PROSPECT OF IN-HOUSE RECYCLING OF GRAY WATER

ABU SALEH MOHAMMAD WAHEDUL HAQUE

DEPARTMENT OF CIVIL ENGINEERING

**BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY.
DHAKA.**

PROSPECT OF IN-HOUSE RECYCLING OF GRAY WATER

BY
ABU SALEH MOHAMMAD WAHEDUL HAQUE

DEPARTMENT OF CIVIL ENGINEERING
BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY,
DHAKA.

DECEMBER 2010

PROSPECT OF IN-HOUSE RECYCLING OF GRAY WATER

BY
ABU SALEH MOHAMMAD WAHEDUL HAQUE

A thesis submitted to the Department of Civil Engineering of Bangladesh University of Engineering and Technology, Dhaka, in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN CIVIL ENGINEERING (ENVIRONMENTAL)

DECEMBER 2010

The thesis titled PROSPECT OF IN-HOUSE RECYCLING OF GRAY WATER Submitted by ABU SALEH MOHAMMAD WAHEDUL HAQUE Roll No.: 040304503 (P) Session APRIL-03 has been accepted as satisfactory in partial fulfillment of the requirement for the degree of M.Sc. in Civil and Environmental Engineering.

BOARD OF EXAMINERS

Dr. Md. Abdul Jalil Professor Dept of Civil Engineering, BUET Dhaka-1000.	Chairman (Supervisor)
Dr. Md. Zoynul Abedin Professor & Head Dept of Civil Engineering, BUET Dhaka-1000.	Member (Ex-officio)
Dr. M Ashraf Ali Professor Dept of Civil Engineering, BUET Dhaka-1000.	Member
Mr. Shamsul Gafur Mahmud National Professional Officer World Health Organization DPHE Bhavan, Kakrail, Dhaka-1000.	Member (External)

December 2010

DECLARATION

It is hereby declared that this thesis or any part of it has been submitted elsewhere for the award of any degree or diploma.

December 2010 **Abu Saleh Mohammad Wahedul Haque**

ACKNOWLEDGEMENT

The author first acknowledges the blessing of Almighty Allah, the Beneficent, and the Merciful for enabling him to complete this thesis successfully.

Secondly the author expresses his deepest and sincere gratitude and profound indebtness to his supervisor Dr. M. A. Jalil Professor, Department of Civil Engineering, BUET, for his constant supervision, continuous guidance, encouragement and valuable suggestion at every stage of work.

The author is very grateful to all laboratory staff of Enviromental Engineering Laboratory, BUET, Department of Civil Engineering, for their assistance during the performance of the laboratory works and thanks to the staff of library of BUET, for providing facility in using the library.

The author also wishes to convey honest gratefulness to S. K. Amzad Hossan (Project Director), Hasan Kabir Khasru and Md. Shafiqur Rahman (Deputy Project Director), and all the staff of STIFPP-2 Project LGED, for there help and support during the thesis work.

The author acknowledges the sacrifice of his family that has enabled him to attain this level. Heartfelt gratefulness extended to his Late mother Saleha Hoque and father Md. Tafazzal Hoque for his continuous encouragement at every phase of this study. Special thanks to Abu Saleh Mohammad Shahidul Haque, Khairunnahar Ruby, Nilufa Parvin, Taslima Akhter, Farida Akhter, Tahmina Akhter, Sabira Tanjir Tanha, Allah Hafiz, Abu Md Shahriar, Shahriar Mahmud Pavel for their invaluable contribution, spirited encouragement in his thesis work.

Abstract

This thesis explored present Dhaka city's situation in order to define the main factors surrounding gray water reuse in urban areas. Suitable treatment technologies that best address the defined gray water reuse factors were identified and clear, standardized and sustainable gray water reuse processes for their application were also established. The major objective of this study was to evaluate the viability of domestic reuse of gray water in Dhaka city for laundry and toilet flushing. The quantification of water uses for different domestic purposes was done mainly by questionnaire survey and by direct measurement in some cases. From the surveys the amount of gray water produced from households has been calculated. The quality of gray water generated from laundry, showers and basins was determined by laboratory analyses of representative samples. Turbidity, suspended solids, BOD, COD and Fecal Coliform (FC) of the collected samples were determined following standard procedure. The viability of reusing untreated gray water for toilet flushing was also evaluated. The treatment requirement of the gray water for in-house recycling for laundry and toilet flushing was determined by comparing its quality with the reuse criteria. A simple gray water treatment system for in-house recycling for laundry and toilet flushing was developed and its performance was tested. For quantification, the questionnaire survey was done on 100 families in different parts of Dhaka city. The average per capita water requirement was estimated at 150 l/day and the average of per capita gray water production was estimated at approximately 95 l/day. The average BOD_5 values are 204, 65, 133, 108 and 13 mg/l; the average COD values are 270, 106, 200, 174 and 33 mg/l; the average turbidity values are 200, 98, 135, 86 and 1.5 NTU; the average FC values calculated are 3440, 2350, 2800, 2920 and 180 cfu/100 ml; the average S.S values calculated are 1296, 737, 978, 672 and 17 mg/l for black laundry water, mix laundry water, bath water, basin water and raw water respectively. The quality of gray water with respect to BOD, COD, Turbidity, S.S and F.C indicated that they are very high. But the results varied depending on methods used for washing, people's choices of soap/detergent/shampoo use, the quantity of soap/detergent/ shampoo used, the time taken for washing or bathing, availability of water and amount of water used. The test results of tap water indicated that the fecal coliform content is very high and thus the quality of DWASA's supply water is very low. A treatment system that is acceptable to urban residents requires the storage of gray water and then simple treatment by disinfection, coagulation, flocculation, settling and sand filtration. The settling time is 30 minutes, optimum coagulant dose is determined 30 mg/l and optimum chlorine dose is determined 3mg/l.

A simple bench scale treatment setup was established. Locally available materials were used to construct the experimental setup and it is very easy to use in household environment. The quality of the treated water sample has been compared with standards and criteria guidelines.

This study is targeted towards the building dwellers of Dhaka city having medium income status. This study is only a small step in forming a gray water management system. More studies considering technical feasibility, public health, social acceptability and sustainability should be undertaken. Skill and knowledge are the main concern for the installation and maintenance of gray water treatment systems. The long-term and broad implications of urban gray water systems are not yet fully understood and paramount to its acceptance is the protection of human health as well as community education and participation in community decision processes.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter-1

INTRODUCTION

1.1 Background

Rapid population growth in urban centers is creating enormous pressure on their water supplies in the context of the scarcity of suitable freshwater resources and the ever-increasing costs of the water supply systems. The problem is acute for Dhaka city.

Water supply problem in some newly developed areas and some areas of the old city is becoming more acute, because the existing facility of DWASA can not keep pace with the growing demand for safe water supply. Both quantity of water produced and water distribution facility are inadequate to serve the present population of the city. The magnitude of the problem is greater during the extreme dry and hot season. Most of the consumers do not get the required quantity of water.

The daily water demand for the city of about 9 million people is 165 crore liter at present and will rise up to about 2.5 times by 2030 (IWM, 2007). DWASA demands that it produces 144 crore liter daily (WASA, 2005). Currently, the physical leakage in the water distribution system stands between 30-40% (IWM, 2007). The water demand at the drought season grows roughly by 25%. Then the shortage becomes about 100-120 crore liter daily. In the last 5 years, DWASA has managed to increase the daily production by 3.5 crore by installing some deep tubewells. Due to poor recharge of the aquifers of the city, heavy abstraction of the groundwater is causing continuous declination at an alarming rate. As a result many deep tubewells have become non-functional. DWASA is planning to augment the water supply by implementing the second phase of Saidabad Surface Water Treatment Plant and by establishing well fields outside the metropolitan area. Even after implementation of these programs, water crisis will continue.

It has been reported that the daily gray water production from baths, showers, wash basins and washing machines is about 56% of the total wastewater produced from indoor uses (Almeida et al., 1999). Under the above circumstance, less polluted gray water (wastewater from showers, basins and laundry) recycling in the individual household will certainly reduce the pressure on the high-quality water supplies as it is readily available throughout the year and lower grade of water can be used for laundry and toilet flushing.

Many state governments of the world have already enacted their own interim legislation and issued guidelines for gray water reuse in urban areas in response to public opinion and their own rapidly depleting water sources (Surendran & Wheatley, 1998). There is a general consensus from regulatory authorities that gray water reuse guidelines must continue to protect human health, as per the traditional guiding design philosophy for traditional centralized wastewater collection and treatment systems. Identifying the likely effects and consequences of urban gray water reuse guides the process of determining the most suitable technologies for gray water treatment. The most effective and efficient treatment systems identified then help to define and implement clear, standardized and sustainable processes for gray water reuse. Current guidelines and policy frameworks now reflect another evolutionary change through the inclusion of water recycling standards in urban areas, of which gray water reuse systems can play an important role (Radcliffe, 2003).

1.2 Justification of the Study

At present no effective gray water treatment, recycle, reuse and management system is available in Bangladesh. The selected study areas mainly constitute middle income families of Dhaka City. No survey work has been done to determine domestic gray water generation rates, its composition for any urban areas of Bangladesh. In the drought season or when the water supply is acute some families reuse the general gray water produced from laundry for toilet flushing and some normally pour the laundry gray water in the garden to reuse. But most people neither reuse gray water for any purpose nor have any idea that it can be reused. Some people just do not like reusing gray water for aesthetic reasons.

This study and analysis can establish some important basic data, which will enable one to design a cost –effective and socially acceptable future gray water management system. The domestic gray water generation rate, total volume of gray water, characteristics of gray water, treatment requirement, resource recovery and recycling possibilities data will be determined.

The technologies that best address the factors that effect gray water reuse must primarily consider the biological characteristics of gray water (Al-Jayyousi, 2003) in order to ameliorate public health concerns. The level of treatment provided by gray water reuse technologies will further vary according to the system's scale and reuse applications. Treatment technologies can be best described in either user-based or technology-based terms.

The technology utilised in gray water reuse systems can be differentiated into primary, secondary and tertiary levels (Jeppesen, 1994). These can then be further characterised in terms of the number of users the gray water reuse system must support (user-defined) and by their likely reuse applications.

Most of these technologies require considerable infrastructure and understanding to operate. As most of the urban populations of Bangladesh obtain their water from WASA/City Corporation/Pourasha, it is therefore necessary to develop a low-cost simple technology that can be implemented on household levels to recycle and reuse gray water, not for drinking or other necessary purposes but for household cleaning works i.e. mainly for toilet flushing and gardening or irrigation.

Relative to wastewater gray water which is predominantly from bathroom and laundry sources is high in dissolved solids (mostly salts) and turbidity, low in nutrients and is likely to contain significant amounts of pathogens (Al-Jayyousi, 2003). The suspended solids that are present are mostly in the form of hair and lint from bath and laundry waste (Jeppesen, 1996). If gray water is sourced from kitchen wastewater it is likely to have a high BOD, high in organic suspended solids and nutrients with low pH (Jeppesen, 1996). The reuse of gray water from bathroom and laundry sources can be relatively simple for garden watering reuse applications up to sophisticated treatments for toilet flushing and laundry applications. However, treatment for kitchen wastewater will generally require more sophisticated technologies and processes to address the high BOD and fatty solids generated (Al-Jayyousi, 2003). In order to primarily address the likelihood of high pathogen contamination and hence public health concerns, gray water must either be disinfected or disposed of in a manner that does not allow human contact (Jeppesen, 1996). For gray water reuse applications where disposal only involves garden watering, sub-surface irrigation systems would remove the possibility of human contact and therefore reduce the level of treatment required (CSIRO, 2004). However, if gray water reuse involved toilet flushing and/ or laundry water applications disinfection would be required as there is a possibility for human contact (Jefferson, 1998).

Finally, all gray water reuse systems must be connected to the centralised sewer collection system as a precaution. If the gray water reuse system malfunctions or if maintenance is to be carried, the system must be capable of being manually or automatically diverted to the sewer line. This would avoid an unlikely event where the gray water is not collected and disposed off which would increase the risk of human contact and threaten public health.

However, there is still a need to develop design and operating criteria for an effective field deployable household/community level treatment and delivery system. Various factors such as gray water quality, volume, generation rate, treatment procedure, recycle and reuse processes, disposal method and finally people's perception and acceptance influence gray water management system. Knowledge on the effects of these factors on gray water management system needs to be studied to develop design and operating criteria for an effective treatment system for use at community and household levels.

1.3 Objectives of the Study

The major objective of this study is to evaluate the viability of domestic reuse of gray water in Dhaka city for laundry and toilet flushing.

The specific objectives of this study are as follows:

- To quantify the classified uses of the supplied water in residential houses.
- To determine the quality of the gray water generated from showers, laundry and basins.
- To evaluate the prospect of reusing untreated gray water for toilet flushing.
- To develop and test a simple gray water treatment system for in-house recycling for laundry and toilet flushing.

1.4 Methodology

A brief description of the procedures followed in order to achieve the above-mentioned objectives of the research is outlined below.

- The quantification of water uses for different domestic purposes was done mainly by questionnaire survey and by direct measurement in some cases.
- The quality of gray water generated from laundry, showers and basins was determined by laboratory analyses of representative samples. Turbidity, suspended solids, BOD, COD, Total Coliform (TC) and Fecal Coliform (FC) of the collected samples were determined following standard procedure.
- The possibility of reusing the untreated gray water generated from laundry for toilet flushing was evaluated considering the quantity and quality of the gray water.
- The treatment requirement of the gray water for in-house recycling for laundry and toilet flushing was determined by comparing its quality with the reuse criteria.
- A simple system for the gray water treatment was proposed based on the treatment requirement of the gray water. Then a small scale treatment plant was installed in Environmental Engineering Laboratory of Civil Engineering Department, BUET and it was operated to evaluate its performance.

1.5 Organization of the Thesis

This thesis presents literature review, data collection method, data analysis and findings of study in six chapters with appendixes. In addition a bibliography of related publications has been presented. A brief description of the chapters is given below.

Chapter 1. Introduction: This chapter explains the background and present state of the problem, justification of the study, objectives and methodology of the study.

Chapter 2. Literature Review: The topics discussed in this chapter are the existing situation of gray water reuse in the world, gray water characteristics, gray water quality, gray water treatment and reuse processes and factors affecting gray water reuse.

Chapter 3. Quantification of Gray Water: In this chapter the methodology for quantifying the water use for different purposes in residential building are described and peoples perception towards gray water reuse is also evaluated.

Chapter 4. Characterization of Gray Water: This chapter presents the quality of different types of gray water determined by laboratory analysis and results are discussed in detail.

Chapter 5. Treatment of Gray Water: This chapter describes the treatment procedure and the simple system used for the treatment of domestic gray water. The quality of the treated water is compared with the original samples.

Chapter 6. Conclusions and Recommendations: This chapter contains the major conclusions of the study and provides a number of recommendations for future study.

<u>**Chapter-2**</u>

LITERATURE REVIEW

2.1 Introduction

Gray water (wastewater from showers, basins, laundry, and possibly kitchen) can be effectively and efficiently recycled for non-potable reuse applications such as industrial, irrigation, toilet flushing and laundry washing depending on the technologies utilized in the treatment process. Gray water recycling offers reductions in urban potable water demand up to 30% - 70% (Radcliffe, 2003).

Gray water reuse offers indirect benefits to public infrastructure in the form of reduced sewage flows, reduced treatment plant size, shorter distribution systems, reduced potable water demand and can help to prolong the need for additional potable water sources. Also, the economic benefits of gray water recycling in relation to potable water savings are obscured by current non-transparent and subsidized pricing mechanisms (Radcliffe, 2003).

Many country & state governments have already enacted their own interim legislation and issued guidelines for gray water reuse in urban areas in response to public opinion and their own rapidly depleting water storages. There is a general consensus from regulatory authorities that gray water reuse guidelines must continue to protect human health, as per the traditional guiding design philosophy for traditional centralized wastewater collection and treatment systems. Identifying the likely effects and consequences of urban gray water reuse, guide the process of determining the most suitable treatment technologies. The most effective and efficient treatment systems identified then help to define and implement clear, standardized and sustainable processes for gray water reuse.

Economic factors are important for implementing gray water reuse systems however, the social and environmental costs are also very important as the current water shortages in many capital cities are alarming. The likely consequences from indirect social and environmental costs of gray water reuse as well as externalities are mostly identifiable, but largely unquantifiable at this stage, especially in economic terms. As a result any cost benefit analysis for gray water reuse systems is relatively incomplete. However there is consensus that any realization of these costs would generally favor the economic case for gray water reuse in urban areas (Jefferson, 1998).

Gray water is characterized as a dilute form of wastewater and makes up 68% of the total domestic wastewater (Emmerson, 1998). It is distinguished from black water by having high inorganic loads, low nutrients with low pathogenic bacterial contamination, lighter gray color and has a sweeter smell (Al-Jayyousi, 2003). Gray water quality is highly variable depending on the household's social preferences (Al-Jayyousi, 2003). The comparison of gray water with waste water quality indicates a relatively low contamination of gray water (Beavers, 1995) and therefore lower treatment requirements. Additionally, the relatively high proportion of gray water generated shows a large potential source for water savings by reuse systems.

2.2 Existing Water Crisis of Dhaka City

The population of Dhaka city is growing rapidly. According to DWASA the population of Dhaka city was 8.5 lac in 1963 (WASA, 2005) and at 2005 it was 121.5 lac. This growing population implies increasing demands for basic city services - the most important one being the demand for a safe and reliable water supply. Currently this growing demand is being met primarily by pumping water from the local aquifers. However, the groundwater reserve is rapidly declining and the progress in tapping surface water sources has been very slow. In other words, the looming threat of a serious water crisis in the city is becoming a real one with each passing day.

Water supply problems in some newly developed areas and some areas of the old city are becoming more acute, because the existing facilities of DWASA can not keep pace with the growing demand for safe water supply. Both quantity of water produced and water distribution facility are inadequate to serve the present population of the city. The magnitude of the problem is greater during the extreme dry and hot season. Most of the consumers do not get the required quantity of water.

At the start of the hot and dry season there is water crisis in many areas of the capital Dhaka. By a recent statistics of WASA the daily water shortage is 50Cr liter (DWASA, 2005), but for this they accuse the irregular electricity supply. Due to the fact that DWASA's water supply is not up to the demand, many buildings in Dhaka have a water pump tapped in the street water main and at the time of water crisis they use this pump to fill their underground water reservoir to get water to meet their need.

At one hand there is insufficient water supply, on the other hand the supplied water is dirty and polluted at many areas. The people there are using this water unwillingly. This causes serious health hazard for the residents. People in these areas are suffering from skin and waterborne diseases.

Dhaka WASA is trying there best to meet the growing demand, fighting with old pipe networks and wastage of supplied water through leakage in the system. DWASA is abstracting water by 426 deep tube wells. The position of 18 wells is deeper. Load shedding and low voltage of electricity does not permit the pumps to work to their proper capacity.

The water demand is rapidly increasing and the productions of the existing wells are decreasing with the lowering water level. In the coming years the demand will surpass the production greatly. To abate this government doesn't have any realistic plans. Without establishing a few deep tube wells there are no other big steps taken in the last five years.

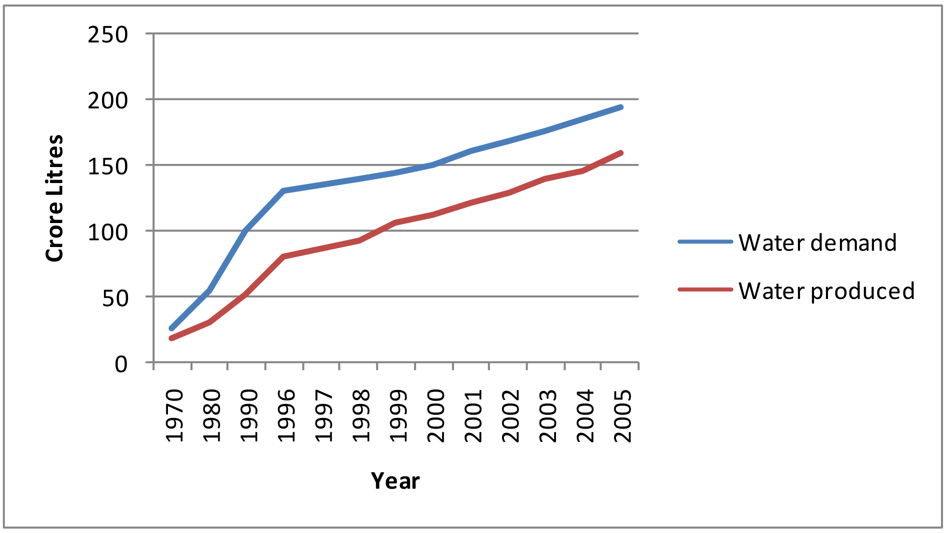


Figure 2.1: Graphical representation of DWASAs daily water demand water production in crore liters.(WASA, 2005)

The daily water demand for the city of about 9 million people is 165 crore liter at present and will rise up to about 2.5 times by 2030 (IWM, 2007). DWASA demands that it produces 144 crore liter daily (WASA, 2005). Currently, the physical leakage in the water distribution system stands between 30-40% (IWM, 2007). The water demand at the drought season grows roughly by 25%. Then the shortage becomes about 100-120 crore liter daily. Besides this the water demand is increasing by 5% to 6% with the growing population every year. In the last 5 years, DWASA has managed to increase the daily production by 3.5 crore liter by installing some deep tubewells. Due to poor recharge of the aquifers of the city, heavy abstraction of the groundwater is causing continuous declination at an alarming rate. As a result many deep tubewells have become non-functional. DWASA is planning to augment the water supply by implementing the second phase of Saidabad Surface Water Treatment Plant and by establishing well fields outside the metropolitan area. Even after implementation of these programs, water crisis will continue.

2.3 Existing Situation of Gray Water Reuse in the World

The main applications for gray water reuse are garden and park irrigation (external uses) as well as toilet flushing and laundry (internal uses). Household gray water systems that reuse gray water for toilet flushing and/ or laundry water must utilize a treatment process that includes coarse suspended solid removal, turbidity reduction and disinfection (Al-Jayyousi, 2003). Gray water reuse has been practiced in rural areas where there are no centralized sewerage systems for many decades in Australia and overseas. The systems used were usually simple crude designs used to irrigate the landscape (Jeppesen, 1996). Gray water reuse systems in urban areas have been used under the regulation of plumbing codes in the United States of America since the 1990's. This was in response to abating severe future water shortages in areas such as California and Florida (Jeppesen, 1996) and they are in similar circumstances under which Australia is now legalizing gray water reuse in urban areas. Likewise in Japan, but more in response to the increased rates of urbanization and population growth, gray water reuse systems have been in use for multi-dwelling buildings since 1990's. The promotion of wastewater reuse at policy level and establishment of technical guidelines marks a change in the traditional view of wastewater as being a waste and consequently is now being recognized as a resource and a source of opportunity (Radcliffe, 2003).

Indeed wastewater is now noted as the only water resource that increases with urban development and planning and design principles are beginning to embrace this as a sustainable resource to reduce the ecological footprint of urban development (Gardner, 2003). Many authorities have included gray water reuse systems into overall water and resource planning strategies such as Water Sensitive Urban Design (WSUD) which is an integral part of overall urban design and new development planning (Melbourne Water, 2004). Under WSUD, gray water reuse systems are investigated at the on-site and neighborhood unit levels and are seen as a tool for conserving water use along with pollution control systems that include landscape design and storm water reuse i.e. rainwater tanks (Melbourne Water, 2004). At the neighborhood unit level, gray water can be collected via a storm water drainage system, treated and re-distributed back to neighborhood homes for garden water use. These systems are called Third Pipe systems.

Gray water comprises between 68% of total household wastewater on average (Emmerson, 1998) and presents the largest potential source of water savings in domestic residences. Most of the gray water systems proposed in urban areas are closed-loop processes. That is, gray water is managed and reused in a decentralised way within a household, neighbourhood or community (Al-Jayyousi, 2003). Gray water systems are assessed in terms of technical feasibility, public health, social acceptability and sustainability and these are reflected in Government policy and guidelines. These criteria can be further contextualised into an environmental framework of social, political and environmental factors.

Gray water has a constant supply and its reuse can provide water saving opportunities that could lead to postponement of traditional planning techniques such as building new dams and catchment diversion projects (Gardner, 2003). Gray water reuse at individual, neighbourhood and community scales offers simpler and more cost effective solutions (Ludwig, 1999) for Government water saving initiatives as they strive for policies that encourage more sustainable use of resources. Whilst there are no reported cases of human illness or disease directly attributable to gray water reuse (Emmerson, 1998), the limited studies investigating the levels of micro-biological contamination of gray water indicates the potential for human infection is high. Also, the traditional centralised sewer collection and treatment system that is currently used was successfully designed to protect human health. On-site reuse of gray water marks a departure from this centralised health-driven system and so attracts legitimate public concern. Additionally, the sensitive public health concerns over gray water reuse systems make them vulnerable to wider and more negative publicity caused from any specific health-related accidents (Radcliffe, 2003). However, no such incidents have been reported to date (Emmerson, 1998).

There is a higher acceptance for non-potable reuse applications for wastewater (Radcliffe, 2003) and studies in the USA indicate greater acceptance as the degree of human contact decreases (Marks, 2004). Also, these studies indicated that when options for reuse are evaluated by the community, the most important factors in order of priority are;

• Human health,

• The environment,

• Conservation,

• Treatment costs, and

• Distribution costs (mainly for third pipe systems). (Marks, 2004)

Decentralisation of the traditional wastewater collection and separate disposal system is caused by using on-site gray water treatment systems in urban areas. As a result, reusing gray water within the same space as it is generated highlights the environmental consequences of user's social habits directly (Al-Jayyousi, 2003). Government gray water reuse guidelines also highlight and reinforce these precautions. Therefore users must scrutinise the environmental effects of the products and chemicals that they use as they become more environmentally aware and responsible for their actions. This could have a flow-on effect to manufacturers and businesses as consumer habits begin to change.

However, if gray water is used to substitute garden irrigation it is debatable whether it will actually reduce overall water consumption habits. There are no studies to investigate this area at present. The reduction in potable water demand generally would contribute to postponing the requirement for developing new water sources (Hunter, 2004). This is usually quantified in terms of extending the time by which future new developments can be undertaken without an increase in public water source and headworks infrastructure. Also, although the costs of the technologies associated with gray water reuse systems have reduced considerably, further cost savings may be realised in reduced or postponed public infrastructure and if the true cost of potable water supply is realised (PWC, 2000).

Gray water is generally generated from domestic activities such as cooking, bathing, doing the laundry and house cleaning. In low-income peri-urban communities especially, existing practices consist of the unsafe disposal of gray water onto the ground in their premises. The resulting surface ponds and gray water run-off often add to an inefficient solid waste management system to endanger health or to create environmental hazards (Salukazana et al., 2006).

2.4 Gray Water Characteristics

2.4.1 What is Gray Water?

Domestic wastewater consists of black water and gray water as shown in Figure 2.2 below.

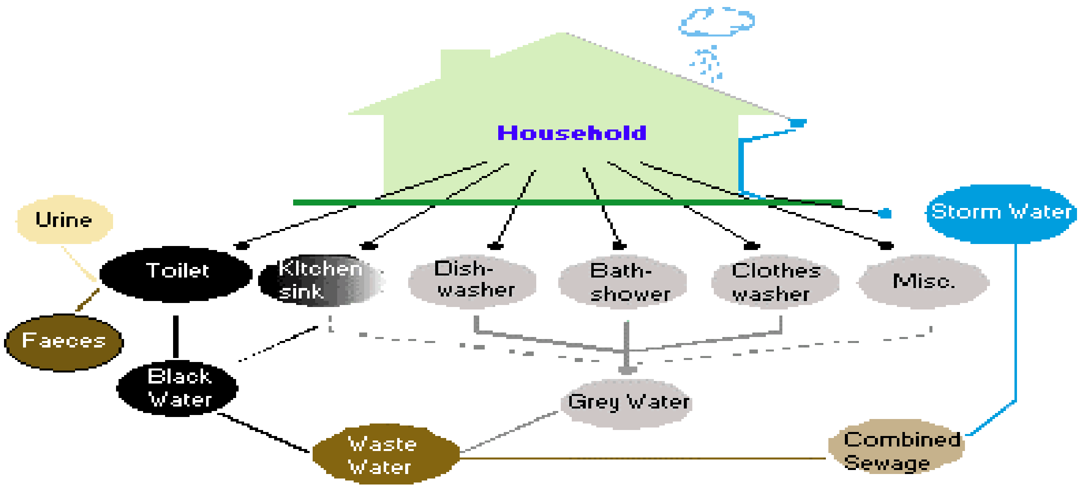


Figure 2.2: Constituent parts of wastewater (UNEP, 2000)

Blackwater describes the sewage toilet waste and this form of wastewater is collected via the sewer drain connection in urban areas and treated at centralised wastewater treatment plants. Black water is characterised by having a very high pathogenic bacterial contamination, high organic loads and nutrients, dark in colour and foul smelling (Al-Jayyousi, 2003).

Gray water consists of other domestic sources such as the laundry and laundry sink, bath and shower wastewater. The kitchen sink and dishwasher wastewater should strictly be included with gray water; however this form of gray water usually contains relatively higher organic nutrients and higher BOD loadings (Al-Jayyousi, 2003). This in turn significantly increases the treatment requirements of gray water reuse systems.

Gray water is characterised as a dilute form of wastewater and makes up 68% of the total domestic wastewater (Emmerson, 1998). It is distinguished from blackwater by having high inorganic loads, low nutrients with low pathogenic bacterial contamination, lighter gray colour and has a sweeter smell (Al-Jayyousi, 2003). Gray water quality is highly variable depending on the household's social preferences (Al-Jayyousi, 2003).

