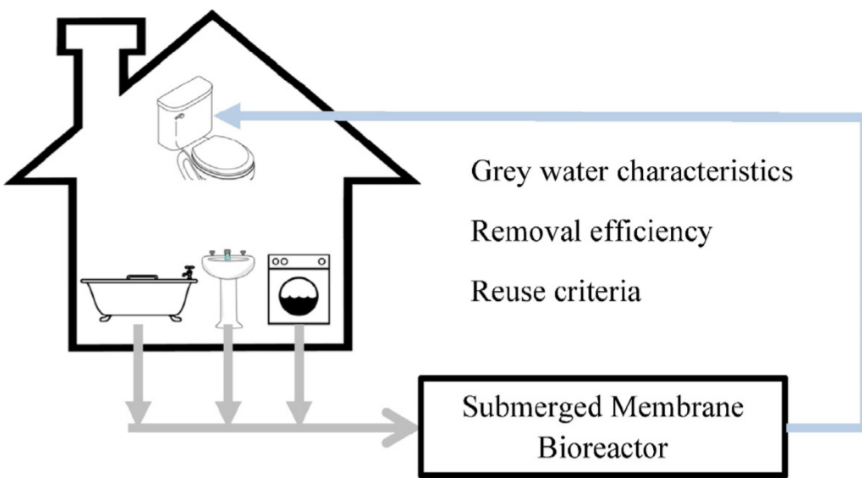


Figure 2.4: On-Site Treatment of Greywater for Toilet Flushing

Source: (Fountoulakis *et al.,* 2016)

Biodegradability of greywater is generally good in terms of ration of COD to BOD_5. De Gisi *et al.,* (2016) mentioned that for the reduction and removal of organics, only physical treatment of greywater is not enough. Organic matter and suspended solids can efficiently be removed by chemical process. But the most feasible and economical way to recycle greywater is the combination of disinfection and filtration with aerobic process. For the conservation of water resources, greywater recycling owes significant status if design of treatment unit can be made feasible and economical in a sustainable manner.

Albalawneh and Chang (2015) reviewed the characteristics of greywater with the main aim of designing the scheme of recycling system of grey water for its reuse in irrigation. Available technologies for the treatment of greywater is divided into natural, chemical, physical, and biological systems. In a household level, where low strength grey water is produced, the attractive process for the treatment of greywater is chemical whereas alone physical treatments is not satisfactory. The most cost-effective and environmentally friendly greywater treatment is through constructed wetland. Scheme of treatment for grey water mainly depends upon its application for reuse, conditions of site and quality of greywater generated. The proposed scheme for light greywater treatment includes the pre-treatment (screening or sedimentation) followed by chemical treatment (ion exchange, coagulation) and filtration process (membrane or sand) done at the end. The recycled water through this scheme can be used for agricultural irrigation unrestrictedly. Whereas, in the treatment scheme for dark grey water chemical treatment is replaced by biological processes or membrane bioreactor as shown in figure 2.5.

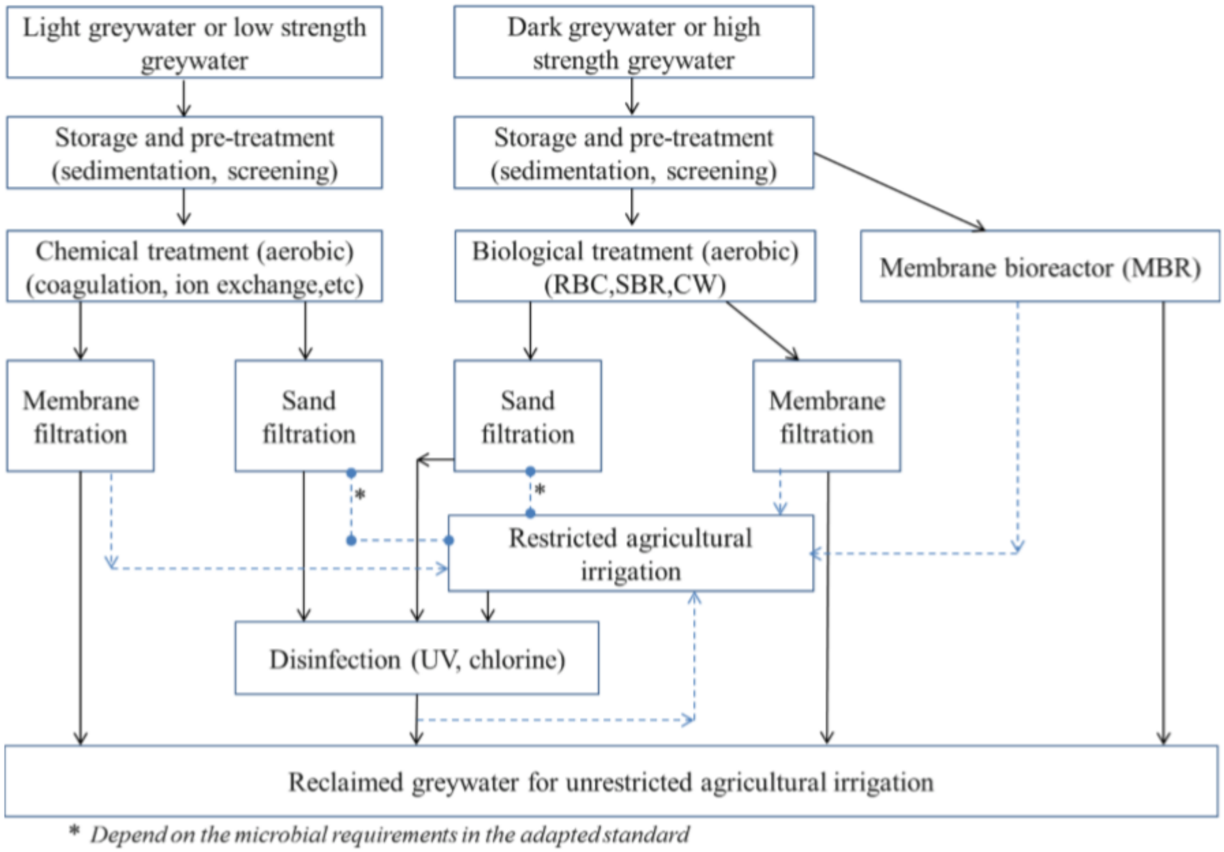


Figure 2.5: Scheme for Greywater Recycling for its Reuse in Irrigation

Source: (Albalawneh and Chang, 2015)

The quality of greywater is different from domestic wastewater therefore the traditional wastewater recycling cannot be done on it for its non-potable reuse in irrigation and other purposes. James *et al.,* (2016) reviewed the solution and challenges for reclamation of greywater for reuse. The pollutants in greywater, due to the detergents and soap, require special treatment in order to reuse it for toilet flushing. A system for recycling greywater was designed by joint partnership of German and Chinese to cater for the area of 60 apartments. Using membrane bioreactor, treatment of greywater was done to reuse treated water for the purpose of toilet flushing. Furthermore, James *et al.,* (2016) recommended few processes to remove the pollutants from greywater. Processes include coagulation and flocculation, ion exchanges method, disinfectant and adsorption. Keeping in view of water scarcity issues, for the sustainable future of developing countries, recycling of grey water and its applications would play a sustainable role in the managing water resources effectively.

In India, due to high density of population and extraction of high amount of groundwater, the emergence of water scarcity is becoming a major problem day by day. Sushmitha *et al.,* (2019) did a research for the efficient treatment of grey water and its best possible use in India. In a household level, greywater reuse is the effective solution to overcome the water shortage problems in India. Sedimentation, grit chamber, screening and filtration process are the physical process for treatment. Biological processes include fixed-film reactor and reed bed. Coagulation, chlorination, electric dialysis and ion exchange methods are fall under chemical treatment technologies. For the treatment of grey water and its reuse, efficient scheme is followed in design of treatment unit in order to reuse it for various purposes. One of the schemes is shown in figure 2.6.

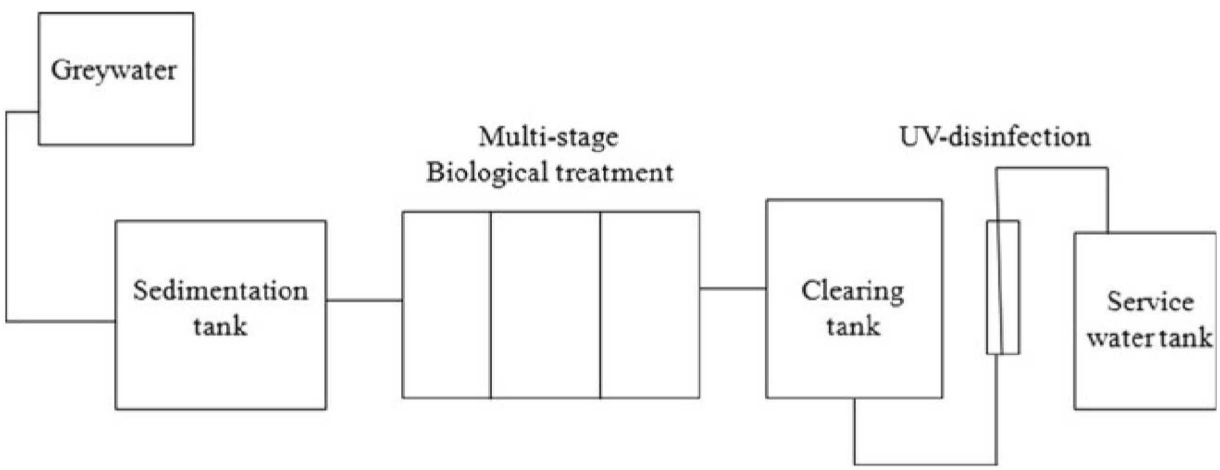


Figure 2.6: Multi-Stage Biological Treatment

Source: (Sushmitha *et al.*, 2019)

The sustainable benefits of greywater reuse cannot be denied. Debnath *et al.,* (2019) claimed that recycling of greywater and it reuse supports the management of water resources in sustainable way. Hence it should be implemented on household level to get maximum benefits. Debnath *et al.,* (2019) developed a packed bed medium for the treating greywater as shown in figure 2.7. The recycled water has applications in reuse in toilet flushing, gardening and irrigation.

Furthermore, greywater recycled through this media is effective in term of economics i.e. low maintenance and operating cost.

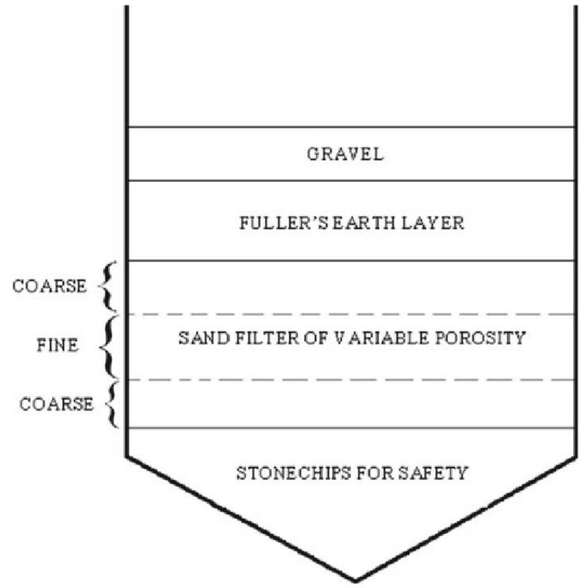


Figure 2.7: Packed Bed Media (Schematic Diagram)

Source: (Debnath *et al.*, 2019)

Ghaitidak and Yadav, (2015) determined the optimum dosage for coagulant required for the treatment of greywater and its reuse. pH has significant effect on optimum dosage of Alum. Mean optimum dosage for alum was detected as 268 ± 89 mg/L at pH 8.5, 252 ± 82 mg/L at pH 7.5, 237 ± 67 mg/L at pH 6.5 and 204 ± 75 mg/L at pH 5.5. Figure 2.8 shows the effect of different values of pH on optimum dosage of alum as coagulant. With the increase in pH of greywater the optimum amount of alum dosage increases. While using these dosages the removal of turbidity from greywater was on average 90% which is shown in figure 2.9. The greywater treated by coagulation process can be used for industrial cooling and irrigation purpose.

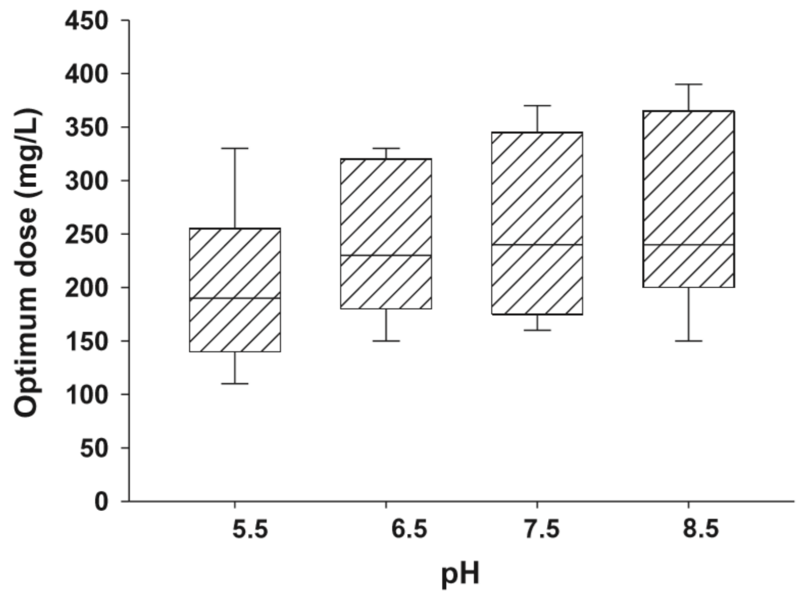


Figure 2.8: Optimum Dosage of Alum at different pH values

Source: (Ghaitidak and Yadav, 2015)

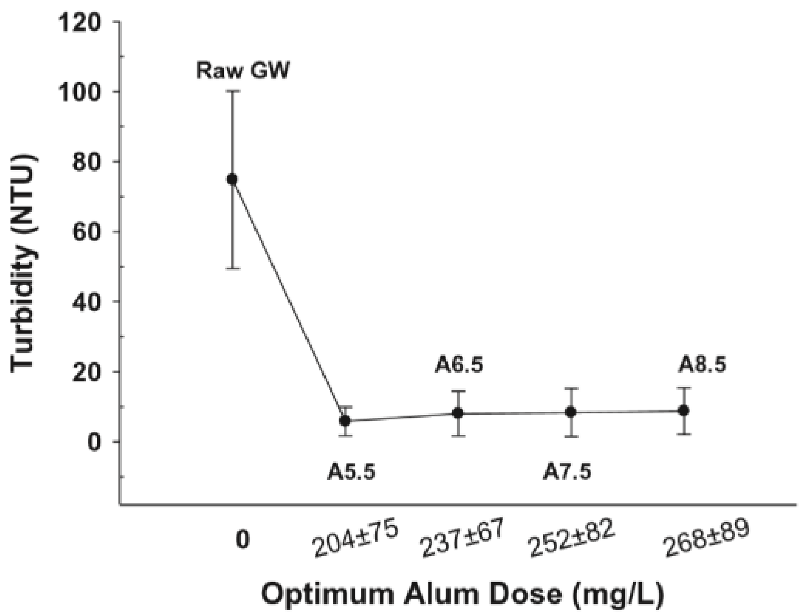


Figure 2.9: Effect of Alum on turbidity

Source: (Ghaitidak and Yadav, 2015)

Ghaitidak and Yadav, (2016) examined the options available for greywater treatment and its reuse applications. Coagulation/Flocculation process was done on grey water using different coagulants (ferric chloride ($FeCl_3$), poly aluminum chloride (PAC) and Alum) and results were analyzed. Sand filtration was done on two stages and potential of treated water was evaluated. For sand filtration, schematic diagram is show in figure 2.10.

