CHARACTERIZATION OF GREYWATER AND ASSESSMENT OF SAND FILTRATION FOR GREYWATER TREATMENT AND REUSE

Submitted in partial fulfillment of the requirements for the award of degree of

Master of Technology

In

ENVIRONMENTAL ENGINEERING

Submitted by

Swati Singh
(2014PCE5083)

Guided by

Dr. Urmila Brighu
(Associate Professor)

DEPARTMENT OF CIVIL ENGINEERING

MALAVIYA NATIONAL INSTITUTE OF TECHNOLOGY JAIPUR

JUNE 2016

A

DISSERTATION REPORT

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MALAVIYA NATIONAL INSTITUTE OF TECHNOLOGY JAIPUR
DEPARTMENT OF CIVIL ENGINEERING
JAIPUR 302017

CERTIFICATE

This is to certify that the dissertation entitled **"Characterization of Greywater and assessment of Sand Filtration for Greywater Treatment and Reuse"** which is being submitted by **Swati Singh**, in partial fulfillment for the award of the degree of Master of Technology in the Department of Civil Engineering (Environmental Engineering), MNIT, Jaipur is a bonafide work done by her under my guidance and supervision.

I hereby further certify that this thesis has been evaluated using the **Turnitin Originality Check** system. I have analyzed the report produced by the system and based on it, I certify that the references in the thesis are in accordance with good scientific practice.

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The dissertation report is approved for submission

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ACKNOWLEDGEMENT

I would like to express gratitude and deep regards to my mentor Dr. Urmila Brighu, Associate Professor, Civil Engineering Department, MNIT Jaipur, for her exemplary guidance, monitoring and constant encouragement. Her supervision and willingness to share her vast knowledge have helped me to complete the assigned task.

I would also like to thank DPGC Convener, Prof. A. K. Vyas, Department of Civil Engineering, MNIT Jaipur, for extending every possible help and encouragement.

I would also like to offer my heartiest regards to Prof. Gunwant Sharma, Head of Department, Department of Civil Engineering, MNIT Jaipur.

SWATI SINGH

ENVIRONEMENTAL ENGINEERING

2014PCE5083

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

1. APHA: American public health association
2. BOD: Biochemical oxygen demand
3. cm: Centimetres
4. COD: Chemical oxygen demand
5. CPHEEO: Central Public Health And Environmental Engineering Organisations
6. hr: Hour
7. Lab: Laboratory
8. m: Metre
9. min: Minute
10. ml: Millilitres
11. mm: Millimetres
12. MNIT: Malaviya National Institute of Technology
13. WHO: World Health Organization
14. EPA: Environmental Protection Agency
15. XOC: Xenobiotic organic compounds

ABSTRACT

Growing population and industrialisation has put a great stress on water resources globally. As the fresh water availability declines, the need to develop ways to recycle and reuse wastewater increases. Greywater is the water generated out of bathroom, wash basin, kitchen sinks and bathrooms and contributes to 70% of total wastewater produced at households. The organic strength of greywater is quite low as compared to blackwater. This quality allows greywater to be treated by simple treatment technology like filtration. Filtration is a very simple, stable and efficient process. In this study, sand filtration using locally available sand is analyzed for greywater treatment and reuse. The process is examined for its efficiency at different loading rate and different water column head. The parameters of evaluation were chemical oxygen demand, biochemical oxygen demand, conductivity and turbidity. Characterisation of greywater regarding these parameters was also done. Characterization, however, indicated mildness of greywater. The COD, BOD and Turbidity removal efficiency of the filter was 57%, 67% and 95% respectively. The study showed that high filtration rate and high water column depth decreases the efficiency of filtration. It also shows that sand filtration is not adequate to meet requirements of reuse for horticulture and toilet flushing. However, it can be used for irrigating crops.

CHAPTER ONE
INTRODUCTION

1.1 General

Water is scarce, and the demand is huge. The demand for water is increasing with increasing population, industrialisation, the standard of living and climate change. This demand is posing a challenge to the world invoking the search of strategies for sustainable use of water, which includes recycling of rainwater, greywater and various other types of wastewater. Recycling and reuse of water are the most desirable options in countries and places where potable water is scarce and not readily available. Several activities can be carried through the use of non-potable water such as gardening, agricultural and landscape irrigation, golf courses, fire suppression, air conditioning, soil compaction, construction works, toilet flushing, public park irrigation, etc. (Amin et al., 2011). Among all the different wastewaters, greywater seems to be a promising alternative for reuse, with lesser use of power consumption for treatment due to its low strength.

Greywater is defined as the water from the bathroom, hand basin, showers, laundry machines and the kitchen sink (Katell Chaillou et al., 2011) except toilet water. Greywater constitutes about 50-80% of the total household wastewater (Fangyue Li, 2008). Greywater is a large source with contributing only 30% to total organic matter and 9-20% to nutrients (Dr. Marc Pidou et al.). Hence, it seems advantageous to treat greywater separately. Some of the authors have excluded kitchen wastewater from greywater streams. The greywater generated from the wash basin, shower and bath are considered by many as low load greywater (Amin et al., 2011).

Greywater due to its low pollutant content has been considered for direct use as irrigation water. It is a success in some cases, reducing the use of potable water. Long-term use of untreated greywater may result to increase in SAR, affect the water infiltration in soil, lead to hydrophobicity and pose a risk to the soil due to the presence of compounds like oil, surfactant, and bacterias present in greywater (Micheal J. Travis et al., 2010). Direct use of greywater might cause clogging in the distribution system due to suspended solids,and production of sulphide which gives odour, causing public nuisance (Abeer albalawneh et al., 2015). Hence, it is necessary to treat the water before use. Water quality parameters enlisted by WHO and CPHEEO for use in different purposes also manifests that there is a need for treatment of greywater before reuse.