2.4.2 Gray water Quality

Gray water quality is usually governed by the use of soap or soap products with water for body and laundry washing. The quality and quantity of these contaminants are highly variable and depend on the user's social and product preferences, geographical location, demographics and level of occupancy of the dwelling (Al-Jayyousi, 2003).

The organic concentration of gray water is similar to wastewater; however their chemical nature is different. Also gray water is relatively low in suspended solids indicating that the contaminants are predominantly dissolved (Al-Jayyousi, 2003).

2.4.2.1 Microbial Quality

The presence of potentially harmful micro-organisms is indicated by measuring for the faecal coliform group and more specifically E. Coli bacteria. These micro-organisms indicate the presence of intestinal pathogens such as Salmonella or enteric viruses and are used as a pollution indicator or safety factor (Emmerson, 1998 p13).

A high E. Coli count in a gray water sample indicates that there is a greater chance of developing human illness from contact with gray water. However, a low E. Coli count does not imply that there are no harmful micro-organisms present. E. Coli is used as an indicator micro-organism only and other harmful micro-organisms may still be present but not measured. They include other bacteria, viruses, protozoa and Helminths (parasitic worms).

In specific studies of household gray water quality, shower water has faecal coliform counts as high as 6000 colony forming units (cfu) per 100mL (Rose et al. 1991) and bathroom water generally was found to contain up to 3300 most probable number (MPN) cfu's (Christova-Boal et al. 1995).

2.4.2.2 Chemical Quality

The COD: BOD ratio of gray water may be as high as 4:1, which is higher than wastewater and is due to the low macro-nutrient (phosphorous and nitrogen) levels. To further reinforce this the COD:NH_3:P ratio for gray water has been measured at 1030: 2.7: 1 compared with 100: 5: 1 for wastewater, which also indicates relatively low values of biodegradable organic matter in gray water (Jefferson et al. 1999).

2.4.2.3 Physical Quality

The likelihood of high COD: BOD ratios in gray water along with the predominant use of soaps and detergents in bath and laundry indicate a high concentration of dissolved solids such as salts. Most of these will not be removed from gray water before reuse unless treated to a relatively high standard.

Although low in suspended solids, hair and lint are common suspended solids in gray water that is collected from laundry and bathroom sources and can potentially foul treatment processes.

The use of mostly alkaline soaps and detergents can also greatly affect the pH of gray water. The diversity of the products used varies the impact on pH and this also depends on the social choices of the household. Similar to addressing the level of dissolved solids, the high pH cannot be corrected without acid treatment. Therefore gray water is generally discharged to the garden or park without treatment and the soil treats the gray water.

Although the quality of gray water is highly variable, the possibility of significant microbial contamination ensures that gray water reuse systems must strive to avoid, minimise or abate human contact.

The generally low nutrient loads will limit biological treatment solutions (especially for small systems) and the high dissolved solids content will require closer scrutiny of their effect within the treatment process and on the soils and environment upon which gray water is discharged (Al-Jayyousi, 2003). Suspended solids such as hair and lint pose problems for gray water reuse systems involving pumps and drip irrigation systems and must be filtered (Ludwig, 1994).

Following is a comparison of typical household wastewater and gray water (Beavers, 1995):

- 63% of BOD load;
- 39% of the suspended solids load;
- 18% of the nitrogen;
- 70% of the phosphorous;
- 65% of the wastewater flow.

The comparison of gray water with wastewater quality indicates a relatively low contamination of gray water (Beavers, 1995) and therefore lower treatment requirements. Additionally, the relatively high proportion of gray water generated shows a large potential source for water savings by reuse systems.

The main applications for gray water reuse are garden and park irrigation (external uses) as well as toilet flushing and laundry (internal) use. Household gray water systems that reuse gray water for toilet flushing and/ or laundry water must utilise a treatment process that includes coarse suspended solid removal, turbidity reduction and disinfection (Al-Jayyousi, 2003).

2.5 Treatment

The most simple and cost affective gray water treatment procedure for in-house recycling is chlorination, coagulation and sand filtration to remove bacterial substances and suspended solids. The process fundamentals of how this Coagulation, Flocculation, Chlorination and Sand filtration tests helps to treat water is given below.

2.5.1 Coagulation and Flocculation

All waters, especially surface waters, contain both dissolved and suspended particles. Coagulation and flocculation processes are used to separate the suspended solids portion from the water.

The suspended particles vary considerably in source, composition charge, particle size, shape, and density. Correct application of coagulation and flocculation processes and selection of the coagulants depend upon understanding the interaction between these factors. The small particles are stabilized (kept in suspension) by the action of physical forces on the particles themselves. One of the forces playing a dominant role in stabilization results from the surface charge present on the particles. Most solids suspended in water possess a negative charge and, since they have the same type of surface charge, repel each other when they come close together. Therefore, they will remain in suspension rather than clump together and settle out of the water.

Working Processes

Coagulation and flocculation occur in successive steps intended to overcome the forces stabilizing the suspended particles, allowing particle collision and growth of floc. If step one is incomplete, the following step will be unsuccessful.

Coagulation

The first step destabilizes the particle's charges. Coagulants with charges opposite those of the suspended solids are added to the water to neutralize the negative charges on dispersed non-settlable solids such as clay and colorproducing organic substances. Once the charge is neutralized, the small suspended particles are capable of sticking together. The slightly larger particles formed through this process and called microflocs, are not visible to the naked eye. The water surrounding the newly formed microflocs should be clear. If it is not, all the particles' charges have not been neutralized, and coagulation has not been carried to completion. More coagulant may need to be added. A high-energy, rapid-mix to properly disperse the coagulant and promote particle collisions is needed to achieve good coagulation. Over-mixing does not affect coagulation, but insufficient mixing will leave this step incomplete. Coagulants should be added where sufficient mixing will occur. Proper contact time in the rapid-mix chamber is typically 1 to 3 minutes.

Coagulation Theory

In water treatment plants, chemical coagulation is usually accomplished by the addition of trivalent metallic salts such as $Al_2(SO_4)_3$ (aluminum sulfate) or $FeCl_3$ (ferric chloride).Although the exact method by which coagulation is accomplished cannot be determined, four mechanisms are thought to occur. These include :

- Ionic layer compression
- Adsorption and charge neutralization
- Sweep coagulation
- Inter-particle bridging

Ionic Layer Compression

The quantity of ions in the water surrounding a colloid has an effect on the decay function of the electrostatic potential. High ionic concentration compresses the layers Prepared predominately of counter ions toward the surface of the colloid. If this layer is sufficiently compressed, then the vander waals force will be predominant across the entire area of influence, so that the net force will be attractive and no energy barriers will exit. Although coagulation such as aluminium and ferric salts used in water treatment ionize, at the concentration commonly used they would not increase the ionic concentration sufficiently to affect ion layer compression.

Adsorption Charge Neutralization

The nature and rather than the quantity of the ions of prime importance in the theory of adsorption and charge neutralization. Although aluminium sulphate (alum) is used as in the example below, ferric chloride behaves similarly. The ionization of aluminium sulphate in water produces sulphate anions (SO_4^{2-}) and aluminium cataions (Al^{3+}). The sulfate ion may remain in this from or combine with other cations. However, the Al^{3+} cataions react immediately with to form a variety of aquometallic ions and hydrogen.

The aquometallic ions thus formed become part of the ionic cloud surrounding the colloid and, because they have a great affinity for surfaces, are adsorbed onto the surface of the colloid where they neutralize the surface charge. Once the surface charge has been neutralized, the ionic cloud dissipater, and the electrostatic potential disappears so that contact occurs freely. Overdosing with coagulants can result in restabilizing the suspension. If enough aquometallic ions ate formed and adsorbed, the charges on the particles become reversed and the ionic clouds reform with negative ions being the counter ions.

Sweep Coagulation

The last product formed in the hydrolysis of alum is aluminium hydroxide, $Al(OH)_3$. The $Al(OH)_3$ forms in amorphous, gelatinous flocs as it is formed, or they may become enmeshed by it sticky surface as the flocs settle. The process by colloids are swept from suspension in this manner is known as sweep coagulation.

Inter-particle Bridging

Large molecules may be formed when aluminium or ferric salts dissociate in water. Although lager ones are probably formed also synthetic polymers may be used or branched and are highly surface reactive. Thus, several colloids may become attached to one polymer and several of the polymer colloid groups may become enmeshed resulting in settlable mass.

Flocculation

Following the first step of coagulation, a second process called flocculation occurs. Flocculation, a gentle mixing stage, increases the particle size from submicroscopic microfloc to visible suspended particles. The microflocs are brought into contact with each other through the process of slow mixing. Collisions of the microfloc particles cause them to bond to produce larger, visible flocs called pinflocs. The floc size continues to build through additional collisions and interaction with inorganic polymers formed by the coagulant or with organic polymers added. Macroflocs are formed. High molecular weight polymers, called coagulant aids, may be added during this step to help bridge, bind, and strengthen the floc, add weight, and increase settling rate. Once the floc has reached it optimum size and strength, the water is ready for the sedimentation process. Design contact times for flocculation range from 15 or 20 minutes to an hour or more.

Operational Considerations

Flocculation requires careful attention to the mixing velocity and amount of mix energy. To prevent the floc from tearing apart or shearing, the mixing velocity and energy input are usually tapered off as the size of the floc increases. Once flocs are torn apart, it is difficult to get them to reform to their optimum size and strength. The amount of operator control available in flocculation is highly dependent upon the type and design of the equipment.

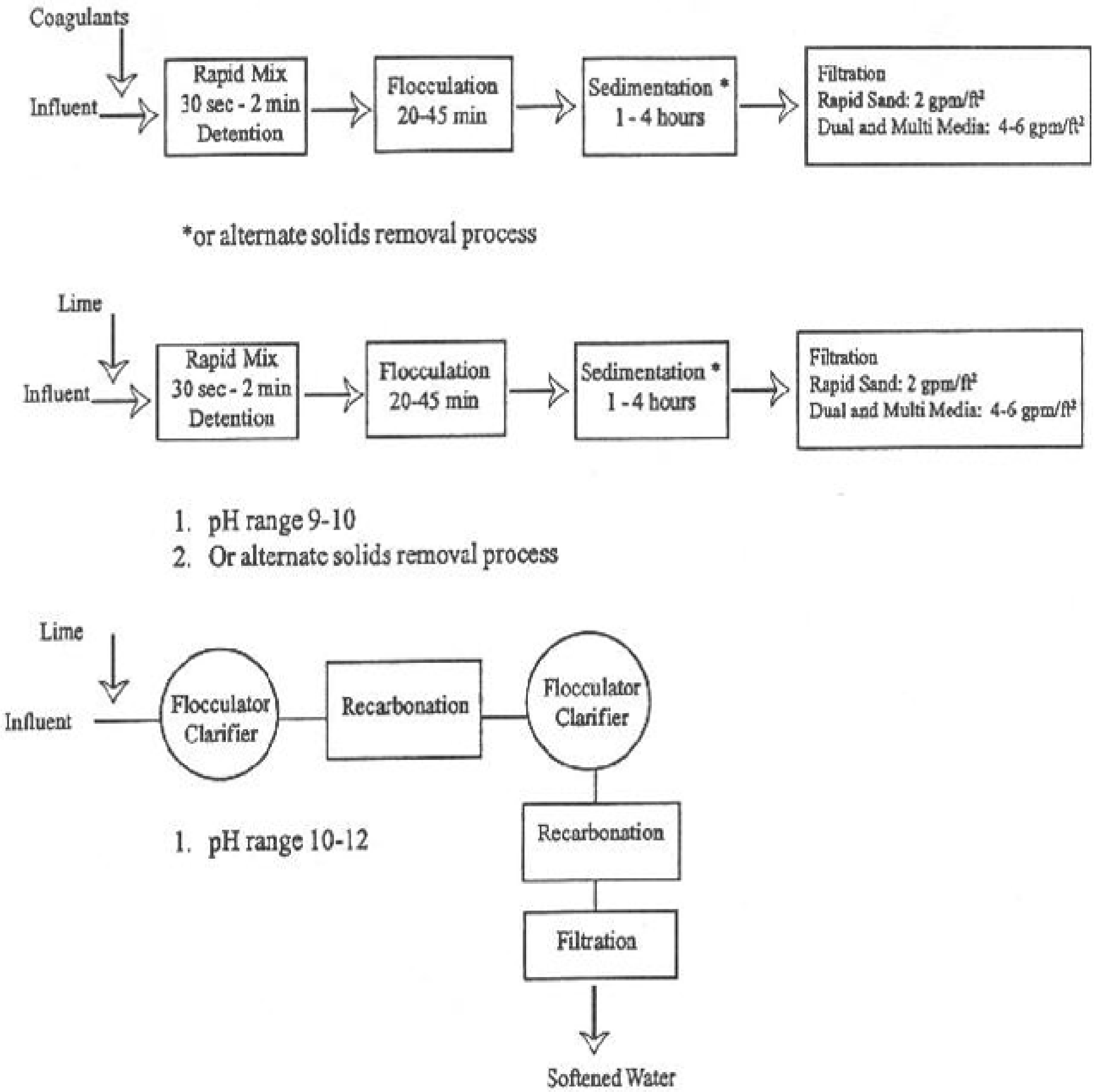


Figure 2.3(a): Design consideration of conventional plants (Source: www.mrwa.com).

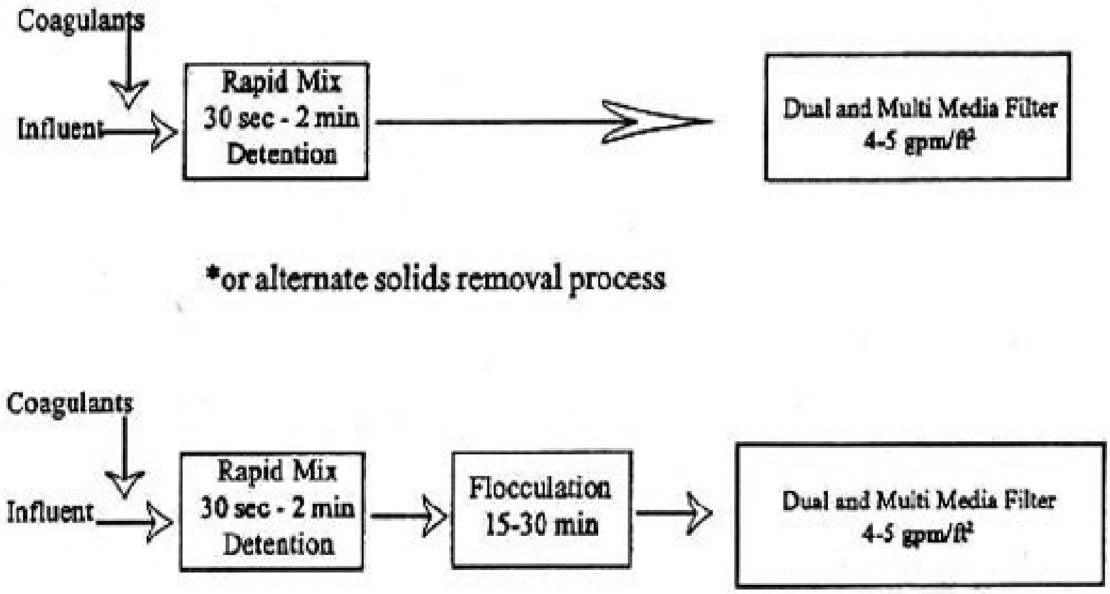


Figure 2.3(b): Design consideration of Conventional plants (Source: www.mrwa.com).

Retention or detention time is the theoretical time in minutes that water spends in a process. It is calculated by dividing the liquid volume, in gallons, of a basin by the plant flow rate in gallons per minute. Actual detention time in a basin will be less than the theoretical detention time because of "dead areas" and short circuiting, which could be due to inadequate baffling.

$$\text{Retention time} = \frac{\text{basin volume (gallons)}}{\text{gpm flow}}$$

The rise rate is calculated by dividing the flow in gallons per minute by the net upflow area of the basin in square feet.

$$\text{Rise Rate} = \frac{\text{gpm flow}}{\text{surface area}}$$

Coagulant Selection:

The choice of coagulant chemical depends upon the nature of the suspended solid to be removed, the raw water conditions, the facility design, and the cost of the amount of chemical necessary to produce the desired result. Final selection of the coagulant (or coagulants) should be made following thorough jar testing and plant scale evaluation. Considerations must be given to required effluent quality, effect upon down stream treatment process performance, cost, method and cost of sludge handling and disposal, and net overall cost at the dose required for effective treatment.

Inorganic Coagulants

Inorganic coagulants such as aluminum and iron salts are the most commonly used. When added to the water, they furnish highly charged ions to neutralize the suspended particles. The inorganic hydroxides formed produce short polymer chains which enhance microfloc formation. Inorganic coagulants usually offer the lowest price per pound, are widely available, and, when properly applied, are quite effective in removing most suspended solids. They are also capable of removing a portion of the organic precursors which may combine with chlorine to form disinfection by-products. They produce large volumes of floc which can entrap bacteria as they settle. However, they may alter the pH of the water since they consume alkalinity. When applied in a lime soda ash softening process, alum and iron salts generate demand for lime and soda ash. They require corrosion-resistant storage and feed equipment. The large volumes of settled floc must be disposed of in an environmentally acceptable manner.

Inorganic Coagulant Reactions

Common coagulant chemicals used are alum, ferric sulfate, ferric chloride, ferrous sulfate, and sodium aluminate. The first four will lower the alkalinity and pH of the solution while the sodium aluminate will add alkalinity and raise the pH. The reactions of each follow:

ALUM

$$A1_2(SO_4)_3 + 3\,Ca(HCO_3)_2 \text{ ------------> } 2\,Al(OH)_3 + 3CaSO_4 + 6\,CO_2$$

Aluminum +	Calcium	gives	Aluminum +	Calcium +	Carbon
Sulfate	Bicarbonate		Hydroxide	Sulfate	Dioxide

(already in the water to treat)

FERRIC SULFATE

$Fe_2(SO_4)_3$ + $3\,Ca(HCO_3)_2$ -----------> $2\,Fe(OH)_3$ + $3CaSO_4$ + $6\,CO_2$

Ferric Sulfate + Calcium Bicarbonate (present in the water to treat) gives Ferric Hydroxide + Calcium Sulfate + Carbon Dioxide

FERRIC CHLORIDE

$2\,Fe\,Cl_3$ + $3\,Ca(HCO_3)_2$ -----------> $2\,Fe(OH)_3$ + $3CaCl_2$ + $6CO_2$

Ferric Chloride + Calcium Bicarbonate (present in the water to treat) gives Ferric Hydroxide + Calcium Chloride + Carbon Dioxide

FERROUS SULFATE

$FeS0_4$ + $Ca(HCO_3)_2$ -----------> $Fe(OH)_2$ + CaS04 + $2CO_2$

Ferrous Sulfate + Calcium Bicarbonate (present in the water to treat) gives Ferrous Hydroxide + Calcium Sulfate + Carbon Dioxide

SODIUM ALUMINATE

$2\,Na_2A1_2O_4$ + $Ca(HCO_3)_2$ -----------> $8\,Al(OH)_3$ + $3\,Na_2CO_3$ + $6\,H_20$

Sodium Aluminate + Calcium Carbonate (present in the water to treat) gives Aluminum Hydroxide + Sodium Carbonate + Water

$Na_2Al_2O_4$	+	CO_2	----------->	2 $Al(OH)_3$	+	$NaCO_3$
Sodium Aluminate	+	Carbon Dioxide (present in the water to treat)	gives	Aluminum Hydroxide	+	Sodium Carbonate

$Na_2Al_2O_4$	+	$MgCo_3$	----------->	$MgAl_2O_4$	+	Na_2CO_3
Sodium Aluminate	+	Magnesium Carbonate (present in the water to treat)	gives	Magnesium Aluminate	+	Sodium Carbonate

2.5.2 Chlorination

Chlorination is a water treatment that destroys disease-causing bacteria, nuisance bacteria, parasites and other organisms. Chlorination also oxidizes iron, manganese and hydrogen sulfide so they can be filtered out. Disease-causing bacteria can infect humans and animals in several ways. Fecal waste from an infected host frequently carries organisms which cause diseases such as typhoid fever, paratyphoid fever, bacillary dysentery, infectious hepatitis and others. Disease-causing organisms are transmitted from host to host in many ways including through a contaminated water supply. Chlorination is the process of adding the element chlorine to water as a method of water purification to make it fit for human consumption as drinking water. Water which has been treated with chlorine is effective in preventing the spread of disease. The use of chlorine has greatly reduced the prevalence of waterborne disease as it is effective against almost all bacteria and viruses. Chlorination is also used to sterilize the water in swimming pools and as a disinfection stage in sewage treatment.

Chemistry in Water

When chlorine is added to water, hypochlorous and hydrochloric acids form:

$Cl_2 + H_2O \bullet \quad HClO + HCl$

Depending on the pH, hypochlorous acid partly dissociates to hydrogen and hypochlorite ions:

$HClO \bullet \quad H^+ + ClO^-$

The hypochlorite ion then most often degrades to a mixture of chloride and chlorate ions:

$3\ ClO^- \bullet \quad 2\ Cl^- + ClO_3^-$

Advantages of Chlorination

1. **Controls Disease-Causing Bacteria:** Disease-causing bacteria may enter your well during construction, repair, flooding or as a result of improper construction. Proper chlorination will kill these bacteria. If disease-causing bacteria enter your water supply on a continuous basis, you must eliminate the source or construct a new water supply.
2. **Controls Nuisance Organisms:** Chlorine treatment will control nuisance organisms such as iron, slime and sulfate-reducing bacteria. Iron bacteria feed on the iron in the water. They may appear as a slimy, dark-red mass in the toilet tank but microscopic examination is needed to confirm their presence. Iron bacteria colonies may break loose from the inside of pipes and flow through faucets to cause stains in laundry, plumbing fixtures, etc. A thorough shock chlorination of the well and water system may destroy all iron bacteria colonies. However, iron bacteria that have penetrated the water-bearing formation will be difficult to eliminate and will likely re-infest the system. In this situation you will need to repeat chlorination treatment periodically. Other nuisance organisms include slime bacteria and sulfate reducing bacteria which produce a rotten-egg odor. Chlorination will kill or control these bacteria. Nuisance bacteria **do not** cause disease.

3. **Mineral Removal:** You can remove large amounts of iron from water by adding chlorine to oxidize the clear soluble iron into the filterable reddish insoluble form. Chlorine helps remove manganese and hydrogen sulfide in the same way.

Disadvantages of Chlorination

1. No Nitrate Removal: Chlorine will not remove nitrates from water. The claims of some water treatment firms imply that nitrates can be removed by chlorination. This is not true. Adding chlorine may prevent nitrates from being reduced to the toxic nitrite form; however, nitrates are not removed from water by chlorination**.**

2. **Causes Smell and Bad Taste:** Chlorine in water is not poisonous to humans or animals. However, if the concentration is great enough the water will taste bad so consumption may be reduced. Some people object to the smell and/or taste of very small amounts of chlorine. In those cases an activated carbon or charcoal filter may be used to remove the chlorine from the drinking water.

Trihalomethanes (THMs) are organic chemicals that may form when chlorine is used to treat water supplies that contain humic compounds. Humic compounds form as a part of the decomposition of organic materials such as leaves, grass, wood or animal wastes. Because THMs are very seldom associated with groundwater, they are primarily a concern where surface water supplies are used.

Lifetime consumption of water supplies with THMs at a level greater than 0.10 milligrams per liter is considered by the Environmental Protection Agency to be a potential cause of cancer. THMs can be removed from drinking water through use of an activated carbon filter.

The Chlorination Process

To chlorinate a water supply properly it is necessary to understand chlorine demand, free available chlorine residual and contact time.

1. **Chlorine demand** is the amount of chlorine required to kill bacteria, oxidize iron or other elements in the water, and oxidize any organic matter that may be present. There is no easy way to determine the amount of chlorine required—chlorine is added until the chlorine odor persists.
2. **Free available chlorine residual** is the amount of chlorine remaining in the water after the chlorine demand has been met. If the chlorine demand is greater than the amount of chlorine introduced, there will be no free available chlorine residual. Unless a chlorine residual is present, adequate amounts of chlorine have not been added to the water.

3. **Contact time** is the amount of time that the chlorine is present in the water. The combination of chlorine residual and contact time determines the effectiveness of the chlorination treatment. The bacterial "kill factor" is defined as the product of free available chlorine residual and contact time. Thus the greater the chlorine residual the shorter the required contact time for bacterial kill.

2.5.3 Sand Filtration

Sand filters are used for water purification. There are three main types;

1. Rapid (gravity) sand filters
2. Upflow sand filters
3. Slow sand filters

All three methods are used extensively in the water industry throughout the world. The first two require the use of flocculant chemicals to work effectively whilst slow sand filters can produce very high quality water free from pathogens, taste and odour without the need for chemical aids.

Passing flocculated water through a rapid gravity sand filter strains out the floc and the particles trapped within it reducing numbers of bacteria and removing most of the solids. The medium of the filter is sand of varying grades. Where taste and odour may be a problem (organoleptic impacts), the sand filter may include a layer of activated carbon to remove such taste and odour.

Sand filters become clogged with floc after a period in use and they are then backwashed or pressure washed to remove the floc. This backwash water is run into settling tanks so that the floc can settle out and it is then disposed of as waste material. The supernatant water is then run back into the treatment process or disposed off as a waste-water stream. In some countries the sludge may be used as a soil conditioner. Inadequate filter maintenance has been the cause of occasional drinking water contamination.

Sand filters are occasionally used in the treatment of sewage as a final polishing stage (see Sewage treatment). In these filters the sand traps residual suspended material and bacteria and provides a physical matrix for bacterial decomposition of nitrogenous material, including ammonia and nitrates, into nitrogen gas.

Sand Bed Filtration

A sand bed filter is a kind of depth filter. Broadly, there are two types of filter for separating particulate solids from fluids:

- Surface filters – where particulates are captured on a permeable surface
- Depth filters – where particulates are captured within a porous body of material

In addition, there are passive and active devices for causing solid liquid separation such as settling tanks, hydrocyclones and centrifuges.

There are several kinds of depth filter some employing fibrous material and others employing granular materials. Sand bed filters are an example of a granular lose media depth filter. They are usually used to separate small amounts (<10 parts per million or <10 g per cubic metre) of fine solids (<100 microns) from aqueous solutions. In addition, they are usually used to purify the fluid rather than capture the solids as a valuable material. They therefore find most of their uses in liquid effluent treatment.

Particulate Solids Capture Mechanisms

Sand bed filters work by providing the particulate solids with many opportunities to be captured on the surface of a sand grain. As fluid flows through the porous sand along a tortuous route, the particulates come close to sand grains. They can be captured by one of several mechanisms:

- Direct collision
- Van der Waals or London force attraction
- Surface charge attraction
- Diffusion

In addition, particulate solids can be prevented from being captured by surface charge repulsion if the surface charge of the sand is of the same sign (positive or negative) as that of the particulate solid. Furthermore, it is possible to dislodge captured particulates although they may be re-captured at a greater depth within the bed. Finally, a sand grain that is already contaminated with particulate solids may become more attractive or repel addition particulate solids. This can occur if by adhering to the sand grain the particulate loses surface charge and becomes attractive to additional particulates or the opposite and surface charge is retained repelling further particulates from the sand grain.

In some applications it is necessary to pre-treat the effluent flowing into a sand bed to ensure that the particulate solids can be captured. This can be achieved by one of several methods:

• Adjusting the surface charge on the particles and the sand by changing the pH

• Coagulation – adding small, highly charged cations (aluminium 3+ or calcium 2+ are usually used)

• Flocculation – adding small amounts of charge polymer chains which either form a bridge between the particulate solids (making them bigger) or between the particulate solids and the sand

Operating Regimes

They can be operated either with upward flowing fluids or downward flowing fluids the latter being much more usual. For downward flowing devices the fluid can flow under pressure or by gravity alone. Pressure sand bed filters tend to be used in industrial applications and often referred to as rapid sand bed filters. Gravity fed units are used in water purification especially drinking water and these filters have found wide use in developing countries (slow sand filters).

Overall, there are several categories of sand bed filter:

1. rapid (gravity) sand filters

2. rapid (pressure) sand bed filters

3. upflow sand filters

4. slow sand filters

Rapid Pressure Sand Bed Filter Design

Smaller sand grains provide more surface area and therefore a higher decontamination of the inlet water, but it also requires more pumping energy to drive the fluid through the bed. A compromise is that most rapid pressure sand bed filters use grains in the range 0.6 to 1.2 mm although for specialist applications other sizes may be specified. Larger feed particles (>100 microns) will tend to block the pores of the bed and turn it into a surface filter that blinds rapidly. Larger sand grains can be used to overcome this problem, but if significant amounts of large solids are in the feed they need to be removed upstream of the sand bed filter by a procsss such as settling.

The depth of the sand bed is recommended to be around 0.6-1.8 m (2-6 ft) regardless of the application. This is linked to the maximum throughput discussed below.

Guidance on the design of rapid sand bed filters suggests that they should be operated with a maximum flow rate of 9 m3/m2/hr (220 USgal/ft2/hr – check calc). Using the required throughput and the maximum flowrate the required area of the bed can be calculated

The final key design point is to be sure that the fluid is properly distributed across the bed and that there are no preferred fluid paths where the sand may be washed away and the filter be compromised.

Operating Parameters for Rapid Pressure Sand Bed Filters

Rapid pressure sand bed filters are typically operated with a feed pressure of 2 to 5 bar(a) (28 to 70 psi(a)). The presssure drop across a clean sand bed is usually very low. It builds as particulate solids are captured on the bed. Particulate solids are not captured uniformly with depth, more are captured higher up with bed with the concentration gradient decaying exponetially.