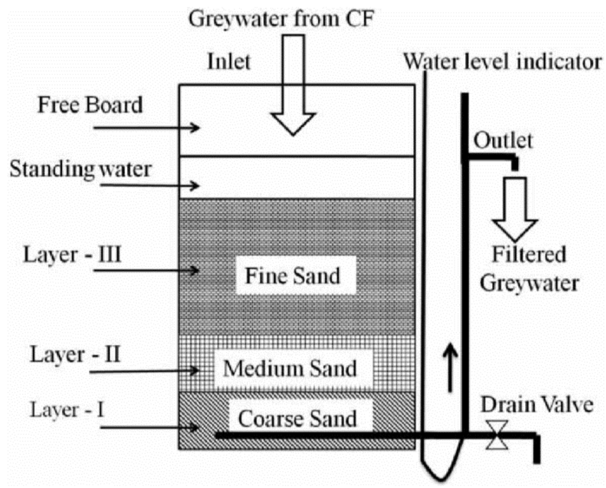


Figure 2.10: Sand Filter (Schematic Diagram)

Source: (Ghaitidak and Yadav, 2016)

After reviewing literature and research that was done on greywater treatment technologies and its applications, we come to know that by combination of different process, scheme of greywater treatment plant can be made economical and feasible. Design is plant is affected by its application for reuse and characteristics required. Therefore, an efficient and effective scheme should be proposed in term of good feasibility and economy while designing greywater recycling unit for a single house. Greywater reuse contribute in lowering the demand of fresh water in water scare countries and hence it plays an effective role in managing water resources in a sustainable manner.

METHODOLOGY

3.1. Study Area and Site:

The target area that we selected for our study on the grey water was Risalpur Cantonment. It is situated in Nowshera District of province Khyber Pakhtunkhwa, Pakistan. The cantt area is mostly under the military use which includes mostly residential use of water and minimal to none industrial use. As this site was the most feasible regarding to the collection of samples for greywater and the testing of the samples which was to be done in the nearby laboratories (Public Health Engineering Lab, Military College of Engineering) so it was most preferred.

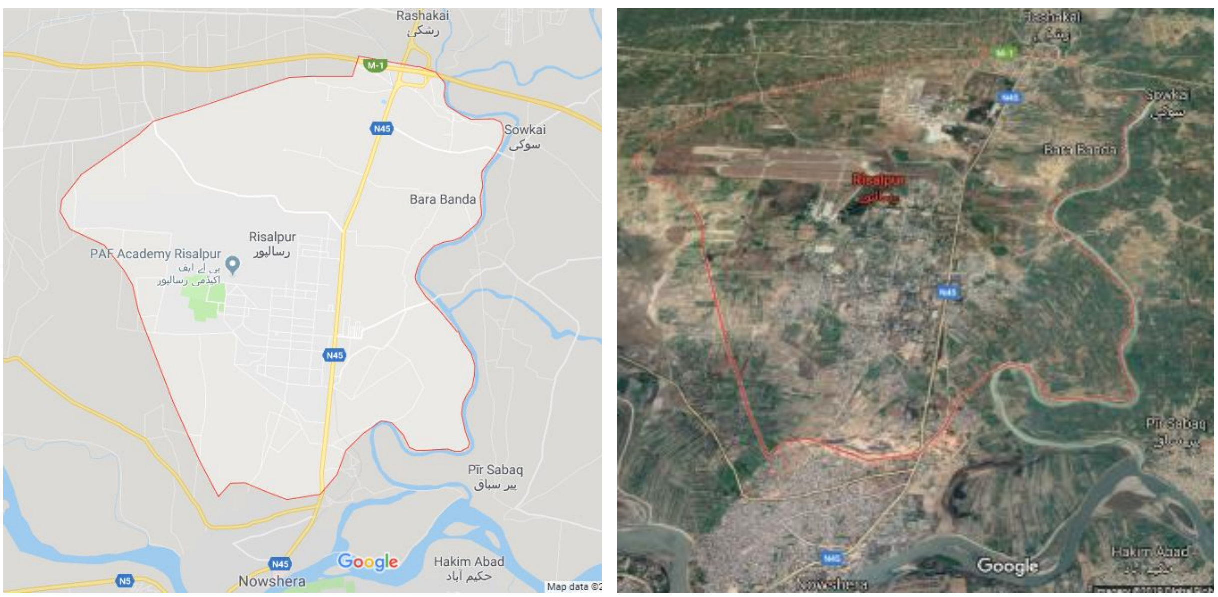


Figure 3.1: Study Area (Risalpur, KPK, Pakistan)

As the objective of the research says that we are developing a system for the “In house water recycling”, for which we required to collect the sample of water from a residential house which will make our study on the characteristics of the water more precise and will enable us to select the appropriate design and purification method.

3.2. Sample Collection and Settings:

In order to collect the samples, we had to look for the appropriate residencies where we could get grey water separately from the black water, as in most of the houses the grey water was mixing with the black water and it was difficult to collect clean greywater sample from there. We selected three such houses where there was ease in collection of greywater sample.

While collecting the sample adequate precautionary measures were taken, the collectors wore a pair of gloves in order to protect their hands from any filthy matter, face mask was used for protection from inhaling of dirt particles and minimization of odor, a bucket was used for the collection which washed with distilled water prior to collection.

3.2.1. Bathroom Greywater:

The greywater from bathroom included some water from shower drain, some from laundry drain and washbasin drain and all were mixed together. At time of the collection was managed such that there is maximum discharge of waste in it so that the tests are done for the worst-case scenario and adequate methods and chemicals are selected for the treatment of the wastewater.

3.2.2. Kitchen Greywater:

The greywater from kitchen was collected separately from the washroom and laundry greywater as the GW of kitchen has greater organic components in it as compared to the GW of washroom. Both the collected greywater was poured into 1.5-liter bottles and stored in a cool dry place.

Figure 3.2: Greywater Samples

3.3. Laboratory analysis of sample:

After the sample was collected it was taken to the laboratory for the testing of physical and chemical parameters. Testing of sample for physicochemical and biological parameters was done at Public Health Engineering (PHE) lab, MCE Risalpur. Following are the parameters which were tested for the collected samples of kitchen and bathroom greywater separately.

3.3.1 Physical and Chemical Parameters:

a. pH:

It is a parameter of water quality which tells about the degree of acidity or alkalinity of the solution or water. It is expressed by the negative log of hydrogen ion concentration. It is determined by the pH meter in a laboratory. The normal pH range of drinking water set by WHO standards is 6.5-8.5. In grey water the range of pH is generally 6.3 to 8.1.

b. Turbidity:

Cloudiness and muddiness in water is due to turbidity. A turbid water is one which contains suspended particles or in which the vision through the water is restricted by a number of suspended elements i.e. silt, organic matter, clay, microorganisms etc. of varying sizes. Turbidity causes an unaesthetic look to water and people might feel guilty to use turbid water. It is measured using the turbidity meter. It is expressed as NTU or FTU.

Figure 3.3: Turbidity Meter and pH Meter

c. EC:

The electrical conductivity of water is a parameter which shows its ability to conduct the electrical current. The elements like salt and different chemicals present in water breakdown to form ions, which provide the medium for electricity to flow through water, greater the number of ions present greater will be the conductivity. The salinity and TDS define the EC of water and resultantly its purity. The more the EC of water the less pure it will be and the less EC of water the purer it will be. It is measured using an EC meter.

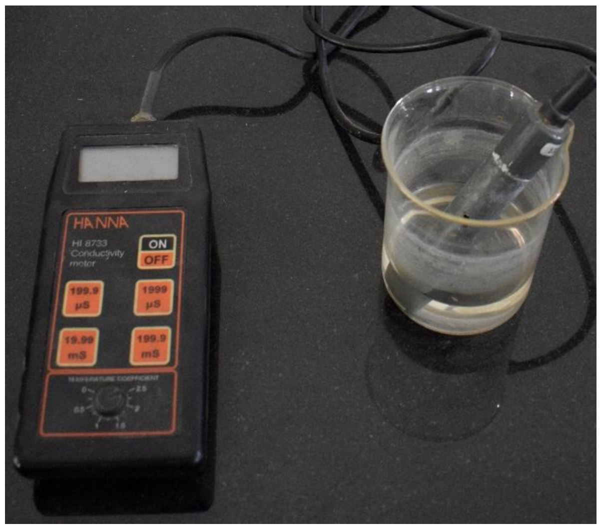


Figure 3.4: Conductivity Meter

d. Temperature:

The increase in temperature of a water body indicates the presence of waste in it, it may either be industrial or domestic waste. The presence of such waste causes increased molecular motion and as a result increased kinetic energy in water. The temperature of water is measured by a thermistor/thermometer or electrically by pH meter.

e. Sulfates:

The sulfates in a water body is such a parameter which helps in getting info about the quality of water. Their concentration in water varies from a few hundred to several thousands. Usually the water gets sulfate from certain rocks or in case of grey water it gets contaminated by the chemicals or the sulfate compounds present in soaps and shampoos. The presence of sulfate only up to a certain amount is good, excess sulfate will affect the usage of water for irrigation and will react with plants and soil. The safe values of sulfate as per NEQS is 600 mg/L. the amount of sulfate in a water sample is determined using “spectrophotometer”, an amount of SulfaVer 4 is added to the dilute sample for testing.

f. Nitrates:

The nitrate in water is good for plant and living being use up to a certain amount. The excess amount of it will cause detrimental health impacts like “blue baby syndrome” and cancer. Usually nitrate in surface water comes from the acidic rain or from fertilizers, nitrate in grey water is very less as compared to that in black water. The amount of nitrate in water is determined using the spectrophotometer. The limit for nitrate as per WHO standards is 50 mg/L.

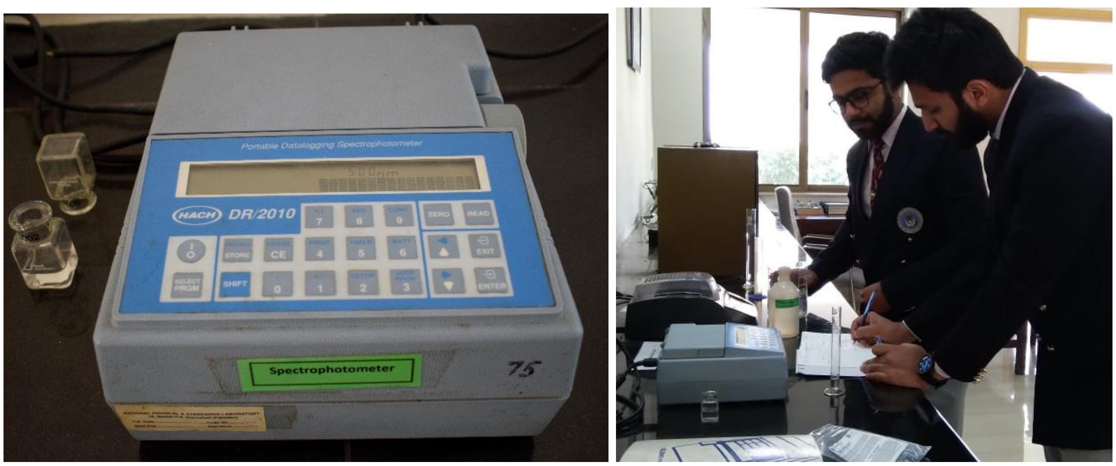


Figure 3.5: Spectrophotometer

g. Chlorides:

Chlorides in water are like salts that come in water by a combination of the gas chlorine with a metal. Chlorides in grey water may come from the human waste or from the chemical detergents. Excess amount of chloride is also harmful for living beings. The safe amount of chloride in water as per NEQS is 1000 mg/L. The chlorides in water are determined by the process of titration and method is known as Argentometric Method.

Figure 3.6: Apparatus for Titration

h. COD:

COD is the amount of oxygen required by the wastewater to stabilize the organic and in organic compounds chemically. The amount of COD that is present in wastewater is always higher than BOD. In lab it is measured using the Open Reflux Method. COD reactor is used to measure COD value.

Figure 3.7: COD Reactor

i. BOD:

BOD is the amount of oxygen required by the bacteria in water/wastewater to decompose the organic substance present in it. It is a very important parameter to be considered in wastewater treatment. In lab the BOD is measured using the 5-Day BOD test or the Dilution Method.

j. TDS:

TDS includes all of the dissolved inorganic and organic solids and salts in water. The substances dissolved may include sodium, calcium, magnesium, bicarbonates, chlorides and sulphates. It is measured in the lab using the Gravimetric method.

3.3.2. Optimum Coagulant dosage:

a. Selection of Coagulant:

The main objective of coagulation process is to enhance settling of small size particles by agglomeration of particles with the addition of chemical coagulants. Most commonly used coagulants are; Aluminum sulfate (alum), $FeSO_4$ (ferric) and $FeCl_3$.

The coagulant we selected for our treatment process is aluminum sulphate (alum). As alum is readily available in market at considerable low cost.

b. Optimum Dosage:

Optimum dosage of coagulant has significant effect on the treatment of greywater by coagulation and flocculation process. To achieve maximum removal of pollutants from greywater, optimum dosage has greater concerns. Mean optimum dosage for alum was detected as 268 ± 89 mg/L at pH 8.5, 252 ± 82 mg/L at pH 7.5, 237 ± 67 mg/L at pH 6.5 and 204 ± 75 mg/L at pH 5.5 (Ghaitidak and Yadav, 2015).

While laboratory testing, we took an amount of 200 mg/l as optimum amount of alum to get maximum removal of turbidity and other parameters.

c. Jar Test:

In lab, to achieve the process of coagulation and flocculation and to determine the optimum coagulant dosage jar test is generally conducted. Apparatus consist of six jars and different amount of coagulant has to be added in it to find optimum dosage. Rapid mixing at 100-

120 rpm for 3-4 minutes has done to achieve coagulation after adding coagulant. Then slow mixing at 15-30 rpm is achieved for 40-45 minutes for flocculation process. After this treated water from each jar has tested to determine the removal percentage of turbidity and other parameters as desired. The sample which give maximum percentage removal is the one in which optimum amount of coagulant was added.

Figure 3.8: Jar Test

3.3.3. Methods for Laboratory Testing:

Table 3.1: Methods for Laboratory Testing

S. no.	Parameters	Method	Test Name/ Main Apparatus
1	pH	Electrometric Method	pH Meter
2	EC	Electrometric Method	Conductivity Meter
3	Temperature	Electrometric Method	pH Meter
4	Turbidity	Nephelometric Method	Turbidity meter
5	Sulphates	Sulfa ver 4 Method	Spectrophotometer
6	Nitrates	Cadmium Reduction Method	Spectrophotometer
7	Chlorides	Argentometric Method	Titration
8	COD	Open Reflux Method	COD Reactor
9	BOD	Dilution Method	5 Day BOD Test
10	TDS	Gravimetric Method	China Dish, Filter Paper, Oven

3.4. Treatment Scheme of Recycling Unit:

To achieve the objective of our project, simple but cost effective and technically feasible scheme for greywater treatment has been selected. Main treatment is coagulation and flocculation as coagulant use for this process is readily available in market at low cost.

At first, raw greywater coming from a house is stored in pre-storage tank which is also used as screening chamber. Screens/mesh is installed in this tank to remove floating or coarse particles from greywater i.e. hair, solid particles etc. Main treatment selected for greywater treatment is coagulation and flocculation. After screening, greywater enters in coagulation tank (rapid mix basin) where optimum amount of coagulant (alum) is added in greywater. During coagulation process, charges gets neutralized and heavy mass particle has formed so that it can settles easily. In flocculation tank, slow mixing for designed detention time has done and heavy mass of particles is formed and settles down at quick rate. Flocculation basin is followed by sedimentation tank where suspend solids settles down by the action of gravity and then at last, greywater make its way towards sand filtration chamber for further treatment. Flocs formed in during flocculation process settles down in sedimentation tank and they are further trapped in sand to get the maximum removal of bacteria and pathogens. Schematic flow chart for our recycling plant is shown in figure 3.9. Detail design of each tank has been discussed later in this report.