Greywater can be treated either by physical processes, chemical processes or biological processes of filtration, coagulation, adsorption, RBC, MBR, SBR, wetlands etc. Physical process especially sand and gravel filtration are the most opted method of treatment for greywater.

1.2 Goal of the study

To reduce the stress on the fresh water resources by utilising treated greywater. Reusing of greywater will reduce the demand for potable water. The activities which require less stringent standards of water quality parameter can be executed using this reclaimed water (non potable water), without relying on fresh water. This will increase the service life of fresh water resources.

1.3 Aim of the study

The study directs at assessing the efficacy of locally available sand for treatment of greywater and check whether the treatment fulfils the reuse criteria of toilet flushing and horticulture. Filtration is a simple, economic and efficient technology. Before adopting any technique it is necessary that its feasibility is studied. This research, through experimental work, will be helpful in evaluating the potential of filtration method (by using local sand) for greywater treatment.

1.4 Objectives of the study

1. To characterize greywater for Chemical oxygen demand (COD), Biochemical oxygen demand (BOD), Conductivity, pH and Turbidity.
2. To check the removal efficiency for these parameters experimentally, by setting up a lab scale sand filter. The sand used is the locally available sand.
3. To examine and compare the removal efficiency of filter at two different flow rate.
4. To examine and compare the removal efficiency of filter at two different water column head.

CHAPTER TWO
LITERATURE

2.1 General

Before treating any wastewater, it is necessary to know its quality. As seen in the studies, greywater quality has a wide range and varies from place to place. Many technologies that have been evolved for wastewater treatment have been used for greywater treatment. One of the most economic and stable technique is filtration. Filtration involves many processes which help in effective removal of pollutants.

This chapter is constructed with the discussion of Characterisation of greywater, direct use of greywater for irrigation, treatment technologies of greywater and reuse guidelines of greywater. A general discussion of filtration process is also done.

2.2 Characterisation of Greywater

The qualitative and quantitative characteristics of greywater differ from country to country and place to place, as observed from published papers. The factors that cause this variation are the difference in standard of living, climatic conditions, quality of water supply, social and cultural activities of residents, etc (Georgia Antonopoulou et al., 2013).

2.2.1 Quantitative Characterization of Greywater

Greywater ranges from 50% to 80% of the total wastewater volume generated by households (Abeer Albalawneh et al., 2015). Greywater comprises of water from shower, laundry, kitchen sinks, dishwasher machines, and hand basins. The volume of greywater varies from 90 to 120 l/p/d, but for low-income countries experiencing chronic water shortages, this volume can be as low as 20-30l/p/d. Volume of greywater generation of few countries are Australia: 117 l/p/d, India (urban area): 79 l/p/d, India (rural area): 48 l/p/d, Jordan (urban area): 59 l/p/d, Jordan (rural area): 30 l/p/d (Abeer Albalawneh et al., 2015).

The rough fractions of water produced from laundry, kitchen sinks, wash basin and showers as shown in published literature, is shown in figure 2.1.

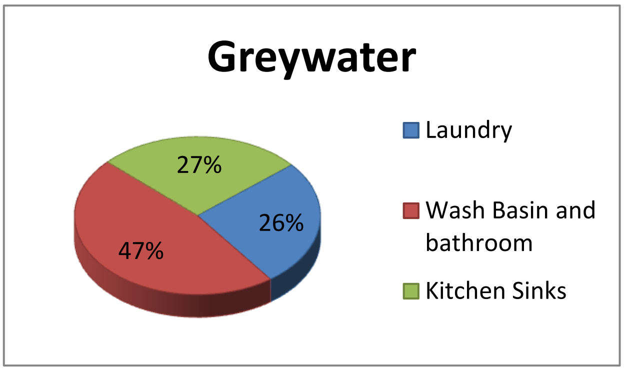
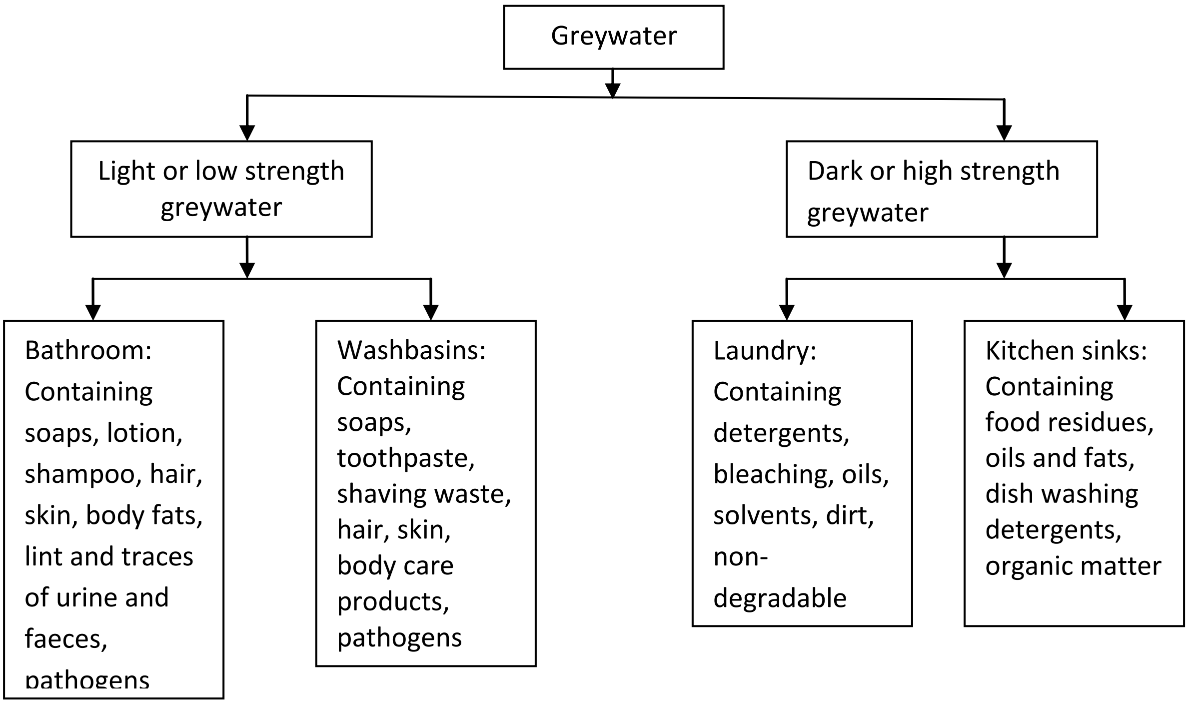