This filter type will capture particles down to very small sizes, and does not have a true cut off size below which particles will always pass. The shape of the filter particle size-efficiency curve is a U-shape with high rates of particle capture for the smallest and largest particles with a dip in between for mid-sized particles.

The build up of particulate solids causes an increase in the pressure lost across the bed for a given flow rate. For a gravity fed bed when the pressure available is constant, the flow rate will fall. When the pressure loss or flow is unacceptable the bed is back washed to remove the accumulated particles. For a pressurised rapid sand bed filter this occurs when the pressure drop is around 0.5 bar. The back wash fluid is pumped backwards through the bed until it is fluidised and has expanded by up to about 30% (the sand grains start to mix and as they rub together they drive off the particulate solids). The smaller particulate solids are washed away with the back wash fluid and captured usually in a settling tank. The fluid flow required to fluidise the bed is typically 3-10 m3/m2/hr but not run for long (a few minutes). Small amounts of sand can be lost in the back washing process and the bed may need to be topped up periodically.

Uses in Water Treatment

All three methods are used extensively in the water industry throughout the world. The first two and third in the list above require the use of flocculant chemicals to work effectively whilst slow sand filters can produce very high quality water free from pathogens, taste and odour without the need for chemical aids.

Passing flocculated water through a rapid gravity sand filter strains out the floc and the particles trapped within it reducing numbers of bacteria and removing most of the solids. The medium of the filter is sand of varying grades. Where taste and odour may be a problem (organoleptic impacts), the sand filter may include a layer of activated carbon to remove such taste and odour.

Sand filters become clogged with floc after a period in use and they are then backwashed or pressure washed to remove the floc. This backwash water is run into settling tanks so that the floc can settle out and it is then disposed of as waste material. The supernatant water is then run back into the treatment process or disposed off as a waste-water stream. In some countries the sludge may be used as a soil conditioner. Inadequate filter maintenance has been the cause of occasional drinking water contamination.

Sand filters are occasionally used in the treatment of sewage as a final polishing stage. In these filters the sand traps residual suspended material and bacteria and provides a physical matrix for bacterial decomposition of nitrogenous material, including ammonia and nitrates, into nitrogen gas.

Discussion of Mechanism of Alum for Waste water treatment

When $Al_2(SO_4)_3.18H_2O$ (alum) is added to the waste water, the aluminum ion hydrolyses by reactions that consume alkalinity in the water such as:

$$Al(H_2O)_6^{3+} + 3HCO^{3-} \rightarrow Al(OH)_3\ (s) + 3CO_2 + 6H_2O$$

The gelation of hydroxide thus formed carries suspended materials with it as it settles. Furthermore it is likely that positively charged hydroxyl-bridged dimmers or higher polymers are formed that interact with colloidal particles bridging about coagulation. Sodium silicate partly neutralized by aids of coagulation. Particularly when used with alum. Metal ions in coagulation also react with virus proteins and destroy viruses from water. This process remove large amount of suspended solid particles which account large part of BOD in the effluent/waste water. Removal of solid also reduced turbidity.

Use of chlorine/bleaching/chlorinedioxide for water treatment

Chlorine/chlorine dioxide is an effective water disinfectant employed for killing bacteria in water. When chlorine is added to water, it rapidly hydrolyzed as follows

$Cl_2 + H_2O \rightarrow H^+ + Cl^- + HOCL$

Hypochlorous acid (HOCL) is a weak acid and dissociates as follows

$HOCL \leftrightarrow H^+ + OCL^-$

Sometimes, hypochloride salts are substituted for chlorine gas as disinfectants. The most important one is bleaching powder $Ca(OCl)_2$ which is safer to handle than gaseous chlorine.

When chlorine is dissolved in water it gives HOCl and OCl^- which are known as free available chlorine. Free available chlorine is very effective in killing bacteria which can remove fecal colliform from waste water.

2.5.4 Urban Treatment

The technologies that best address the factors that effect gray water reuse must primarily consider the biological characteristics of gray water (Al-Jayyousi, 2003) in order to ameliorate public health concerns. The level of treatment provided by gray water reuse technologies will further vary according to the system's scale and reuse applications. Treatment technologies can be best described in either user-based or technology-based terms.

The technology utilised in gray water reuse systems can be differentiated into primary, secondary and tertiary levels (Jeppesen, 1994). These can then be further characterised in terms of the number of users the gray water reuse system must support (user-defined) and by their likely reuse applications.

The main scales of use in user-defined terms are single dwellings, multi-dwellings (Jeppesen, 1994) and community-based systems (Thomas, 1997) with the general applications of gray water reuse being garden watering/ irrigation (external use) and toilet flushing/laundry washing (internal use).

2.5.4.1 General Design Considerations

These main design factors are consistent with most Government guidelines as present.

Relative to wastewater gray water which is predominantly from bathroom and laundry sources is high in dissolved solids (mostly salts) and turbidity, low in nutrients and is likely to contain significant amounts of pathogens (Al-Jayyousi, 2003). The suspended solids that are present are mostly in the form of hair and lint from bath and laundry waste (Jeppesen, 1996). If gray water is sourced from kitchen wastewater it is likely to have a high BOD, high in organic suspended solids and nutrients with low pH (Jeppesen, 1996).

The reuse of gray water from bathroom and laundry sources can be relatively simple for garden watering reuse applications up to some degree of treatments for toilet flushing and laundry applications. However, treatment for kitchen wastewater will generally require more sophisticated technologies and processes to address the high BOD and fatty solids generated (Al-Jayyousi, 2003).

In order to primarily address the likelihood of high pathogen contamination and hence public health concerns, gray water must either be disinfected or disposed of in a manner that does not allow human contact (Jeppesen, 1996). For gray water reuse applications where disposal only involves garden watering, sub-surface irrigation systems would remove the possibility of human contact and therefore reduce the level of treatment required (CSIRO, 2004). However, if gray water reuse involved toilet flushing and/ or laundry water applications disinfection would be required as there is a possibility for human contact (Jefferson, 1998).

Finally, all gray water reuse systems must be connected to the centralised sewer collection system as a precaution. If the gray water reuse system malfunctions or if maintenance is to be carried, the system must be capable of being manually or automatically diverted to the sewer line. This would avoid an unlikely event where the gray water is not collected and disposed of which would increase the risk of human contact and threaten public health.

2.5.4.2 Technology-based Gray water Systems

Primary treatment systems are designed to convey the gray water to a garden watering or irrigation application from its source and little refinement or treatment of gray water quality occurs. However, secondary and tertiary treatment technologies offer different and varying improvements in the treated gray water quality.

2.5.4.3 Primary Treatment Systems

These systems do not store or treat gray water and as such are best to reuse gray water for sub-surface applications.

The simplest forms of primary gray water reuse systems are best described as gray water diversion devices (Ludwig, 1994) and are the most economical.

A simple plumbing device diverts gray water in the wastewater drainage line to a sub-surface garden irrigation system via gravity without any external energy. This system does not treat the gray water and as such the sub-surface garden irrigation system must be able to cope with fouling material such as hair and lint (Ludwig, 1994). With this in consideration the irrigation pipe is usually oversized and outlets to specific sub-surface points in the garden that contain mini-leachfields. These filter the solids and allow sub-surface infiltration without gray water solids fouling tree root zone. In these applications the soil treats the gray water and consideration must be given to the type and depth of soil available to complete the process without compromising the environment or public health.

Figure 2.4: Simple gravity diversion (Van Dok, 2004)

The diversion systems (shown in Figure 2.4) are always connected to the sewer system as well as the irrigation drainage system and usually have a manual valve to divert gray water back to the centralised sewer collection system if required.

Sub-surface irrigation reuse applications avoid human contact with untreated gray water and diversion systems are simple to install and maintain, especially in retrofitting to existing dwellings (Ludwig, 1994). However, these simple systems rely upon gravity flow to apply the gray water and therefore are reliant upon favourable topographical conditions, building and plumbing designs. Also, the intermittent and relatively low flows provided by gray water sources can cause incomplete draining of the sewer lines and cause fouling in some installations (Ludwig, 1994).

To further stabilise flows and clarify gray water a surge tank can be incorporated into the diversion gravity feed/ discharge system – as shown in figure 2.5. The surge tank is usually no larger than 100L (Ludwig, 1994) and is sealed to avoid human contact. The surge tank provides some primary clarification of the gray water solids and provides a regulated flow through the irrigation lines, thus reducing the likelihood of fouling. The relatively-low storage time is designed not to allow the gray water to enter the anaerobic state, which would increase its pathogen contamination and become foul smelling (Jeppesen, 1996).

Figure 2.5: Surge tank (Van Dok, 2004)

For applications where gravity flow is not workable or mini-leachfield point irrigation is not preferred, a pumped surge tank system can be utilised (Ludwig, 1994 p17). These systems utilise external electrical energy and in order for this system to work effectively, coarse and/ or fine filtration is desired in order to prevent fouling of pumps and irrigation lines. Additionally, filtration will reduce organic loads and solids levels which will inhibit microbial growth in the gray water (Al-Jayyousi, 2003).

Coarse filtration will mainly prevent fouling of the surge tank pump and can take the form of disposable "sock" or mesh-type filters. The geo-textile and nylon sock-type filters (shown in Figure 2.6) are the most efficient and require low maintenance (Christova-Boal et al, 1996). These coarse filters would typically be installed in the gray water drain line when discharging into the surge tank prior to pumping. The synthetic sock filters expand as they fill-up with filtered material which maintains adequate flow and they require replacing or cleaning fortnightly on average (Christova-Boal et al, 1996). Their removal and disposal is an acceptable health risk provided adequate safety equipment is worn.

Other forms of coarse filters include disc or mesh filters that can be fitted with automatic back-washing systems. They will utilise more external energy and have high initial capital costs, however their operating costs are comparable to sock-type filters (Christova-Boal et al, 1996). On average these filters must be cleaned or will self-clean once a week and automating the filter cleaning process will simplify operator maintenance and lessen the likelihood of human contact with gray water (Christova-Boal et al, 1996). Disc-type filters operate more efficiently at coarser settings (Christova-Boal et al, 1996) and therefore are better utilised as coarse filters.

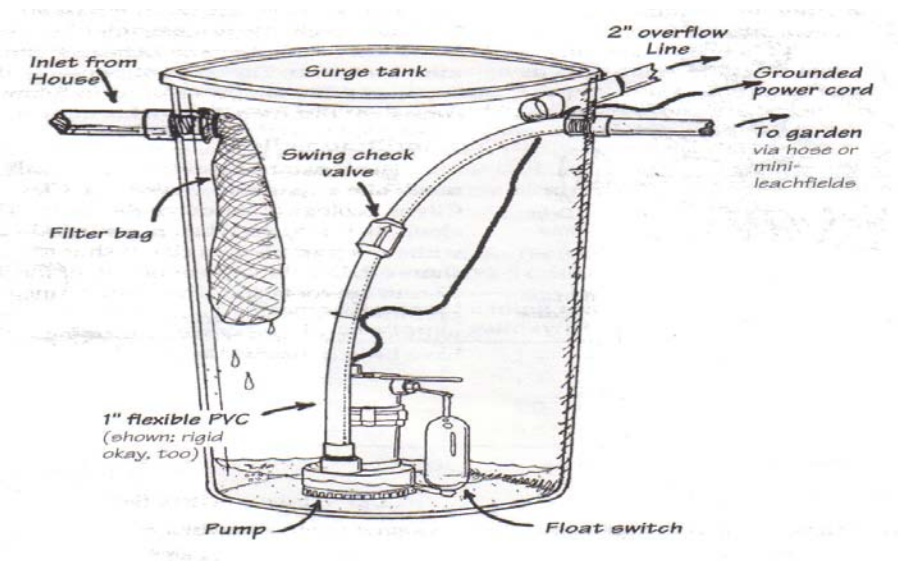


Figure 2.6: Primary treatment system with coarse Filtration (Ludwig, 1994)

Fine filtration is utilised primarily to prevent fouling in irrigation lines and are typically installed in-line just after the surge tank pump and before the irrigation discharge line. Therefore they mostly operate under pressure and the most common and cost effective form is a sand filter.

Sand filters will increase the pump design pressure and can also include automatic back-washing systems that self-clean and are very effective at removing finer particles that foul more intricately designed irrigation systems (Gardner & Millar, 2003). Therefore the most efficient gray water reuse applications that utilise drip sub-surface irrigation systems require finer filtration and should incorporate a sand filter as the fine filtration treatment step.

More natural forms of fine filtration such as the soil box (shown in Figure 2.7) or infiltration bed (Ludwig, 1994) and the vertical swamp (Thomas & Zeisel, 1997) can be utilised, but their filtration rates and overall effect in the hydraulic design must be closely scrutinised in order to be successful.

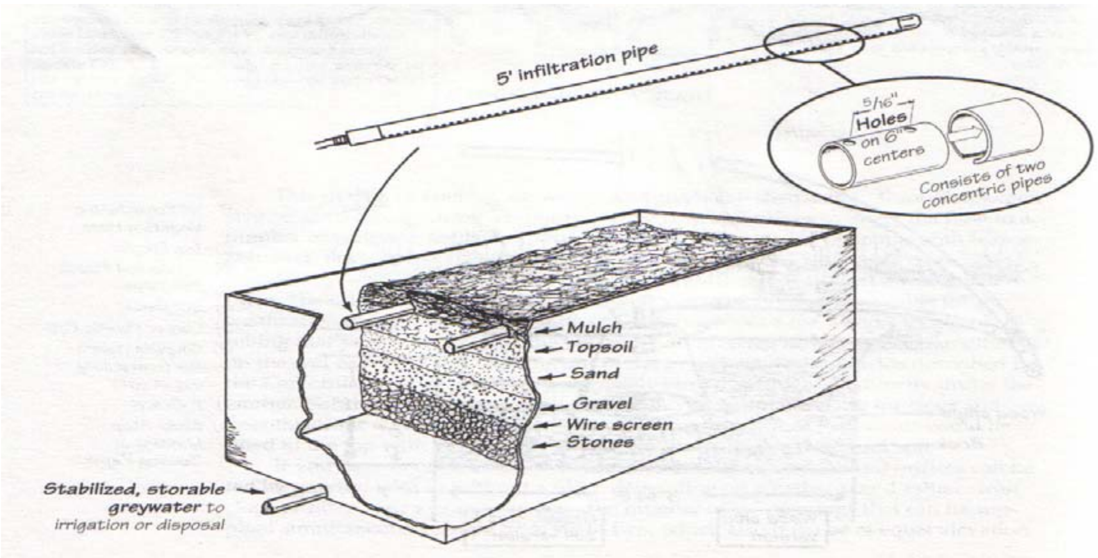


Figure 2.7: Soilbox design (Ludwig, 1994)

The soil box or infiltration bed can be mounted above ground or in-ground and consists of layers of gravel, sand, and a top layer of peat or mulch. In soil boxes a top layer of soil can be utilised to support plants, whilst treatment takes place lower down. As with the sand filter process, gray water is pumped or fed in via gravity at one end, through the layers of natural material in the filter and is discharged at the opposite end to other irrigation applications. Disinfection and dissolved solids clarification treatments can also take place in the soil box (Ludwig, 1994).

The vertical swamp utilises a series of relatively large soil boxes mounted vertically on a wall or similar structure. Gray water is pumped into the top box and is allowed to flow via gravity through the series of cascading soil boxes until it is collected in a sump at ground level and redistributed to other irrigation applications. Each soil box supports plants that thrive in saturated soil states, such as reeds. The vertical swamp is generally more effective for higher flows, where space is limited and where it can be mounted in areas away from human contact. The vertical cascading flow created between the soil boxes aerates gray water and further treats the gray water.

The soil boxes are natural filtration processes whereby the filtrate is broken down by the soil or mulch microbes and can also be utilised for plant growth. By supporting plant growth the filter has a positive energy balance in the process train – rather than at the end of the process, i.e. plant growth after irrigation.

For small irrigation areas or relatively lower pressure irrigation systems a submersible-type pump is most efficient. These constantly operate under a positive suction head and are also easily connected to a float-type level switch which automatically controls the pumping operation and surge tank levels (refer to Figure 2.4). This lowers the maintenance required to operate and maintain the pump in service and can be mounted inside a sealed surge tank, which also dampens its operating noise.

Centrifugal pumps provide greater pressure and flow capacities for larger gray water reuse systems and must be mounted outside the surge tank. Whilst, these pumps require constant priming, they can be mounted at ground level under a positive suction head. However, a suction line must be mounted at the base of the surge tank through its wall and the surge tank level control device must be mounted separately in the surge tank. This makes the centrifugal pump set-up relatively more complex and vulnerable to ongoing operating and maintenance problems compared to using a submersible pump.

For gray water irrigation applications open-type pump impellers best suit as they are unlikely to foul if filtration fails or is limited. However, open impeller-type pumps have limited pressure requirements and may limit the size and type of irrigation system utilised – within both the submersible and centrifugal pump ranges.

However, given the relatively small land areas of most urban blocks it is unlikely that household gray water reuse systems will require pump pressures and flowrates outside the range of submersible-type pumps and it is therefore more effective to use submersible pumps generally for primary treatment systems.

2.5.4.4 Secondary Treatment Systems

These systems allow storage of gray water and therefore must include disinfection treatment to avoid further contamination of gray water during storage.

In order to most efficiently disinfect, the gray water must be reasonably clarified and/ or filtered and the filtration options are the same as for primary treatment systems. Sand filtration can reduce the BOD_5 and COD loadings as well as reducing turbidity (Al-Jayyousi, 2003), which aids the disinfection process.

Generally, systems that store gray water seek to maximise the gray water reuse applications available. That is, gray water is most likely to be reused under pressure for garden irrigation, toilet flushing and/ or laundry water applications.

However, these systems can be used for gravity flow garden irrigation applications as well, but this does not maximise the gray water reuse benefits available.

A typical secondary treatment system (refer to Figure 2.8) will comprise a surge tank for primary clarification and diversion, a centrifugal pump that transports the gray water from the surge tank through a fine filter and an in-line disinfection system to a storage tank. From the storage tank the treated gray water can then be applied under pressure via another centrifugal pump or under gravity flow to reuse applications.

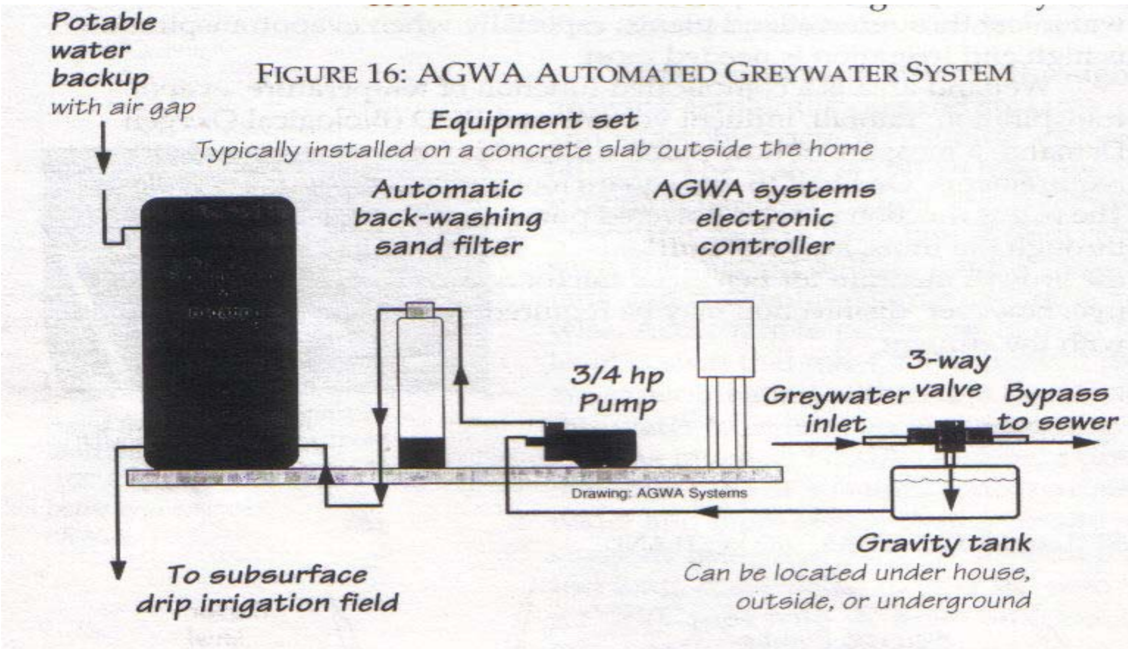


Figure 2.8: Secondary gray water treatment technology (Ludwig, 1994)

In systems without storage the disinfection process is applied just prior to point-of-use. This ensures that the gray water is properly disinfected just prior to use, however it is only suited to disinfection technologies that do not require contact time to react with the gray water.

Also, if gray water is passed through fine filtration, but not disinfected before being stored and thus reducing pathogenic growth, during storage pathogen numbers can still significantly increase. This situation can be inhibited by using a black or dark sealed storage tank that prevents natural light and oxygen coming into contact with the stored gray water. Oxygen and natural light promote growth of aerobic micro-organisms and photosynthetic organisms such as algae to grow and reproduce. Therefore by limiting these organism's life-sustaining factors their growth rates will be reduced (Al-Jayyousi, 2003).

If disinfection does not take place before storage there is a risk of creating an anaerobic state within the gray water thereby increasing its contamination levels, however if constant source and discharge flows are provided this could be avoided. Also, if the stored gray water is to be used for toilet flushing and/ or laundry applications a larger sized point-of-use disinfection system may be required as pathogen numbers may have significantly increased during storage.

UV disinfection is a favourable technology for gray water reuse and is most advantageous for in-line operations. It does not require long contact times (just the time taken to flow over the UV lamp) and it will not adversely change the chemical structure of the gray water.

However, UV disinfection technology requires relatively low turbidity and suspended solids in order to prevent shadowing of pathogens when the gray water passes over the UV lamp (Tchobanoglous et al, 2003). Fine filtration will significantly improve the turbidity and suspended solids levels in gray water and will be further minimised after storage if microbial growth is restricted (Tchobanoglous et al, 2003). Therefore it is preferred to use UV disinfection with pre-filtration.

Using chemicals such as chlorine or bromine for disinfection would change the chemical characteristics of the gray water and would require at least twenty (20) minutes contact time (Clifford White, 1972). Further, it may react with certain waste products in the gray water and form more toxic by-products (Christova-Boal et al, 1996). Additionally, overdosing the disinfectant would adversely affect the soil and plants irrigated (Christova-Boal et al, 1996). Other forms of disinfection such as ozone and chlorine dioxide are more complex and more costly technologies and were not be considered for these reasons.

Whether applied in liquid, tablet or powder form, dosing of chemical disinfectants would also require injection and/ or monitoring/ controlling equipment in order to control the disinfection process. This would increase the complexity of the system for maintenance and operating tasks and therefore chemical disinfection was not generally accepted as a preferred disinfection process.

The preferred storage tank size would be from 200L to 500L (Ludwig, 1994) and would comprise a surge tank, centrifugal pump, sand filter, storage tank and an in-line UV disinfection unit. Figure 2 shows a similar system however the UV disinfection system is not shown and would normally be positioned in the process train after fine filtration and prior to storage.

The system can be automated incorporating automatic backwashing filters, solenoid valves and tank level and pump controls. Also an extra centrifugal pump can be utilised for pressurised reuse applications such as toilet flushing, higher pressure irrigation and laundry washing.

The storage tank in a secondary gray water treatment system can also be augmented with rainwater storage (Dixon et al, 1999). This would dilute the generally higher quality run-off water to a lessor quality however the stochastic nature of run-off supply can be alleviated by the more consistent gray water (Dixon et al, 1999). The diluted and treated gray water quality would improve and this would aid disinfection and if post-storage disinfection was utilised the combination of treated gray water/ rainwater would provide more effective internal household reuse applications.

2.5.4.5 Tertiary Treatment Systems

This classification includes treatment processes that further increase the quality of gray water or polish it for reuse applications. Fixed film biological rotating drums, membrane bioreactors, biologically aerated filters, activated sludge and membrane treatment systems are all included in this category.

However, only two (2) basic forms of biological treatment systems will be described. Whilst utilised on larger scales for more general effluent applications the other tertiary treatment technologies mentioned lack sufficient studies into gray water applications and current literature indicates that costs are high (Al-Jayyousi, 2003).

2.5.4.6 Biological Treatment Systems

This level of treatment involves utilising the biological content in gray water to reduce organic matter, microbial contamination, suspended solids, turbidity and nutrients (nitrogen and phosphorous). The treatment process requires a significant level of automation and energy to power the aeration technology as well as pumps and disinfection systems. Kitchen waste may also be included in the gray water biological treatment process.

Gray water is characteristically low in nutrients and this would inhibit the efficiency of biological treatment systems for individual household systems. However, for larger gray water treatment systems that incorporate gray water from multiple households the nutrient levels would improve the overall biological treatment efficiency. Consistency in treated gray water quality can also be achieved through greater storage volumes which assist in the biological treatment process (Al-Jayyousi, 2003).

However, the consistency of biological treatment systems could vary greatly according to the types of chemicals used at gray water sources. Some substances or products used such as laundry washing products, soaps or shampoos with high amounts aluminium or zeolite could poison or hinder the biological process (Christova-Boal et al, 1995).

Basic biological systems would involve simple aeration using a blower within the storage tank for a set timeframe (batch operation) and then discharged through a UV disinfection system to point of use. The aeration process could involve a system vertical swamp type system.

Although gray water is generated frequently, the volume is variable and therefore a batch system is more effective. The process would remain the same as for secondary treatment systems prior to storage, except that fine filtration could be substituted for coarse filtration and a second primary storage tank will most likely be required to store incoming gray water generated while the batch aeration process takes place in the other storage tank.

For systems with larger or more continuous gray water flows a continuous biological system can be used. A rotating drum system can effectively process gray water by creating a fixed biological film on the rotating drum and as it rotates above and below the tank level. The organic content of the gray water remains in an aerobic state and reacts with the biofilm on the drum as it submerges and re-emerges in and out of the tank. This effectively aerates and dilutes the gray water continuously. The processing speed and process effectiveness is determined by the speed of the rotating drum (Thomas & Zeisel, 1997). However the drum must remain wet to keep its biological film active and after retention in the rotating drum tank the biologically-active gray water is clarified and stored for disinfection and then reuse application as shown in figure 2.9.

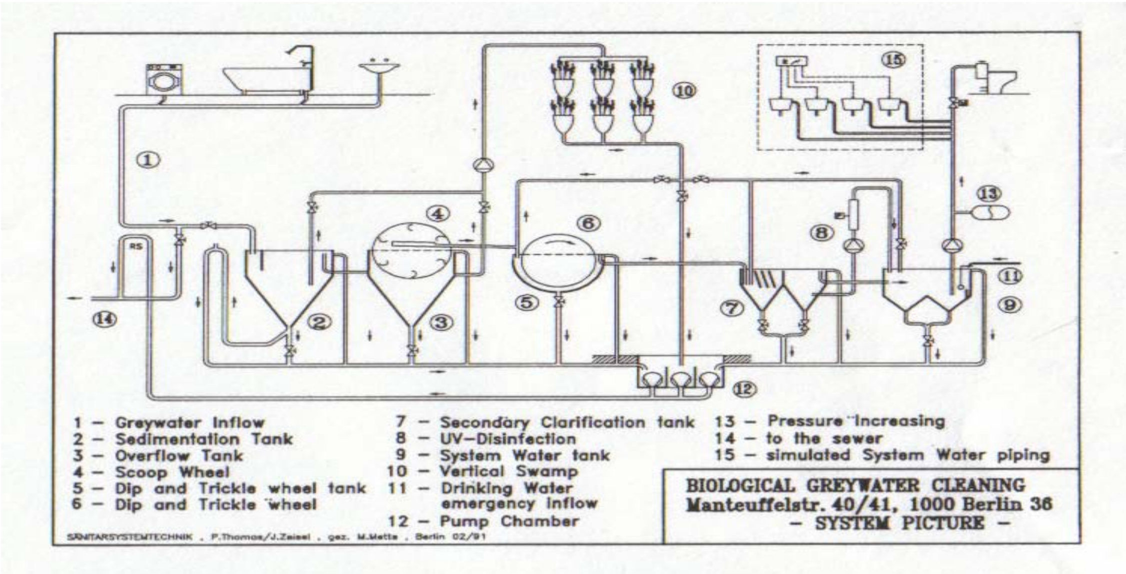


Figure 2.9: Rotating drum biological gray water treatment system (Thomas, 1997)

The adjustable rotating drum speed can accommodate variable nutrient levels in the gray water and the system can achieve reductions in organic loadings down to less than 5mg BOD_7/ L with loadings as little as 3g BOD_7/ m^2/ day without nutrient enrichment (Thomas & Zeisel, 1997). However, the addition of nutrients (Nitrogen and phosphorous) would improve the treatment quality (Thomas & Zeisel, 1997).

Although the relatively moderate nutrient load in gray water is considered generally positive for single dwelling garden irrigation applications, it is likely that for multi-dwellings the collected gray water would have significantly increased nutrient loads (Thomas & Zeisel, 1997). If a gray water treatment system of this scale only utilised secondary treatment processes the higher nutrient-rich processed gray water may increase the likelihood of adverse environmental effects if applied to garden irrigation.

Biological treatment systems are effective and efficient when storing and treating large gray water volumes. The initial low nutrient levels of gray water require larger storage volumes to increase organic loads, however the process is vulnerable to shock loads caused by the variable quality of gray water and toxicity of household products used (Thomas & Zeisel, 1997).

Biological treatment systems are more complex and require greater knowledge to operate and maintain. They also require a considerable amount of energy to operate and close attention must be paid to the types of chemicals used at source i.e. social preferences of the users must be scrutinised.

2.5.5 User-Defined Gray Water Systems

The technologies used in gray water treatment systems can be further defined by the scale of their design and there are three (3) distinct scales of systems identified;

- Single dwellings
- Multi-dwellings
- Community-based systems.