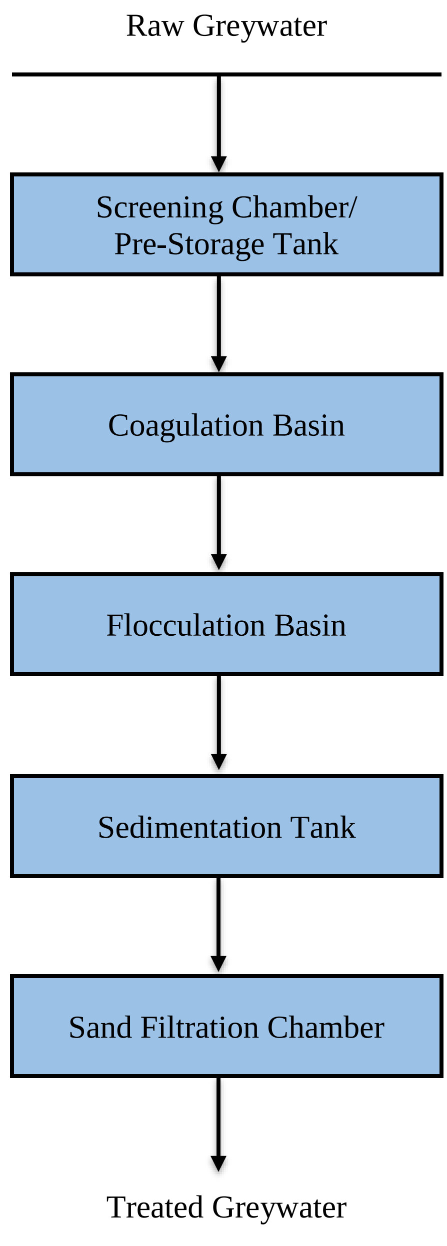


Figure 3.9: Schematic Diagram of Greywater Recycling Plant

3.5. Design of Recycling Plant:

3.5.1. Design Discharge:

From the literature review, it has been observed that generally, greywater volume fluctuates from 90 to 120 liters per capita per day, depends upon the habits, water abundance, living standards and lifestyles (Li *et al.*, 2009). The average value of greywater generated in a household level is 79 LPCD (Ukpong and Agunwamba, 2012). This is the average value from the data of 100 houses greywater generation in a week. In Queensland, total of 95 LPCD greywater is generated from an average house (Ghaitidak and Yadav, 2013).

Hence, we have taken value of 100 liters per capita per day for our project. As the scope of our project is to design a recycling unit for a home. Hence, we considered 8 persons in an average home for this project. Therefore:

Volume of greywater = 100 LPCD

For 8 persons in a home

Volume of greywater = 800 Liters/day

Hence, Design Discharge = 800 Liters/day = **0.8 m^3/day**

3.5.2. Design of Coagulation and Flocculation Basins:

a. Rapid Mix Basin (Coagulation Tank):

In this chamber the addition of alum as coagulant and its rapid mixing take place. Usually the speed of shaft is 100-120 rpm. Design steps are as followed:

Discharge = 0.8 m^3/day

Assume HRT, t_D = 4 min = 4 / (60*24) day = 2.778×10^{-3} day

Volume of basin = Q * t_D

$$= (0.8\ m^3/day) \times (2.778 \times 10^{-3}\ day)$$

Volume of basin = $2.222 \times 10^{-3}\ m^3 = 0.0785\ ft^3$

Consider **Square tank**,

Dimensions = 0.428’ x 0.428’ x 0.482’ = 5.14” x 5.14” x 5.14”

Rounding up…

Dimensions of coagulation tank = 1/2’ x 1/2’ x 1/2’ = 6” x 6” x 6”

Actual Volume of Basin = 0.5’ x 0.5’ x 0.5’ = 0.125 $ft^3 > 0.0785$ ft^3 **OK**

Overall Dimensions = 6” x 6” x 9” (Including freeboard) **(L x W x D)**

Paddle Dimensions = Diameter x W = 4” x 2”

Diameter to dimension ratio = D/W = 4/6 = 0.66 = 66% **OK**

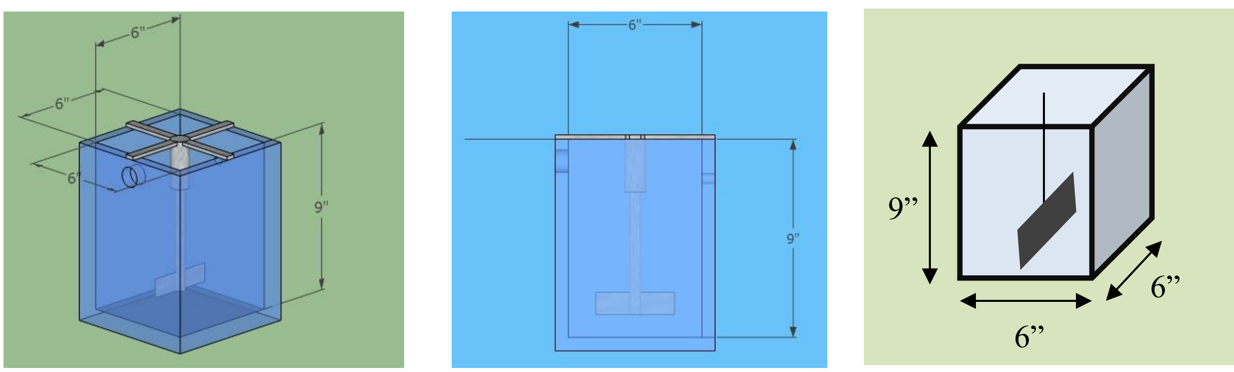


Figure 3.10: Coagulation Basin

b. Slow Mix Basin (Flocculation Tank):

In flocculation basin, flocs are formed by slow mixing and they are heavy enough to settle down. The speed of paddle in slow mixing is usually 10 to 15 rpm. Design steps for flocculation basin are as follow:

Discharge = Q = 0.8 m^3/day

Assume HRT, t_D = 40 min = 40 / (60*24) day = 0.02778 day

Volume of basin = Q * t_D

= (0.8 m^3/day) x (0.02778 day) = 0.0222 m^3 = 0.785 ft^3

Taking Width and Depth of the tank equal to Coagulation Basin

W = 6”, D = 6”

Length = Volume / (W x D)

Length = 0.785 / (0.5 x 0.5) = 3.14’ = 3’ 2”

So, Actual Volume of basin = 3.167’ x 0.5’ x 0.5’ = 0.792 ft^3 > 0.785 ft^3 **OK**

Overall Dimensions = 3’2” x 6” x 9” (Including Free board) **(L x W x D)**

(2 Compartments of length 1’7” each)

Paddle Dimensions = Diameter x W = 4” x 2”

Diameter to dimension ratio = D/W = 4/6 = 0.66 = 66% **OK**

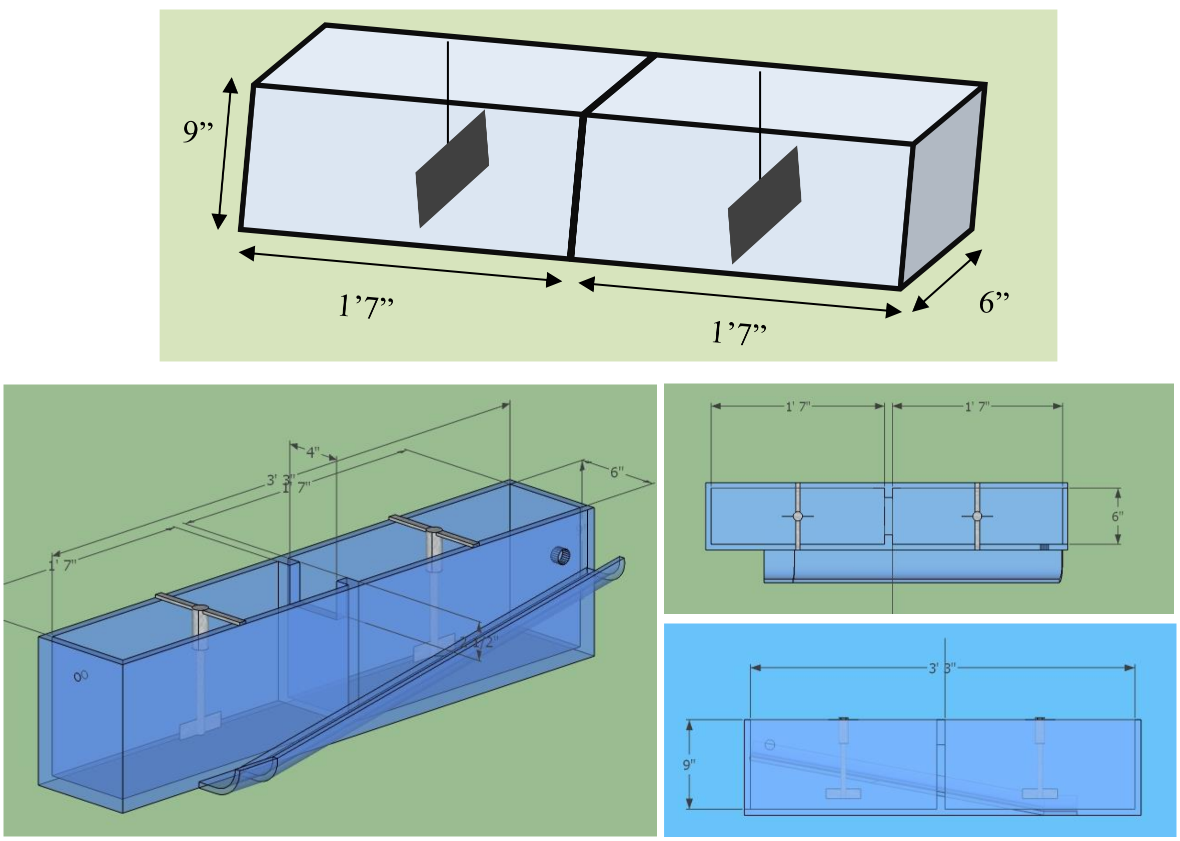


Figure 3.11: Flocculation Basin

3.5.3. Design of Sedimentation Tank:

Discharge = Q = 0.8 m^3/day

Assume HRT, t_D = 6 hours = 6 / 24 day = 0.25 day

Volume of basin = Q * t_D

= (0.8 m^3/day) x (0.25 day)

= 0.20 m^3 = 7.064 ft^3

Take 20% additional volume for sludge storage

Volume = 1.2 x 7.064 = 8.477 ft^3

Take Depth = 2.5 ft (D = 3 ft, including freeboard)

Surface area = Volume / Depth = 8.477 / 2.5 = 3.391 ft^2

Rectangular Tank (L: W = 2:1) L x W = 3' x 1.5'

Actual Surface Area = 4.5 ft^2 > 3.391 ft^2 **OK**

Actual Volume = 3' x 1.5' x 2.5' = 11.25 ft^3 > 8.477 ft^3 **OK**

Overall Dimensions = 3' x 1.5' x 3' (Including Free board) **(L x W x D)**

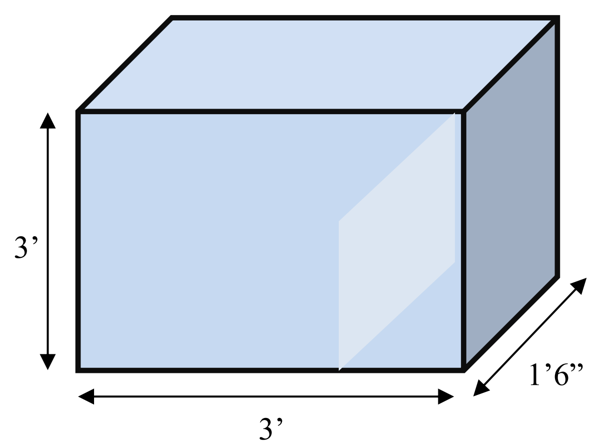


Figure 3.12: Sedimentation Tank

3.5.4. Design of Sand Filtration Chamber:

In order to remove solids and reducing bacteria, sand filters are significantly beneficial. Generally sand filtration chamber is circular or square with a depth of 1.0-1.5 ft of sand. The size of sand is usually 600-800 µm. At the bottom of tank, 3-5-inch-thick layer of aggregate is placed for effective effluent of water discharge from sand filtration chamber.

Thickness of Sand Layer = 15” , Sand Size = 600 µm

Thickness of Aggregate Layer = 4”

Size of Screening Mesh = 2 mm x 2 mm

Overall Dimensions of Sand Filtration Chamber = 1.5” x 1.5’ x 3’ (L x W x D)

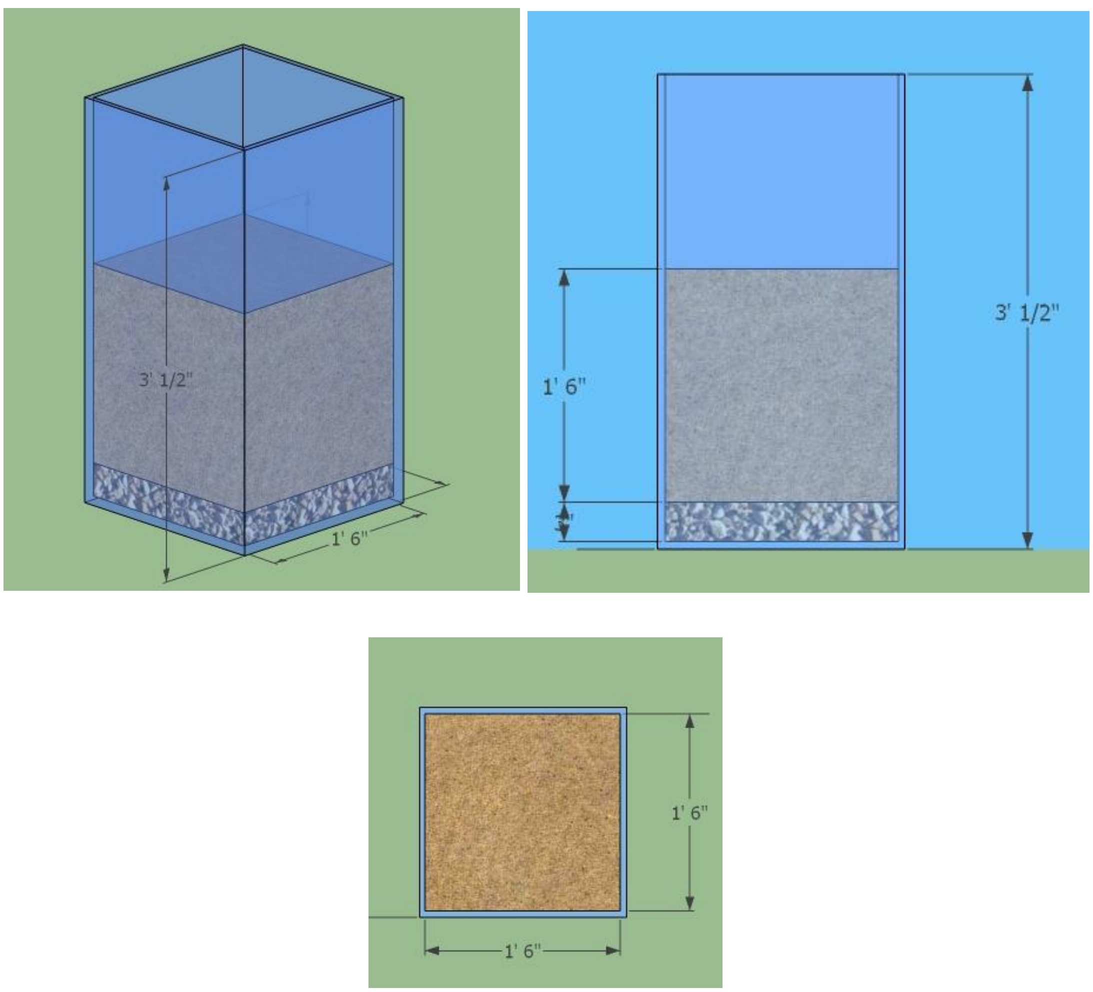


Figure 3.11: Sand Filtration Chamber

3.5.5. Pre-Storage Tank / Screening Chambers:

Before main treatment, greywater has been stored in a pre-storage tank where screening of floating material has been done. It is recommended to have enough storage capacity of tank to store greywater generated in day. However, in over model, keeping in view of dimensions of other tanks and symmetry of the recycling plant, the dimensions of this tank are as followed:

Overall Dimensions of chamber = 9" x 1.5' x 3' (L x W x D)