Figure 2.1 Contribution by laundry, bathroom and kitchen to greywater

2.2.2 Qualitative Characterization of Greywater

Kitchen wastewater is quite heavily loaded with organics, containing food particles, cooking oils and fats and dishwashing powder. Water from laundry contains soap powder (sodium, nitrogen, phosphorous and surfactants), bleaches, and disinfectants, dirt from clothes, and nonbiodegradable fibres from clothes. Shower and bathroom wastewater contain soap, shampoo, human skin, hair, dye and body oils, traces of faeces and urine (Abusam, 2008). Although greywater is not grossly contaminated with faeces or (Alit Wiel-Shafran et al., 2006) urine, yet some contamination may be there from shower, bathroom and laundry waters (Abusam, 2008).



References: (Abeer Albalawneh et al., 2015 & Abusam, 2008)

Figure 2.2 Composition of greywater

Despite considering greywater as low in pollutants, many have published higher than usual values (Abeer Albalawneh et al., 2015; Dalahmeh, 2013). The physical, chemical and biological parameters of greywater include suspended solids, conductivity, dissolved solids, total phosphorous, TN, COD, BOD_5, turbidity, total coliform, xenobiotic organic compounds (XOCs) and heavy metals such as Cd, Pb, Cu, Zn, Cr. The BOD/COD ratio lies between 0.31-0.71 with an average of 0.45 ± 0.13. The average COD: N: P ratio when excluding kitchen waste was 100:3.5:1.6 in the studies, notifying inability of biological processes to treat the water as the required ratio is 100:20:1 (Metcalf & Eddy, 2003; Abeer Albalawneh et al., 2015).

The chemical contaminants which are mainly contributed by laundry and bathroom are surfactants i.e. surface active agents. Surfactants are further classified as cationic, anionic and amphoteric or non –ionic. Anionic surfactants are the most common surfactantas used in detergents for laundry and general cleansing, followed by cationic surfactants. Anioinc surfactants like linear alkylate sulfonate (LAS) are used quite often due to their foaming, low price, and biodegradability. Some of the cationic surfactants use are quaternary ammonium salts, dialkydimehtyl ammonium chlorides, distearyldimethlyammonium chloride and alkyldimethlybenzylammonium chlorides which are used in fabric softners and as disinfecting agents. Detergent builders which are alkali substances and complexing agents are also chemicals used to build the effectiveness of the detergent formulation. A heterogenous compound XOC is found in surfactants, bleachers, builders, softners, and solvents. It is found that high levels of XOC results in higher COD (Nurul Widiastutia et al., 2008).

Regarding microbial contamination, microorganisms in greywater are in the form of faecal contamination, peripheral pathogens (e.g. skin and mucous), and pathogens from hand washing (Adi Maimonet al., 2014). Human pathogens are found in detectable numbers in greywater (Hills et al., 2007).

Characterisation of greywater as reported by some authors is shown in Table 2.1.

Reference	Abeer Albalaw-neh et al., 2015	Abeer Albalaw-neh et al., 2015	Katell Chaillou et al., 2011	C. Santos et al., 2012	Georgia Antonopo-ulou et al., 2013	H.I. Abdel-Shafya et al., 2014	Adi Maimon et al., 2014	Cornelia Merz et al., 2007
Greywater	Dark greywater	Light greywater	Shower and wash basin	Showers	Showers / bathtub	Greywater from 12 houses	Greywater excluding kitchen waste	Greywater from Sports and leisure club
Turbidity (NTU)	19-444	12.6-375	49.5					29 ±11
COD (mg/l)	50-2568	55-633	112	197	399 ±183	481		109 ±33
BOD (mg/l)	48-1056	20-300	78	129		260	123.9	59 ±13
Conductivity (µS/cm)	190-1830	14-921	358		939 ± 238		1200	645 ± 67
TSS	12-315	29-505		58	632 ± 152	124	75.9	
TP	0.062-42	0.11-1.8	0.2	1.3	0.4 ± 0.6	12		1.6 ±0.5
TN	21-57.7	4.1-16.4	5.4					
Total Coliform (CFU/100 ml)			7×10^6				1.4×10^5	$1.4 \times 10^5 \pm 1.1 \times 10^5$

Table 2.1 Characterisation of greywater

2.3 DIRECT USE OF GREYWATER FOR IRRIGATION

Recently, there has been increasing interest in reuse of greywater, without prior treatment, for garden irrigation and irrigation of crops. This strategy is cropping up as one of the water conservation technique. Greywater being less polluted and generated in large amounts is best suitable for such activities. Greywater used for garden irrigation have been found useful and safe, regarding water –borne diseases (Allison Busgang et al., 2015). In one of the study four residential houses successfully used greywater for irrigating lots for four years with only environmental risk caused by an excess of phosphorous (Ryan D.R. Turner et al., 2013). Use of raw greywater for irrigation on different soils studied by (Micheal J. Travis et al., 2010) reported hydrophobicity, increase in SAR, presence of surfactants, O&G and coliform bacteria in soil, restricting long term use of greywater for irrigation. Alit Wiel-Shafran, et al. ,2006 also reported surfactant accumulation and water–repellence in soil affecting its productivity. High amount of microorganisms and BOD compels treatment to reduce contamination, if greywater is to be recovered. To minimise biofilm growth in the distribution pipe and to remove pathogens, disinfection is essential (Hills et al., 2007). Although greywater is considered environment-friendly, there is a need for greater understanding of its impacts on soil, human health and effect on surrounding environment due to infiltration and irrigation with greywater.