Primary, secondary and tertiary treatment levels can be characterised into these identified gray water system scales.

2.5.5.1 Single Dwellings

This is the most popular gray water system scale in urban areas and involves on-site reuse systems designed for single households/ dwellings.

Single dwellings are more likely to have gardens requiring irrigation, which offers the greatest benefit of gray water reuse. Therefore significant reuse opportunities are available at this scale. However, the level of technological understanding by gray water reuse system operators is likely to be lower and therefore the level of sophistication of systems on these scales would generally be low as well (Jeppesen, 1996). However, ownership of the system is high (Al-Jayyousi, 2003).

The relatively low volume of gray water produced from single dwellings most benefits primary and secondary treatment designs, as biological treatment may not achieve the organic loads required to work effectively. Also other tertiary treatment systems would effectively polish the gray water to a very high standard, but at a considerably higher cost because of the relatively low treatment volumes and these would generally be above single dwelling requirements.

The level of reuse applications as well as cost budgets would be the main factors to consider in determining the most appropriate level of treatment – a primary or secondary treatment system for a single dwelling i.e. for internal and external reuse disinfection would be required.

To then determine the level of sophistication of the identified treatment, factors such as building layouts, scale of reuse and topography would be scrutinised i.e. if a pump/ pressurised system is required.

2.5.5.2 Multi-dwellings

These are single land parcels supporting multiple buildings or households such as a block of apartments or townhouses for typically residential, education, tourist or commercial purposes.

The characteristics of gray water from multi-dwellings include high variability in quality however this can be offset by the relatively high volumes produced (Thomas & Zeisel, 1997). The volumes of gray water produced will also be greater relative to the land or garden available for irrigation reuse applications.

For maintenance and operation the users are likely to employ a dedicated caretaker of the system, however individually each user is likely to take less responsibility or ownership in general.

Therefore parameters for a gray water treatment system would involve large volume storage to dilute varying gray water quality and a high quality of treatment with safe application to reduce public health concerns (Thomas & Zeisel, 1997).

Typically a gray water reuse system design would include storage, biological treatment, filtration and disinfection. This system will be able to have the nutrient loads required to treat and polish the gray water and can typically have a footprint (physical size) of only a car space or two. With this level of treatment other applications such as toilet flushing and laundry wash water are possible also, which improves the systems cost benefit. However, whilst the gray water characteristics are likely to improve the treatment process, costs per capita diminish as the levels of users increase in multi-dwelling applications.

2.5.5.3 Community-Based

Gray water treatment and reuse on this scale involves centrally collecting, treating and distributing gray water from small neighbourhoods or communities (i.e. sub-division or residential street).

The relatively large gray water flows and more consistent quality would further improve gray water treatment effectiveness at these larger scales and there will also be more land available for irrigation applications such as public parks and sporting/ recreational areas.

The biological treatment of gray water naturally clarifies and filters the gray water before disinfection and as a result utilises less energy and less space compared to other treatment processes that rely on mechanical separation/ filtration. However, collecting the gray water would require separate drainage lines in addition to sewer and stormwater systems and additional return lines for reuse distribution. This would be a significant cost and the additional plumbing would mostly suit new developments.

Therefore, at this scale it is more efficient and effective to treat the total effluent produced (blackwater and gray water) from the community and reuse it for non-potable applications. Less plumbing and drainage is required, hence less development cost and the concept can be retrofitted to existing systems i.e. existing sewer lines can be utilised. Also nutrient loads are higher and this will help the biological treatment process.

2.5.6 Gray Water Reuse Applications

The general applications that are most economically feasible and best reflect public health concerns are garden watering and irrigation for external reuse and toilet flushing and/ or laundry washing for internal reuse.

2.5.6.1 Garden Watering/ Irrigation (External) Reuse Applications

All levels of gray water treatment technologies - primary, secondary and tertiary systems can be utilised for garden watering which are relatively small areas or irrigation which refer to larger areas such as parks. The different levels of treatment systems are determined mostly by the scale of use and landscape-based factors such as topography, climate and building type. When small-scale garden watering is desired as per most household applications, a simple gray water diversion or primary treatment system will suffice and the watering system utilised will be a sub-surface system in order to prevent human contact with untreated gray water. If the topography of the land and building design is favourable, gravity discharge to the sub-surface irrigation system may be possible otherwise a pressurised pump system would have to be employed, which would also require filtration to prevent the pump from shortening its service life. The choice of filtration, if desired at all will also be determined by the choice of irrigation system employed.

If simple gray water diversion or surge tank control under gravity flow is desired, then the only adequate reuse application is a sub-surface irrigation system – which is the most efficient form of irrigation. This type of system would utilise a relatively large diameter irrigation tube (25-100mm) to carry the untreated gray water to key locations in the garden where sub-surface mini-leachfields or leaching chambers disperse it within 200mm of the sub-soil surface (Ludwig, 1994) and is shown in Figure 2.10. Sealed distribution boxes may also be incorporated in the irrigation distribution lines.

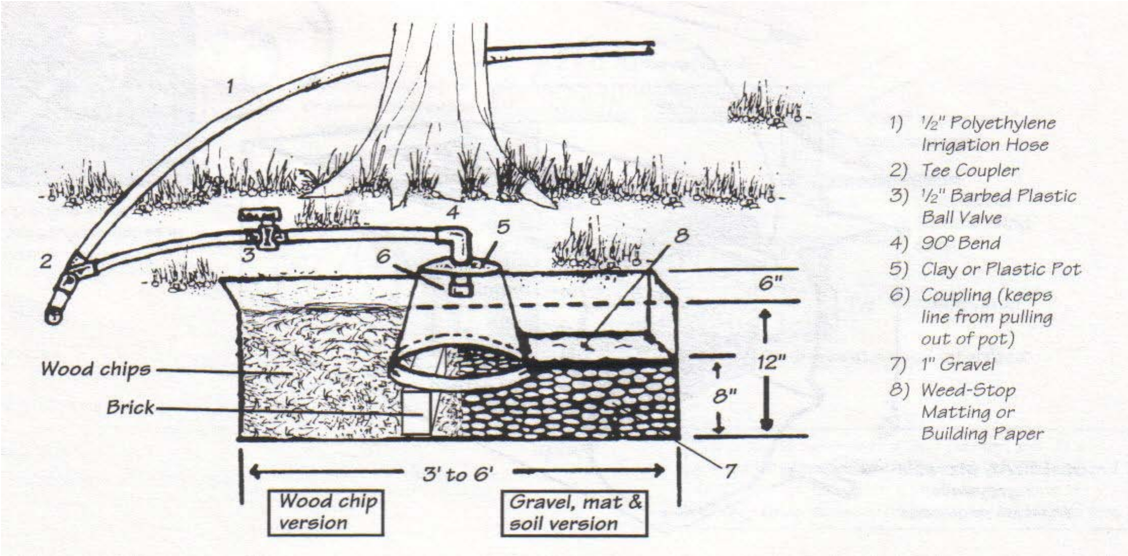


Figure 2.10: Mini-leachfields (Ludwig, 1994)

Key design parameters of basic irrigation systems are;

• Use large irrigation tubing to avoid solids build-up within the system.

• Ensure that the sub-surface discharge points (mini-leachfields or leaching chambers) adequately disperse the gray water and not hinder flow or allow tree root and vermin ingress.

• Ensure that there is adequate static head to allow gravity flow of the system without allowing the system to "back-up" at the point of use i.e. ensure that there is enough height difference between the point of gray water generation and discharge to overcome the friction losses in the irrigation system. (Ludwig, 1994)

If the topography and/ or building design of the area identified for gray water reuse is unfavourable for gravity flow, then a pressurised system will be required that includes a submersible pump located inside a sealed surge tank with automatic float level control and coarse filtration to protect the pump (Ludwig, 1994).

If an irrigation system with wider dispersion or lawn irrigation is desired then a drip feed system can be utilised. However this system has high pressure losses and is vulnerable to fouling at the dripper outlets. Therefore for this type of irrigation a pump and fine filtration system is required and this would involve coarse filtration, a pump and then a sand filter process. The sand filter would be located in-line after the pump and is shown in Figure 2.11 (Ludwig, 1994).

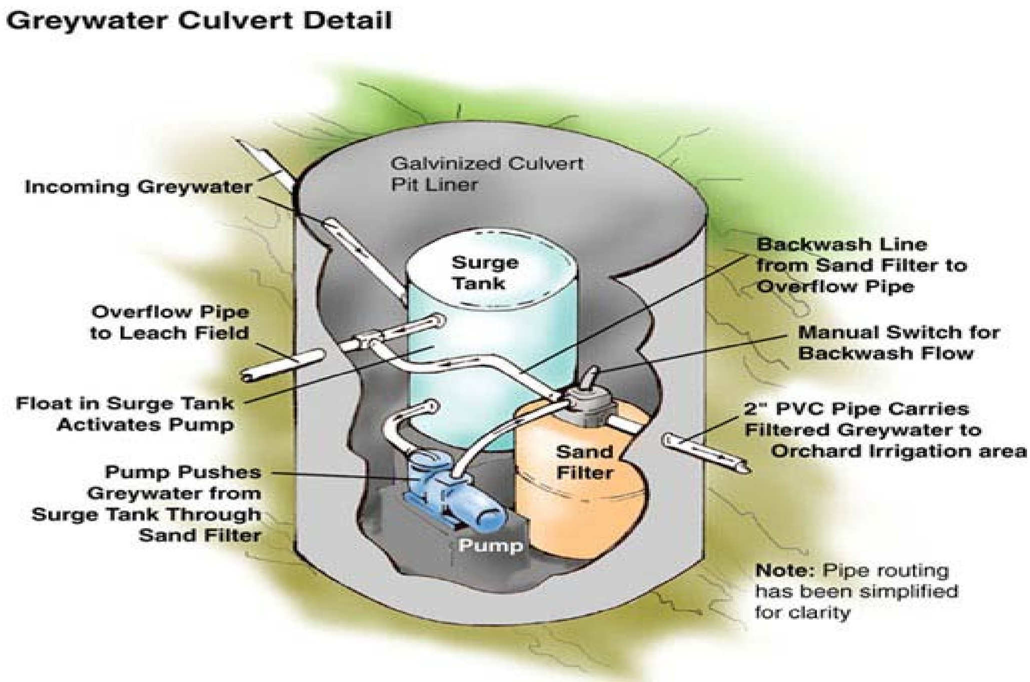


Figure 2.11: Gray water treatment sand filter arrangement (Ludwig, 1994)

If surface dripper or spray system is desired the gray water must be disinfected and this would involve locating an in-line UV disinfection system after the sand filter.

If large-scale irrigation is desired, then gray water storage may be required that will in turn require filtration and disinfection – hence a secondary treatment system would be a minimum standard. It is also likely that the irrigation system will be required to be pressurised, therefore requiring pumped discharge. Also with secondary treatment systems spray irrigation systems may be possible.

Large-scale irrigation applications of gray water reuse may also utilise combined rainwater/ gray water storage systems. Whilst these systems lower the quality of rainwater (Dixon et al, 1999), they compliment their respective storage capacities when utilised for irrigation purposes.

Rainwater storage depending on climate will mostly be variable and unpredictable, where as gray water is relatively constant and predictable. The dilution of polluted gray water with relatively clean rainwater will aid the filtration, pump and disinfection (if required) processes and hence improves the quality of the treated gray water and the equipment service life.

2.5.6.2 Toilet Flushing/ Laundry Washing (Internal) Reuse Applications

Due to the high likelihood of human contact with these reuse applications, disinfection is required, therefore secondary and tertiary systems are applicable.

However, for laundry washing it is more desirable to lower the turbidity and neutralise the pH of the gray water during the treatment process. A tertiary treatment system would provide this higher reuse quality, but the costs are higher and mostly suits multi-dwelling scales where these higher costs can be shared.

Gray water reuse for toilet flushing offers significant water savings, however if a gray water reuse system requires upgrading to a secondary treatment level only for this purpose, it can be cost inhibitive.

An alternative from using or upgrading to a secondary gray water treatment system is to use a combined handwash/ cistern system (Ludwig, 1994). This is a proprietary product and is used extensively in Japan. It is shown in Figure 2.10 and involves locating a wash basin that is supplied by mains water and located directly above the toilet cistern. It is an integral part of the cistern structure and the gray water from the wash basin drains directly into the cistern storage to be used for the next toilet flush. The cistern also uses the mains to top-up if the washbasin gray water does not fill the required flush storage.

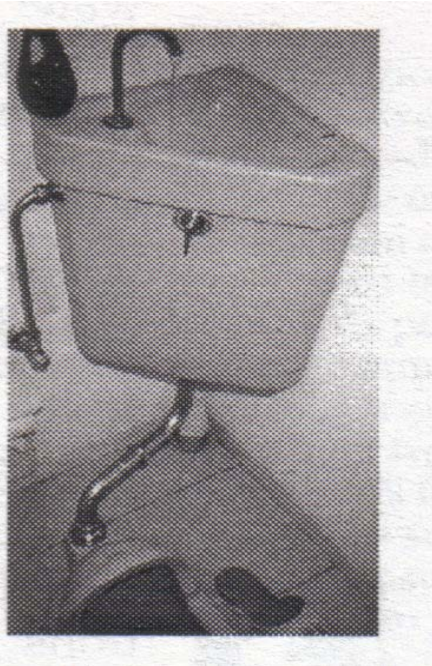


Figure 2.12: Combined handwash/ cistern system.

Effective and efficient gray water treatment systems designed to Government regulations and guidelines can be utilised for single and multi-dwellings. The variety of treatment processes available allow site specific determining factors such as topography, soil, climate and building designs as well as different cost budgets and reuse applications to be accommodated. Single dwelling gray water reuse systems are most adaptable for retrofitting to existing building sites.

Biological treatment processes can be more effectively utilised for multi-dwelling gray water reuse systems and the occupants of these dwellings generally do not have as much demand for garden watering/ irrigation. However, kitchen waste can be included and the quality of the treated gray water produced from biological treatment can be applied for toilet flushing and laundry applications in addition to irrigation.

Maintenance is critical to ensuring that public health is kept a priority concern. Whilst all gray water treatment processes include a sewer overflow/ diversion system to guard against treatment and public health failure, all of the gray water reuse systems defined requires regular maintenance to operate efficiently and effectively for the applications they are designed.

To alleviate this key concern, maintenance should be carried out by trained operators on a regular basis. The scope of this task would include gray water treatment system and irrigation system maintenance as well as inspections of irrigated areas to ensure adverse environmental impacts are noted and acted upon if required. This could be undertaken in the form of a periodic contract with a specialist or experienced gray water system supplier that operates within the Government policies and guidelines.

2.5.6.3 Reusing Gray Water

There are no Standards and criteria/guidelines for gray water reuse for toilet flushing in Bangladesh. But at the time of crisis many people are already reusing gray water for toilet flushing without treatment. The Standards and criteria/guidelines for water reuse for toilet flushing and domestic water recycling for other countries is shown in the Table 2.1.

Table 2.1: Standards and criteria/guidelines for water reuse for toilet flushing and domestic water recycling (Surendum & Wheatly, 1998)

Parameter	**Toilet flushing**		**Domestic water recycling**					
	US	Japan	WHO	US, EPA	USA, NSF	Australia	UK (BSIRA)	Germany (g)
pH	6-9	5.8-8.6		6-9				6-9
BOD_5 (mg/L)	• 10			10		20		20
Turbidity (NTU)	• 2			5		2		1-2
TC (no./100mL)			1000 (m) 200 (g)	< 10		< 1	ND	100
FC (no./100mL)	ND[$]	• 10 (E.Coli)		< 10	< 240	< 4		10
Residual Cl_2 (mg/L)	1	Retained *						
Odour	Odourless	NU [£]						
Appearance		**NU**						

[$]ND = Not-detectable; [£]NU = Not Unpleasant; (g) = guideline; (m) = mandatory;
* at last holding tank in distribution line.

The quality of different sources of gray water collected from household is determined in the laboratory and the results were compared with the Standards of the Table- 2.1.

Then again there is a greater part of gray water that is generated without soap or detergent powder during laundry washing, basin use and bathing. People sometimes just wash and rinse their clothes in the bucket without using soap or detergent, they also sometimes just have a bath without soap and wash of their hand and face in the basin without using soap. This sort of gray water comprises between 30-60% of the total volume of gray water that is generated from a household.

Comparison of quality of this kind of gray water with the Standards and criteria/ guideline represents that this water can be reused for toilet flushing without much treatment. For reusing, addition of a little amount of bleaching powder for disinfection is enough for the treatment of this kind of gray water and than it can be reused for toilet flushing.

2.6 Factors Affecting Gray Water Reuse

Gray water comprises between 68% of total household wastewater on average (Emmerson, 1998) and presents the largest potential source of water savings in domestic residences. Most of the gray water systems proposed in urban areas are closed-loop processes. That is, gray water is managed and reused in a decentralised way within a household, neighbourhood or community (Al-Jayyousi, 2003).

Gray water systems are assessed in terms of technical feasibility, public health, social acceptability and sustainability and these are reflected in Government policy and guidelines. These criteria can be further contextualised into an environmental framework of social, political and environmental factors.

From a broad catchment resource perspective, significant opportunities and constraints of gray water reuse are;

- Availability of a non-potable water source.
- Local climate conditions.
- Development layouts and building/ landscaping designs.
- Local soil types.
- Community perceptions and concerns.

In the later part of the 19th Century the largest increase in human life expectancy (from about 30 years of age to over 50 years of age) occurred and was directly attributed to the establishment of a reticulated potable water supply. This was the creation of our current system and few changes have occurred since (Emmerson, 1998). The centralised system prevented a significant mode of transmission for infectious disease epidemics and in urban areas this must remain the most important factor for gray water reuse design (Al-Jayyousi, 2003).

2.6.1 Political Factors

Public concern for the environment has evolved over the past few decades. Ecologically sustainable development (ESD) principles have been progressively integrated with Government policies, planning and industry guidelines as well as water resource planning. Organizations also recognize the growing environmental concerns of the public by embracing "green" marketing and developing mission statements and corporate goals around ESD principles (Dryzek & Schlosberg, 2003).

The recent droughts have caused Governments to re-evaluate the economic costs of human development upon the environment in social terms. This along with positive public opinion has provided political support for wastewater reuse systems as part of water saving initiatives (Radcliffe, 2003). Additionally, the increased strains of population growth and urbanisation have necessitated Governments to review and investigate new ways of providing the additional water resources available to sustain future growth. Gray water has a constant supply and its reuse can provide water saving opportunities that could lead to postponement of traditional planning techniques such as building new dams and catchment diversion projects (Gardner, 2003).

Gray water reuse at individual, neighbourhood and community scales offers simpler and more cost effective solutions (Ludwig, 1999) for Government water saving initiatives as they strive for policies that encourage more sustainable use of resources.

Whilst Government policies promote and strive for profitable operation of the water authorities, the Government must also support environmental conservation policies.

These policies fundamentally contradict each other and they are dualistic. Ultimately they could hinder progress towards achieving each policy's respective goals (Radcliffe, 2003).

2.6.2 Social Factors

Whilst there are no reported cases of human illness or disease directly attributable to gray water reuse (Emmerson, 1998), the limited studies investigating the levels of micro-biological contamination of gray water indicates the potential for human infection is high. Also, the traditional centralised sewer collection and treatment system that is currently used was successfully designed to protect human health. On-site reuse of gray water marks a departure from this centralised health-driven system and so attracts legitimate public concern.

Public health concerns regarding the potential for gray water becoming a mode of transmission for infectious diseases and viruses in high density urban areas is a significant issue and must be addressed by gray water reuse system design.

Additionally, the sensitive public health concerns over gray water reuse systems make them vulnerable to wider and more negative publicity caused from any specific health-related accidents (Radcliffe, 2003). However, no such incidents have been reported to date (Emmerson, 1998).

Community or public support for gray water reuse systems is critical to the success of implementing policies and guidelines and is conditional upon:

- Community involvement in decision making processes.
- Public education.
- Community demographics.
- Trust in water authorities. (Marks, 2004)

Trust in water authorities was identified as the major factor in gaining public support and historically strong public trust has always been given to all public utilities who provide essential community services (Marks, 2004).

There is a higher acceptance for non-potable reuse applications for wastewater (Radcliffe, 2003) and studies in the USA indicate greater acceptance as the degree of human contact decreases (Marks, 2004). Also, these studies indicated that when options for reuse are evaluated by the community, the most important factors in order of priority are;

- Human health,
- The environment,
- Conservation,
- Treatment costs, and
- Distribution costs (mainly for third pipe systems). (Marks, 2004)

These are similar to in Bangladsh, however gray water reuse does not attract the public caution that effluent reuse does (Radcliffe, 2003).

The global environmental issue such as population growth, urbanisation and climate change is directly related to recent droughts and it affects the communities. This has heightened public awareness of the natural water cycle which they are part of and the environmental strains imposed by human development. This has encouraged Governments and communities to consider their actions in respect to the environmental effects imposed by them (Radcliffe, 2003).

Decentralisation of the traditional wastewater collection and separate disposal system is caused by using on-site gray water treatment systems in urban areas. As a result, reusing gray water within the same space as it is generated highlights the environmental consequences of user’s social habits directly (Al-Jayyousi, 2003). Government gray water reuse guidelines also highlight and reinforce these precautions. Therefore users must scrutinise the environmental effects of the products and chemicals that they use as they become more environmentally aware and responsible for their actions. This could have a flow-on effect to manufacturers and businesses as consumer habits begin to change.

However, if gray water is used to substitute garden irrigation it is debatable whether it will actually reduce overall water consumption habits. There are no studies to investigate this area at present.

2.6.3 Environmental Factors

Traditionally, new water resource planning involved the development of new dams and catchment water diversion schemes. The link between the natural environmental costs (such as loss of habitat, landscape and groundwater changes) and human health from these developments was not given great consideration (Gardner, 2003). However, the recent natural disasters in Bangladesh such as drought, fire and flooding has highlighted the vulnerability of the environment and the costs to human health as a consequence of these large projects (Radcliffe, 2003).

The importance of determining and monitoring the capacity of the environment to sustain human activity is now more widely understood and is recognised in striving to achieve more sustainable living practices. These environmental factors are encapsulated in Ecologically Sustainable Development (ESD) principles (Gardner, 2003).

The commitment by Governments to integrate ESD principles into public planning now ensures that factors such as resource allocation and environmental costs are considered in development processes (Sydney Water, 2002).

As a result, policies that address future water resource requirements investigate the environmental costs of new water sources such as building dams or diverting catchment water for human use and in comparison, policies that promote water saving solutions are more favourable (Sydney Water, 2002). Reusing gray water at on-site, neighbourhood or community scales can in part abate or avoid the environmental costs of new water resource projects.

By reusing gray water, households have the capacity to reduce potable water demand by 30-70% (Radcliffe, 2003) and this in turn reduces the wastewater volume to be collected and treated at wastewater treatment plants. This can then reduce the overall nutrient load during treatment and on the environment when the treated wastewater is returned to the environment.

New residential developments could then reduce infrastructure requirements by reducing sewer collection pipe capacities and sizes and treatment plants could reduce size (Emmerson, 1998). Additionally, the energy required to pump and treat the wastewater would be reduced and considering most of the energy provided in Bangladesh is from non-renewable sources such as coal, natural gas and oil, reducing energy consumption would in turn reduce the environmental strains of extracting and burning these fuels.

The higher nutrient loads and turbidity effects of polluted wastewater being returned to the environment results in immediate and significant changes to the environment it is being discharged into (Gardner, 2003). By reducing mainly the volume of this pollution the environment in principle should improve, however studies on the quality of the improvement are lacking and therefore difficult to quantify.

The reduction in potable water demand generally would contribute to postponing the requirement for developing new water sources (Hunter, 2004). This is usually quantified

in terms of extending the time by which future new developments can be undertaken without an increase in public water source and head works infrastructure.

However, whilst reusing gray water can reduce the environmental effects of potable water demand and wastewater collection and treatment on a broad scale, at the local scale its use on gardens and recreational areas presents many more issues.

Watering gardens or irrigating grounds with gray water introduces a level of pollution to the landscape which may change soil characteristics, effect nutrient availability or poison plants (Al-Jayyousi, 2003). The nature of these potential problems are mainly long-term and due to gray water reuse being only recently embraced, these potential environmentally-related on-site issues are still largely unknown as there is a lack of studies that verify them. Many guidelines promote vigilant checking of adverse environmental impacts such as soil pH and plant growth factors (Department of Health WA, 2002).

The high dissolved solid content in gray water indicates that it is mainly consists of salts that could increase the salinity and/ or sodicity of soils (Al-Jayyousi, 2003). A soil with high clay content can be more affected by gray water with a high salt content and as a result may become sodic and increase the likelihood of erosion as well as hinder a plant's ability to securely anchor itself. Also a soil with high salinity can severely reduce a plants' ability to take up water and nutrients (Singer & Munns, 1996).

Additionally, the influence of gray water-related salinity and other pollution problems in soil may also contaminate groundwater supplies and influence other geographic locations far away from the source of the pollution, thus having a much wider effect (Emmerson, 1998).

If many households within the same geographic location reuse gray water on gardens then collectively the possible adverse environmental affects described above will be more widely exacerbated if soil types and groundwater conditions were greatly affected by the pollution levels in the gray water.

However, these adverse environmental consequences are highly variable as a result of the variable quality and quantity of gray water reused, the variability of soil conditions, the variability of groundwater conditions and the variability of climatic conditions such as rainfall. These highly situational and geographic conditions make the determination of these environmental factors very difficult and may only be realised over the long term (Emmerson, 1998). Thus if a problem does occur, it may be realised when it is too late or more difficult to abate.

The relatively low levels of microbial contamination of gray water can be effectively processed by the bacteria within soil (Jeppesen, 1996). However, if untreated gray water was stored on the soil surface (i.e. ponding) or were released as droplets to the atmosphere, (i.e. spray irrigated) the high availability of oxygen could potentially increase pathogen colony numbers rapidly and substantially increase the risk of disease from human contact as well as become breeding areas for mosquitos and other vermin.

The nitrogen and phosphorous levels in gray water will generally provide essential nutrients for plants, having a positive environmental effect and may reduce or ameliorate the requirement for fertiliser on many gardens and parks (EPA Victoria, 2004), which can create adverse affects such as toxic run-off during rainfall events.

The environmental strains caused from the recent Bangladesh droughts and the generally accepted global climate changes have altered the political and social factors that hinderes the acceptance of gray water reuse in urban areas. However, public health must be addressed and maintained to gain general community acceptance of gray water reuse as part of Government water saving policies and guidelines.

Whilst gray water reuse has positive broad environmental sustainability affects, the specific environmental consequences of its application are as yet not fully determined.

Also, although the costs of the technologies associated with gray water reuse systems have reduced considerably, further cost savings may be realised in reduced or postponed public infrastructure and if the true cost of potable water supply is realised (PWC, 2000).

Chapter-3

QUANTIFICATION OF GRAY WATER

3.1 Introduction

Initially, an understanding of the current factors surrounding the issues of gray water and its reuse possibilities in urban environments were gained by reviewing relevant overseas policy frameworks, guidelines and their supporting reports. To determine the actual amount of gray water produced from households, questionnaire surveys were performed at different parts of Dhaka city. This Chapter presents the structure of the questionnaire, the procedure for the collection of household gray water related data and the results of the questionnaire survey. In the questionnaire survey, the household characteristics where survey was performed, water supply system in the households and its problems, the sources and quantity of gray water and their disposal method were determined and lastly peoples perception towards reuse of gray water for toilet flushing and other simple household works was evaluated.

3.2 Questionnaire Survey

The questionnaire survey provides information relating to the possible design and implementation of a system for treating gray water in the communities of the Dhaka city. Semi-structured questionnaire interviews were undertaken in different areas of the city. Rather than attempting to collect an exhaustive list of problems as already determined in previous water crisis related studies, this sociological part of the study was attempted to collect gray water related data and to identify the community's perception and choices to reuse gray water.

The semi-structured interviews were specifically aimed to:

- ✓ Assess the current situation in terms of gray water generation and management in different area of Dhaka city.
- ✓ The quantification of water uses for different domestic purposes mainly by questionnaire survey and by direct measurement in some cases.

- ✓ Evaluate the community's perception about environmental and health risks linked to reuse of gray water for the selection of the treatment process.

The collection of information was done in different areas of Dhaka City. It combines results from a series of about hundred interviews and from direct observations.

The questionnaire used in this survey is presented in Appendix-A. It combines questions and observations used by the interviewer and were completed during the time of the interviews. Four main themes constituted the questionnaire:

a) Household characteristics,

b) Access to hardware,

c) Waste (Gray) water disposal and

d) Level of perception of the risks.

For quantitative questions such as the amount of water consumed per day estimates were made in terms of the number of buckets used per day. In order to highlight the beneficial or inhibiting environment for a local gray water disposal system, the occupants were asked about previous experiences of sensitization campaigns and participation in any water association.

3.2.1 Household Characteristics

Survey was done mainly to gain knowledge about the families. The number of residents, their economic status and general condition are determined in this section. This survey was done in different areas of Dhaka city i.e. Bashabo, Motijheel, Shahjahanpur, Madartek, Kallyanpur, Shyamoly, Uttara, Banani. This study comprises data collected from people who live in buildings. Slum dwellers were not included in this study. The number of children and there age is specially included in this study, because little children's wet clothes get washed and their faeces gets mixed up with gray water which makes it difficult to treat.

3.2.2 Access to Hardware

In this section data was collected to know the source of water supply in the household mainly to calculate the total amount of water required for each household per day. Waste generation and disposal for each household; number of toilet, their location; method of children faeces disposal data were also collected. This data helped us to know about their status and if the gray water produced is contaminated by this waste.