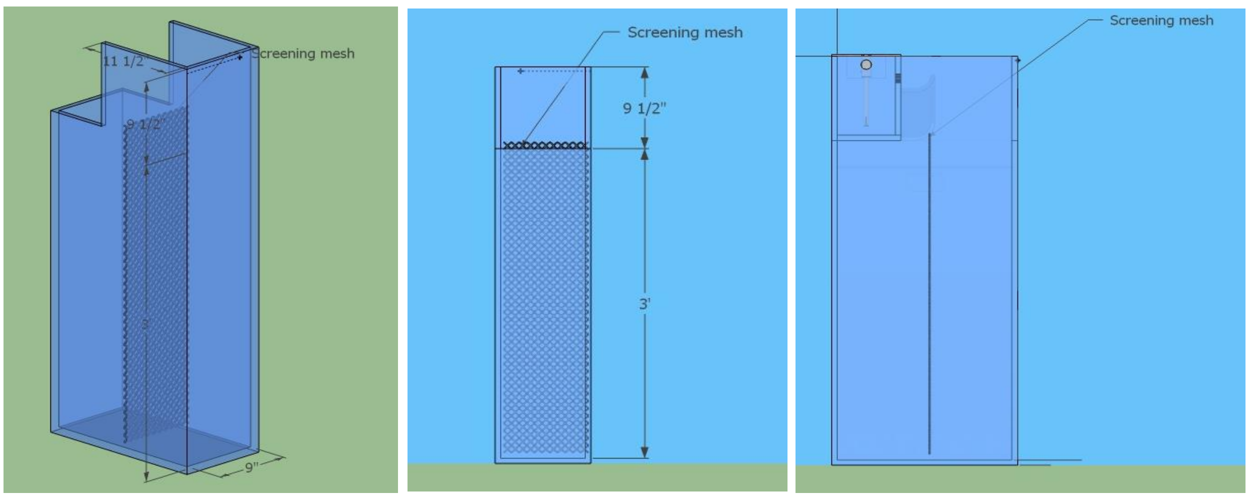


Figure 3.12: Pre-Storage Tank/Screening Chamber

3.5.6. Flow Chart for Greywater Recycling:

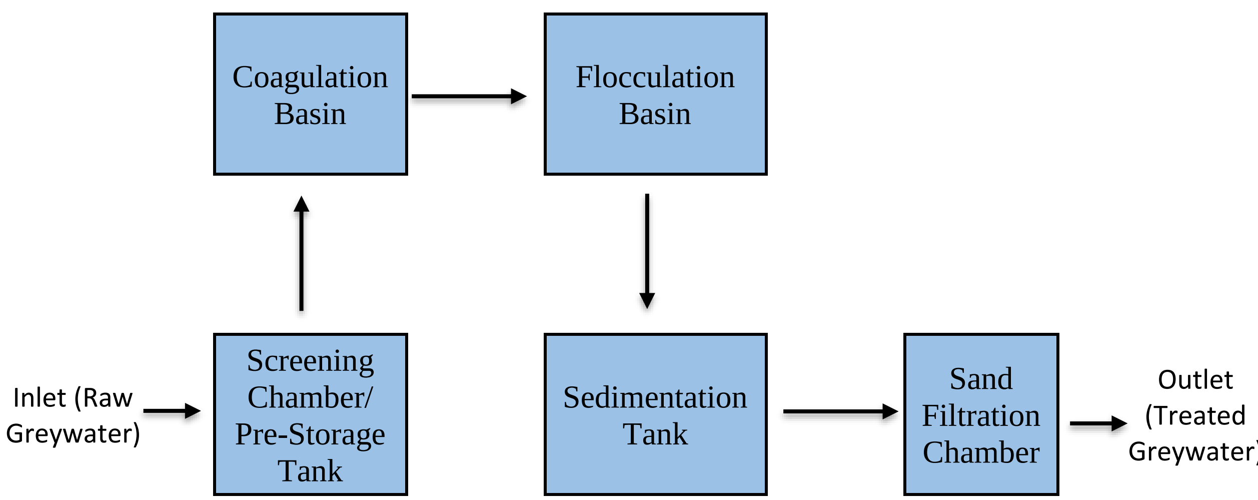


Figure 3.13. Flow Chart for Greywater Treatment

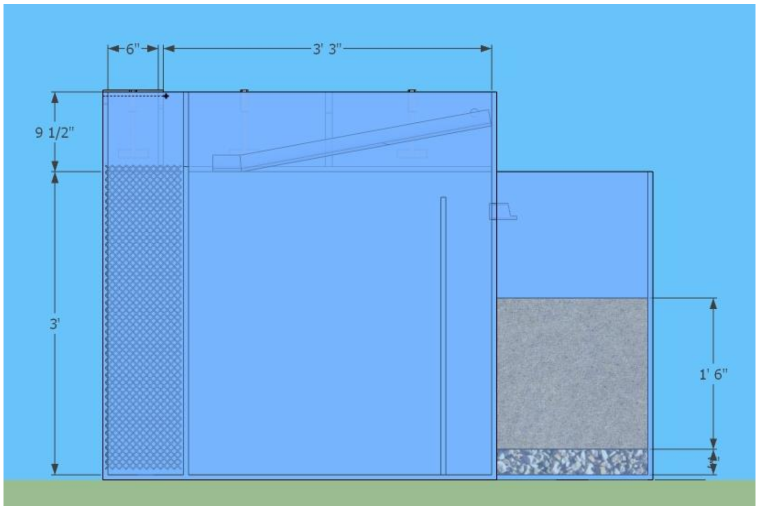
3.6. Design Summary and Final Sketch of Model:

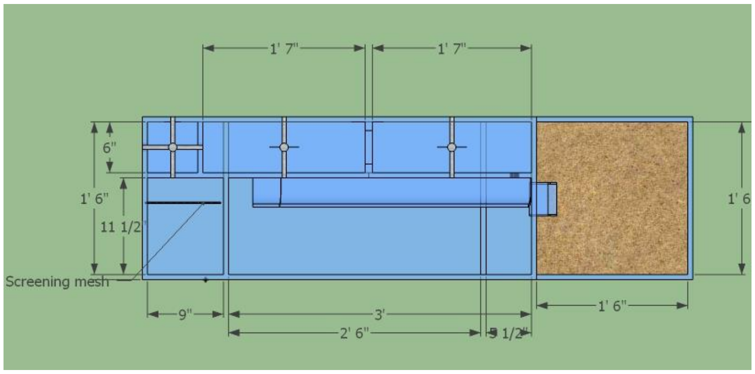
3.6.1. Design Summary:

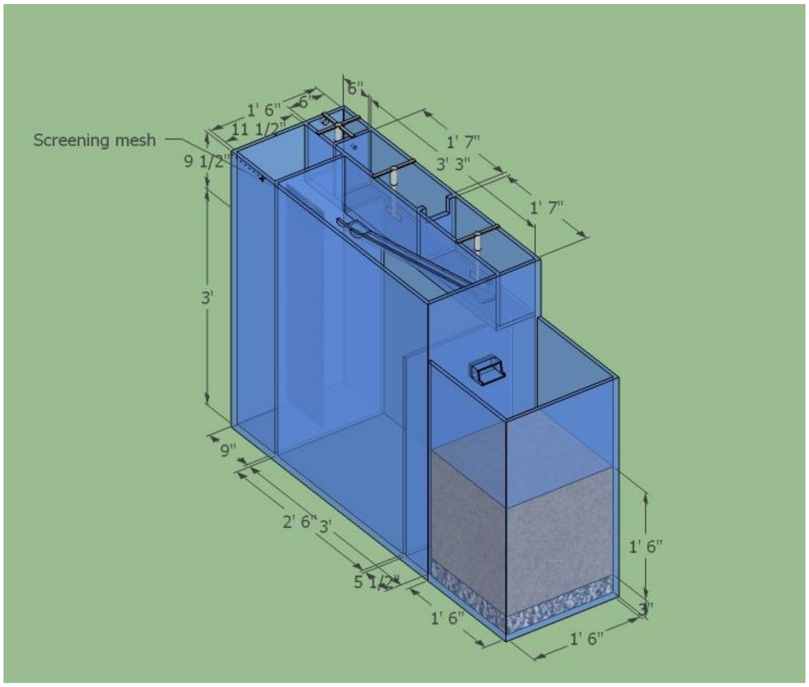
Table 3.2: Design Summary for Treatment Plant

Screening Chamber/ Pre-Storage Tank	Overall Dimensions	9" x 1.5' x 3' (L x W x D)
	Size of Screen (Mesh)	2 mm x 2mm
	Volume of Tank	95 liters, 3.375 ft3
Coagulation Basin	Overall Dimensions	6" x 6" x 9" (L x W x D)
	Paddle Dimensions	4" x 2"
	Volume of Basin	3.54 liters,0.125 ft^3
Flocculation Basin	Overall Dimensions	3'2" x 6" x 9" (L x W x D)
	Paddle Dimensions	4" x 2"
	Volume of Basin	22.42 liters, 0.792 ft^3
Sedimentation Tank	Overall Dimensions	3' x 1.5' x 3' (L x W x D)
	Volume of Tank	318.52 liters,11.25 ft^3
Sand Filtration Chamber	Overall Dimensions	1.5" x 1.5' x 3' (L x W x D)
	Thickness of Sand Layer	15"
	Size of Sand	600 µm
	Thickness of Aggregate Layer	4"
	Aggregate Size	1"-1.5"
	Depth of Standing Water	9"
	Volume for Standing Water	48 liters, 1.69 ft^3

3.6.2. Final Sketch of Model:







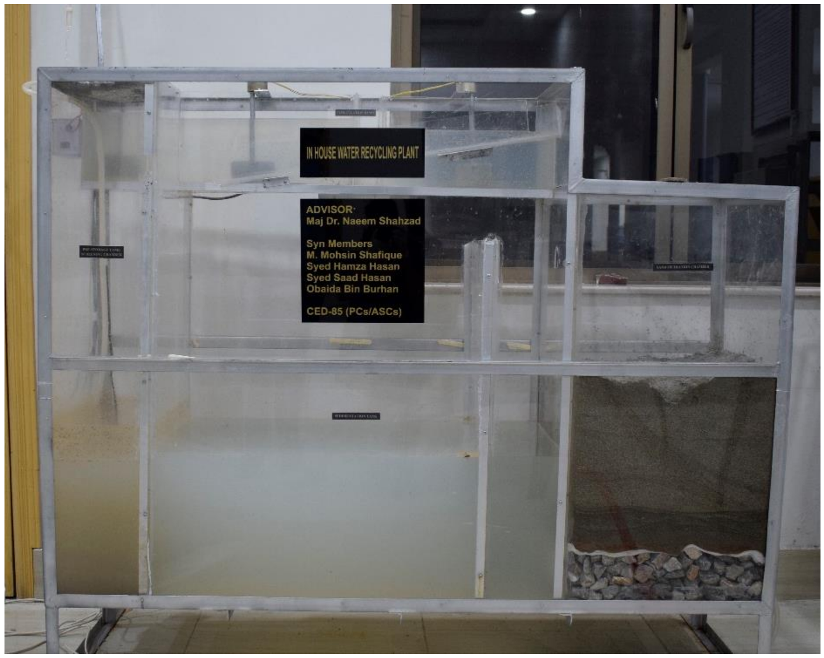


Figure 3.14: Final Sketch of Treatment Unit

3.6.3. Selection of Material for Treatment Unit:

As in our project model we have to show the mechanism of treatment plant from inside. Therefore, acrylic glass is selected for the preparation of model. Simple glass was one of the options that was in our mind but due to its fragile behavior it is not technically feasible and suitable for over model. Table 3.3 shows the comparison of glass with acrylic glass.

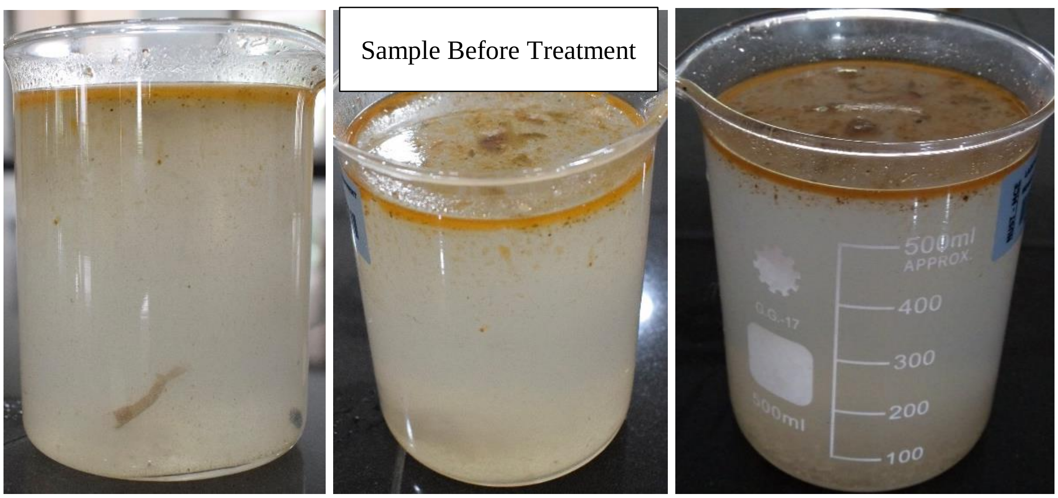
Table 3.3: Comparison of Acrylic Glass and Glass

Acrylic Glass	Glass
For storing same volume of water, acrylic glass requires less thickness and have more strength.	Glass require more thickness for same storage of water and have less strength than acrylic glass.
It is flexible and can be molded easily.	Glass is brittle and rigid.
Do not easily crack able and hence no leakage problems.	Sudden impact will cause cracking of glass and hence leakage.
Acrylic glass tank is lighter than glass.	It is denser with more weight than acrylic glass
Relatively expensive than glass.	Relatively cheaper than acrylic glass.

By the comparison shown in table 3.3, it has been concluded that acrylic glass is little expensive than glass but more feasible and fit in all the ways.

3.7. Laboratory Analysis of Filtered/Treated Greywater:

Greywater was treated in plant by series of treatment processes and then analyzed in laboratory. Different physical and chemical parameters were obtained by laboratory testing and then results were analyzed and compared against reuse standards of water required for irrigation, garden watering, toilet flushing and cleaning purposes. Results and analysis on treated greywater have discussed later in this report along with the reuse applications of recycled greywater.



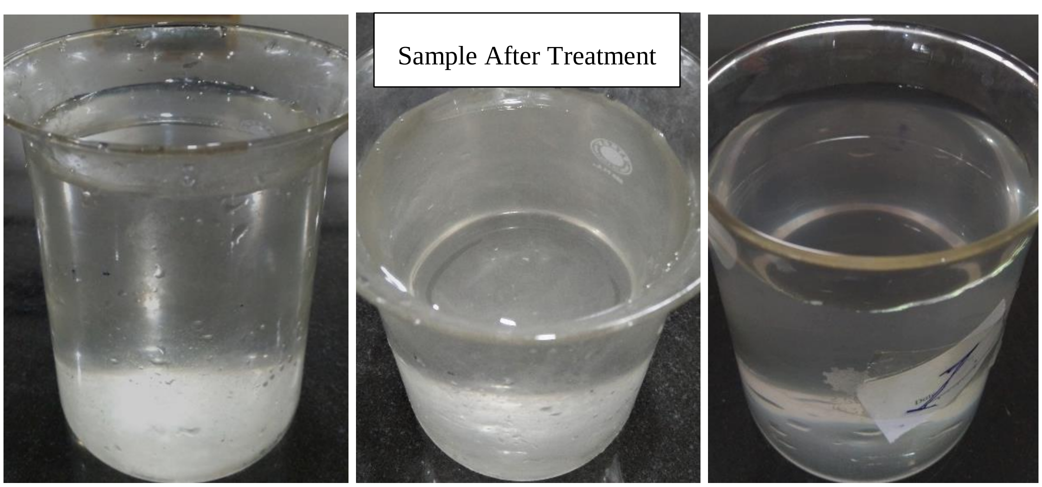


Figure 3.15: Treatment of Greywater and Samples Before & After Treatment

3.8. Recommended Installation Procedure of Plant in House:

Greywater from the kitchen, bathroom and laundry of a house is stored in pre-storage underground concrete tank where screen/mesh is also installed for the process of screening to remove floating and coarse particles from greywater. Floating value is recommended to be installed in pre-storage tank, in case, if excess greywater has generated in unusual condition it will be run off to normal drain.