2.4 TREATMENT TECHNOLOGIES OF GREYWATER

Low strength allows greywater to be treated much more easily than domestic wastewater. Simple, low-cost treatment technologies like primary and secondary treatment conventional processes are often sufficient for the treatment. As greywater contributes maximum in the domestic wastewater, its segregation, and separate treatment will reduce the wastewater treatment cost and relieve wastewater plants from organic and hydraulic overloads. However, sometimes it is recommended to treat kitchen and laundry wastewater with the Blackwater as this water have a good organic strength (Abusam, 2008).

Various well- known physical, chemical and biological processes applied to the wastewaters in general, have also been used for greywater treatment. The processes include the use of Filtration by sand, bark, charcoal, membranes, etc., bioreactors, a natural system like wetlands, advanced oxidation processes (Georgia Antonopoulou et al., 2013). Most of the processes are preceded by a liquid-solid separation step as pre-treatment and followed by disinfection as post treatment. The pre –treatments like a septic tank, screen and filters, filter bags are used to remove oil and grease, and other particles to avoid clogging of the treatment system. The disinfection is done to meet the microbiological requirements (Fangyue Li et al., 2008). The quality of greywater depends upon the type of treatment, inclusion/ exclusion of kitchen wastewater and skill of the system designer (Adi Maimon et al., 2014).

2.4.1 Treatment by physical processes

The key physical process is filtration. The conventional filters are beds of granular material or sand. Other techniques of filtration such as membrane filtration, use of different filter medium like nylon sock, charcoal, natural zeolite, bark, foam (Fangyue Li et al., 2009; Dalahmeh, 2013) have also evolved. The coarse filters are less efficient in pollutant removal; sand filters are however successful due to a combination of filtration and biological degradation; membrane filtration give the best result, but energy consumption and membrane fouling are the main factors that limit the economic viability of these systems (Fangyue Li et al., 2009).

In the context of greywater treatment, filtration is the most opted technique both due to the low organic strength quality of greywater and due to the simplicity of the filtration technology. Particulate matters, which are not removed by preceding processes, are removed by filtration. The protozoa are retained by the gravels, the bacteria by the medium gravels and viruses by the sand. Sand filters are known to be simple, economical, efficient and reliable. Sand filters can be used for a broad range of applications, including small residences, large commercial establishments, small communities, campuses, airports and other places effectively. The combination of sand filtration and disinfection was able to accomplish non-restricted nonpotable reuse standards regarding the BOD and turbidity (Fangyue Li et al., 2009) for greywater with extremely low organic strength. Physical processes are sometimes used as post-treatment for polishing motive (Fangyue Li et al., 2009).

Recent researches done on treatment of greywater by sand or gravel filtration have found treatment efficiency being function of particle size of sand, organic loading rate, hydraulic loading rate, depth of filter, depth of water column head, quality of greywater (Dalahmeh, 2013; Cecilia Lalander et al., 2013; Abudi et al., 2011). The application of physical process alone is insufficient for the treatment of greywater.

Some of the works done on the evaluation of efficiency of greywater treatment by physical process both as lone and combined processes are shown in Table 2.2.

Treatment Technology	**Efficiency**	**Remarks**	**Reference**
Sedimentation, Filtration, and disinfection	Efficient in removal of COD, TOC, N,TSS and turbidity	Reuse as toilet flushing with public acceptance	J.G. March et al., 2004
Drawer compacted sand filter	BOD_5 , COD, TSS removal	Effluent satisfies requirement for restricted irrigation	Almoayied Assayed et al., 2015
Sand filter	83% BOD_5 89% Turbidity removal	Efficiency depends on upon the particle size of sand, the surface area of the filter to depth ratio and flow rate.	Abudi et al., 2011
UF Membrane	83.4% TOC removal	Effluent can be used for irrigation, toilet flushing after disinfection	Fangyue Li et al., 2008
Filter using bark, charcoal, and sand	BOD EHEC AND ΦX174	Pathogen removal maximum by Bark, Efficiency increased with increasing OLR	Cecilia Lalander et al., 2013
Sand filtration	Not efficient for COD and pathogen removal	Could not meet international guidelines for reuse	Katell Chaillou et al., 2011
Sand filtration + Adsorption on GAC + chlorination	COD Efficient removal	Meet the guidelines for reuse	Katell Chaillou et al., 2011
Filtration using bark, charcoal, sand, foam	BOD_5, Tot-P,NH_4-N,MBAS, TTFC removal	Bark and charcoal are the most efficient	Sahar S Dalahmeh et al., 2012
Filter + disinfection	BOD, 56% COD, TP,TSS removal	BOD removal is less, coagulation suggested	C. Santos et al., 2012

Table 2.2 Greywater treatment by various physical methods

2.4.2 Treatment by chemical processes

The chemical processes employed for the greywater treatment include coagulation, ion exchange, and photo-catalytic oxidation. However, chemical purposes are reported to have been more efficient than physical processes. Chemical processes are effective for a single household or low strength greywater. Variability in greywater characteristics and flow do not affect the treatment performance of chemical processes (Fangyue Li et al., 2008). There are many electrochemical treatment systems like electrocoagulation, electroxidation and electroflotation which can be used. Coagulation is efficient in pathogen removal. Poor organic removal has been reported by flocculation (Sibel Barıs et al., 2016). However, Marc Pidou et al., (2008) reports that coagulation and adsorption have potential of removing dissolved organic matter present in greywater. Coagulants and ion exchange resin are efficient for treating low strength greywater, but failed to achieve required standard of treatment for medium and high strength. Some of the works done on the evaluation of efficiency of greywater treatment by chemical processes are shown in Table 2.3.