3.2.3 Waste (Gray) Water Disposal

This is the main and most important part of the survey. The total amount of gray water production for each household, their sources, the time of most gray water generation, their disposal method and their characteristics data are gathered in this section. The amount of soap or washing powder used, to produce this gray water is also determined. The quality of gray water depends on how much soap or washing powder is used.

3.2.4 Level of Perception of the Risks

This study helped us to know if the people are aware of gray water related risks or it's reuse perspectives. The acceptance of gray water reuse and recycle to the people is also evaluated in this section.

3.3 Questionnaire Survey Results on Different Areas of Dhaka City

3.3.1 Data Collection

The Questionnaire survey (Shown in Appendix-A) was done in different areas of Dhaka city to asses the general condition of the city's water supply and gray water management system. In this survey building dwellers with a medium income status were mainly targeted to high light the general condition of Dhaka city. The survey was done by door to door interviews and on some occasions by direct observations. The data collected were gathered mostly from the mistresses of the houses who have a clear understanding of their house and their family member's behavior.

3.3.2 Household characteristics

The survey is done on different areas of Dhaka city. This survey comprises data on the number of residents in each family, their occupation, and number of children in the family their age and number of years they are living in the same area.

Table: 3.1 Number of Family's Surveyed in Different Areas

Area	Family's
Kallyanpur	28
Shyamoly	11
Uttara	9
Gulshan & Banani	14
Dhanmondi	7
Bashabo & Madartek	21
Shahjahanpur	10
Total	**100**

This data helps to understand the water requirement and the waste water produced from each household along with their sources. If the family has more people with job then the demand of water and production of waste water gets lower during the daytime because most of the day they spent outside the house. And if the family has babies of age less than 1 year then their water demand and waste water production gets higher. This survey showed that for building dwellers with a medium status, the average number of residence in each household is 4 that means usually every family has at least 1 child to 3 children but more than 3 children is now a days very rare.

The number of children in each household is 2-3. As people's general habit is to live in a friendly and known environment, the occupants were mostly living in the same area for 7-12 years, this data was mainly collected because people who live in a same area for a longer period of time has a clear knowledge about the merits and demerits of water supply system of the area.

Table: 3.2 Household Characteristics

Item	Number
Total No. of Households Surveyed	100
Avg. No. of Residents in each Households	4
Avg. No. of Children in each Households	2-3
Avg. No. of Occupants with Job in each Households	1-2
Avg. No. of Years for the families living in the Same Area	10

The survey was done on 100 families in different part of Dhaka city. As shown in Table: 3.1, the average number of occupants in each family is 4 including an average number of children (under five years of age) are 1 and total no. of children is 2-3. The occupants have been living in the area for an average of 10 years.

3.3.3 Access to Hardware

DWASA’s water supply pipe network was the main source of water for the households. However because of some problems with leaks or broken pipes and mainly the irregularities of WASA's water supply, tube wells also became an important source of water for those with piped water. Moreover, due to the fact that DWASA's water supply is not meeting the demand, most of the buildings in Dhaka have a high horse power water pump tapped in their main water supply system and at the time of water crisis they use this pump to fill their underground water tank to get water for their requirement. This unreliability of the water source made it difficult to determine accurately the water consumption for some of the households. The reading of the water meters are also not accurate because during water crisis most of the time people get water from hand pumps (every area has one or two hand pumps installed in there area) or from neighbors.

Table: 3.3: Per Capita water consumption per day

Sources for Per capita water use each day.	Amount in liter	Amount in %
Washing Dish	10	6.84
Laundry	22	15.04
Bathing and Washing	48.5	33.16
Cleaning house	7	4.78
Prayer	3	2.05
Cooking and Drinking	11	7.52
Basin	6.6	4.51
Car Wash	0.14	.097
Toilet	38	26.1
Total	**146.24**	**100%**

As shown in the Table: 3.2 the average quantity of water required for one person calculated was approximately 146 l/day. The amount of water for each source shown in the table is average amount calculated from the data collected during the survey. Depending on availability of water and nature of a person this quantity can be as low as 90 l/day to as high as 210 l/day. This water consumption calculated is not only for drinking, bathing and toilet purposes but for all the uses for a person in a whole day. Regarding sanitation, most of the families have two toilets in their house with some exceptions. All the toilets were located inside their dwellings. Solid waste was collected at regular intervals from houses by private companies. Comments about the problems of smell and general unsightliness generated from waste dumping sites on the street were added by the inhabitants. It is clear from the information gathered that water supply service was not acceptable in terms of quality, quantity and access in most of the cases.

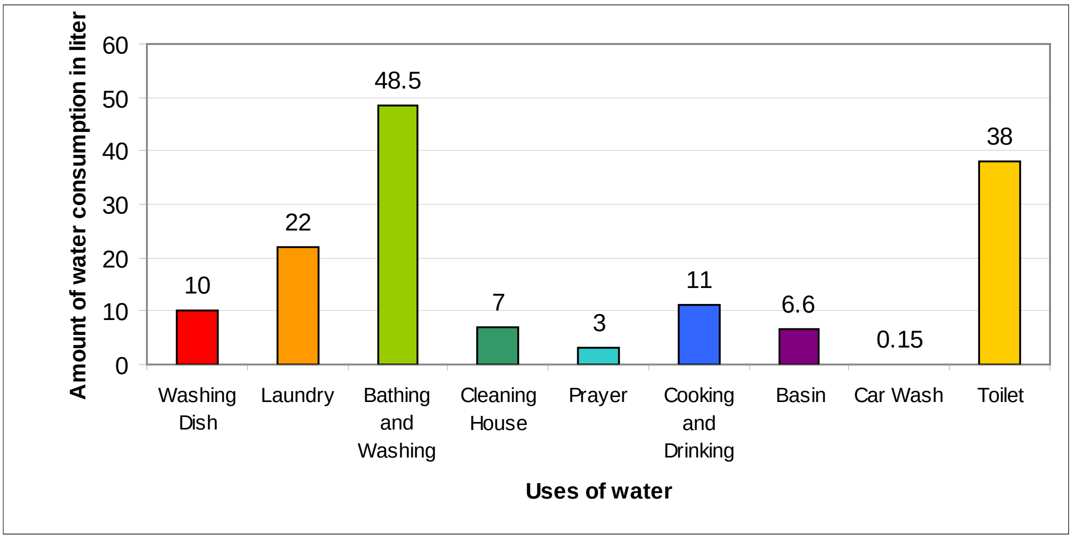


Figure-3.1: Per capita per day water consumption for different purposes at households.

The graph above shows the per capita water consumption per day for different purposes at households. The source of highest water used by one is bathing and washing, then toilet followed by laundry. Car wash has the lowest amount because only a few families own a Car. But the above graph is a average for all the family members under survey.

3.3.4 Gray Water Production and Disposal

As for the quantification of gray water production it was very hard to get the actual amount in liters because nobody could tell the real amount produced in liters. The quantity was measured by just taking the number of buckets of water used for each purpose and their sizes.

From the data collected under this section at first the residents of Dhaka city were divided into two classes i.e. class-1 and class-2. The families who have a higher economic status are in class-1 and families with a medium economic status are in class-2. In this regard the average per capita gray water production is 82.5 l/day for class-1 people and 98 l/day for class-2 people. The difference is because at higher standard living people use washing machine, closed door air conditioned environment and vacuum cleaners which requires less cleaning involving water. And comprising both results for general condition the amount of per capita gray water production for per person is 95 l/day. Again these results are calculated taking average value of each gray water source this value can be as low as 50 l /day to as high as 120 l /day depending on supply waters availability, weather condition and each person's hygienic behavior.

Table: 3.4 Per capita gray water production per day.

Sources for Per capita Groy water production each day.	Amount in liter	Amount in %
Washing Dish	10	10.49
Laundry	22	23.10
Bathing and Washing	48.5	51.00
Cleaning house	7	7.35
Cooking	1	1.04
Basin	6.6	6.93
Car Wash	0.15	0.16
Total	**95.25**	**100 %**

The sources of gray water for households are washing dish, laundry, bathing, and cleaning house, cooking, car washing and basin. The production of gray water from each of these sources is shown in the chart below. It shows that bathing and washing generates the highest amount of gray water followed by laundry and dish washing. The time of most gray water produced from household is in the morning session and before lunch. In responses to questions related to the disposal of their gray water (or reuse) were relatively homogenous. All the gray water and waste water are disposed in piped drains or septic tank. Average no. of soap used monthly is 4; Shampoo is one bottle, Toothpaste one tube, washing powder 2-4 kg. The figures below show results of the gray water survey.

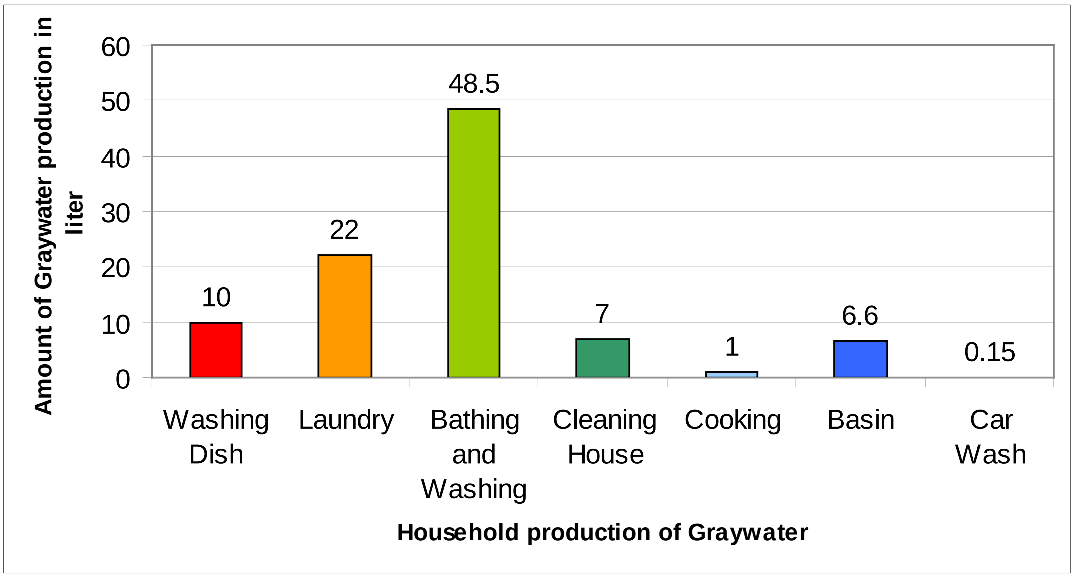


Figure-3.2: Gray water production from household per capita per day.

The graph above shows the gray water production from different sources of household Per capita per day. Bathing has the highest production of gray water and then laundry followed by dish washing.

3.3.5 Level of Perception of the Risks

In this part people's knowledge about gray water and their perception towards gray water reuse possibility is evaluated. Many people are aware of gray water related risks or it's reuse perspectives, but most of the people do not think gray water related risks for the environment is a major thing. Some of them are really knowledgeable about this prospect and knows how to reuse gray water for other purposes. Generally most of the interviewees know that gray water contaminates environment and harmful to health but they are not clear about this pollution. When the crisis for supply water is acute then some people (about 35% of total family surveyed) even reuse gray water produced from laundry for toilet flushing, some people use this laundry gray water for gardening. Many interviewees asked the method for treatment and reuse of gray water because they suffer greatly during water crisis. Toilet flushing is the most acceptable reuse method for recycled gray water. But if the water supply is adequate then none of them agreed to reuse gray water for any purpose.

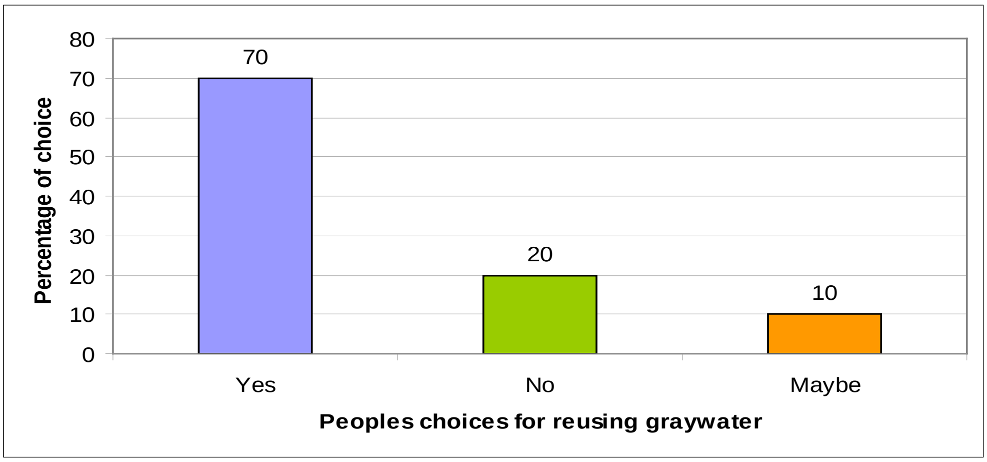


Figure-3.3: Peoples perception towards gray water reuse

About 70% of total people surveyed agreed and are willing to reuse gray water at the time of acute water supply crisis, 20% said they do not want to reuse gray water for any purposes and about 10% expressed their dilemma about reusing gray water. But the fact remains that if the water supply is adequate they will not reuse gray water for any purpose.

3.4. Conclusions

Based on the questionnaire survey results, the following conclusions can be drawn:

1. DWASA's water supply is not at all adequate regarding consumers demand and the water supply and drainage system in Dhaka city must be improved.

2. Concerning household characteristics as determined by the survey, the average number of occupants in each family is 5 including an average number of children (under five years of age) are 1 and total no. of children is 2-3. The occupants have been living in the area for an average of 10 years.

3. The average quantity of water required for one person is approximately 146 l/day and depending on availability of water and nature of a person this amount can be as low as 90 l/day to as high as 210 l/day

4. The average quantity of gray water production for per person is approximately 95 l/day. This value can be as low as 50 l /day to as high as 120 l /day depending on different causes.

5. Bathing and washing generates the highest quantity of gray water which is approximately 50 l/day followed by laundry 22 l/day per person.

6. The time of most gray water produced from household is in the morning session and before lunch.

Chapter-4

CHARACTERIZATION OF GRAY WATER

4.1 Introduction

After the quantification of gray water generated from household the quality of gray water produced from different sources like laundry, bathing, basin was determined by Turbidity, Total Dissolved Solid, Suspended Solid, Biochemical Oxygen Demand, Chemical Oxygen Demand and Feacal Coliform tests. These tests were also done using tap water from which this gray water was generated.

4.2 Testing of Gray Water Samples

Several tests were done to determine the quality of gray water from different household sources. These tests were TDS, TSS, BOD, COD, Turbidity and FC. The gray water samples collected during the experimental investigation were analyzed for these parameters following Standard methods. The main sources of household gray water were laundry, bathing and basin water which were taken for the determination of quality and the other sources were excluded because either they had little generation rate or their quality needed more complex treatment, i.e. like washing dishes had oily and organic substances and laundry black water had more mud or dusty substances, which made them difficult to treat in a simple setup. A brief description of the gray water samples that were collected for quality testing is as follows.

4.2.1 Description of Gray Water Samples

Laundry black water, is generated when the clothes are put in a bucket mixed with washing powder and water that is kept for half to one hour onwards to wet the cloths and clean properly. Laundry mix water, is produced during the whole process of washing the clothes excluding the laundry black water. Bath water is produced from bathing with soap or without soap. Basin water is simply the water generated from basin use like brushing, hand and face washing but excluding other waters like dish washing which contains oil in them.

Raw water is the water directly taken from the tap. The quality of gray water was evaluated by the tests TDS, TSS, BOD, COD, Turbidity and FC.

Among the samples tested, 5 sets of samples contained soap, shampoo and detergents whereas 2 sets of samples did not contain those cleaning agents.

4.3 Results and Discussion

As mentioned the quality of gray water was determined by doing the BOD, COD, TDS, TSS, FC and Turbidity tests following standard methods in the Environmental Engineering laboratory of BUET. The qualities as determined by these tests are shown graphically and discussed in this section.

4.3.1 Variation of BOD_5 Results

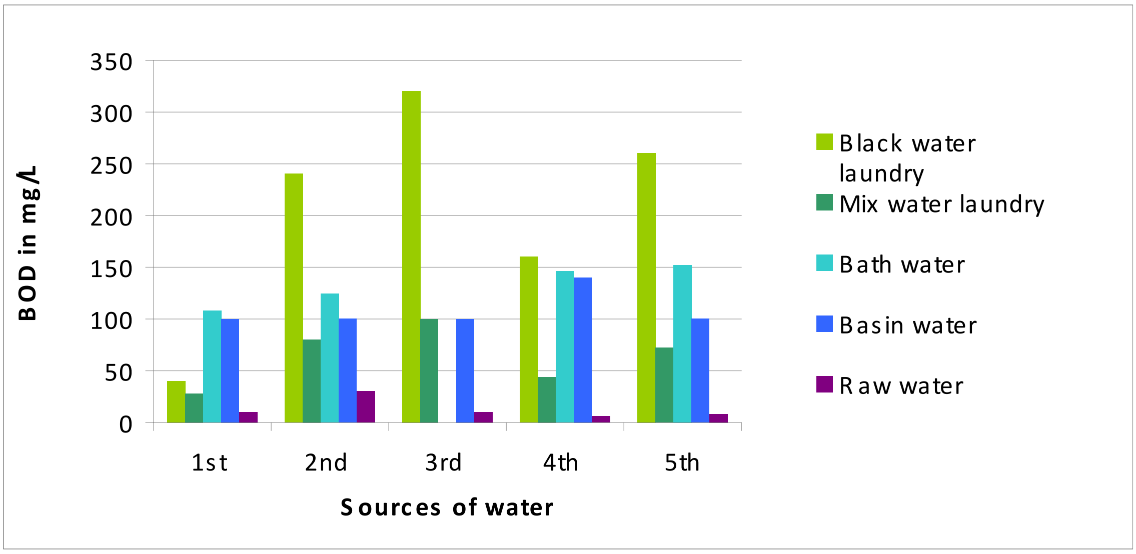


Figure- 4.1: Graphical representation of BOD_5 test results

BOD_5 tests were done separately on Laundry Black water, Laundry Mix water, Bath water and Basin wash water, the main sources of domestic gray water. Raw water (water directly taken from tap) was also tested for BOD_5 just to make comparison with other gray water sources. Five sets of samples were analyzed for BOD_5. As seen in the Fig- 4.1 the BOD_5 results are highest in most of the cases for the Laundry Black water as it contains the highest amount of organic matter. But for laundry gray waters (both black and mixed) the result is not stable as it always varies with the type and no of clothes washed, the process of washing clothes, the quantity of water used and also on the amount of soap or detergent used. The Second highest BOD_5 value is for the Bath water. In the third test unfortunately there was some problem with the sample of Bath water while performing tests and the BOD_5 and COD result could not be taken. Unlike laundry water, the BOD_5 values of Bath water and Basin water are relatively stable. Laundry Mix water has the fourth highest organic matters and as expected Raw water has the lowest BOD_5 results. The average BOD_5 values are 204, 65, 133, 108 and 13 mg/l for black laundry water, mix laundry water, bath water, basin water and raw water respectively.

4.3.2 Variation of COD Results

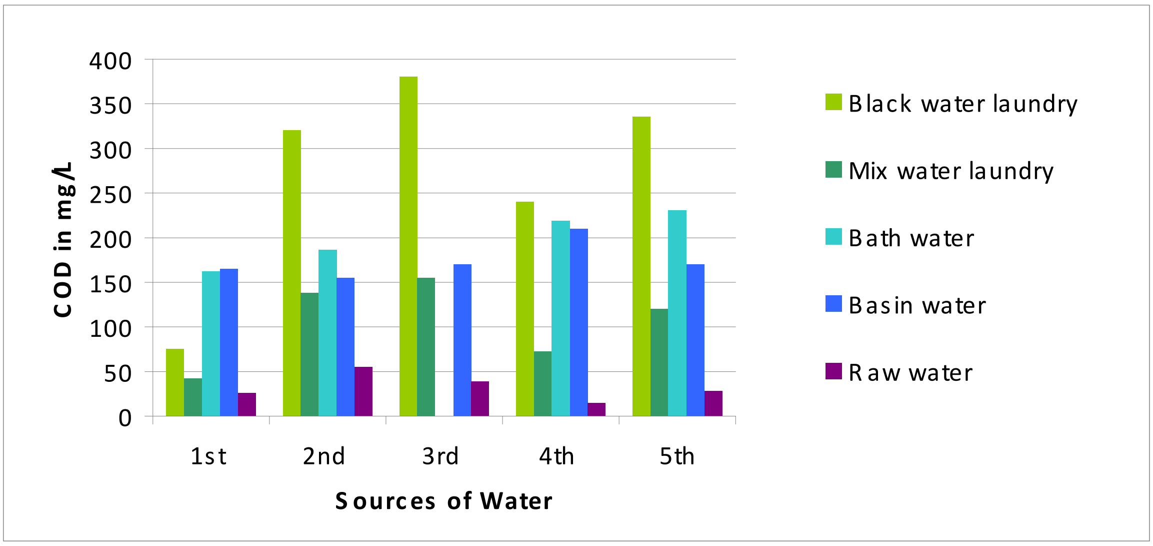


Figure- 4.2: Graphical representation of COD test results

COD tests as BOD_5 were also done separately on Laundry Black water, Laundry Mix water, Bath water, Basin wash water and Raw water. COD results are related to BOD_5 results and the graph is almost similar to that of BOD_5 graph, only the COD results are a little higher for each sample. The average COD values are 270.5, 106, 200, 174 and 33 mg/l for black laundry water, mix laundry water, bath water, basin water and raw water respectively.

4.3.3 Variation of Turbidity Results

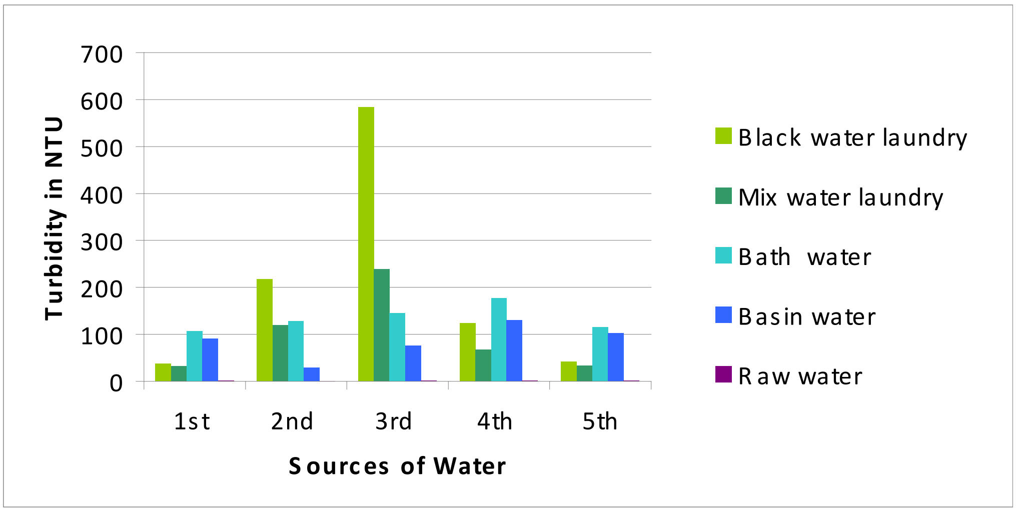


Figure- 4.3: Graphical representation of Turbidity test results

Again Turbidity tests were done on Laundry Black water, Laundry Mix water, Bath water, Basin wash water (the main sources of domestic gray water) and on Raw water. The results are shown in the Fig- 4.3. As seen in the Figure the turbidity results are not at all stable or constant for any of the gray water samples. Depending on the type and no of clothes washed, the process of washing clothes, the amount of water used and also on the amount of soap or detergent used the turbidity results change at every wash. As turbidity is caused by individual particles (Suspended Solids), the results indicate that laundry waters and Bath water has the highest particle contents followed by basin water and lastly raw water. The average turbidity values are 200, 98, 135, 86 and 1.5 NTU for black laundry water, mix laundry water, bath water, basin water and raw water respectively.

4.3.4 Variation of FC Results

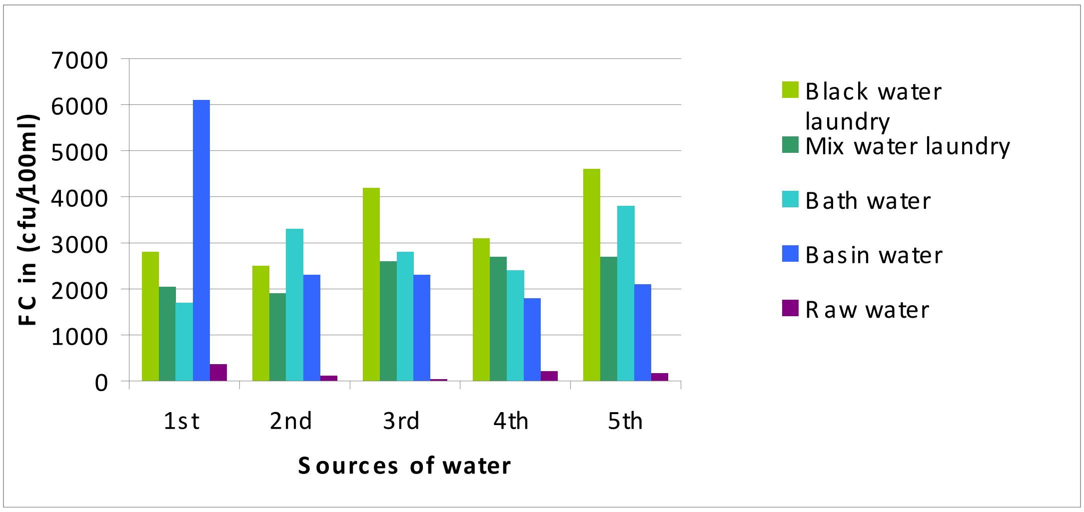


Figure- 4.4: Graphical representation of FC test results

FC tests were also done on all the selected sources. The results are shown in the Fig. 4.4. As the results depend on the Fecal Coliform content, the graph represents that laundry black water generally contains the highest fecal coliforms. The second is bath water, laundry mix water is third highest then consecutively basin gray water is fourth and raw water is at the bottom as expected. Again the results are not at all stable or constant for any of the gray water sample, as we can see at the first set of test the highest was basin gray water and in the second test bath water has the most fecal coliform content. In the 1st set of samples the basin water that was collected contained more FC then any of the other results because an amount of kitchen waste water was added but in the other tastes the kitchen waste water was excluded. This variation in results indicates that the gray water that mostly came in contact with human contains the highest coliforms. The result that Raw water (collected directly from the supply system) also contains fecal coliforms is very disturbing because the data is not very small it goes as high as 370 (cfu/100 ml) and the average comes (180 cfu/100 ml) which shows that the quality of our supply water is very poor. The average FC values calculated are 3440, 2350, 2800, 2920 and 180 cfu/100 ml for black laundry water, mix laundry water, bath water, basin water and raw water respectively.

4.3.5 Variation of Suspended Solids Results

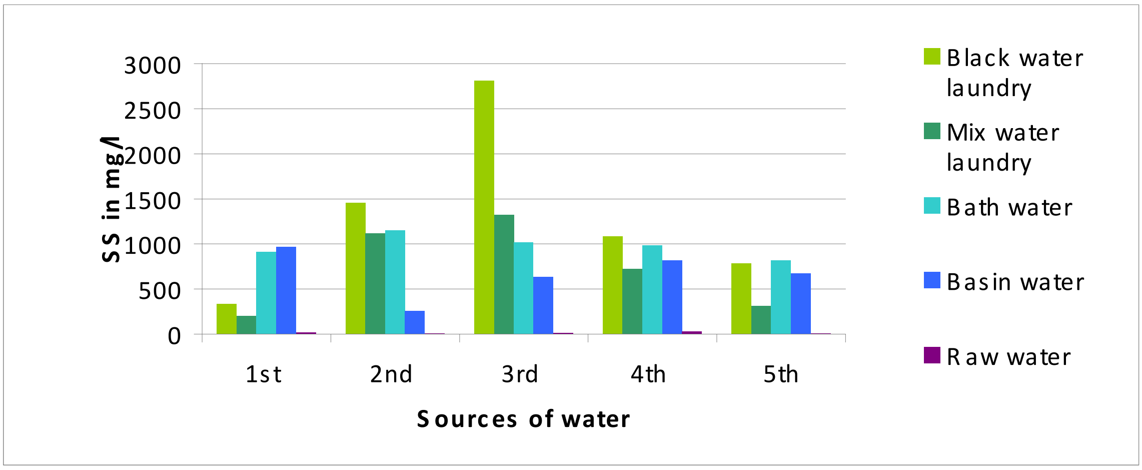


Figure- 4.5: Graphical representation of S.S test results

S.S tests were also performed on each selected sample, as suspended solids content is related with turbidity, the resultant graph is similar to that of the turbidity graph. The data collected shows that the results are not stable and changes at every wash. Depending on the type and no of clothes washed, the process of washing clothes, the amount of water used and also on the amount of soap or detergent used the S.S results change at every wash. As caused by individual particles (Suspended Solids), the average S.S values calculated are 1296, 737, 978, 672 and 17 mg/l for black laundry water, mix laundry water, bath water, basin water and raw water respectively.