Greywater from pre-storage tank/screening chamber is then pumped to the main treatment unit/recycling plant where it will pass through different treatment chambers. The outlet of treatment plant is connected to underground concrete storage tank. Recycled greywater is then used for garden watering, house cleaning, car washing and toilet flushing directly pumped from storage tank. The estimated cost of whole mechanism for in house greywater recycling is discussed in next chapter. Figure 3.16 shows the whole mechanism of greywater collection, treatment and its storage to reuse in various purposes.

Dimensions of storage tank = 3’ x 3’ x 3’ (1 for pre-storage, 1 for treated water).

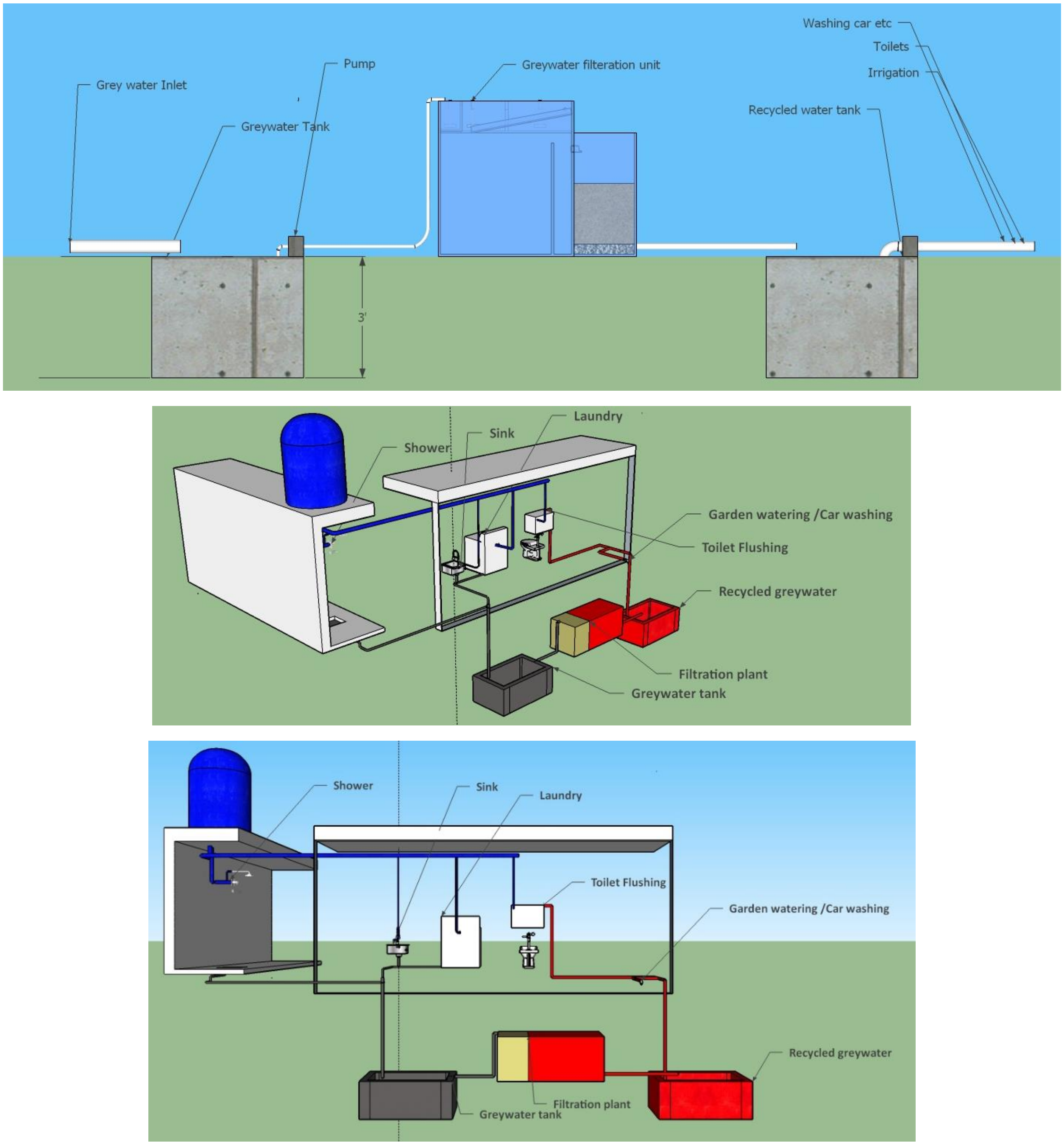


Figure 3.16: Layout for Installation of Plant in a House

Chapter 4

Results and Discussions

4.1. Parameters of Greywater:

Laboratory tests conducted on greywater gave us the value of different parameters of bathroom and kitchen greywater. The pH of bathroom greywater was 6.83 while kitchen grey water has pH of 6.79. The turbidity of bathroom greywater was high as compared to kitchen greywater. Prominent amount of chlorides was present in both kitchen and bathroom greywater. The COD value for kitchen greywater was greater than greywater generated from bathroom. Bathroom greywater has BOD of 74.1 mg/l while BOD value of 60.75 mg/l was observed in Kitchen greywater. Table 4.1 shows the values of different parameters that was observed during the laboratory analysis of greywater. These values are the average of water collected from three different houses.

Table 4.1. Parameters of Greywater

S. no.	Parameters	Grey Water	
		Bathroom	Kitchen
1	pH	6.83	6.79
2	EC (mS/m)	6.5	6.2
3	Temperature (°C)	14.8	14.1
4	Turbidity (FTU)	23.84	8.16
5	Sulphates (mg/L)	360	351
6	Nitrates (mg/L)	109.8	11.7
7	Chlorides (mg/L)	377.88	359.89
8	COD (mg/L)	298	364
9	BOD (mg/L)	74.1	60.75
10	TDS (mg/L)	2940	3220

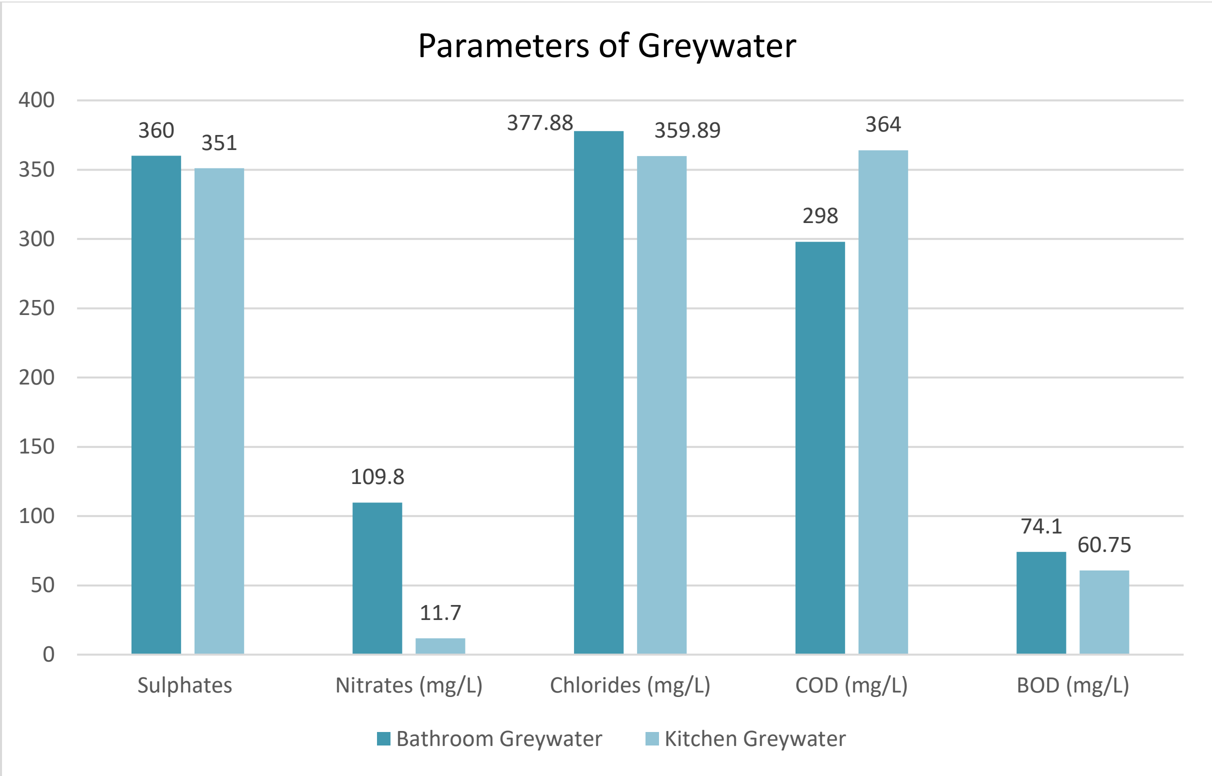


Figure 4.1. Parameters of Greywater

4.2. Effect of Coagulant on Greywater:

An optimum amount of coagulant was added in greywater and process of coagulation and flocculation was done in laboratory by jar test. The amount of coagulant used was 200 mg/l, is the value taken by reviewing literature. It has been observed that this treatment was effective in the treatment of greywater. As, in general, addition of coagulant decreases the pH of water and it has been observed during laboratory analysis of treated samples. The turbidity removal from bathroom and kitchen greywater was 77.18 and 80.15 % respectively. The removal of nitrates from greywater was observed to be 82.79 % from bathroom and 76.92 % from kitchen greywater. A significant removal percentage of COD, BOD and TDS was also observed during testing on treated greywater. Table 4.2 show the parameters of greywater before and after coagulation and flocculation process along with their percentage removal. Figure 4.2 shows the removal percentage of different parameters of greywater after addition of coagulant.

Table 4.2. Parameter of Greywater Before and After Coagulation

S. no.	Parameters	Grey Water					
		Before Coagulation		After Coagulation		Percentage Removal (%)	
		Bathroom	Kitchen	Bathroom	Kitchen	Bathroom	Kitchen
1	pH	6.83	6.79	5.48	6.02	19.77	11.34
2	EC (mS/m)	6.5	6.2	7.8	8.2	-	-
3	Temperature (°C)	14.8	14.1	15.1	15.2	-	-
4	Turbidity (FTU)	23.84	8.16	5.44	1.62	77.18	80.15
5	Sulphates (mg/L)	360	351	630	969	-	-
6	Nitrates (mg/L)	109.8	11.7	18.9	2.7	82.79	76.92
7	Chlorides (mg/L)	377.88	359.89	377.88	359.88	0.00	0.00
8	COD (mg/L)	298	364	203	260	31.88	28.57
9	BOD (mg/L)	74.1	60.75	45.47	40.51	38.64	33.32
10	TDS	2940	3220	2460	2600	16.33	19.25