Type of Greywater	**Treatment Process and Type of greywater**	**Treatment Efficiency**	**Remarks**	**References**
Shower, laundry, hand basin	UVC/H_2O_2	Good COD removal	Useful in removing XOCs, treated water must be checked for toxicity before reuse.	W.H. Chin et al., 2009
Synthetic Greywater	Fluidized 3-D electrode reactor + GAC	98% COD removal	Satisfying reuse standards	Kyung-Won Jung a et al., 2015
Shower, kitchen,sink	Electrocoagulation	Good removal of COD	Satisfying allowable limits of reuse	Sibel Barıs et al., 2016
Bath, shower and hand basin	Ferrate salt	Good TOC removal	Cost effective , Satisfying criteria of reuse	Yarui Song et al., 2016
Bath, shower and hand basin	Magnetic Ion Exchange Resin (MIEX)	Good organic removal	Successful for low strength greywater	Marc Pidou et al., 2008

Table 2.3 Greywater treatment by some of the chemical methods

2.4.3 Treatment by biological processes

Among several biological processes, Rotating Biological Contractor (RBC), Sequencing Batch Reactor (SBR), Upflow Anaerobic Sludge Blanket (UASB), Constructed Wetland, Membrane Bioreactors (MBR), have been used for greywater treatment. Here too, biological processes receive greywater pre-treated by septic tank or sedimentation tank.

All types of greywater show good biodegradability regarding (Fangyue Li et al., 2009) regarding BOD: COD ratio. However, the COD: N: P ratio required for biological processes can only be satisfied when greywater contains kitchen waste. Excellent turbidity and organic removal are achieved in the aerobic process while the same is unachieved by the anaerobic process. L. Herna´ndez Leal et al.(2007) worked on finding the efficiency of aerobic and anaerobic (UASB) processes in treating greywater. He found 90% COD removal in the aerobic process while anaerobic was able to remove only 40% of COD. Greywater quality has an inhibitory effect on the anaerobic bacteria. The advantage of using anaerobic process is the production of biogas. The biological systems have the advantage of being efficient in shorter HRT (Marc Pidou et al., 2008). Micro-organisms removal was only efficiently achieved when there was disinfection (Dr. Marc Pidou et al.,) MBR are the only ones to achieve good microbial removal without needing disinfection (Marc Pidou et al., 2008). MBR have qualities of compact structure, producing low excess sludge, excellent removal efficiency of organic, surfactants and microbial contamination, producing stable effluent.

Constructed Wetland is an engineered system designed and constructed to make use of natural processes like soil, vegetation, and microbial assembly to facilitate treatment wastewater. They are capable of removing suspended solids, organic matter and nutrients by microbiological degradation, physical-chemical processes like filtration, sedimentation and adsorption, and plant uptake. V. Arunbabu et al., (2015) reported that wetland are capable of tolerating influent wastewater and are efficient in removal of nutrients. Constructed wetlands are environmentally friendly and cost-effective process but require large space. One of the benefits of using wetland is the removal of toxic organics and metals like Cr, Cd, Fe, Mn, Pb, Zn (Dilip et al.,2013).

Some of the works done on the evaluation of efficiency of greywater treatment by biological processes are in Table 2.4.

Greywater	Treatment technique	Efficiency	Remarks	Reference
Kitchen wastewater, laundry, and bathroom	SBR + coagulation by alum	Good removal of COD	Removal of COD from Bathroom wastewater was highest	B.S.sahani et al., 2013
Shower, bathtub, hand basin; 70 persons	RBC with UV disinfection	BOD_7 <5mg/l	Fulfilling service water quality requirement	Nolde et al., 1999
Shower and bathtub; two people household	Fluidized bed reactor with UV disinfection	<5mg/l 4-8mg/l	Fulfilling service water quality requirement	Nolde et al., 1999
Greywater from sports and leisure club	Membrane BioReactors	Good BOD_5 and faecal coliform removal	Meeting non potable use standards, require disinfection, high investment cost	Lisa M. Avery et al., 2007
Low –organic strength domestic greywater	Constructed Wetland	Good removal of pathogens, suspended solids	Meeting USEPA reuse standards	Lisa M. Avery et al, 2007

Table 2.4 Greywater treatment by some of the biological processes

The high COD/BOD ratio and the nutrients deficiency are the limiting factors for the use of biological processes. The problems faced are of inefficient sludge settling and formation of foaming (Georgia Antonopoulou et al., 2013). Thus, it is required to attain a deeper understanding of biological processes to treat greywater successfully. The use of biological process requires the use of skilled staff. Hence, it cannot be used at household level by the inhabitants.

2.4.4 Conclusion

Characteristics of greywater vary drastically from place to place. Hence, it is hard to select a single process for its treatment. Through all the discussion, it is clear that no single treatment technique is alone adequate for greywater treatment. Greywater treatment is thus a two step or three step process.

Greywater treatments at some places are preferred to be done at household levels, where residents build their own small treatment plants and reuse water for themselves. The onsite household greywater treatment requires a process that is simple, stable in efficiency and robust on daily variations of greywater strength and flow system that could easily be monitored by inhabitants (Georgia Antonopoulou et al., 2013). Decentralized reuse systems are preferred as long as the reuse is by the users and not a municipality, also because it consumes less energy and emits less CO_2.