4.3.6 Variation of BOD_5 Results Without Cleaning Agents

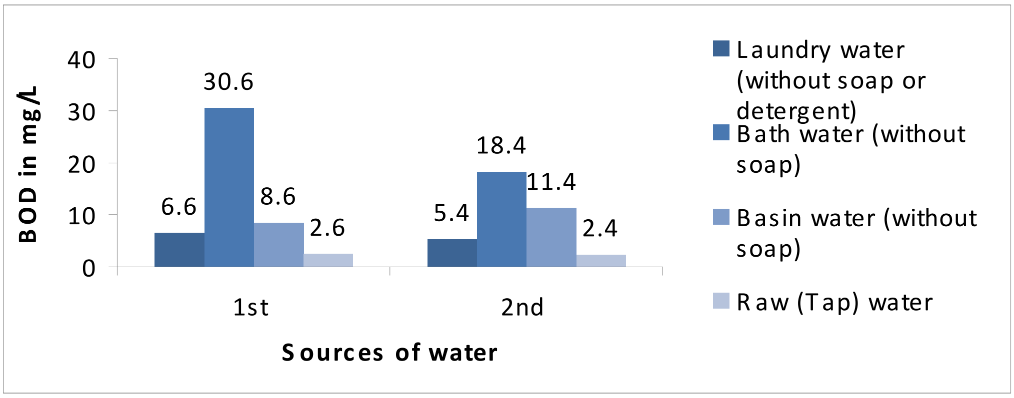


Figure- 4.6 Graphical representation of BOD_5 test result without cleaning agents

The BOD_5 tests were done on Laundry water, Bath water, Basin water and raw water. The results BOD_5 tests for domestic gray water without cleaning agents are shown in Fig. 4.6. It reveals that the values are much lower than the samples which contain cleaning agents. Bath water contains the highest amount of biodegradable organic matter; basin water is the next and then comes the laundry water. The absence of soap, detergent or shampoo is responsible for low release of organic matter from cloths and human body. The average BOD_5 values without cleaning agent, calculated are 6, 24.5, 10 and 2.5 mg/l for laundry water, bath water, basin water and raw water respectively.

4.3.7 Variation of COD Results Without Cleaning Agents

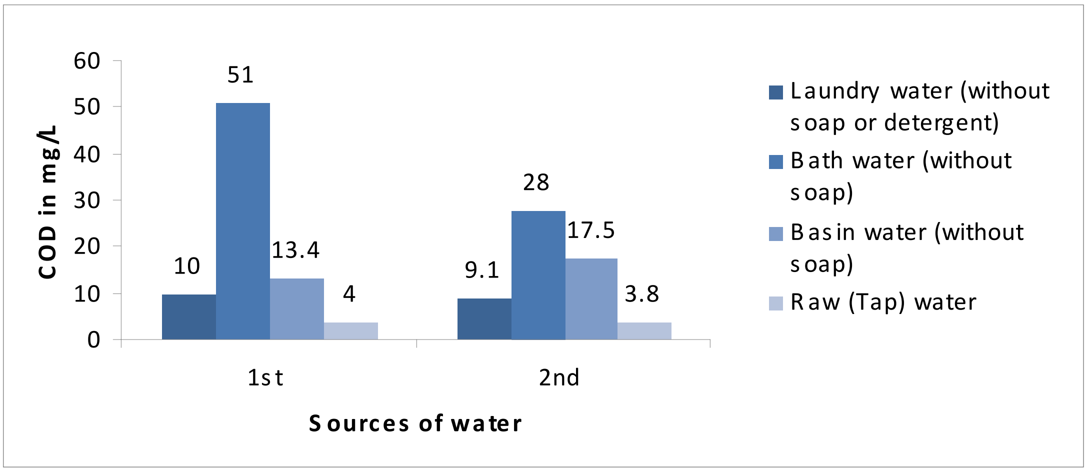


Figure- 4.7 Graphical representation of COD test result without cleaning agents

COD tests were also done on the samples. As COD results are related to BOD_5 results and the graph is almost similar to that of BOD_5 graph. The COD results for the gray water samples without cleaning agents are shown in Fig. 4.7. Similar to the BOD_5 results the values are much lower than the samples which contain cleaning agents. The average COD values without cleaning agents, calculated are 9.5, 40, 15.5 and 4 mg/l for laundry water, bath water, basin water and raw water respectively.

4.3.8 Variation of Turbidity Results Without Cleaning Agents

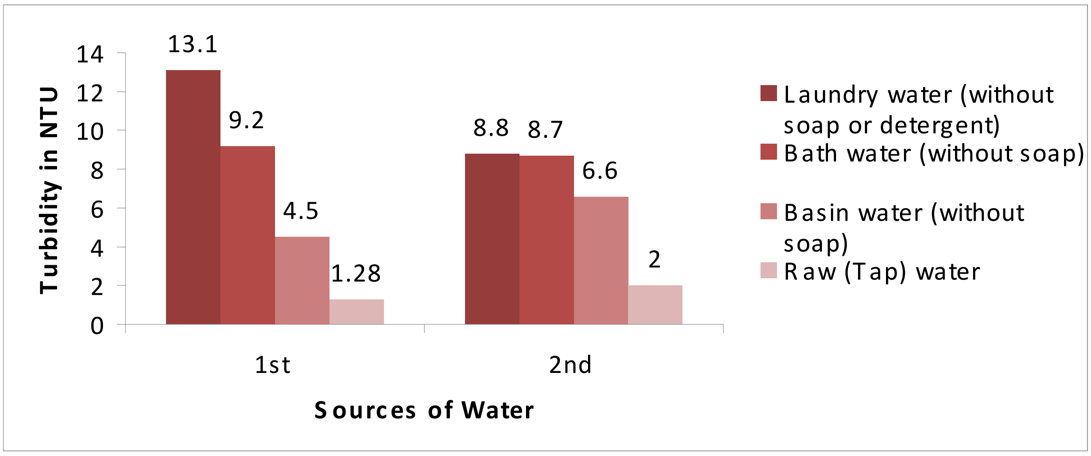
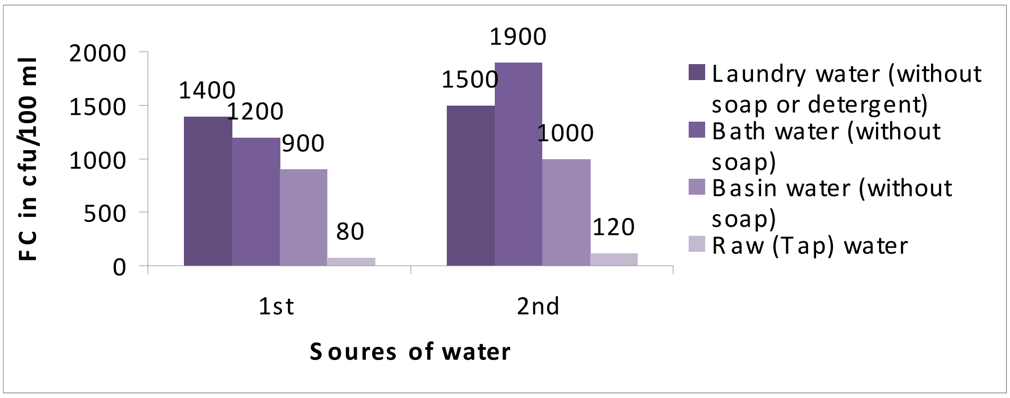


Figure- 4.8 Graphical representation of turbidity test result without cleaning agents.

Turbidity tests were also done on Laundry water, Bath water, Basin water and Raw water. The results are shown in the Fig- 4.8. As turbidity results are depended on the solids content of the sample the results indicate that without the use of any kind of cleaning agent the resultant washing cleans less effectively and thus contains very low solids. The process of washing clothes, bathing and washing hand without any cleaning agent is same so the results of the two sets of sample are very much similar. Laundry water generally contains highest suspended solids so it has the highest result for turbidity. After that bath water and basin water samples have the second and third highest results. The average turbidity values without cleaning agents, calculated are 11, 9, 5.5 and 2 NTU for laundry water, bath water, basin water and raw water respectively.

4.3.9 Variation of F.C Results Without Cleaning Agents



<u>Figure- 4.9 Graphical representation of F.C test result without cleaning agents</u>

The F.C tests were also done on Laundry water, Bath water, Basin water and raw water. The graph shows that the results are different for the two set of tests done on the samples. In the first test set the highest in fecal colifirm content is laundry water, bath and basin water samples are second and third highest. But for the second set of samples bath water is highest and laundry water is second highest. The duration time for human contact and the presence of human body wastes usually determines the fecal coliform content results. The result indicates that Laundry water, Bath water, Basin water contains very high amount of the fecal colifirm regardless if the washing process includes cleaning agent or not. The average F.C values without cleaning agents, calculated are 1450, 1550, 950 and 100 cfu/100ml for laundry water, bath water, basin water and raw water respectively.

4.3.10 Variation of S.S Results Without Cleaning Agents

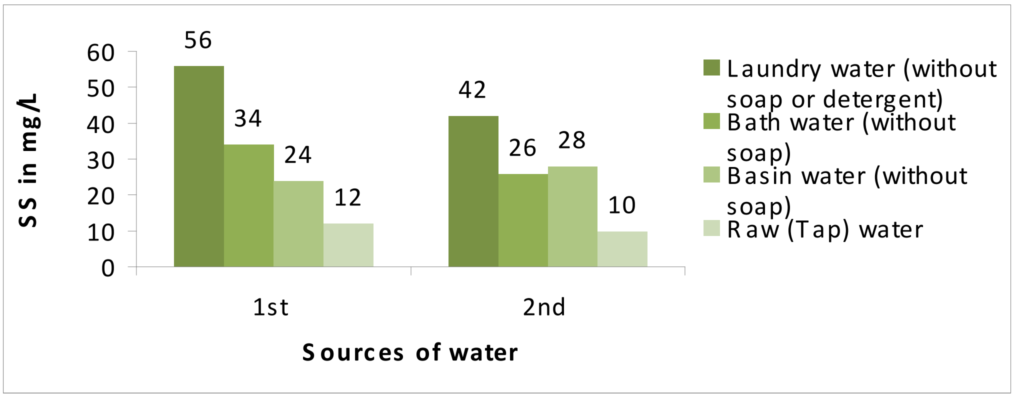


Figure- 4.10 Graphical representation of S.S test result without cleaning agents

The Fig. 4.10 above shows the S.S results of the two set of samples. The data indicates that without the use of any cleaning agent the resultant wash water contains very low suspended solids comparing with the results of fig. 4.5. This result clarifies that without a cleaning agent the washing only with water is not very efficient for removing suspended solid particles. Depending on the suspended solids content, the graph suggested that laundry water contains the highest amount. Bath and basin water comes next. The average suspended solids values without cleaning agents are 49, 30, 26 and 11 mg/l for laundry water, bath water, basin water and raw water respectively.

4.4 Reusing Gray Water for Toilet Flushing and Laundry

The quality determined by tests showed that for Bangladeshi environment to reuse gray water for toilet flushing the most simple and cost effective way is to disinfect the gray water by using bleaching powder.

Due to high likelihood of human contact with this reuse application, disinfection is required. However, for laundry washing it is more desirable to lower the turbidity and neutralise the pH of the gray water during the treatment process. A tertiary treatment system would provide this higher reuse quality, but the costs are higher and mostly suits multi-dwelling scales where these higher costs can be shared.

Gray water reuse for toilet flushing offers significant water savings, however if a gray water reuse system requires upgrading to a secondary treatment level only for this purpose (i.e. only require a primary system for garden watering), it can be cost inhibitive.

An alternative from using or upgrading to a secondary gray water treatment system is to use a combined hand wash/ cistern system (Ludwig, 1994). This is a proprietary product and is used extensively in Japan. It is shown in Figure 2.10 and involves locating a wash basin that is supplied by mains water and located directly above the toilet cistern. It is an integral part of the cistern structure and the gray water waste from the wash basin drains directly into the cistern storage to be used for the next toilet flush. The cistern also uses the mains to top-up if the washbasin gray water does not fill the required flush storage.

Effective and efficient gray water treatment systems designed to Government regulations and guidelines can be utilised for single and multi-dwellings. The variety of treatment processes available allow site specific determining factors such as topography, soil, climate and building designs a well as different cost budgets and reuse applications to be accommodated. Single dwelling gray water reuse systems are most adaptable for retrofitting to existing building sites.

Biological treatment processes can be more effectively utilised for multi-dwelling gray water reuse systems and the occupants of these dwellings generally do not have as much demand for garden watering/ irrigation. However, kitchen waste can be included and the quality of the treated gray water produced from biological treatment can be applied for toilet flushing and laundry applications in addition to irrigation.

Maintenance is critical to ensure that public health is kept a priority concern. While all gray water treatment processes include a sewer overflow/ diversion system to guard against treatment and public health failure, all of the gray water reuse systems defined requires regular maintenance to operate efficiently and effectively for the applications they are designed.

To alleviate this key concern, maintenance should be carried out by trained operators on a regular basis. The scope of this task would include gray water treatment system.

4.5 Conclusions

- The quality of gray water determined is not stable. It always varies depending on a number of causes. The quality of bath water and basin water is comparatively stable than the other sources. But the quality of laundry water always varies. The quality of gray water changes almost at every wash.

- The average BOD_5 values are 204, 65, 133, 108 and 13 mg/l for black laundry water, mix laundry water, bath water, basin water and raw water respectively.

- The average COD values are 270.5, 106, 200, 174 and 33 mg/l for black laundry water, mix laundry water, bath water, basin water and raw water respectively.

- The average turbidity values are 200, 98, 135, 86 and 1.5 NTU for black laundry water, mix laundry water, bath water, basin water and raw water respectively.

- The average FC values calculated are 3440, 2350, 2800, 2920 and 180 cfu/100 ml for black laundry water, mix laundry water, bath water, basin water and raw water respectively.

- The average S.S values calculated are 1296, 737, 978, 672 and 17 mg/l for black laundry water, mix laundry water, bath water, basin water and raw water respectively.

- The average BOD_5 values without cleaning agent are 6, 24.5, 10 and 2.5 mg/l for laundry water, bath water, basin water and raw water respectively.

- The average COD values without cleaning agents are 9.5, 40, 15.4 and 4 mg/l for laundry water, bath water, basin water and raw water respectively.

- The average turbidity values without cleaning agents are 11, 9, 5.5 and 2 NTU for laundry water, bath water, basin water and raw water respectively.

- The average F.C values without cleaning agents are 1450, 1550, 950 and 100 cfu/100ml for laundry water, bath water, basin water and raw water respectively.
- The average suspended solids values without cleaning agents are 49, 30, 26 and 11 mg/l for laundry water, bath water, basin water and raw water respectively.
- For bath and basin water it depends on certain factors like the time for washing or bathing, surplus ness of water, the amount of water used and the amount of soap and shampoo used for washing. If the amount of water used is high in single wash then the quality of gray water regarding test values of BOD, Turbidity, S.S and F.C will be low. On the other hand if less water is used then the value will increase. Contrarily the quantity of gray water will increase if the amount of soap/ shampoo used is higher and the value will be lower if the amount of soap used is lower. For basin water if more oily substances are washed then its quality will be more complicated to treat.
- Quality of gray water from laundry sources depends on the quantity of clothes washed, quality of clothes like whether the clothes are cotton, linen, silk, gabardine, jeans or mixed types etc. Some form of clothes attracts more dust or gets dirtier than the other forms. The quantity of soap and detergent powder used and their quality plays an important role in the quality of laundry gray water.
- In general the quality of gray water always varies depending on the methods used during washing, people’s choices of soap/ detergent/ shampoo use, the quantity of soap/ detergent/ shampoo and the amount of water used in each wash.
- The quality of the gray water produced without use of soap, shampoo or detergent is better and does not changes as much as the other gray water (using soap, shampoo or detergent) and it can be reused for simple purposes like toilet flushing, and gardening.

Chapter-5

TREATMENT OF GRAY WATER

5.1 Introduction

The tests for determining the quality of gray water (FC, Turbidity, BOD, COD, TDS, TSS, TS) yielded that it contains high amount of organic matter and large number of fecal coliforms that needs to be treated before reusing.

For the treatment of gray water, our main objective was to develop and test a simple cost effective gray water treatment system for in house recycling for laundry and toilet flushing. The most simple and cost affective gray water treatment procedure is chlorination and sand filtration to remove bacterial substances and suspended solids. To determine the dosing of chlorination, tests were performed on different types of gray water and prepared gray water samples and finally a rate was determined at which gray water can be treated. The first consideration was to reduce the turbidity of gray water by settling but no matter how long the settling time is taken the turbidity of gray water does not come to the required level. So Coagulation and Flocculation tests were done and a successful rate of coagulation and settling time was determined to treat gray water.

Thus the most simple method used for treating gray water for house hold recycling can be:

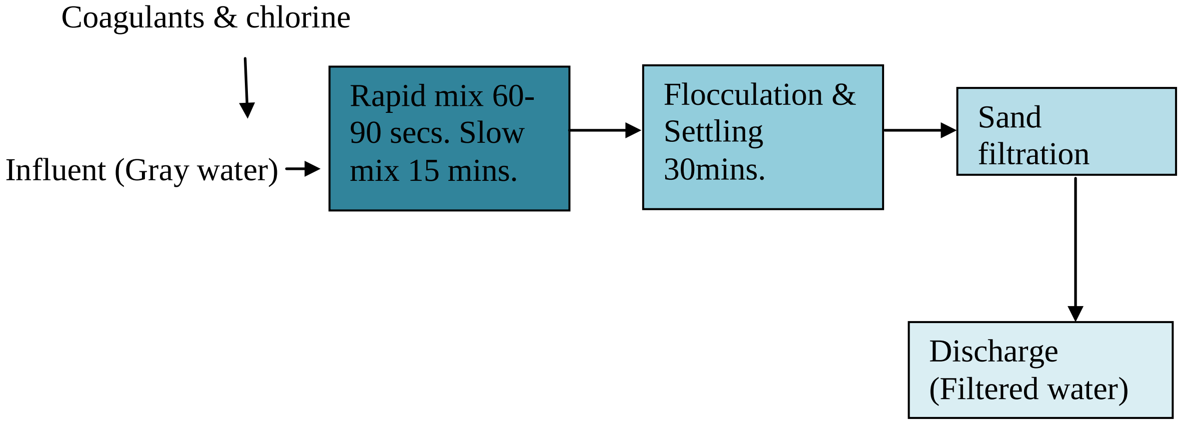


Figure- 5.1: Simple design layout used for gray water treatment.

This simple system allows storage of gray water and includes disinfection and coagulation treatment to avoid further contamination of gray water during storage. In order to produce efficient disinfect, the gray water must be reasonably clarified and/ or filtered. So the sand filtration is used. Sand filtration can reduce BOD_5 and COD loading as well as reduces turbidity, which aids the disinfection process.

5.1.1 Prepared Gray Water Sample

Our goal is to treat gray water from domestic households. To collect and treat domestic gray water, at first a general sample is taken, which is a mixture of different types of gray water. This prepared gray water sample is produced by different sources based on their generation rate and quality. Experiments are conducted on prepared gray water samples. The quality of this prepared gray water sample is also determined to make further comparison with the filtered water.

5.1.2 Preparation of Prepared Gray Water Sample

The sample of prepared gray water is simply the mixture of bath water, laundry water and basin water. Since the data collected during the questionnaire survey shows that the bath, laundry and basin water is the main source of gray water generated from a household. The sample is prepared by mixing this sources by the percentage at which they are generated from the households. Table: 5.1 shows the gray water production from households.

Table: 5.1 Gray water production from household (All sources)

Source of G.W	Amount in %	Amount in liter
Washing dish	10.39%	**3893**
Laundry	23.21%	**8698**
Bathing	51.00%	**19109**
Cleaning house	7.24%	**2715**
Cooking	1.04%	**390**
Basin	6.95%	**2605**
Car wash	0.15%	**56**
Total	**100%**	**37466**

Table: 5.2 Gray water production from household (Only laundry, bathing and basin)

Source of G.W	Amount in %	Amount in liter
Laundry	28.60%	**8698**
Bathing	62.94%	**19109**
Basin	8.56%	**2605**
Total	**100%**	**30412**

Now excluding the other sources and only taking the bath, laundry and basin water (as shown in Table: 5.2) and assuming the production from this sources as 100% the percentage becomes 64% of bath water, 28% of laundry water and 9% of basin water. The experiments were conducted on 10 liter of prepared gray water sample; therefore it comprises 6.5 liters of bath water, 2.5 liters of laundry water and 1 liter of basin water (as shown in Table: 5.3).

Table: 5.3 Prepared Gray Water Sample

Source of G.W	Amount in %	Amount in liter
Laundry	25.00%	2.50
Bathing	65.00%	6.50
Basin	10.00%	1.00
Total	**100.00%**	**10.00**

5.2 Determination of Chlorine and Coagulant Doses

Several Chlorination and Coagulation tests were done on gray water generation sources which have higher coliform contamination or turbidity. So when a successful rate is determined to treat this water, it is assumed that this rate will be enough for prepared gray water sample to treat.

5.2.1 Determination of Chlorine Dose

To determine the chlorine dose several tests were performed on laundry black water because the quality determined showed that fecal coliform content is highest for laundry black water. Therefore a sample of laundry black water was taken to evaluate the chlorine dosing to remove fecal coliforms. Chlorination tests were done on this sample and a successful dosing was determined.

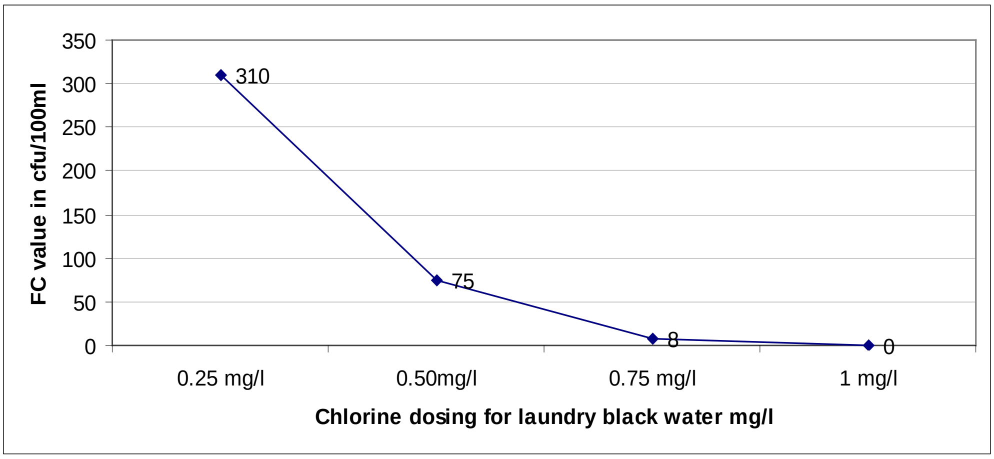


Figure- 5.2: Determination of chlorine dose

The target was to determine chlorine dose which will satisfy the recycle criteria for gray water shown in table 2.1, 0.75mg/l chlorine dosing treated the gray water sample and the FC value content was below 10, therefore this dose was taken as the treatment dosing for chlorine. But when prepared gray water sample was treated with this rate it didn't fulfill the required criteria because the FC content in prepared gray water sample was much greater than laundry black water. Therefore the dosing was increased and required rate was determined as 3mg/l chlorine dosing.

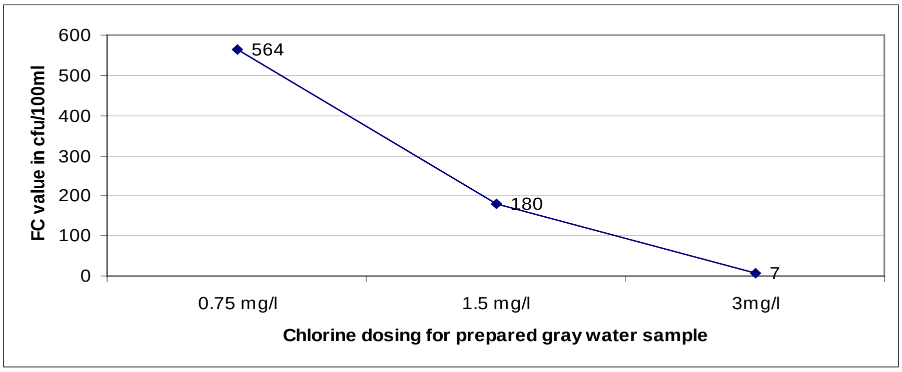


Figure- 5.3: Determination of chlorine dose for prepared gray water sample

5.2.2 Determination of Coagulant Dose

Similarly to determine a successful coagulant dosing to treat gray water several tests were done directly on prepared gray water sample. At first settling test was done on this sample but no matter how much time given the turbidity value never decreased that much.

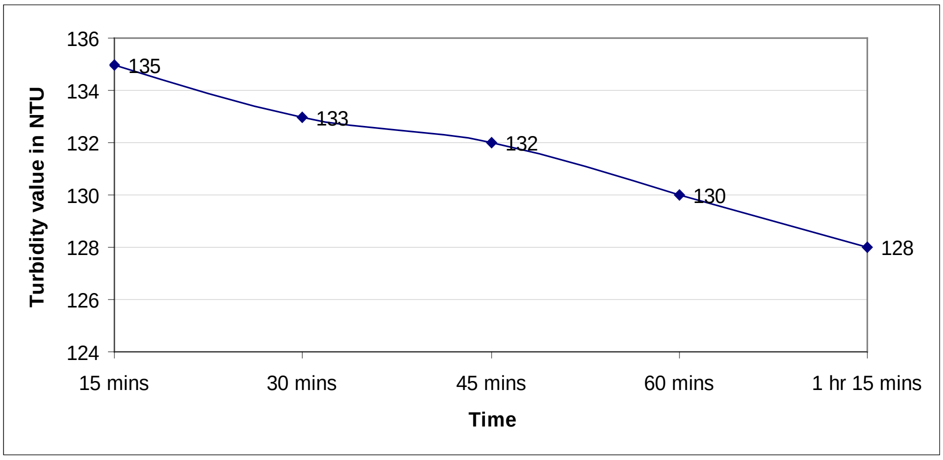
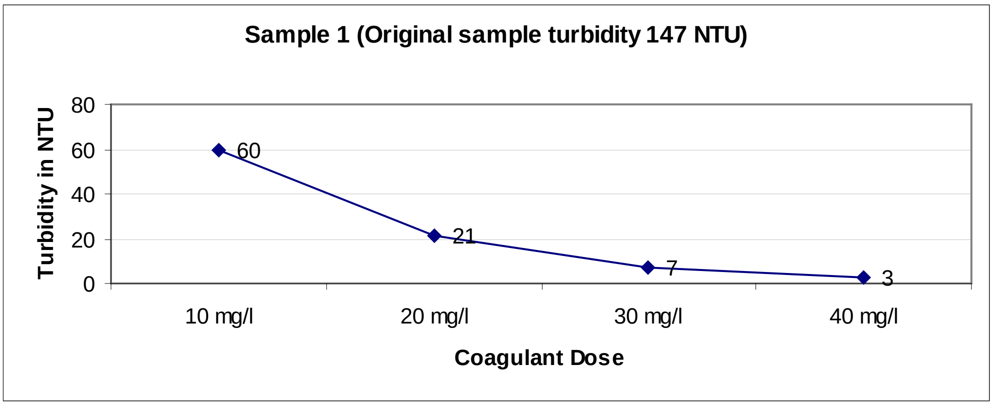


Figure- 5.4: Settling with time for prepared gray water sample

After that aelum Coagulation tests were done on prepared water to bring the turbidity value at a required level. Jar test apparatus set in the BUET Environmental laboratory was used for this purpose. Four tests were done on each sample of prepared gray water. The original turbidity of the sample was first determined then alum solution of 1mg/1ml was made and added in the four samples at different doses. The four samples were then rotated at 45 rpm for 1 minute and 25 rpm for 15 minute in the Jar test apparatus and then settled for 15 minutes. After that the turbidity of each value was measured. Several tests were performed on different samples and a successful alum dose was evaluated.



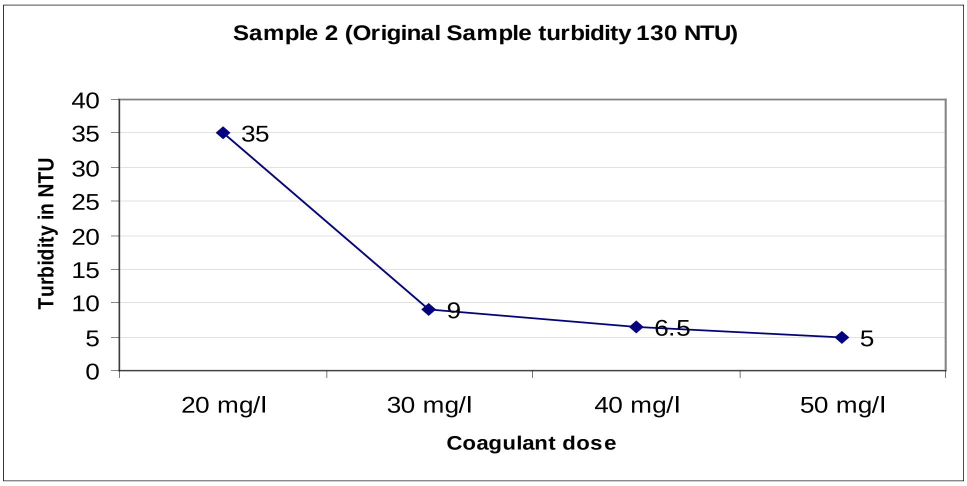


Figure- 5.5: Determination of coagulant dose for prepared gray water sample

5.3 Gray Water Treatment

A treatment system that will be most acceptable to Bangladeshi Urban residents requires the storage of gray water and then simple treatment by disinfection, coagulation, flocculation and sand filtration. The easiest way of disinfection of gray water is applying bleaching powder in a known rate to lower the F.C content of the gray water. To reduce the turbidity of gray water to reuse for laundry and toilet flushing can be achieved by adding alum in the gray water during storage and just stirring it to flocculate. The time gray water remains in the storage tank will help settling the flocs in the bottom of the storage tank. After ½ to 1 hour will be enough for settling and then the water from the tank excluding the bottom layer is passed through a sand filter for additional reduction of turbidity and F.C of the gray water. Using sand filtration the BOD, COD content of gray water is also reduced. The removal of BOD, COD, F.C, S.S and Turbidity is achieved by using this simple treatment setup.