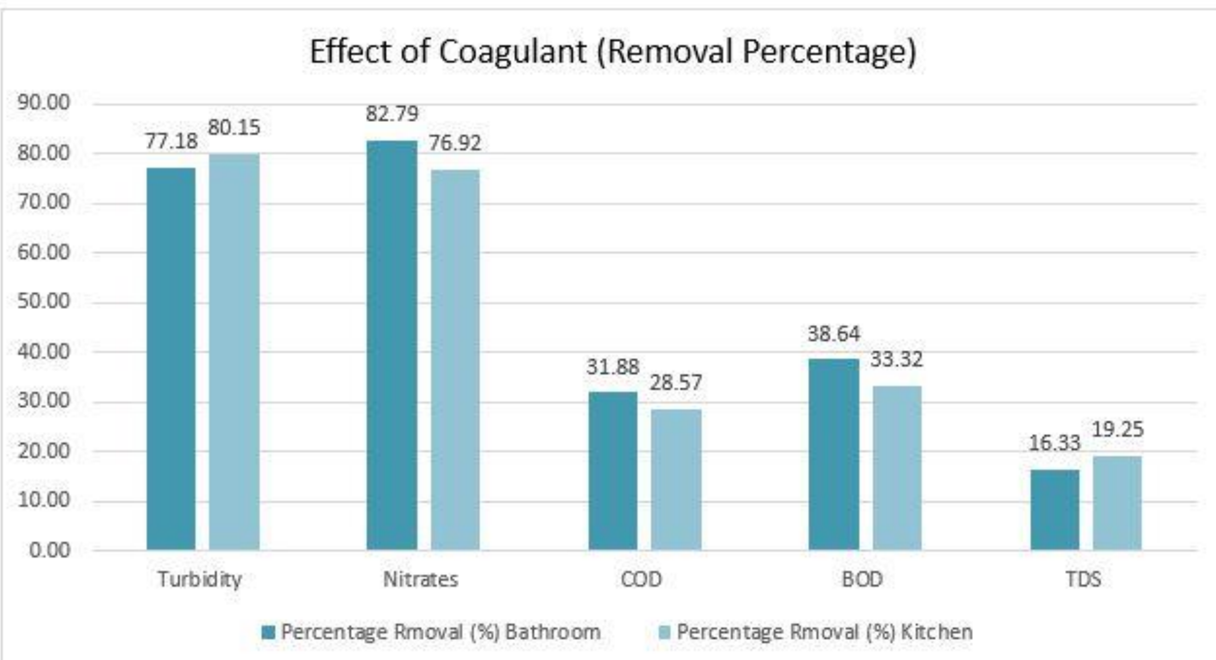


Figure 4.2. Removal Percentage for Greywater Parameters After Coagulation

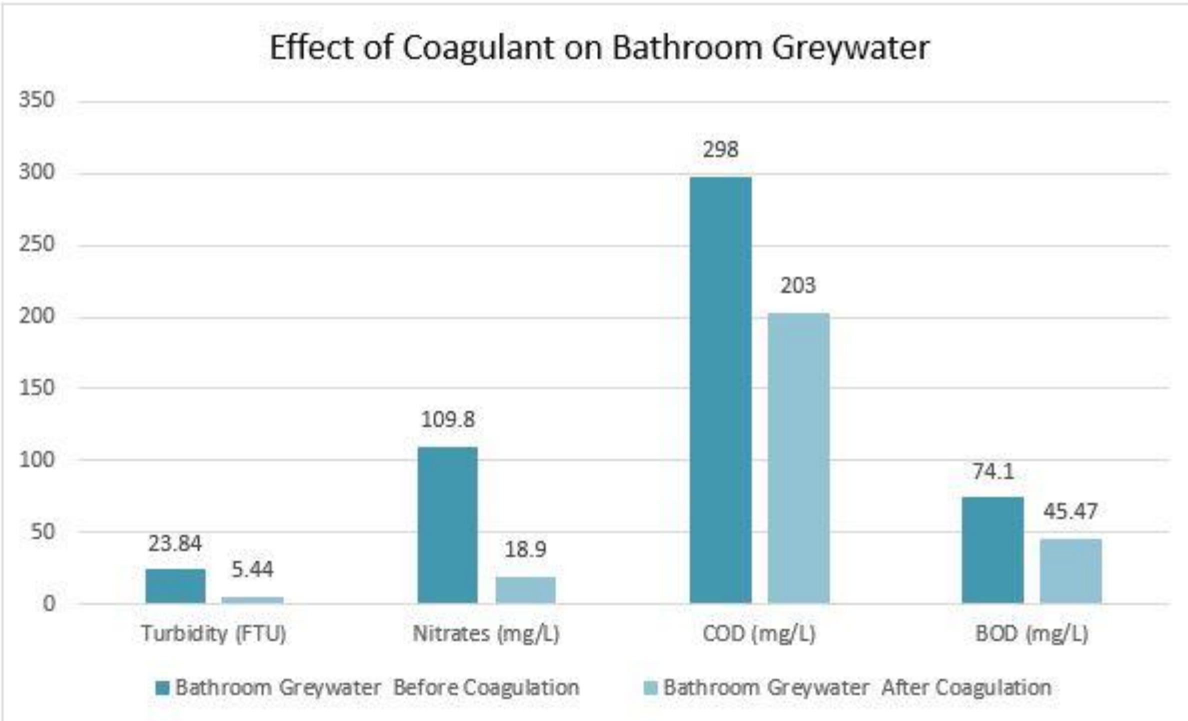


Figure 4.3. Effect of Coagulant on Parameters of Bathroom Greywater

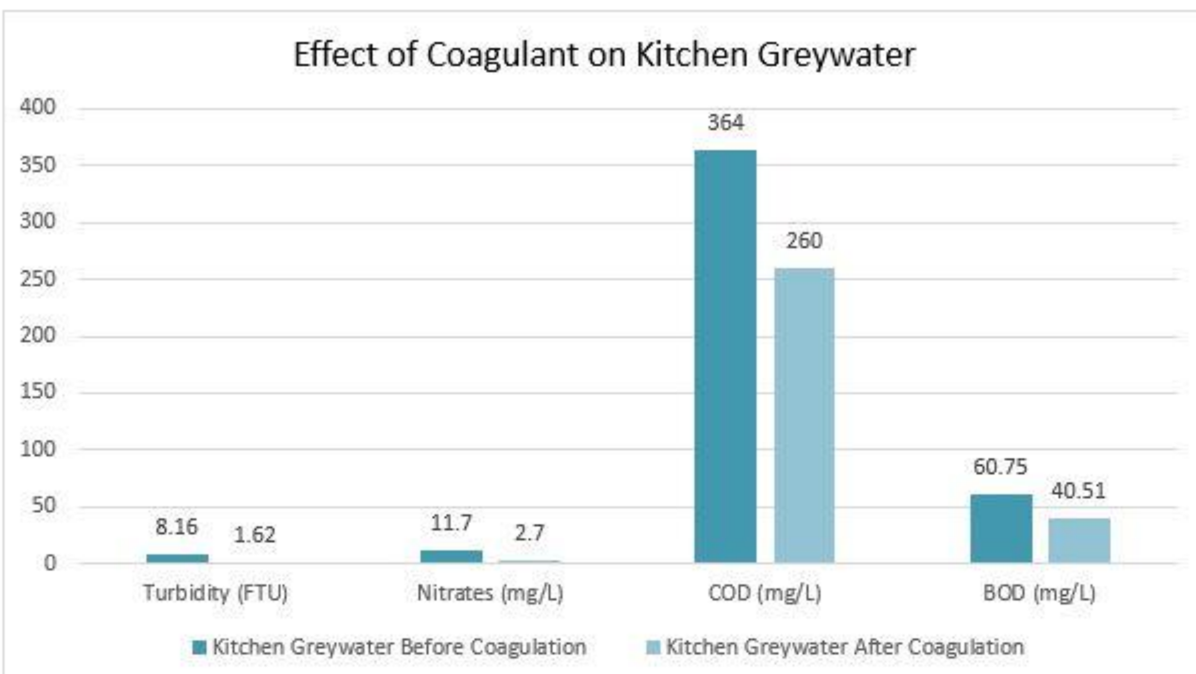


Figure 4.4. Effect of Coagulant on Parameters of Kitchen Greywater

4.3. Analysis on Treated Greywater:

4.3.1. Parameter of Raw and Treated Greywater:

Laboratory tests were conducted on both raw and treated greywater, before and after recycling of greywater. Observed parameters are shown in table 4.3. As the pH has to be increased due to addition of coagulant, it can be observed in results. Turbidity of the treated greywater has decreased effectively from 125 NTU to 6.57 NTU. Significant reduction in the amount of chlorides and nitrates has been observed. Sulphates in treated greywater has increased as alum was used as a coagulant. Prominent amount in the reduction of COD, TDS and TSS can be seen in table 4.3. We have to reuse this recycled water in toilet flushing, car and house cleaning and for watering the lawns in house, so we have to compare our results with the reuse standards. Reuse standards for greywater set by different countries is shown in table 4.4.

Table 4.3: Parameter of Raw and Treated Greywater

S. no.	Parameters	Raw Greywater	Treated Greywater
1	**pH**	6.64	7.8
2	**EC (mS/m)**	1.38	4.58
3	**Temperature (°C)**	25.3	25.3
4	**Turbidity (NTU)**	125	6.57
5	**Sulphates (mg/L)**	36	243
6	**Nitrates (mg/L)**	35.1	9
7	**Chlorides (mg/L)**	1179.63	470.44
8	**COD (mg/L)**	1766	895
9	**BOD (mg/L)**		
10	**TDS (mg/L)**	1640	1020
11	**TSS (mg/L)**	560	50

4.3.2. Standards for Greywater Reuse and its Applications:

The parameters that effect the reusability of greywater are generally pH, turbidity, BOD and total coliform. Different countries have their own standards and guidelines for reuse of recycled greywater. For the reuse of greywater in toilet flushing, UK has specified the pH range from 5.0 to 9.5 and turbidity less than 10 NTU. pH range for the non-potable reuse of greywater in China, Australia and USA is from 6 to 9. For irrigation and toilet flushing, the reuse standards set by Japan are pH 5.8 to 8.6, turbidity less than 10 NTU and BOD less than 20 mg/l. Table 4.4 shows the standards of greywater reuse according to reuse application set by different countries across the globe.

Table 4.4: Standards for Greywater Reuse and its Applications

Country	Reuse Application	Parameters				
		pH	Turbidity (NTU)	BOD (mg/l)	E. Coli number /100ml	Total Coliform
UK	Toilet Flushing	5.0-9.5	<10		<25	
Australia	Washing Machine, Toilet Flushing	6.5–8.5	<5	<10	<1	
China	Toilet Flushing	6 – 9	<5	<10	TDS<1500 mg/l	
USA	Unrestricted Reuse (landscape Irrigation, Toilet flushing, car washing)	6 – 9	<2	<10		≤100/ml
Australia	Surface Irrigation, Toilet Flushing, car washing, Laundry use	6 – 9		< 20		<100 /100ml
UK	Garden watering and Car washing	5-9.5	<10		<250	
Japan	Toilet Flushing and Irrigation	5.8–8.6	<10	< 20		<1000 /100ml

Source: (Fountoulakis *et al.*, 2016; De Gisi *et al.*, 2016; Oh *et al.*, 2018; Albalawneh *et al.*, 2015; Li *et al.*, 2009; Pidou *et al.*, 2007; Agency-UK, 2011; Capital, 2004, Chaillou *et al.*, 2011; Government of Western Australia, 2011).

4.3.3. Removal Percentage:

In house recycling plant has efficiently treated greywater, removal percentages of various parameters are shown in table 4.5. After effective treatment on raw greywater, 94.74% turbidity has been removed. Treated greywater has turbidity of 6.57 NTU, which has met the reuse standard set by UK and Japan (<10 NTU) for reuse of greywater in toilet flushing, car washing, irrigation and garden watering. The observed percentage removal for COD is almost 50%. Percentage removal for chlorides and nitrates are 60.12 % and 74.36%. Beside this treated greywater has no unpleasant odor and can freely be used for recommended purposes. The amount of TDS and TSS has also significantly reduced and their percentage removal of 37.8 % and 83.33 % has been observed.

Table 4.5: Removal Percentage for Different Parameters

S. no.	Parameters	Grey Water				
		Raw Greywater	Treated Greywater	Percentage Removal (%)	Reuse Standard	Remarks
1	pH	6.64	7.8	-	6 – 9	OK
2	EC (mS/m)	1.38	4.58	-	-	
3	Temperature (°C)	25.3	25.3	-	-	
4	Turbidity (NTU)	125	6.57	94.74%	<10	OK
5	Sulphates (mg/L)	36	243	-	-	
6	Nitrates (mg/L)	35.1	9	74.36%	-	
7	Chlorides (mg/L)	1179.63	470.44	60.12%	-	
8	COD (mg/L)	1766	895	49.32%	-	
9	BOD (mg/L)				<20	
10	TDS (mg/L)	1640	1020	37.80%	<1500	OK
11	TSS (mg/L)	300	50	83.33%	-	

The greywater treated by plant has met the reuse standard of greywater set by different counties. Hence, greywater recycled using this plant can freely be used for above discussed purposes.

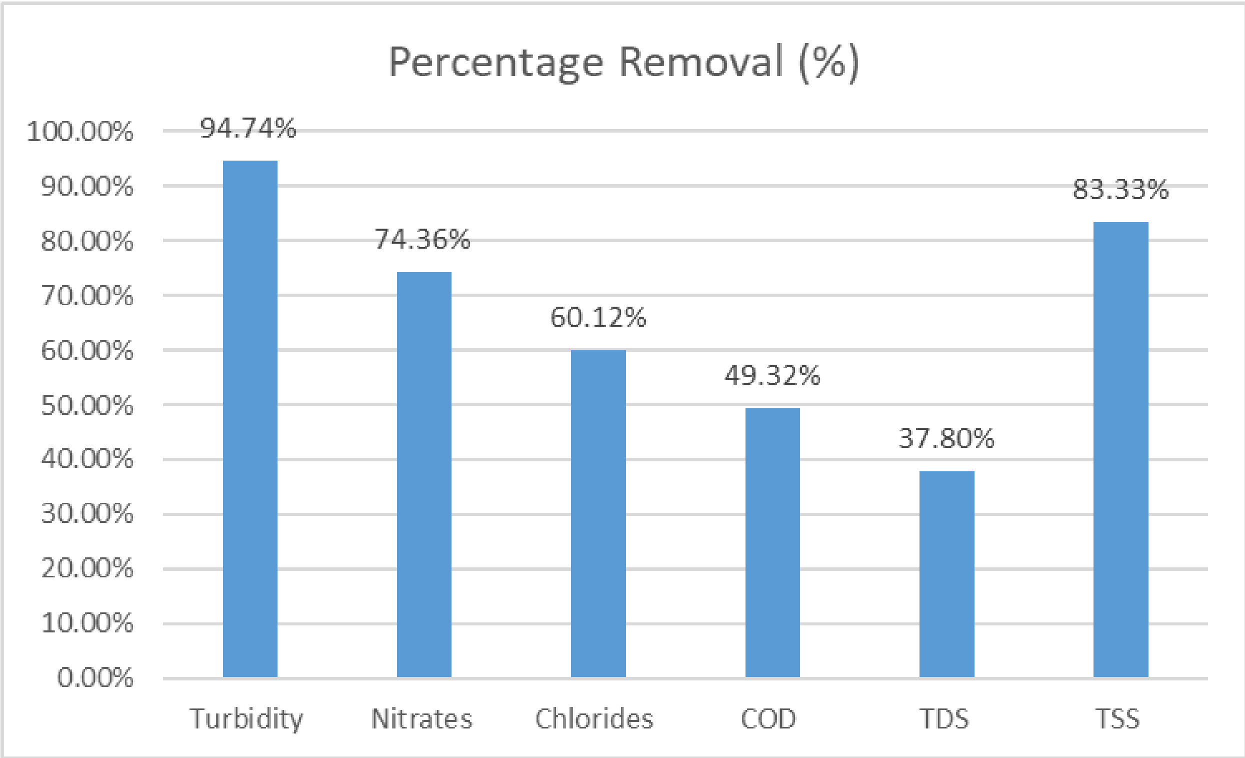


Figure 4.5: Removal Percentage After Treatment of Greywater

4.4. Reuse Applications of Recycled Greywater:

The recycled greywater can effectively be used in toilet flushing, irrigation, garden watering and for cleaning purposes. The reuse standards and guidelines for greywater set by different countries is shown in table 4.3. As the grey water nutrient like phosphorous and nitrogen provide an excellent food source for the plants so it can be used for watering the garden and lawns in a house. Fresh water usage for a house reduced significantly after using recycled greywater for specific purposes. Hence to reduce the demand of fresh water, greywater bears significant importance to reuse it for irrigation and toilet flushing purpose in a sustainable way.

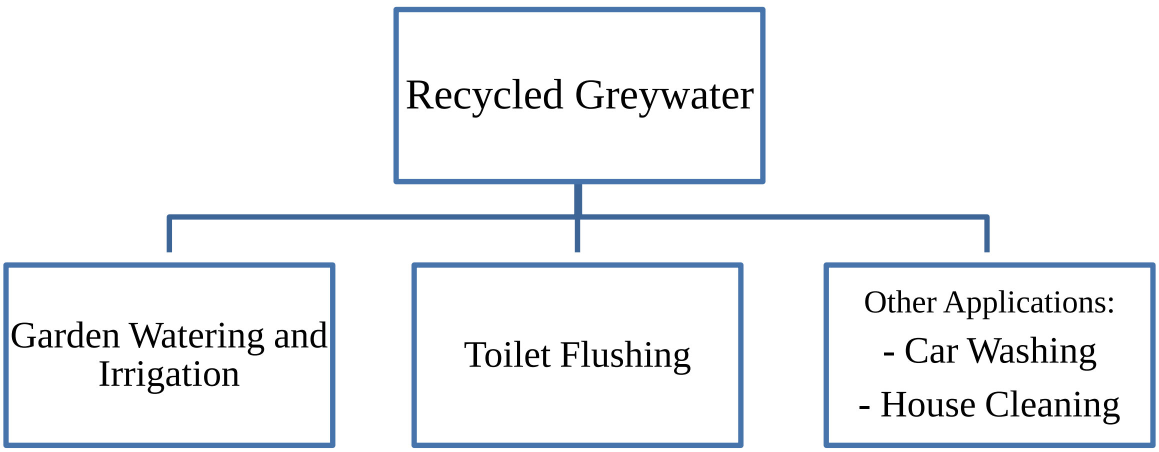


Figure 4.5: Reuse Applications of Recycled Greywater

4.5 Public Perception for the Reuse of Recycled Greywater:

The success of our project also depends upon the public acceptance, perception and affordability of users who would willing to pay for treatment plant and willing of reuse recycled greywater. Acceptance of human beings toward the use of water in daily life activities is usually determined by the odor, color, turbidity and suspended solids in water. Generally, people are willing to use water if it looks clean and clear (less turbid) and do not have unpleasant smell. Quality analysis of recycled greywater showed that it is totally safe to use and do not have health risk issues. However public perception towards reuse of treated grey water is positive as indicated in literature. James *et al.,* (2016) conducted research on the reuse of greywater and its challenges. It is mentioned that 95% to 97% of the people are willing to reuse greywater for toilet flushing and garden watering. Hence public would show their positive interest when it come for saving of water by using recycled greywater due to prevailing water crisis in Pakistan.

In UAE, Maraqa and Ghoudi (2015) did a research on public perception of reclamation and reuse of greywater and mentioned that almost 70 to 80% of the people are willing to use recycled greywater for toilet flushing, car wash, garden watering and landscaping irrigation. 50% of the residential persons in UAE were willing to install greywater recycling system in their homes and the main reason and motivation for them to reuse recycled greywater would be the saving conservation of water resources in the state. While people are least interested for using of greywater for the purpose of laundry and bathing. In another study, the percentage of people willing to reuse recycled greywater for car washing, toilet flushing and garden irrigation was 56%, 68% and 82% (Khong, 2009). Apart from reducing the demand of freshwater, greywater reuse could be a step toward sustainable development and improves the surrounding ecosystem by reducing the volume of wastewater discharge from house.

4.6. Savings of water (Effectiveness in Reducing Water Crisis of Pakistan):

The average water consumption for residential use in India is 138.7 liters /per person/ per day (Jongwanich, 2007). In USA, average water consumption varies from 161 to 227 LPCD (Kadlec & Wallace, 2008). According to EU statistics the average water consumption in Europe is 150 LPCD. In Spain, a person uses 171 liters of water per day.

Typically, greywater is 50-80% of the total wastewater generated from house. We took value of 100 LPCD as greywater i.e. recycled in treatment unit for reuse. The aim of our project is to reuse greywater for garden watering, car/floor washing and toilet flushing. To calculate the quantity of water saved by installing greywater recycling plant, we have to find the water usage in abovementioned activities.

The quantity of water used for toilet flushing varies from 6 liters to 10 liters per flush. 24% to 36% of total water consumption is used for toilet flushing, as mentioned in literature. On average 8 to 10% water is used for house cleaning purpose. In 2010, a survey was conducted by Bhatti & Nasu (2010) to collect the household water consumption data from different cities of Pakistan (Lahore, Rawalpindi & Faisalabad); results have shown in figure 4.6. Hence after analyzing the usage of water for toilet flushing, house cleaning and car washing purposes, it has been observed that generally 30% of the total water consumptions in an average household used for abovementioned activities. Therefore, by replacing this 30% freshwater with recycled greywater will save huge amount of water in Pakistan where water scarcity conditions are prevailing at significant rate.