2.5 GREYWATER REUSE GUIDELINES

As more and more countries are showing interests in reusing greywater, there is a need for the establishment of greywater reuse guidelines. The reuse of greywater must fulfil four criteria: hygienic safety, environmental tolerance, economic feasibility and aesthetics (Fangyue Li et al., 2009). The lack of appropriate water quality standards has hindered suitable greywater reuse. Different applications require different requirements of water quality parameter. Hence, it is very important to establish international guidelines of reuse for various purposes and parameters. Few countries such as UK, Germany, Jordan, Japan and Australia have established specialized standards for greywater reuse (Abeer Albalawneh et al., 2015). Some countries use standards applied to reclaimed municipal wastewater for greywater reuse (Fangyue Li et al., 2009).

WHO provide guidelines for greywater reuse for restricted and non-restricted agricultural irrigation (Fangyue Li et al., 2009). However, WHO outline only microbiological requirements and does not consider physical and chemical parameters (Abeer Albalawneh et al., 2015). Parameters such as BOD_5, COD, turbidity, pH, TSS, TDS, TN, NH_4-N, TP, TN, total coliform, faecal coliform, chlorine residual, heavy metals must be included in the guidelines. Some guidelines consider only a few of these parameters. Many greywater reuse standards prohibit use of the kitchen waste (Adi Maimon et al., 2014).

2.6 FILTRATION

Filtration is the process of passing the water through a stationary layer of a granular material. Water on passing gets filtered, and the solids are retained or entrapped by the filter media. Different modes of operation are possible in filtration. These include down flow, up flow, bi flow, vacuum and pressure filtration (Howard S. Peavy, 1985). The classification of filtration processes used in wastewater treatment is shown in Figure 2.2.

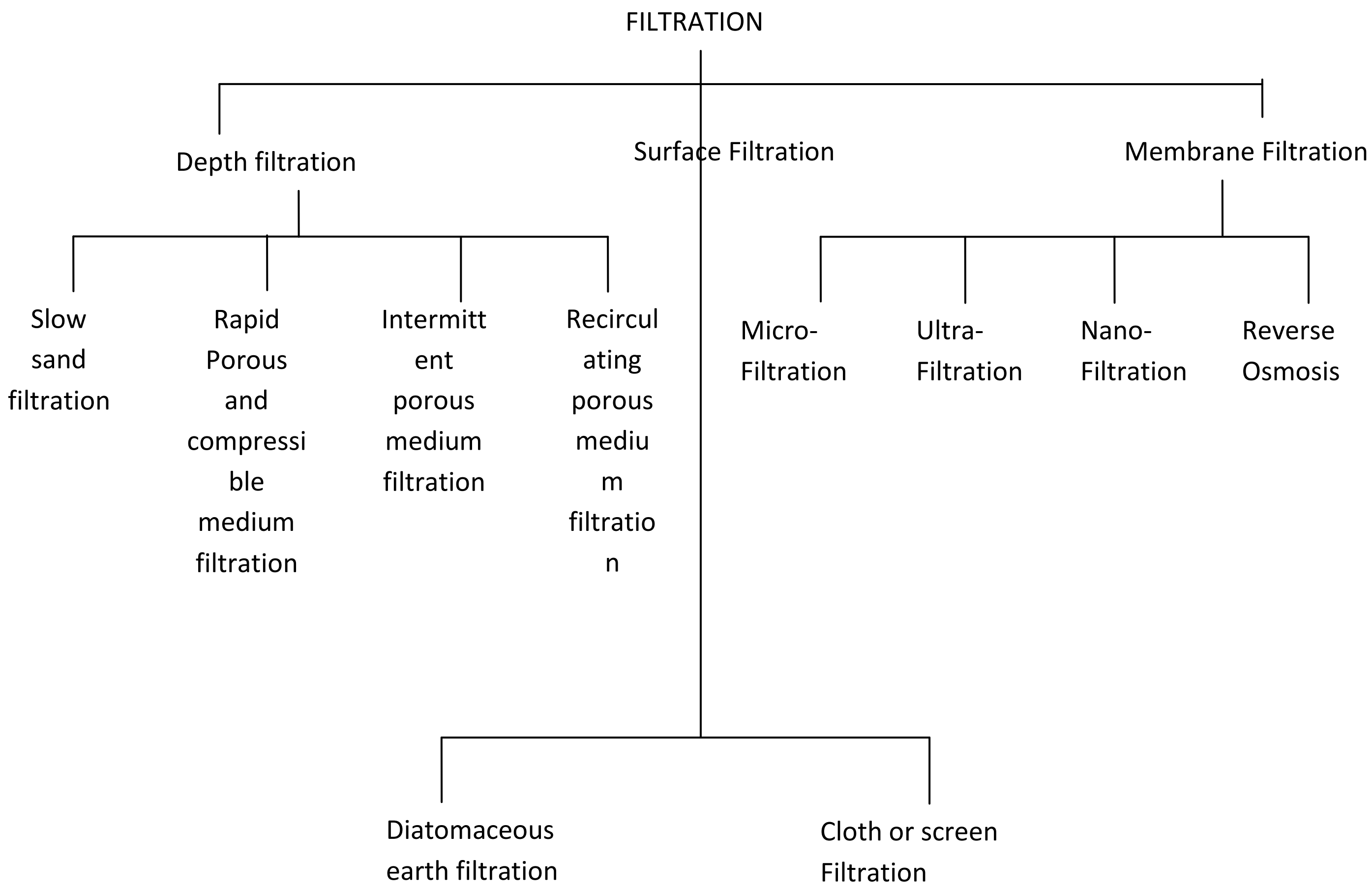


Figure 2.3 Classification of filtration processes used in wastewater management (Metcalf & Eddy, 2015)

The most commonly practiced mode is down flow filtration wherein the weight of the water column above the filter provides the driving force (Howard S. Peavy, 1985). The basic mechanisms of filtration are straining and depth filtration.

The principal mechanisms and phenomena contributing to the removal of material within a granular medium-depth filter are shown in Table 2.5.