The most simple gray water treatment procedure is coagulation, chlorination and sand filtration. The F.M of sand in which the gray water sample is filtered is 2.37. Rate of filtration is 1146ml/min/ft^2. Settling time of gray water sample after coagulation and chlorination and before filtration is 30 minutes. Contact time is 30 minutes.

5.4 Experimental Setup

After both chlorination and coagulation rates were determined, a simple test setup was established in the Environmental Engineering Laboratory of Civil Engineering Department, BUET. The experimental setup is shown in fig: 3.1. Locally available materials were used to construct the experimental setup. It consists only a bowl, a bucket, sand, pipe, filter pipe and tap. The bowl (feed tank) is about 25-liter capacity and to obtain sufficient head it is placed on a high platform above the bucket.

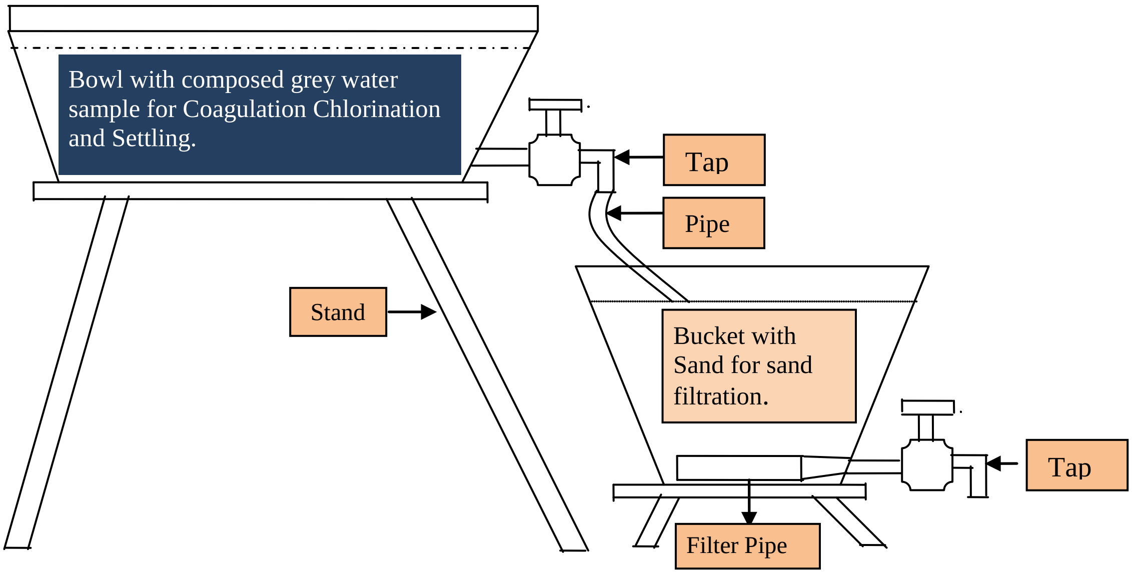


Figure: 5.6 - Simple gray water treatment setup

The Bowl is a very important part of the treatment setup; it acts both as a feed tank and storage tank. The treated gray water flows from the bowl to the lower bucket via plastic pipe and the flow is controlled by a tap fitted slightly above the bottom of the bowl to avoid inflow of settled flocs in the lower bucket in which sand filtration will occur. The lower bucket is 25-liter capacity and consists (3/4th filled) sand for sand filtration. At the bottom of the bucket a filter pipe is placed and a plastic pipe is attached with this filter pipe to allow the filtered water flow out of the bucket. There is another tap fitted slightly above the bottom of the bucket attached with the filter pipe to initiate the flow of filtered water from the bucket. From this tap treated and filtered water is collected.

5.5 Treatment Procedure

The sample of prepared gray water is at first taken in the bowl and the turbidity of this sample is measured. Then for coagulation and disinfection both alum (1mg/1ml) solution and chlorine (0.250 mg/1ml) solution is added in the sample at a rate of 30mg/l (30ml/l) and 3mg/l (12ml/l) (for laboratory) respectively. The alum and chlorine solution are mixed manually with the sample water in the bowl by vigorously stirring the sample water with a wooden stick for 60 to 90 seconds and then by gentle stirring for about 15 minutes. The mixed water is then allowed to settle for half an hour. During the time of settling the bowl must be covered so that the sample should be untouched of any human contact and outside dust should not get mixed with the sample. After settling the turbidity is measured because for sand filtration the turbidity unit must be less then 30 NTU. When desired turbidity is achieved then the tap attached with the bowl is opened and a pipe passes the settled upper layer of the sample by gravity pressure to the lower bucket of sand for filtration. The sand in the bucket must be clean and cleared of vegetation and other harmful materials. The bucket is $3/4^{th}$ full of sand at the bottom of the bucket there is a filter pipe that is attached to the tap. The sample gray water is passed through this sand filter bed and after filtration the filtered water was collected by opening the tap attached with the bucket. Then the quality of this treated gray water is determined and compared with the original sample.

After a couple of tests hot water must be passed through the sand to kill the fecal coliforms remained in the sand and this method should be repeated to keep the sand clean of coliforms.

Then BOD, COD, TDS, SS and FC tests were done on this collected filtered water, and also this same tests were done on the sample gray water and tap water to compare their quality. The quality of the treated sample is than compared with standards and criteria guidelines given in table: 2.1. After several tests the quality matched with the standards and a level of simple cost effective treatment system was determined.

5.5.1 Treatment Procedure for Household Environment

The experimental setup shown in figure: 5.6 can be used in any household environment. The material that comprises the setup is very easy to purchase from any sanitary hardware store and can be easily build and operated. The chemicals like alum used for treatment can be bought from chemical stores and for chlorination bleaching powder is used which is available in all areas.

Step 1:- At first the setup should be established at an indoor space. The stands shown in the figure is not that necessary because the collection bowl can be kept on a higher level on any kind of unused furniture. Just keep the bowl at a higher level connect a tap at the lower part of the bowl (2 inch above the bottom) and then connect a flexible plastic pipe of small dia in this tap whose open end should discharge the water at another bucket which should be kept lower than the bowl. 3/4th part of the bucket must be filled with sand preferably with Sylhet sand. A filter pipe should be at the bottom of the bucket which is connected with another tap attached at the lower part of the bucket (1.5 inch above the bottom) from which filtered water can be collected.

Step 2:- Any person who wants to treat gray water have to take water at the bowl. Alum and bleaching is found in powdered form. So 30 mg of alum and 10 mg of bleaching powder should be added for each liter of gray water to be treated. After adding the powder the gray water should be stirred or rotated to mix the chemicals with the gray water thoroughly. A wooden stick or a big spoon can be used for this purpose. First the gray water sample should be rotated very quickly for 60 to 90 seconds and then slowly rotated for 15 minutes; this will mix the sample with the chemicals perfectly. After that the sample should be kept untouched for at least 30 minutes or more for settling. The alum will react and flocs will be settled at the bottom. During the time of settling the bowl should be covered with a lid.

Step 3:- After settling and the water is much clear than before. The tap attached with the bowl is opened and water is discharged (without the bottom layer of water containing flocs in the bowl) to the sand filled bucket for sand filtration. After discharging for about 1 minute the tap attached with the bucket is opened and filtered and treated water can be collected.

5.5.2 Maintenance

The maintenance of the setup is very easy. The bowl where the treatment is done must be clean and should be washed properly. The connection pipes should be kept clean also. After a few treatment operation is done the sand filter bed gets clogged and doesn't perform smoothly, so after a few operation hot water can be poured in the sand bucket and passed through the sand this will make it clean and clear. Scrapping the upper layer of the sand in the bucket and stirring the sand bed with hand or with a stick will also remove the clogs. Backwashing can be done but this operation is very complicated to perform in household level.

5.5.3 Cost of Gray Water Treatment

The total cost of constructing this unit is about Tk. 1700/- The cost of chemical per liter is around Tk. 0.005/-. This cost calculated is only for a single household dweller and if this setup is established in a wide range basis like at a building for all the residents then the setup cost will be increased because plumbing, sanitary construction and pump cost will be included with this estimate.

Detailed breakdown of the cost is provided in Table 5.4 and Table 5.5.

Table 5.4 Estimated cost of the household gray water treatment setup

Items	Quantity	Price (Tk.)	Remarks
25 liter bucket+lid	2 pc.	320.00	
Collection bowl	1 pc.	140.00	
Tap	2	90.00	
Spoon	1 pc.	10.00	
Jam Nut	2 pc.	20.00	
Washer	4 pc.	16.00	
Strainer	1 ft	50.00	
Stopper Cap	2 pc.	20.00	
Connecting Pipe (1 cm dia)	2 ft	30.00	
Sand (Sylhet sand)	1 cft	15.00	
Wooden Stirrer	1 pc.	25.00	
Others	L. S.	100.00	
Sub-total		836.00	
Stand (Wooden- Optional)		850.00	
Total		1686.00	

Cost of Alum powder is 500 gm Tk. 60/-
Cost of Bleaching powder is 500 gm Tk. 70/-
Taking strength as approximately 33% it will take about 10mg/l of bleaching powder.

Table 5.5 Cost of chemical per liter of treated water

Items	Quantity	Price (Tk.)	Remarks
Alum (commercial grade)	30 mg/l	0.0036	
Bleaching powder	10 mg/l	0.0014	

The operating cost of treated water was Tk. 0.005 per liter.

5.5.4 User Acceptance

Information about user acceptance was gathered from discussion with people during questionnaire survey. The questionnaire is presented in Appendix A. Many people showed interest about this kind of setup and asked more about the treatment process for reusing gray water and whether the quality of the treated water can be acceptable for reusing. Most people reuse gray water at the time of water crisis for simple purposes like toilet flushing and gardening. When we informed them about the simple operation and maintenance of the setup and that gray water generated from laundry or bathing can be reused for laundry again they were very willing to know more. We assured that this treated water is not for drinking just for other household purposes which made this setup very acceptable to them. About 70% of people that we surveyed agreed to reuse gray water at the time of acute water supply crisis. But the fact remains that if the water supply is adequate they will not reuse gray water for any purpose.

5.5.5 Recovery Rate

From the survey data collected the total water consumed by 100 families is 57684 liter. The total gray water produced from 100 families is 37466 liter which is about 65% of total water consumed. Gray water generated from bathing, laundry and basin which is targeted for the recycle and reuse purpose, comprises about 80% of total gray water produced and about 50% of total water consumed. Therefore if this water is treated and reused then the deficit between DWASA's water supply can be greatly reduced and the DWASA's water

5.6 Results and Discussion

5.6.1 BOD_5 Test Results Before and After Treatment

Prepared Water = Mixture of domestic gray water (Bath water = 63%, Basin water = 9% and Laundry mix water = 28%).

Treatment

Dosing Alum = 30mg/l.
Dosing Cl_2 for 1st Test = 0.75mg/l.
Dosing Cl_2 for 2nd to 5th Test = 3 mg/l.
Settling time = 30 minutes before filtration.

Table-5.6: BOD_5 test results before and after treatment

Samples	BOD_5 in mg/l				
	1st Test	2nd Test	3rd Test	4ht Test	5th Test
Prepared Water before treatment	129	104	113.4	96.6	224.4
Prepared Water after treatment	13	8	10.4	6.6	9.4
Tap Water	1.8	1	2.4	1.8	0.4

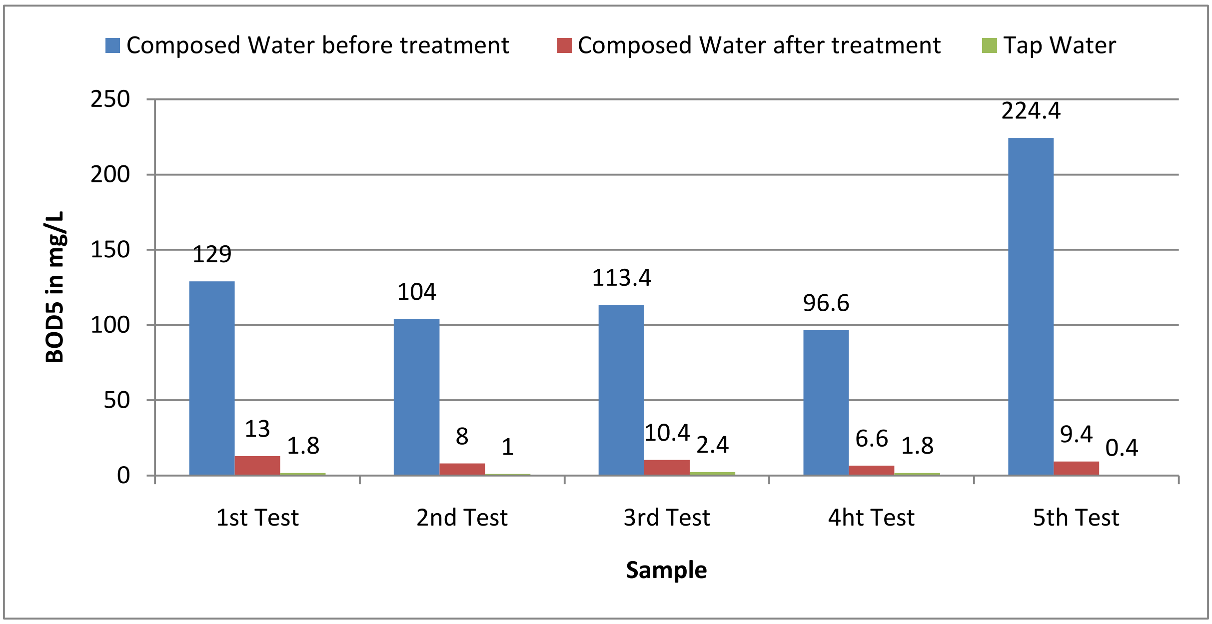


Figure 5.7: Graphical representation of BOD_5 test results before and after treatment

The results above represents that the value of BOD_5 of the Prepared gray water sample is very high before the treatment and after the treatment procedure using alum coagulation, flocculation, settling and sand filtration, it reduces to a very low value, so thus indicates that it is very effective in reducing the BOD content of gray water. This process remove large amount of suspended solid particles which account large part of BOD in the effluent/waste water. When coagulation and flocculation experiments were done in the gray water the BOD load content is reduced because at the addition of alum in the gray water, it reacts with the dissolved solids of gray water and creates flocs and by stirring this mixed gray water flocculation occurs and the flocs get bigger. After half an hour of settling these flocs gets separated from the gray water and accumulates in the bottom of the storage tank, thus the BOD load of gray water is reduced. In addition to this when this gray water is passed through the sand filtration bed the BOD load is more reduced because the organic contents gets stuck in the sand and removed from the gray water. The average BOD_5 values are 133.5, 9.5 and 1.5 mg/l for prepared gray water sample before treatment, prepared gray water sample after treatment and raw tap water respectively.

As BOD is often used as a robust surrogate of the degree of organic pollution of water the reduction of BOD of the gray waste water thus indicates that this process can be very effective for controlling water pollution also.

5.6.2 COD Test Results Before and After Treatment

Prepared Water = Mixture of domestic gray water (Bath water = 63%, Basin water = 9% and Laundry mix water = 28%).

Treatment

Dosing Alum = 30mg/l.
Dosing Cl_2 for 1st Test = 0.75mg/l.
Dosing Cl_2 for 2nd to 5th Test = 3 mg/l.
Settling time = 30 minutes before filtration.

Table-5.7 COD test results before and after treatment

Sample	COD in mg/l				
	1st Test	2nd Test	3rd Test	4ht Test	5th Test
Prepared Water before treatment	188	175	200	127	158
Tap Water	9	7	8	7	5
Prepared Water after treatment	36	24	52	13	27

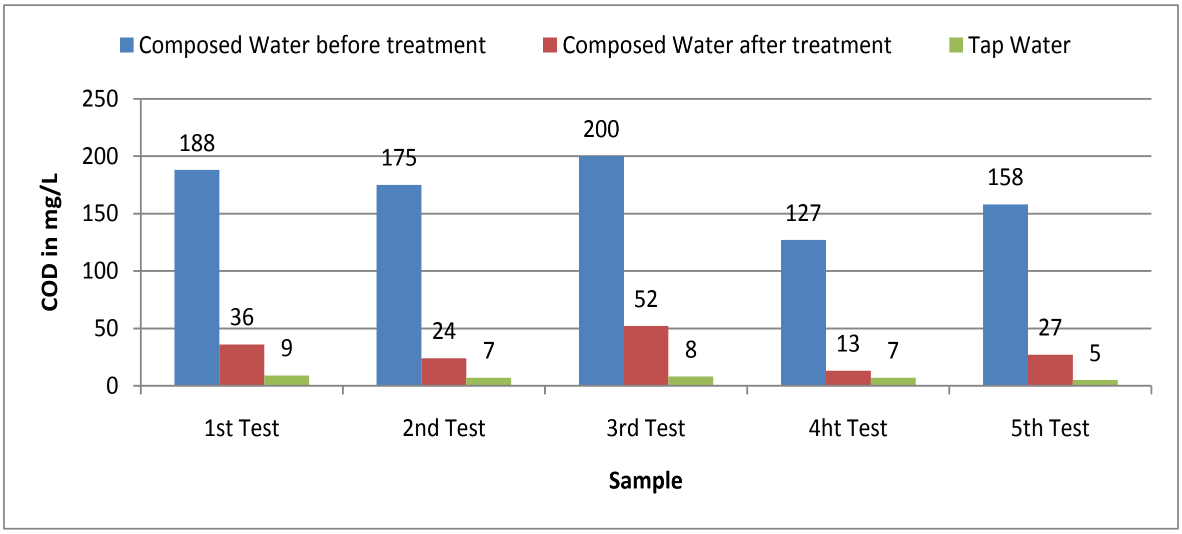


Figure 5.8: Graphical representation of COD test results before and after treatment.

BOD and COD results are related and the graphs are similar. As like BOD_5, the results above represents that COD value was very high before the treatment and after it reduced to a very low value, so the experiment showed that it is very effective in reducing the COD content of gray water also. The average COD values are 170, 30.4 and 7.2 mg/l for prepared gray water sample before treatment, prepared gray water sample after treatment and raw tap water respectively.

5.6.3 Turbidity Test Results Before and After Treatment

Prepared Water = Mixture of domestic gray water (Bath water = 63%, Basin water = 9% and Laundry mix water = 28%).

Treatment

Dosing Alum = 30mg/l.
Dosing Cl_2 for 1st Test = 0.75mg/l.
Dosing Cl_2 for 2nd to 5th Test = 3 mg/l.
Settling time = 30 minutes before filtration.

Table-5.8: Turbidity test results before and after treatment

Sample	Turbidity in NTU				
	1st Test	2nd Test	3rd Test	4th Test	5th Test
Prepared Water before treatment	80	70	87	73	110
Prepared Water Before filtration After Settling	16	9	20	15	19
Prepared Water After filtration	3.5	2.6	7	5.4	4.8
Tap Water	2.6	2	1.7	1.5	1.7

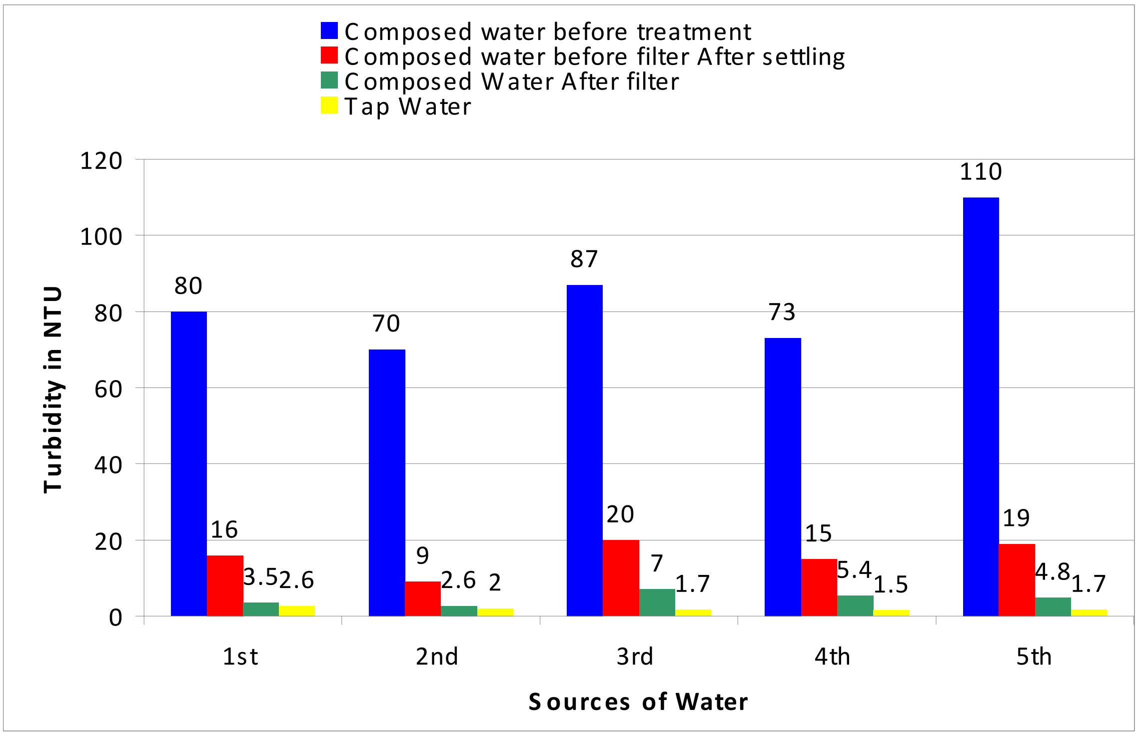


Figure 5.9: Graphical representation of turbidity test results before and after treatment.

The graph shows that the value of turbidity is high before the treatment and after the treatment procedure using alum coagulation, flocculation, settling and sand filtration, it reduces to a very low value. Gray water samples contain suspended solid matter consisting of particles of many different sizes. While some suspended material will be large enough and heavy enough to settle rapidly to the bottom of the container if a liquid sample is left to stand (the settable solids), very small particles will settle only very slowly or not at all if the sample is regularly agitated or the particles are colloidal. These small solid particles cause the liquid to appear turbid. When alum is added to the prepared gray water sample, the aluminum ion hydrolyses by reactions that consume alkalinity in the water. The gelation of hydroxide thus formed carries suspended materials with it as it settles. The turbidity should be less than 30 NTU before it is passed through the sand filter bed therefore turbidity results were measured just before filtration. This process remove large amount of suspended solid particles. Removal of solid also reduces turbidity and from the results it can be seen that the turbidity was reduced less then 30 NTU. Furthermore when this gray water is passed through the sand filtration bed the solid particles is more reduced because the particles the sand acts as filter and removes them from gray water. Thus turbidity is much more reduced. The average turbidity values are 84, 16, 3.3 and 2 mg/l for prepared gray water sample before filtration and settling, prepared gray water sample before filtration and after settling, prepared gray water sample after treatment and filtration and raw tap water respectively.

5.6.4 F.C Test Results Before and After Treatment

Prepared Water = Mixture of domestic gray water (Bath water = 63%, Basin water = 9% and Laundry mix water = 28%).

Treatment

Dosing Alum = 30mg/l.
Dosing Cl_2 for 1st Test = 0.75mg/l.
Dosing Cl_2 for 2nd to 5th Test = 3 mg/l.
Settling time = 30 minutes before filtration.

Table- 5.9: F.C test results before and after treatment.

Sample	F.C (cfu/100 ml)				
	1st Test	2nd Test	3rd Test	4ht Test	5th Test
Prepared Water	15000	14000	53900	26000	36500
Filter Water	564	8	8	2	4
Tap Water	200	480	224	120	44

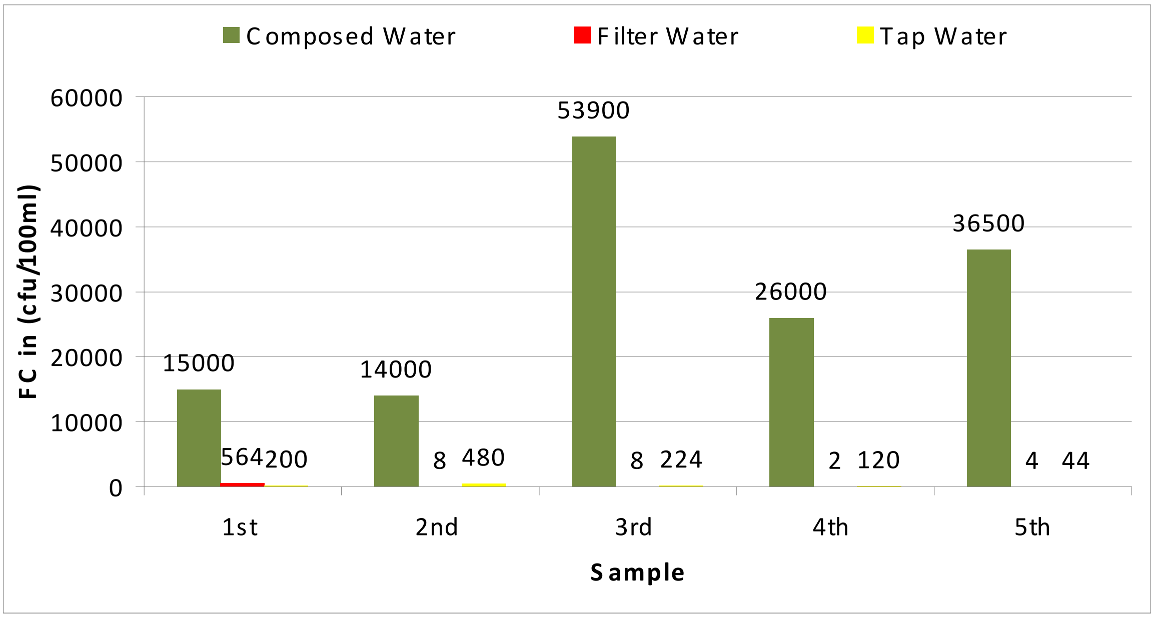


Figure 5.10: Graphical representation of FC test results before and after treatment.

FC tests were also done on all the selected sources. The results are shown in the graph. As the results depend on the Fecal Coliform content, the graph above represents that the value of F.C was very high before the treatment and after it reduced to a very low value, so the experiment was a success in reducing the F.C content of gray water. When Alum is added in the prepared gray water sample, metal ions in coagulation react with virus proteins and destroy viruses from water. When chlorine is dissolved in water it gives HOCl and OCl^- which are known as free available chlorine. Free available chlorine is very effective in killing bacteria which can remove fecal colliform from waste water. When chlorination is done in the gray water the F.C content is reduced because at the addition of chlorine in the gray water it reacts with the pathogens/ coliforms of gray water and kills them. After half an hour of settling these pathogens/ coliforms is reduced and gets clear as the time passes. In addition to this when this gray water is passed through the sand filtration bed the F.C is more reduced because the sand bed helps to reduce the fecal coliforms of gray water. In the 1st test the dosing of Cl_2 was low so after treatment the required level couldn't be reached therefore the dosing of Cl_2 was increased in remaining sets of tests and the resultant data fulfilled the treatment criteria. The FC values for the first 1st set of samples are 15000, 564 and 200 and the average FC values for the first 2nd to 5th set of samples are 32600, 5.5 and 217 cfu/100ml for prepared gray water sample before treatment, prepared gray water sample after treatment and raw tap water respectively.

5.6.5 S.S Test Results Before and After Treatment

Prepared Water = Mixture of domestic gray water (Bath water = 63%, Basin water = 9% and Laundry mix water = 28%).

Treatment

Dosing Alum = 30mg/l.
Dosing Cl_2 for 1st Test = 0.75mg/l.
Dosing Cl_2 for 2nd to 5th Test = 3 mg/l.
Settling time = 30 minutes before filtration.

Table- 5.10: S.S test results before and after treatment.

Sample	S.S in mg/l				
	1st Test	2nd Test	3rd Test	4ht Test	5th Test
Prepared Water	110	130	138	108	266
Tap Water	14	22	40	26	22
Filter Water	10	48	44	30	28

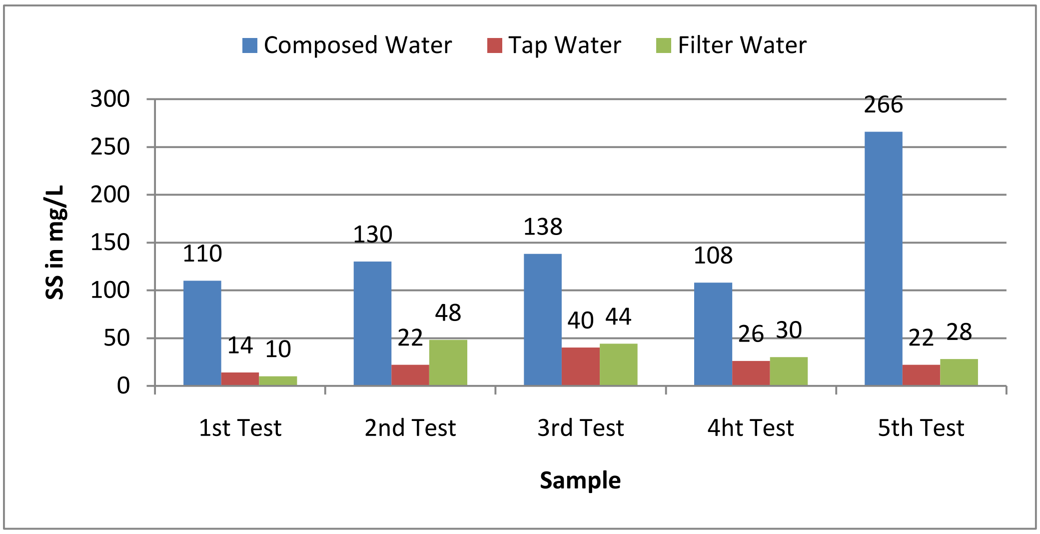


Figure 5.11: Graphical representation of S.S test results before and after treatment.