Moreover, the recycled greywater from house can also be used for garden watering or landscaping irrigation purposes. Generally, 10 to 35% of water is used for watering lawns and gardens in a household, depending upon the size and nature of garden/lawn (Oh *et al.,* 2018; De Gisi *et al.,* 2016). We considered 15% of total water consumption that is used for watering gardens.

Table 4.6: Household Water Consumption in various activities (%)

Description	Water Usage Percentage				
	A	B	C	D	E
Bath/Showers	28%	19.69%	14%	18.50%	20%
Kitchen/Dishwasher	16%	2.99%	12%	1.50%	19%
Laundry/Washbasin	22%	24.83%	8%	21.70%	20%
House Cleaning	4%	-	12%	15.70%	6%
Car Cleaning	5%	-	8%	-	-
Toilets Flushing	18%	26.32%	36%	26.70%	35%
Leaks	-	11.45%	-	13.70%	-
Others	7%	14.72%	10%	2.20%	-
Total	100%	100%	100%	100%	100%

Sources: **A:** (Bhatti & Nasu, 2010), **B:** (DeOreo *et al.*, 1996), **C:** (Mourad *et al.*, 2011), **D:** (Mayer *et al.*, 1999). **E:** (Pidou *et al.*, 2007)

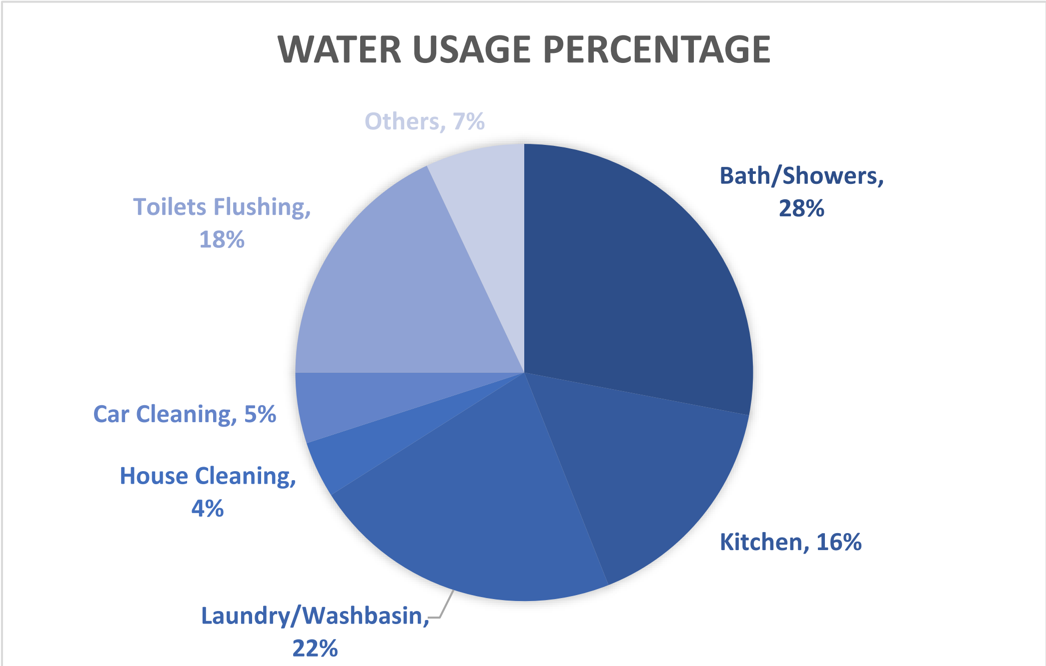


Figure 4.6: Household Water Consumption in various activities (%)

Sources: (Bhatti & Nasu, 2010)

Calculations for the savings of fresh water is as follow:

Fresh water usage = 150 LPCD

In a house of 8 persons, water consumption = 150 x 8 = 1200 liters/day

Greywater generated = 800 liters/day

Greywater recycled = 800 liters/day

Reuse for toilet flushing, car and house cleaning = 30% of total usage

= 0.3 x 1200 = 360 liters/day

Reuse for garden watering = 15% of total usage

= 0.15 x 1200 = 180 liters/day

Total quantity of reused water = 360 + 180 = 540 liters/day

As the fresh water is being replaced with recycled greywater, hence demand for fresh water is:

Fresh water required for daily use = 1200 – 540 = 660 liters/day

Saving of freshwater = **540 liters/day**

Saving of freshwater = $\frac{1200-660}{1200}$ x 100 = **45%**

After using recycled water in activities of toilet flushing, garden watering, car and house cleaning there is 45% saving of fresh water (shown in figure 4.7). This will reduce the demand of freshwater in daily life activities and hence will reduce the stress of water shortage in major cities of Pakistan.

There may be a chance of urine traces in greywater of showers hence if we do not consider shower greywater in recycling then the saving of greywater is reduced to approximately 35 to 40% of the total usage.

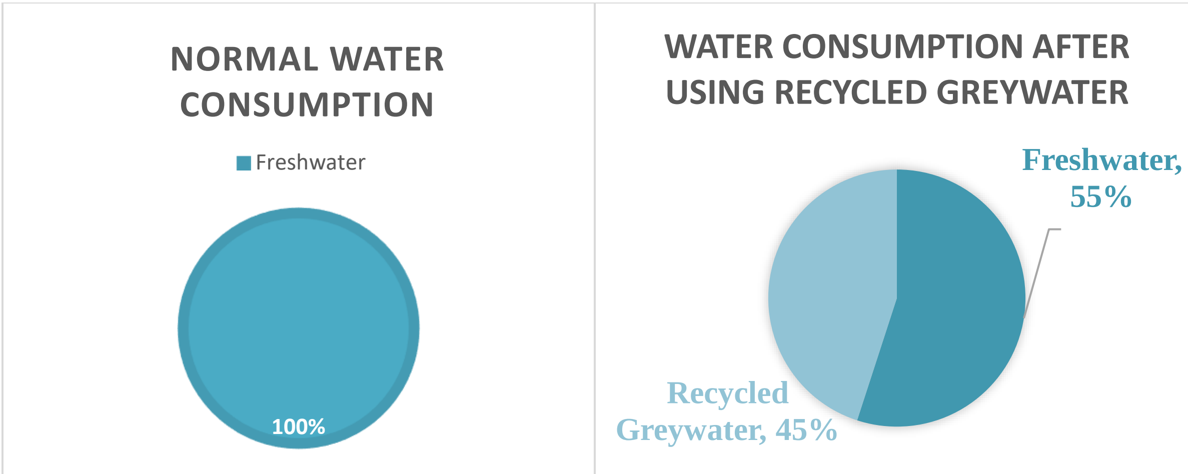


Figure 4.7: Effect on Freshwater Demand after Using Recycled Greywater

In an average house of **8 persons**,

Saving of freshwater = **540 liters/day**

For a month, saving of freshwater = **16,200 liters/month**

For a year, saving of freshwater = 1,94,400 liters/month = **194.4 m^3/year**

Per capita water saving in a year = 194.4 / 8 = 24.3 m^3/per capita/year

This saving of freshwater can be used for other useful purposes to fulfill the water requirements of dinking, cooking, bathing and laundry and can be supplied to areas where scarcity conditions are increasing at alarming rate.

4.7. Economic Analysis:

4.7.1. Cost of Installation of Plant:

a. Capital Cost:

Cost of Recycling Plant = Rs 42,000 (made with acrylic glass with pre-storage tank)

It is recommended to use filtration plant made up of brick masonry or concrete in order to use it in a house. The detail cost of whole assembly is shown in table 4.7. The cost was estimated by using MES schedule rates and also confirmed from 2 to 3 on field contractors.

Cost of Recycling Plant = Rs 35,000 (made with acrylic glass without pre-storage tank)

Table 4.7: Capital Cost for In House Greywater Recycling System

Capital Cost for In House Greywater Recycling System					
S.no	**Description**	**Estimated Cost per unit**	**Required Volume, Quantity**	**Estimated Cost**	**Remarks**
1	Recycling Plant	Rs 500/ ft^3	20 ft^3	Rs 10000	Brick Masonry
2	Pre- Storage Tank for Raw Greywater	Rs 500/ ft^3	27ft^3	Rs 13500	Brick Masonry
3	Storage Tank for Recycled Greywater	Rs 500/ ft^3	27ft^3	Rs 13500	Brick Masonry
4	Pump		1 x 0.5 HP pump	Rs 3500	Summit Pump, Inc
5	PVC Pipes	Rs 250/ 13ft length	6 x 13 ft length pipes	Rs 1500	Master Pipes (pvt) ltd
6	Miscellaneous Cost			Rs 2000	
	Total			**Rs 44,000**	

b. Operational Cost:

Price of Coagulant (alum) = Rs 200 per kg

Amount of Coagulant used = 200 mg/l = 0.2 g/l

Amount of recycled greywater in a month = 800 liters/day x 30 days= 24000 liters

Amount of Coagulant used in a month = 4.8 kg

Power of mini pump and paddle motors = 70 Watts

Approx. time for recycling greywater = 15 hrs. /day

Consumption of Electricity = (70/1000) x 15 hrs. = 1.05 unit/day

Electricity consumed for running mini pump and paddles = 31.5 units/month

Price per Unit (IESCO) = (5.79 + 8.11)/2 = Rs 6.95

Further details are shown in table 4.8.

Table 4.8: Operational Cost for Greywater Recycling System

Operational Cost			
Description	**Per unit Cost**	**Amount**	**Price**
Alum	Rs 200/kg	4.8 kg	Rs 960
Electricity	Rs 6.95/ unit	31.5 units	Rs 220
Total	Per Month		**Rs 1180**

4.7.2. Reduction in Cost of Water:

Saving of freshwater = 45%

Approximate calculations for recovery of capital cost and reduction in cost of water is shown in table 4.9 for Karachi and Rawalpindi/Islamabad.

Table 4.9: Reduction in Cost of Water and Capital Cost Recovery Time

S.no	Description	Karachi	Rwp/Isb	Remarks
1	Approx. Price of Water Bowser	Rs 5000	Rs 2000	Rs 1500 -2500 (Rwp) Rs 4500 -5500 (Kci)
2	Approx. Volume of Bowser	4000 liters	4000 liters	
3	Usage of water in a month for a house of 8 persons	36000 liters	36000 liters	1200 lit/day, 150LPCD
4	No. of Bowsers Required in a month	9	9	
5	Cost of water per month	Rs 45000	Rs 18000	
6	Saving of Water in a month	16,200 liters	16,200 liters	45% of total usage
7	No. of Bowsers Required in a month after using recycled greywater	5	5	per month
8	Estimated Cost of water after using recycled greywater	Rs 25000	Rs 10000	per month
9	**Reduction in Cost**	Rs 20000	Rs 8000	Per month Saving
9	Capital Cost of Recycling System	Rs 44000	Rs 44000	
10	Operation Cost per month	Rs 1180	Rs 1180	
11	**Cost Recovery Time**	**2-3 months**	**6-7 months**	Approximate Time

4.7.3. Cost-Benefit Analysis:

Reuse of recycled greywater in various activities will reduce the demand of freshwater and hence reduces the cost of water. Reuse of greywater can save cost of water bowsers in major cities where water requirements are being met through private water bowsers.

This project must not be analyzed only by the saving of water cost but it will play an effective role in reducing the demand of freshwater in Pakistan where water shortage is increasing at significant rate. The major advantage of reusing recycled greywater at household level is the reduction in the demand of freshwater and the reduction of wastewater discharge, as the fresh water used for toilet flushing, garden watering, car washing and cleaning purpose can be replaced by recycled greywater saving a huge amount of freshwater for other activities. This project is an efficient solution of all the ongoing water crisis problems of Pakistan.

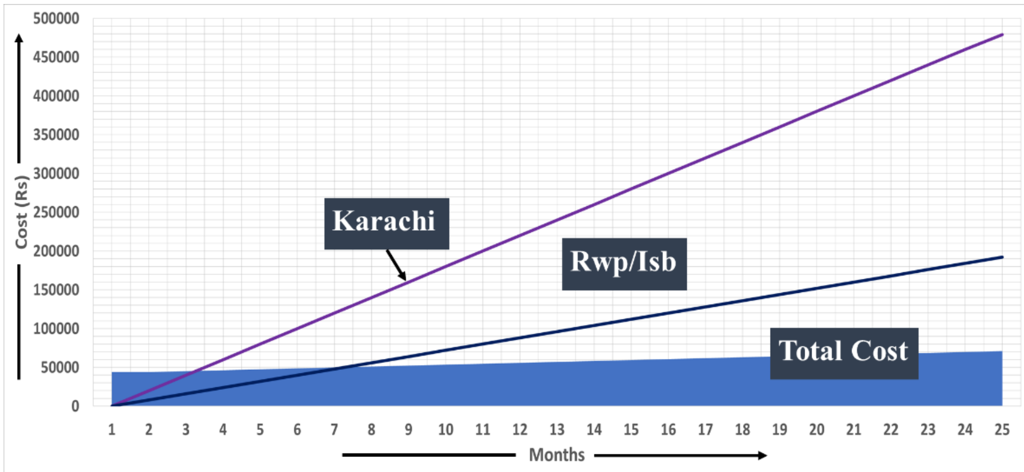


Figure 4.8: Cost Benefit Analysis

4.8. Maintenance of the Treatment Plant:

Recycling plant for in-house greywater recycling do not have complex treatment processes. The maintenance required for all chambers is simple cleaning which can be done after one or two months. Back washing will be required for sand filtration chamber to clean the sand to avoid clogging of sand. Maintenance of the plant can be carried out at almost negligible cost comparing to the cost of water saving in a month.

4.9. Sustainable Benefits:

Recycling of greywater and its reuse is a great step toward the sustainability and water resources management in a sustainable way. By reusing greywater in various purposes can reduced the demand of freshwater and efficiently reduced the volume of wastewater that is discharged from house. Greywater reuse has no negative impact on environment rather it contributes positively toward sustainability development and improves the surrounding ecosystem by reducing the volume of wastewater. Properly treated greywater has no health hazards for reuse in toilet flushing, garden watering, landscaping irrigation and car washing.

Figure 4.7 shows the goals for sustainable development. The reuse of recycled greywater for various purposes can be closely related to goal 6 (Clean water and sanitation), 11 (sustainable cities and communities) and 17 (partnership for goals). Recycling of greywater effectively supports the goal 6 if it is implemented at household level. Appropriate waste management and recycling systems for wastewater are the essentials for sustainable cities (Goal 11). Hence by reducing wastewater volume and recycling greywater, our project closely relates to the criteria of goal 11. For sustainable future, partnerships and technology transfer are likely cases where involvement can be done (Goal 17).

Figure 4.9: Sustainable Development Goals

4.10. Discussion on Achievement of Objectives of the Project:

The main aim of our project was to design a sustainable, cost efficient and compact unit which can recycle the waste grey-water of a house, and make it reusable again. We have successfully designed the in-house water recycling plant which has sustainable benefit and cost effective. Cost-benefit analysis of the project has discussed earlier in this section.

Recycled/treated greywater can be used for garden watering, car washing, house cleaning and toilet flushing. Replacing freshwater with recycled greywater can approximately save 45% of the freshwater. Therefore, to reduce the demand of fresh water and solve the issue of water crisis of Pakistan our project could effectively contributes in a sustainable way.