Mechanism	Description
1.Straining • **Mechanical** • **Chance contact**	Particles larger the pore size of the media are mechanically strained Particles smaller than the pore space are trapped by the chance contact
2.Sedimentation	Particle settle on the filtering medium within the filter
3. Impaction	Heavy particles will not follow the path of flow streamline
4. Interception	Particles moving in streamline are removed when coming in contact with the media
5. Adhesion	Attachment of particles as they pass by. As the water flows some particle may not attach firmly and are pushed deeper into the filter. As the filter gets clogged, the surface shear might make materials to break through the bottom of the filter, causing turbidity in effluent
6. Flocculation	It occurs within the interstices of the filter medium.
7. Diffusion	Diffusion of colloids into areas of lower concentration or low hydraulic shear
8. Chemical Adsorption	Bonding and chemical interaction
9. Physical Adsorption	Electrostatic forces, Van der wall forces and electro kinetic forces
10. Biological Growth	Biological growth within the filter bed will reduce the pore volume and may enhance the removal of particles

Table 2.5 Pollutant removal mechanisms from the wastewater by filtration (Metcalf & Eddy, 2015)

Figure 2.3 show some of the above mentioned mechanisms.

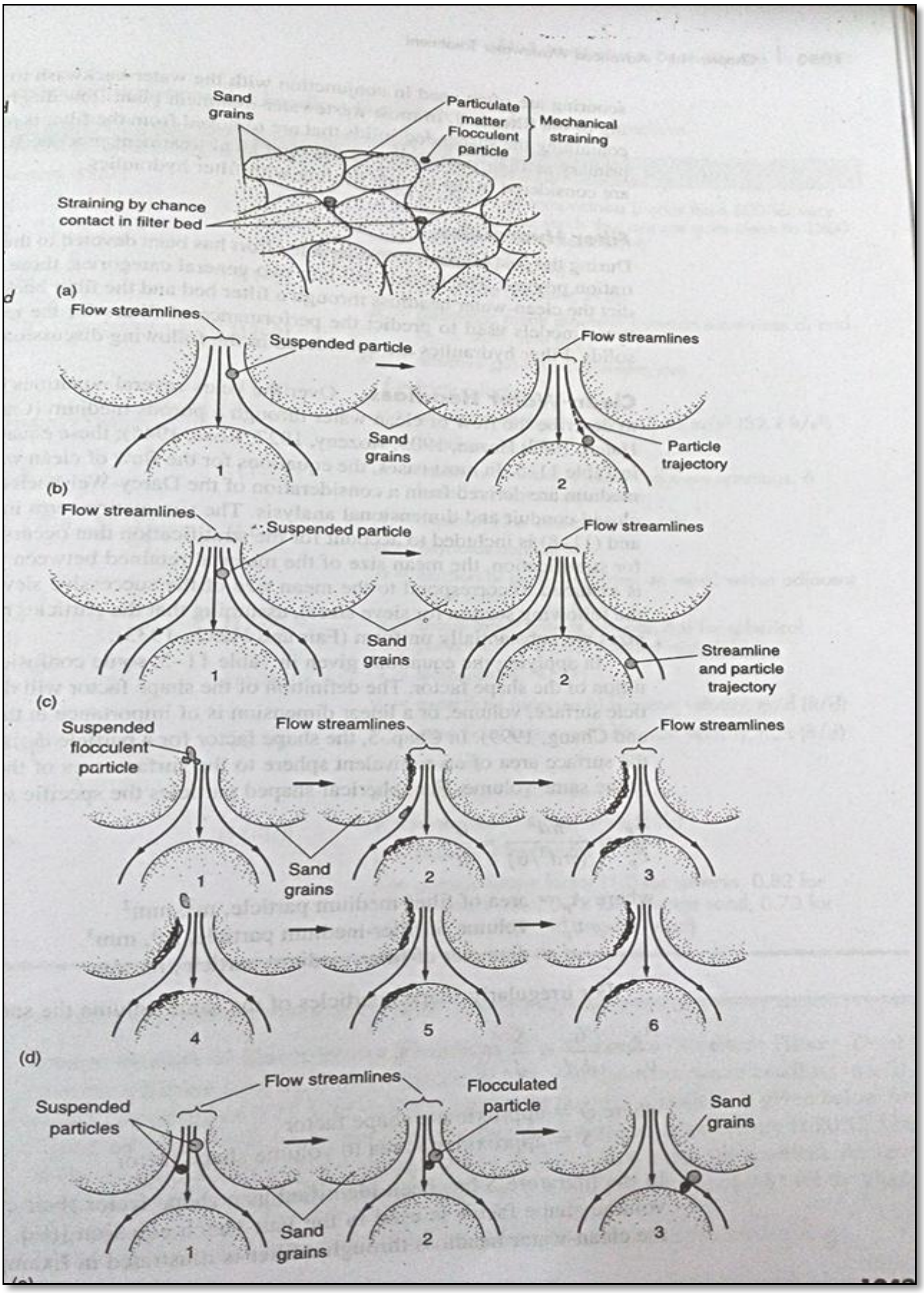


Figure 2.4 Removal of suspended particulate matter within a granular filter (a) Straining, (b) Sedimentation & Impaction, (c) Interception, (d) Adhesion and (e) Flocculation (Metcalf & Eddy, 2015)

As the particles get retained inside the filter, onto the media the filter start working slowly this storage of particles within the filter is termed as clogging (Hendricks, 2006). When the storage capacity of bed gets exhausted, the filter is cleaned. One of the goal of filter design is to get clogging occur throughout the bed depth and not just on the top layer of the medium. Clogging results in head loss and at some point the filter reaches its terminal head-loss. At the same time the effluent particle concentrations reaches its breakthrough limit. This breakthrough is measured by increase in turbidity or particle concentration.