Turbidity of waste water is depended on suspended solids present in the water. As discussed the reasons of turbidity reduction is exactly similar for reducing SS content of prepared gray water sample. This is followed by disinfection by chlorine to ensure that any free floating pathogens, or pathogens associated with the small remaining amount of suspended solids, are rendered ineffective. The results above shows that the value of S.S was very high before the treatment and after the treatment procedure using alum coagulation, flocculation, settling and sand filtration, it reduces to a very low value, so thus indicates that it is very effective in reducing the suspended solid content of gray water. This was notable that the SS values of tap water and the treated filter water was very similar to one another. The average suspended solids value are 752, 32 and 25 mg/l for prepared gray water sample before treatment, prepared gray water sample after treatment and raw tap water respectively.

5.7 Conclusions

- A treatment system that will be most cost effective and acceptable to Bangladeshi Urban residents requires the storage of gray water and then simple treatment by disinfection, coagulation, flocculation and sand filtration.

- To treat gray water from domestic household, a general sample is taken comprising mixture of different types of gray water. This prepared gray water sample is produced by different sources based on there generation rate and quality.

- Several Chlorination and Coagulation tests were done on bath water because it has the highest generation rate among the gray water sources and also coliform contamination of bath water is higher than others. So when a successful rate is determined to treat bath water it is assumed that this rate will be enough for prepared gray water sample to treat. The rate for Alum Dosing is 30ml/l or 30mg/l. (1mg/1ml solution) and for disinfection dosing Cl2 is 12 ml/l or 3 mg/l. (0.250mg/1ml solution).

- After both chlorination and coagulation rates were determined, a simple test setup was established in the Environmental Engineering Laboratory of Civil Engineering Department, BUET. The experimental setup is shown in fig: 5.1. Locally available materials were used to construct the experimental setup and it is very easy to use in household environment.

- BOD, COD, TDS, SS and FC tests were done on this collected filtered water, and also these same tests were done on the sample gray water and tap water to compare their quality. The quality of the treated sample is than compared with standards and criteria guidelines given in table: 2.1. After several tests the quality matched with the standards and a level of simple cost effective treatment system was determined.

- The average BOD_5 values are 133.5, 9.5 and 1.5 mg/l for prepared gray water sample before treatment, prepared gray water sample after treatment and raw tap water respectively.

- The average COD values are 170, 30.4 and 7.2 mg/l for prepared gray water sample before treatment, prepared gray water sample after treatment and raw tap water respectively.

- The average turbidity values are 84, 16, 3.3 and 2 mg/l for prepared gray water sample before filtration and settling, prepared gray water sample before filtration and after settling, prepared gray water sample after treatment and filtration and raw tap water respectively.

- The average FC values are 32600, 5.5 and 217 cfu/100ml for prepared gray water sample before treatment, prepared gray water sample after treatment and raw tap water respectively.

- The average suspended solids value are 752, 32 and 25 mg/l for prepared gray water sample before treatment, prepared gray water sample after treatment and raw tap water respectively.

- Gray water generated from bathing, laundry and basin which is targeted for the recycle and reuse purpose, comprises about 80% of total gray water produced and about 50% of total water consumed. Therefore if this water is treated and reused then the deficit between DWASA's water supply and demand can be greatly reduced.

Chapter -6

CONCLUSIONS AND RECOMMENDATIONS

6.1 General

The present study focused on developing a simple cost effective gray water treatment system for in-house recycling for laundry and toilet flushing. In order to achieve this, questionnaire interviews were undertaken in different areas of Dhaka city to quantify the classified uses of the supplied water in residential houses. Also the quality of different sources of gray water was determined by laboratory experiments. A simple setup was established in the Environmental Engineering Laboratory, BUET for the treatment of gray water and the experimental data was collected.

6.2 Conclusion:

Based on the results of the present study the following conclusion can be drawn:

1. Average quantity of water required for one person was calculated at 146 l/day. This water consumption rate does not only include drinking, bathing and toilet purposes but also for other uses for a person in a whole day.

2. The quantity of per capita gray water production for per person is 95 l/day.

3. The main source of gray water for per person per day from households are washing dish (9.88 l/day), laundry (21.52 l/day), bathing (49.13 l/day), cleaning house (6.89 l/day), cooking (1.0 l/day), car washing (0.142 l/day) and basin (6.61 l/day).

4. The time of most gray water produced from household is in the morning session and before lunch.

5. The quality determined for domestic prepared gray water sample (Bath water = 63%, Basin water = 9% and Laundry mix water = 28%) shows that average value of BOD is 133.54 mg/l, COD is 169.6 mg/l, Turbidity is 84 NTU, F.C is 32600 nos./100ml and S.S is 150.4 mg/l respectively.

6. For treating gray water, the rate for Alum Dosing is 30ml/l or 30mg/l (1mg/1ml solution) and for disinfection Cl_2 dosing is 12 ml/l or 3 mg/l (0.250mg/1ml solution). Settling time is 30 minutes before filtration.

7. The quality determined for this domestic prepared gray water sample after treatment shows that average value of BOD_5 is 9.48 mg/l, COD is 30.4 mg/l, Turbidity is 4.654 NTU, F.C is 6.4 nos./100ml and S.S is 32 mg/l respectively.

8. The process of treatment is very effective in the removal of BOD, COD, F.C, S.S and Turbidity of gray water. This process is also very simple and cost effective to be used at household environment.

9. The quality determined by tests showed that for Bangladeshi environment to reuse gray water for toilet flushing, the most simple and cost effective way is to disinfect the gray water by using bleaching powder.

10. Presently, the deficit between DWASA's water supply and demand is high and growing day by day, so if we can introduce this kind of setup the deficit will be reduced significantly.

6.3 Recommendations for further study

Based on the findings and experiences of the research work presented in this thesis the following recommendations can be forwarded for future study.

1. This study is targeted towards the building dwellers of Dhaka city having medium income status. It is only a small step in forming a gray water management system. A broad study based on Bangladeshi environment on factors affecting the gray water reuse system like technical feasibility, public health, social acceptability and sustainability can be conducted. These factors can be further contextualized into an environmental framework and can be discussed under social, political and environmental characteristics.

2. Proper storage of gray water is a very important part of gray water treatment system. It is very important that gray water remains untouched of any human contact or any kind of outside particles like air or dust. The design of sanitation system of a building, third pipe system, design of storage tank, their discharge these criteria based on Bangladeshi environment should be well studied and the possibility of improvement of the design can be evaluated.

3. Commercial products (soaps and laundry powders etc) affect gray water quality and can have great effect on garden health, groundwater, soil and the type of gray water treatment technology used. More research can be undertaken on the quality of different kinds of soaps and laundry powders and their effect on gray water quality for reuse.

4. Generally, long-term and broad implications of urban gray water systems are not yet fully understood and paramount to its acceptance is the protection of human health as well as community education and participation in community decision processes. So, further study can be undertaken to understand this matters also.

5. The prolonged application of garden watering and irrigation with gray water on relatively-small urban blocks may have significant environmental effects. The relatively-new acceptance of gray water reuse in urban areas has resulted in a deficiency of long-term studies and therefore an incomplete understanding of the long-term environmental consequences of gray water reuse.

6. The cost calculated in this study is only for a single household dweller and if this setup is established in a wide range basis like at a building for all the residents then the setup cost will be increased because plumbing, sanitary construction and pump cost will be included with this estimate. Further study is required into identifying and quantifying the significance of indirect costs and externalities that result from gray water reuse in urban areas. Although direct costs are identified in the study, there may be additional costs and they must be quantified in order to be realised. Analysis of these costs would complete the full cost benefit analysis and form a suitable basis for a framework to pass these costs back to consumers.

7. Gray water reuse is generally described as a resource conservation strategy by Governments and regulators. However, if gray water is used to supplement current potable water demands and applications, will it result in consumer behavior changes in demand management, which is also the goal of resources conservation? Work should be undertaken to characterize and determine the changes in potable water consumer behavior and the effect of gray water substitution.

References

References :

1. Al-Jayyousi, Odeh R. (2003). “Greywater Reuse: Towards sustainable Water Management”. *Desalination* 156: 181-192

2. Almeida M.C., Butler D. and Friedler E. (1999) : At-source domestic wastewater quality. *Urban Water*, 1 (1999), 49-55.

3. Australia. Dept of Environment, Sport and Territories. (1996). *Australia: state of the environment 1996*. Canberra: CSIRO Publishing.

4. Beavers, P. (1995) *Greywater, An Alternative Water Source*, Townsville: Effluent Reuse and Alternative Treatment Seminar.

5. BUET, CE 332: Environmental Engineering Sessional 1. Bangladesh University of Engineering Technology.

6. Christova-Boal, D. Eden, R.E. & McFarlane, S. (1995) “An Investigation into Greywater Reuse for Urban Residential Properties”. *Desalination* 106: 391-397

7. Clifford White, G. (1972). *Handbook of Chlorine*. USA: Van Nostrand Reinhold Company.

8. Davey Pumps, nd. *Commercial Product Selection Guide No. 2*. Promotional Booklet. Davey Products Pty Ltd.

9. Department of Health WA, (2002) *Draft Guidelines for the Reuse of Greywater in Western Australia*. Perth: Department of Health.

10. Dillon, P J. (2000). Water Reuse in Australia: Current Status, Projections and Research, Adelaide: AWA Water Recycling Forum, Proceedings of the first Symposium, 99-104

11. Dixon, A., Butler, D. & Fewkes, A. (1999). “Water Saving Potential of Domestic Water Reuse Systems Using Greywater and Rainwater in Combination”. Water Science Technology 39[5]: 25-32

12. Dryzek, J.S. & Schlosberg, D. (2003) Debating the Earth. New York: Oxford University Press Inc.

13. DWASA (2005) : *Management Information Report for the Month of February, 2005,* Dhaka Water Supply and Sewerage Authority.

14. Emmerson, G. (1998). Every Drop is Precious: Greywater as an Alternative Water Source. Brisbane: Research Bulletin No 4/98, Queensland Parliamentary Library.

15. EPA Victoria, (2001) Domestic Wastewater Management Series: Reuse Options for Household Wastewater. Victoria: Publication 812.

16. Gardner, E. A. (2003) “Some Examples of Water Recycling in Australian Urban Environments: A Step Towards Environmental Sustainability”. Water Science and Technology 3[4]: 21-31

17. Gardner, T. & Millar, G. (2003). The Performance of a Greywater System at the Healthy Home in South East Queensland – Three Years of Data. UNE: Proceedings of On-site 03 Conference: Future Directions for On-site systems, Best Management Practice.

18. Hunter, D. (2003). Potable Substitution and Externalities: How to Make Recycling Economic. Melbourne: Proceedings from Managing the Changing Colours of Water AWA/ SIAV Joint Seminar.

19. IWM (2007) : *Draft Final Report on Demand Management, Water Abstraction Strategy and Monitoring System, Part II,* Institute of Water Modelling, Dhaka.

20. Jefferson, B. Laine, A. Parsons, S. et al. (1999). “Technologies for Domestic Wastewater Recycling”. Urban Water 1: 285-292

21. Jeppesen, B. (1996) “Domestic Greywater Reuse: Australia’s Challenge for the Future”. Desalination 106: 311-315

22. Jeppesen, B. & Solley, D. (1994). Domestic Greywater Reuse – Overseas Practice and its Applicability to Australia. Brisbane: Res. Report 73 Urban Water Research Association of Australia.

23. Ludwig, A. (1994) Create an Oasis with Greywater. Santa Barbara: Oasis Design.

24. Marks, J S. (2004), “Advancing Community Acceptance of Reclaimed Water”. Water Journal of the Australian Water Association 31[5]: 46-51

25. Melbourne Water, (2004) “Water Sensitive Urban Design: Integrated Water Cycle Tools”. http://wsud.melbournewater.com.au/system

26. Price Waterhouse Coopers (PWC), (2000) Economic Aspects of Water Recycling in Queensland. Queensland: Department of Natural Resources.

27. Radcliffe, J. (2003). Water Recycling in Australia. Victoria: The Australian Academy of Technological Sciences and Engineering.

28. Rose, J.B. Sun, G-S, Gerba, C.P. et al. 1991. “Microbial Quality and Persistence of Enteric Pathogens in Greywater from Various Household Sources”, Water Res. 25[1]: 37

29. Salukazana, L., Jackson, S., Rodda, N., Smith, M., Gounden, T., McLeod, N., et al. (2006). Re-use of grey water for agricultural irrigation. Paper presented at the Third international conference on ecological sanitation

30. Singer, M.J. & Munns, D.N. (1996). Soils and Introduction. New York: Prentice Hall, Inc.

31. Shouler, M., Griggs, J. and Hall, J. (1998). Water conservation. British Research Establishment (BRE)Information Paper, IP 15/98.

32. Surendran S. and Wheatley A. D. (1998) : Gray water reclamation for non-potable reuse. *J. CIWEM, 12, 406-413.*

33. Sydney Water, 2002. Towards Sustainability Report (2002) Summary. Sydney: Sydney Water.

34. Tchobanoglous, G., Burton, F.L. & Stensel, H.D. (2003). Wastewater Engineering Treatment and Reuse. New York: McGraw-Hill.

35. Thomas, P. & Zeisel, J. (1997). "Greywater Recycling in Urban Areas". Ecological Engineering for Wastewater Treatment. USA: CRC Press, Inc.

36. United Nations Environmental Program (UNEP), (2000). Environmental Sound Technologies in Wastewater Treatment for the Implementation of the UNEP Global Program of Action (GPA) "Guidance on Municipal Wastewater". New York: United Nations.

36. Van Dok, W. (2004). "Case Study: The Van Dok Home". http://savewater.com.au/default.asp?SectionId=562&sortTag=680&mode=print

Appendix - A

Questionnaire Survey Information

Questionnaire used for gray water interviews in Dhaka city.

Along the following questions asked during the interviews a series of observations are indicated in capital letters.

I - HOUSELHOLD'S CHARACTERISTICS QUESTIONS

1). Name of the area and unit and House area:

2). House number, or interviewee's name:

3). Relation to the Head of the Household:

4). Number of people in the household:

5). Number of children, age:

NAME

AGE

6). How long have you and your family been living in this area?

II - ACCESS TO HARDWARE

Water Supply System

7). What is the main source of drinking water for members of the household?

1. Piped water	5. Unprotected dug well	9. Small water vendor
2. Stand pipe	6. Protected spring	10. Peddler
3.Tubewell/borehole spring	7. Unprotected	11. Tanker water
4.Protected dugwell	8. Gutter.	

8). Other sources for other uses of water

9). What type of containers and in what capacity do you use in your home?

1. Gallon……..L 2 Jarry can……L 3 Bucket……..L

4 Jerkin………L 5 Drum/barrel ……L 6. Other……… 7. Don't know

10). How many of those containers do you fill per day?…………

11). What is the distance between your house and the water point?

1. <10m	4. 100 – 200m	
2. 10 – 50m	5. 200 – 500m	Not applicable……….
3. 50 – 100 m	6. > 500m	

Quality of the water supplied (and indication of a potential source of contamination of the waste water)

12). Do you store water for drinking in the household?

YES NO

13). OBSERVATION OF CONTAINERS (PLEASE OBSERVE THE CONTAINERS AND FILL IN THE TABLE BELOW)

Narrow mouthed
Wide mouthed
Of both types

14). ARE THE CONTAINERS COVERED?

1. All of them 2. Some of them
3. None

Sanitation and Solid Waste

15). What kind of toilet facility does this household use? (*please observe)No.*

1. Poor flush	2. Flush	3. VIP
4. Pit latrine	5. Composting latrine	6. Bucket latrine
7. Hanging latrine	8. No latrine	9. Other

16). HOW FAR IS THE TOILET FACILITY FROM YOUR LIVING QUARTERS? *(IF FEASIBLE, OBSERVE)*

1. < 10 meters	3. > 50 meters	Not applicable
2. 10-50 meters	4. Don’t know?	

17). Where are children faeces disposed off?

1. Dropped into the toilet facility	7. Buried
2. Rinsed, water discarded into the sink or tub connected to drainage system	8. Left lying on the ground
3. Rinsed, water discarded into a toilet	9. Don’t know
4. Rinsed, water discarded outside	
5. Disposed, outside the yard	

6. Disposed, into solid waste/trash

18). OBSERVE, IF WASHED OR RINSED, WHERE THE WATER DISPOSED OFF

.

19). How do you dispose of your garbage? OBSERVE ANY VISIBLE DUMPING AREAS.

Collected from home by	**Collected at neighbourhood box by**	**Disposed within premises**	**Disposed outside premise**
1. Community association	1. Community association	1. In waste pit	1. In waste pit/dump site
2. Private company	2. Private company	2. No pit	2. Anywhere
3. Government	3. Government		

OR

1. Burn (*where)……………………..*
2. Bury (*where)……………………..*
3. Compost (*where)……………………..*
4. Recycle (*where)………………………..*
5. Feed animals (*where)………………*
6. Other*……………………..*
7. Don't know**.**

III - WASTE (GRAY) WATER DISPOSAL

20). What do you use your water for?

1. Washing dishes
2. Doing laundry
3. Bathing
4. Other……………………………………………………………
5. Cleaning the house
6. Cooking
7. Car washing
8.Basin

21). When do you think you use the most of water?

1. Early morning
2. Morning
3. Lunchtime
4. Afternoon
5. Evening
6. Don't know

22). How do you dispose the following gray water? Where does the water go?

Washing dishes	Laundry	Bathing	Cleaning the house	Cooking	Other (specify)
1.Drain (Piped or not)	1. Drain (Piped or not)	1. Drain (Piped or not)	1. Drain (Piped or not)	1. Drain (Piped or not)	1. Drain (Piped or not)
2. Soak- away, septic, cesspit system	2. Soak- away, septic, cesspit system	2. Soak- away, septic, cesspit system	2. Soak- away, septic, cesspit system	2. Soak- away, septic, cesspit system	2. Soak- away, septic, cesspit system
3. Street surface	3. Street	3. Street	3. Street	3. Street	3. Street
4. Inside the yard	4. Inside the yard	4. Inside the yard	4. Inside the yard	4. Inside the yard	4. Inside the yard
5. Into garden	5. Into garden	5. Into garden	5. Into garden	5. Into garden	5. Into garden
6. In the toilet	6. In the toilet	6. In the toilet	6. In the toilet	6. In the toilet	6. In the toilet
7. Re-use	7. Re-use	7. Re-use	7. Re-use	7. Re-use	7. Re-use
8. ………	8. ………	8. ………	8. ………	8. ………	8. ………

23). For each activity, could you estimate how much water you use each day? (*Indicate the amount) Daily.*

Washing dishes	Laundry	Bathing	Cleaning the house	Cooking	Basin	Other……… …. (specify)

24). If re-use water, give examples of which gray water is re-used. (e.g. *bathing water for gardening)*

25). How many soaps do you use for the following activities that produces gray water? Monthly.

Washing dishes.	Laundry	Bathing	Cleaning the house	Basin	
1. ……….	1. …………	1. ……..	1. …………	1…….	
How often?	**How often?**	**How often?**	**How often?**	**Shampoo**	**& Paste**
2. ………….	2. ……..	2. ………	2. ……..	No. …	No…..

26). DOES THE STANDPIPE HAVE THE FOLLOWING:

1. Soak-away
2. Concrete slab
3. Gulley
4. Wash through

6. Storm water manhole
7. Communal washing/ablution facilities
8. Gray water sand filters
9. Grease traps.

5. Storm water channel

27). DO YOU OBSERVE ANY CHANGES ON THE SURFACE DUE TO DISPOSING OF GRAY WATER?

YES NO

28). COULD YOU ESTIMATE THE LOCATION OF THE STANDPIPE RELATIVE TO WITHDRAWAL POINT? (*ANY POSSIBLE CONTAMINATION*)

IV - LEVEL OF PERCEPTION OF THE RISKS - TOWARDS A SAFE GRAY WATER DISCHARGE SYSTEM

29). Do you think gray water is a major health problem in the community?

YES NO

30). If yes, in what sense? *(What could be the risks of stagnant waste water, infiltrating the ground anywhere or badly manipulated?)*

Viruses transmission by direct contact with water

Virus transmission by ingestion of crops

Soil clogging

Soil degradation

Groundwater contamination

Other

31). What would you like to do with your gray water?

Recycling, Reuse *(What for?)*

Discharge in a 'safe' place

Water plants

Other

32). What choices would you make to resolve the problem of gray water disposal?

Appendix- B

Household Data

Per Capita Water Consumption.

Class 1 (High Income People):

22 Family 69 people, total water consumption per day is 9369 liter.
Per capita water consumption = 9369/69
= 136 liter/day.

% of water use for different house works (liters):

Washing dish	Laundry	Bathing	Cleaning house	Prayer
605(6.46%)	1273(21.64%)	2851(49.37%)	543(9.231%)	252(4.284%)
Cooking and Drinking	Basin	Car wash	Toilet	
687(11.679%)	349(5.933%)	42(0.714%)	2767(47.039)	

Class 2 (General Income people):

78 Family 325 people, total water consumption per day is 48314.5 liter.
Per capita water consumption = 48314.5/325.
= 150 liter/day.

% of water use for different house works (liters):

Washing dish	Laundry	Bathing	Cleaning house	Prayer
3288(6.90%)	7425(15.59%)	16258(34.14%)	2172(4.56%)	902(1.89%)
Cooking and Drinking	Basin	Car wash	Toilet	
3657.5(7.68%)	2256(4.73%)	14(0.088%)	12342(25.91%)	

Class 1 + Class 2:

100 Family 394 people, total water consumption per day is 57683.50 liter.
Per capita water consumption = 57683.50/394
= 146 liter/day.

% of water use for different house works (liters):

Washing dish	Laundry	Bathing	Cleaning house	Prayer
3893 liter (6.73%)	8698 liter (15.04%)	19109 liter (33.05%)	2715 liter (4.69%)	1154 liter (1.99%)
Cooking and Drinking	Basin	Car wash	Toilet	
4344.5 liter (7.51%)	2605 liter (4.50%)	56 liter (0.096%)	15109 liter (26.14)	

% of per person water use for different house works (liters):

Washing dish	Laundry	Bathing	Cleaning house	Prayer
9.88 liter (6.73%)	22.07 liter (15.04%)	48.5 liter (33.05%)	6.89 liter (4.69%)	2.92 liter (1.99%)
Cooking and Drinking	Basin	Car wash	Toilet	
11.02 liter (7.51%)	6.61 liter (4.50%)	0.142 liter (0.096%)	38.34 liter (26.14)	

Per Capita Gray Water production from Households.

100 Family 394 people, total gray water production per day is 37466 liter.
Per capita gray water production = 37466/394
= 95 liter/day.

% of water use for different house works (liters):

Washing dish	Laundry	Bathing	Cleaning house
3893 liter (10.39%)	8698 liter (23.21%)	19109 liter (51%)	2715 liter (7.24%)
Cooking	Basin	Car wash	
390 liter (1.04%)	2605 liter (6.95%)	56 liter (0.15%)	

Accurate % of per person gray water production for different house works (liters):

Washing dish	Laundry	Bathing	Cleaning house
9.88 liter (10.39%)	22 liter (23.21%)	48.5 liter (51.00%)	6.89 liter (7.24%)
Cooking	Basin	Car wash	
0.98 liter (1.04%)	6.61 liter (6.93%)	0.142 liter (0.15%)	

Taking whole figures and % of per person gray water production for different house works (liters):

Washing dish	Laundry	Bathing	Cleaning house
10 liter (10.49%)	22 liter (23.10%)	48.5 liter (51.00%)	7 liter (7.35%)
Cooking	Basin	Car wash	
1.0 liter (1.04%)	6.6 liter (6.93%)	0.15 liter (0.16%)	

Appendix - C

DWASAs Daily Water Demand, Supply and Deficit.

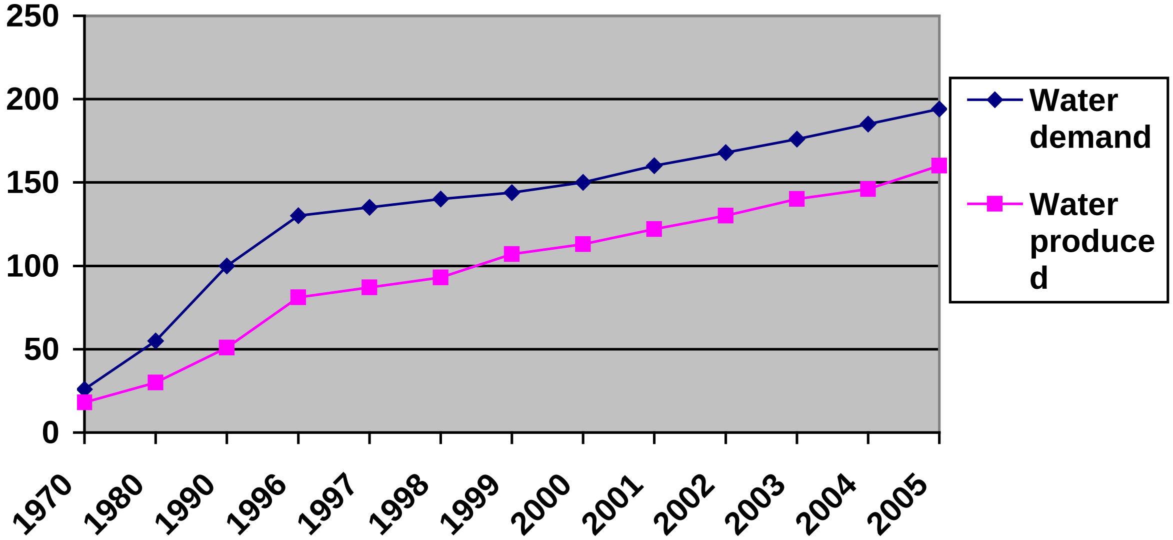


Figure: Graphical Representation of DWASAs Daily Water Demand Water Production in Crore Litres.

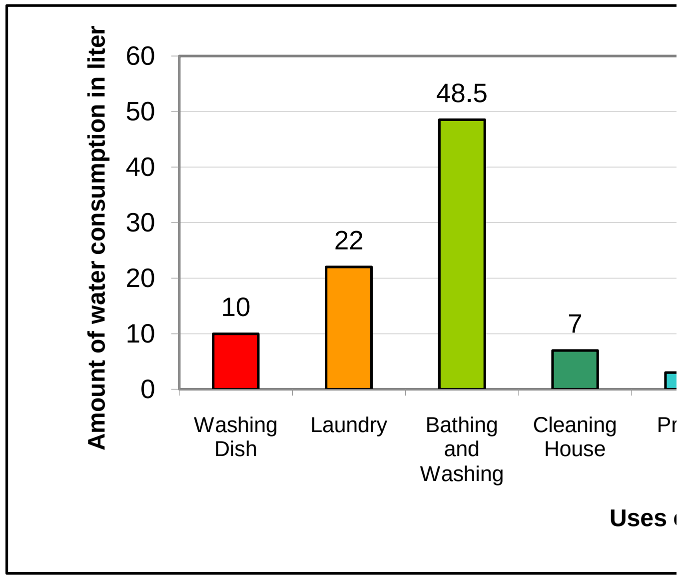
Year	Water Produced	Water Demand
1970	18	26
1980	30	55
1990	51	100
1996	81	130
1997	87	135
1998	93	140
1999	107	144
2000	113	150
2001	122	160
2002	130	168
2003	140	176
2004	146	185
2005	160	194

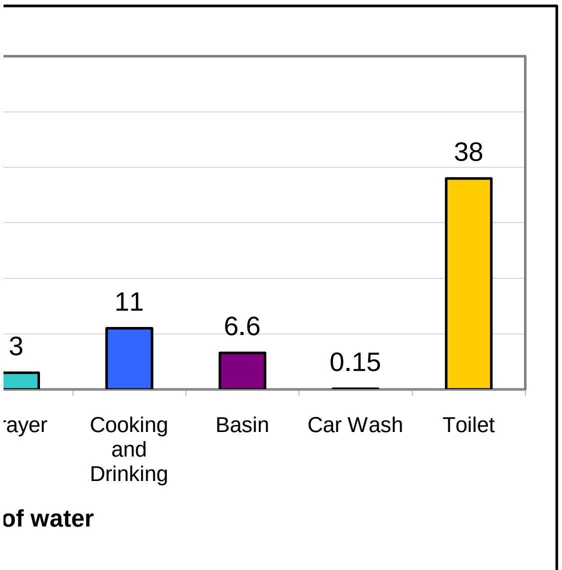
Table: DWASAs Daily Water Demand Water Production in Crore Litres.

DWASAs Daily Water Demand, Supply and Deficit.

Year	Population (Lac)	Water Demand (Cr. ltr)	Water Supply Capacity (Cr. ltr)	Deficit (Cr. ltr)
1963	8.5	15	13	2
1970	14.6	26	18	8
1980	30.3	55	30	25
1990	55.6	100	51	49
1996	75.5	130	81	49
1997	80	135	87	48
1998	85	140	93	47
1999	90	144	107	37
2000	95	150	113	37
2001	100	160	122	38
2002	105	168	130	38
2003	110.25	176	140	36
2004	115.76	185	146	39
2005	121.5	194	160	34

Washing Dish	Laundry	Bathing and Washing	Cleaning House	Prayer	Cooking and Drinking	Basin	Car Wash	Toilet
10	22	48.5	7	3	11	6.6	0.15	38





3
11
6.6
0.15
38
ayer
Cooking and Drinking
Basin
Car Wash
Toilet
of water