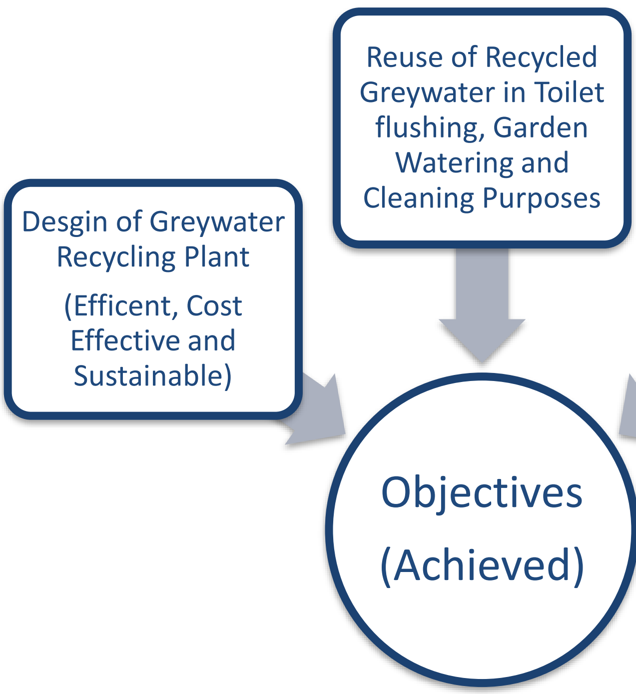


Figure 4.10: Achievement of Aim and Objectives of the Project

Chapter 5

Conclusions and Recommendations

5.1. Conclusion:

This research project concluded that greywater is a type of wastewater has a great potential for reusing it in various purposes and it will play an effective role in managing the water resources of Pakistan in a sustainable way. After analyzing the different parameters of greywater, we have designed a in house greywater recycling plant. The characteristics of treated greywater has been analyzed and the potential for its reuse and its benefit in accordance with national needs has been discussed. Results and analysis of this project concluded that:

- Greywater can be recycled at household level in an economic and efficient way in order to reuse it in various purposes.
- The recycled greywater can be used for garden watering, toiling flushing, car washing and cleaning purposes by substituting freshwater.
- The demand of freshwater can be reduced by using recycled greywater in various household activities.
- Recycled greywater saves approximately 45 % of the freshwater in a house, making the water available for water scarcer regions of Pakistan.
- For solving the issue of water crisis of Pakistan, recycling and reuse of greywater could effectively contributes in a sustainable way.
- The project will help to save the water cost significantly in areas like Karachi and Islamabad where water requirements are being met through private water bowsers.
- This project is an efficient solution of all the ongoing water crisis problems of Pakistan.
- As the percentage of grey water in home wastewater is generally 50 to 80% of the total household wastewater. Therefore, recycling of greywater can efficiently reduce the quantity of wastewater produced from a house.

5.2. Recommendations:

During the project analysis and study stages and while brainstorming and putting the data together, there were certain things which were not considered for the particular project due to certain limitations, but if considered will prove very fruitful for managing the water resources of Pakistan. Following are some of the recommendations that are suggested:

- The large sector of Pakistan is involved in Agriculture. If the greywater is recycled on a large scale then it can also be used for unrestricted irrigation purposes and it will contribute effectively in reducing the virtual water trade of Pakistan.
- The recycled greywater can be used for laundry purpose but due to the religious and cultural norms of the people of Pakistan and the psychological factor in the minds of people that the water may not be clean to use to wash clothes, we did not consider use of recycled greywater for laundry purpose.
- The recycled greywater can be proved beneficial for recharging water table in major cities of Pakistan where due to dense population and excessive pumping water table has depleted.
- The recycled greywater can freely and safely be used in fire protection and construction processes.
- The recycled greywater can be used for landscaping irrigation in parks and recreational places if collected and recycled on relatively larger scale.
- Along with the recycled grey water we can also use rainwater for flushing, car washing, gardening and floor washing by collecting the rainwater from the roof of the house.
- The system can be automated by using automatic control valves and logic gates which will allow the plant to work on its own without any manual aid. Though it will have some increase in the initial cost.
- We can add automated screening systems in pre storage tank for initial screening of water, if the grey water of house contains too many course, floating particles.
- If government provide subsidies and encourage the public to recycle and reuse greywater then it would be a great step in water resources management of Pakistan.

6. References

Abu-Zeid, M. A. (1998). Water and sustainable development: the vision for world water, life and the environment. Water policy, 1(1), 9-19.

Agency-UK, E., 2011. Greywater for domestic users: an information guide. Published by environmental agency. Available at: www.enviroment-agency.gov.uk.

Ahmed, A., Iftikhar, H., & Chaudhry, G. M. (2007). Water resources and conservation strategy of Pakistan. The Pakistan development review, 997-1009.

Al-Jayyousi, O. R. (2003). Greywater reuse: towards sustainable water management. Desalination, 156(1-3), 181-192.

Al-Mughalles MH, Rahman RA, Suja FB, Mahmud M, Jalil NA (2012) Household greywater quantity and quality in Sana'a, Yemen. EJGE 17:1025–1034

Albalawneh, A., & Chang, T. K. (2015). Review of the greywater and proposed greywater recycling scheme for agricultural irrigation reuses. International Journal of Research–Granthaalayah, 3(12), 16-35.

Australian Capital Territory, 2004. Greywater Use: Guidelines for residential properties in Canberra, in: Territory, A.C. (Ed.). Australia: Canberra

Bhatti, A. M., & Nasu, S. (2010). Domestic Water Demand Forecasting And Management Under Changing Socio: Economic Senario.

Birks R, Hills S (2007) Characterisation of indicator organisms and pathogens. Environ Monit Assess 129:61–69

Birks, R., & Hills, S. (2007). Characterisation of indicator organisms and pathogens in domestic greywater for recycling. Environmental monitoring and assessment, 129(1-3), 61-69.

Chaillou, K., Gérente, C., Andrès, Y., Wolbert, D., 2011. Bathroom greywater characterization and potential treatments for reuse. Water, Air, & Soil Pollution 215(1-4), 31-42

Daud, M. K., Nafees, M., Ali, S., Rizwan, M., Bajwa, R. A., Shakoor, M. B., ... & Malook, I. (2017). Drinking Water Quality Status and Contamination in Pakistan. BioMed Research International, 2017.

De Gisi, S., Casella, P., Notarnicola, M., & Farina, R. (2016). Grey water in buildings: a mini-review of guidelines, technologies and case studies. Civil Engineering and Environmental Systems, 33(1), 35-54.

Debnath, B., Raychaudhuri, A., & Mukhopadhyay, P. (2019). Grey Water Recycling for Domestic Usage. In Waste Water Recycling and Management (pp. 85-96). Springer, Singapore.

DeOreo, W. B., Heaney, J. P., & Mayer, P. W. (1996). Flow trace analysis to access water use. Journal-American Water Works Association, 88(1), 79-90.

du Plessis, A. (2017). Global water availability, distribution and use. In Freshwater challenges of South Africa and its Upper Vaal River (pp. 3-11). Springer, Cham.

Environment Agency (2008) International comparisons of domestic per capita consumption. www.environment-agency.gov.uk. Accessed 6 August 2008

Ercin, A. E., & Hoekstra, A. Y. (2014). Water footprint scenarios for 2050: A global analysis. Environment international, 64, 71-82.

Eriksson, E. (2002). Potential and problems related to reuse of water in households. Environment & Resources DTU. Technical University of Denmark.

Food and Agriculture Organization of the United Nations (2012) Coping with water scarcity, an action framework for agriculture and food security. http://www.fao.org. Accessed 23 September 2012

Fountoulakis, M. S., Markakis, N., Petousi, I., & Manios, T. (2016). Single house on-site grey water treatment using a submerged membrane bioreactor for toilet flushing. Science of the total environment, 551, 706-711.

Friedler E, Hadari M (2006) Economic feasibility of on-site greywater reuse in mufti-storey buildings. Desalination 190:221–234

Ghaitidak, D. M., & Yadav, K. D. (2013). Characteristics and treatment of greywater—a review. Environmental Science and Pollution Research, 20(5), 2795-2809.

Ghaitidak, D. M., & Yadav, K. D. (2015). Effect of coagulant in greywater treatment for reuse: selection of optimal coagulation condition using analytic hierarchy process. Desalination and Water Treatment, 55(4), 913-925.

Ghaitidak, D. M., & Yadav, K. D. (2016). Greywater treatment for reuse: comparison of reuse options using analytic hierarchy process. Journal of Water Reuse and Desalination, 6(1), 108-124.

Gössling, S., Peeters, P., Hall, C. M., Ceron, J. P., Dubois, G., & Scott, D. (2012). Tourism and water use: Supply, demand, and security. An international review. Tourism management, 33(1), 1-15.

Government of Western Australia, Guidelines for the Non-Potable Uses of Recycled Water in Western Australia, Department of Health, Australia, p-99, 2011.

Gross A (2008) Reliability of small scale greywater treatment systems and the impact of its effluent on soil properties. Int J Environ Stud 65(1):41–50

Hoekstra, A. Y., Buurman, J., & van Ginkel, K. C. (2018). Urban water security: A review. Environmental Research Letters, 13(5), 053002.

James, D. T. K., Surendran, S., Ifelebuegu, A. O., Ganjian, E., & Kinuthia, J. (2016). Grey water reclamation for urban non-potable reuse–challenges and solutions: a review. In Proceeding 7th International Conference on Sustainable Built Environment At: Sri Lanka (Kandy).

Jamrah A, Al Omari A, Al Qasem L, Abdel Ghani N (2011) Assessment of availability and characteristics of greywater in Amman. Water Int 31(2):210–220

Jongwanich, J. (2007). Workers' remittances, economic growth and poverty in developing Asia and the Pacific countries. United Nations Publications.

Jokerst, A., Sharvelle, S. E., Hollowed, M. E., & Roesner, L. A. (2011). Seasonal performance of an outdoor constructed wetland for graywater treatment in a temperate climate. Water Environment Research, 83(12), 2187-2198.

Jefferson, B., Laine, A., Parsons, S., Stephenson, T., & Judd, S. (2000). Technologies for domestic wastewater recycling. Urban water, 1(4), 285-292.

Jefferson, B., Palmer, A., Jeffrey, P., Stuetz, R., & Judd, S. (2004). Grey water characterisation and its impact on the selection and operation of technologies for urban reuse. Water science and technology, 50(2), 157-164.

Kadlec, R. H., & Wallace, S. (2008). Treatment wetlands. CRC press.

Keshavarzi, A. R., Sharifzadeh, M., Haghighi, A. K., Amin, S., Keshtkar, S., & Bamdad, A. (2006). Rural domestic water consumption behavior: A case study in Ramjerd area, Fars province, IR Iran. Water research, 40(6), 1173-1178.

Kugelman, M. (2018). Water scarcity.

Khong, C. M. (2009). Perception and use of graywater in Berkeley, California.

Krishnan, V., Ahmad, D., & Jeru, J. B. (2008). Influence of COD: N: P ratio on dark greywater treatment using a sequencing batch reactor. Journal of Chemical Technology & Biotechnology: International Research in Process, Environmental & Clean Technology, 83(5), 756-762.

Kumar, P. S., & Pavithra, K. G. (2019). Environmental Footprints of Water—Concepts, Tools, Importance and Challenges. In Environmental Water Footprints (pp. 1-20). Springer, Singapore.

Leal, L. H., Temmink, H., Zeeman, G., & Buisman, C. J. N. (2011). Characterization and anaerobic biodegradability of grey water. *Desalination*, *270*(1-3), 111-115.

Li, F., Wichmann, K., & Otterpohl, R. (2009). Review of the technological approaches for grey water treatment and reuses. Science of the total environment, 407(11), 3439-3449.

Liu, J., Yang, H., Gosling, S. N., Kummu, M., Flörke, M., Pfister, S., ... & Alcamo, J. (2017). Water scarcity assessments in the past, present, and future. Earth's future, 5(6), 545-559.

Maraqa, M. A., & Ghoudi, K. (2015). Public Perception of Water Conservation, Reclamation and Greywater Use in the United Arab Emirates. International Proceedings of Chemical, Biological and Environmental Engineering, 91, 24-30.

Mayer, P. W., DeOreo, W. B., Opitz, E. M., Kiefer, J. C., Davis, W. Y., Dziegielewski, B., & Nelson, J. O. (1999). Residential end uses of water.

Mekonnen, M. M., & Hoekstra, A. Y. (2016). Four billion people facing severe water scarcity. Science advances, 2(2), e1500323.

Merz, C., Scheumann, R., El Hamouri, B., & Kraume, M. (2007). Membrane bioreactor technology for the treatment of greywater from a sports and leisure club. Desalination, 215(1-3), 37-43.

Mourad, K. A., Berndtsson, J. C., & Berndtsson, R. (2011). Potential fresh water saving using greywater in toilet flushing in Syria. Journal of environmental management, 92(10), 2447-2453.

Noah, M. (2002). Graywater use still a gray area. Journal of environmental health, 64(10), 22.

Oh, K. S., Leong, J. Y. C., Poh, P. E., Chong, M. N., & Von Lau, E. (2018). A review of greywater recycling related issues: Challenges and future prospects in Malaysia. Journal of Cleaner Production, 171, 17-29.

Ottoson, J., & Stenström, T. A. (2003). Faecal contamination of greywater and associated microbial risks. Water research, 37(3), 645-655.

Pathan, A. A., Mahar, R. B., & Ansari, K. (2011). Preliminary study of greywater treatment through rotating biological contactor. Mehran University Research Journal of Engineering & Technology, 30(3), 531-538.

Pidou, M., Avery, L., Stephenson, T., Jeffrey, P., Parsons, S. A., Liu, S., ... & Jefferson, B. (2008). Chemical solutions for greywater recycling. Chemosphere, 71(1), 147-155.

Pidou, M., Memon, F. A., Stephenson, T., Jefferson, B., & Jeffrey, P. (2007). Greywater recycling: a review of treatment options and applications.

Rahut, D. B., Ali, A., Imtiaz, M., Mottaleb, K. A., & Erenstein, O. (2016). Impact of irrigation water scarcity on rural household food security and income in Pakistan. Water Science and Technology: Water Supply, 16(3), 675-683.

Rijsberman, F. R. (2006). Water scarcity: fact or fiction? Agricultural water management, 80(1-3), 5-22.

Saqib, Z., Fayyaz, S., Aftab, R., Ghani, U., Anwar, R., Qasim, M., & Khalid, M. (2018). Evaluating Future Water; Climate Change and Urbanization in Gujrat. GSJ, 6(9).

Savenije, H. H. (2000). Water scarcity indicators; the deception of the numbers. Physics and Chemistry of the Earth, Part B: Hydrology, Oceans and Atmosphere, 25(3), 199-204.

Soomro, M., Khokhar, M., Hussain, W., & Hussain, M. (2011). Drinking water Quality challenges in Pakistan. Pakistan Council of Research in Water Resources, Lahore, 17-28.

Sushmitha, M. B., Chanakya, H. N., & Khuntia, H. K. (2019). Efficient Grey Water Treatment and Reuse Options for India—A Review. In Waste Water Recycling and Management (pp. 143-149). Springer, Singapore.

Ukpong, E. C., & Agunwamba, J. C. (2012). Grey water reuse for irrigation. Int. J. Appl. Sci. Technol, 2(8).

United Nations (UN) (2012) The global water crisis. http://www. un.org/works/sub2.asp?lang=en&s=19. Accessed 23 September 2012

Washington State Department of Health (2009) Reuse of greywater outside the building for subsurface dispersal and irrigation. www.doh.wa.gov/Portals/1/Documents/Pubs/337-108.pdf. Accessed 19 September 2012

Wilcox, J., Nasiri, F., Bell, S., & Rahaman, M. S. (2016). Urban water reuse: A triple bottom line assessment framework and review. Sustainable cities and society, 27, 448-456.

World Economic Forum, Global Risks 2015, 10th Edition (World Economic Forum, Geneva, Switzerland, 2015)

World Health Organization (WHO). (2004). Minimum water quantity needed for domestic uses. WHO Regional Office for South-east Asia: New Dehli.

World Health Organization (2006) WHO Guidelines for the safe use of wastewater, excreta and greywater. Volume 4, excreta and greywater use in agriculture. http://www.who.int/water_sanitation_ health/wastewater/gsuweg4/en/index.html. Accessed 28 September 2012

World Health Organization (2006) WHO Guidelines for the safe use of wastewater, excreta and greywater. Volume 4, excreta and greywater use in agriculture. http://www.who.int/water_sanitation_ health/wastewater/gsuweg4/en/index.html.

Zhu, J., Wagner, M., Cornel, P., Chen, H. and Dai, X. (2016). Feasibility of on-site greywater reuse for toilet flushing in China. Journal of Water Reuse and Desalination, 8(1), pp.1-13.

Zhu, J., Wagner, M., Cornel, P., Chen, H., & Dai, X. (2018). Feasibility of on-site grey-water reuse for toilet flushing in China. Journal of Water Reuse and Desalination, 8(1), 1-13.