CHAPTER THREE
MATERIAL AND METHODOLOGY

3.1 General

Greywater treatment by sand filtration is studied by a lab-scale filter. The material used for filtration is sand. The study is performed on vertical down-flow four sand columns located inside the PHE Laboratory, Department of Civil Engineering, MNIT, Jaipur under natural conditions of room temperature and natural humidity. The elements of the research concerning material properties, system set-up, working of the system and test procedures are discussed in this chapter.

3.2 The Set Up

The set up as displayed in Figure 3.1 comprised of the cylindrical column used as lab scale filter, sand as media, plastic can for storage of greywater, pumps for feeding water to the filter, borosilicate beakers for collection of the effluent.

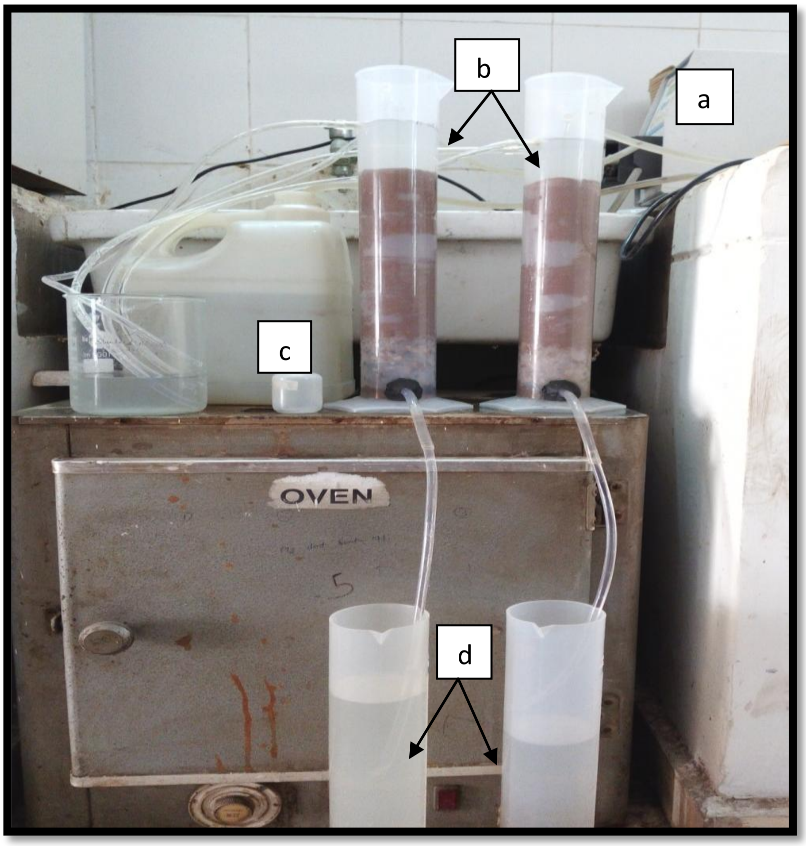


Figure 3.1System set up, where a = peristaltic pump, b = sand columns, c = storage can, and d = effluent container

3.2.1 Media

Collection of sand

The sand used was collected from the central lawn of the MNIT campus, Jaipur. The sand is first washed with tap water and oven dried at 105^{o}C before use.

Properties of sand

Sieve analysis of the sand is done using sieves of size 300µm, 150µm, 90µm, and 75µm. D_{10} (effective size) and D_{60} sizes were 0.127 and 0.256 respectively giving uniformity coefficient as 2.0157. The sand size ranging between 300µm to 150µm made the maximum proportion in the sand, of about 70%. Hence, the sand lying in this range is used for the experiment. The Table 3.1 shows sieves analysis of the sand (2kg).

Sieve size (mm)	Weight retained (gm)	% Weight retained	Cumulative retained %	% Finer
0.3	330	16.5	16.5	83.5
0.15	1393.63	69.6815	86.1815	13.8185
0.09	202.77	10.1385	96.32	3.68
0.075	27	1.35	97.67	2.33
0.001	36.88	1.844	99.514	0.486

Table 3.1 Sieve analysis of the sand

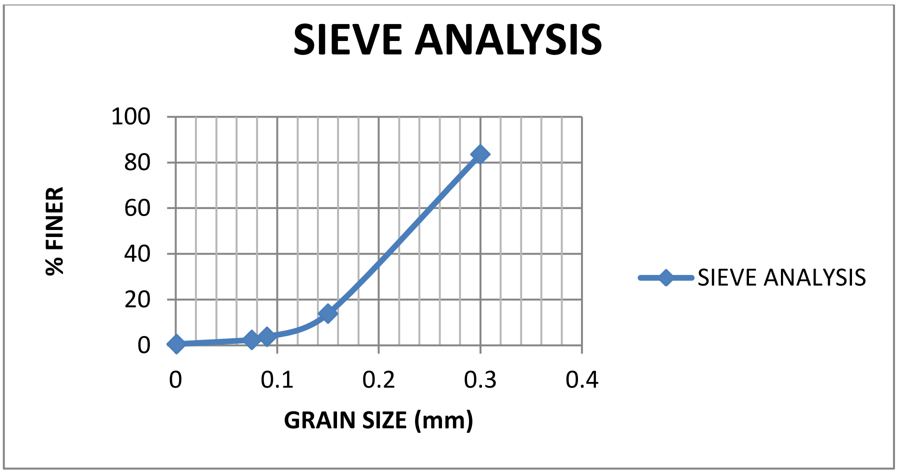


Figure 3.2 Sieve analysis

The properties of sand (300µm- 150µm) used are given in Table 3.2.

Sr. No.	**Property**	**Value**
1	Bulk density	1.43 g/cm^3
2	pH	8.1
3	Conductivity	350 µS/cm
4	Specific gravity	2.63
5	Porosity	0.45

Table 3.2 Properties of sand used

3.2.2 Greywater Collection and Storage

Greywater sample was taken from Gargi Hostel, MNIT, Jaipur and then transported to the lab. The sample is grab sample, taken any time between 9:00am-11:00 am in 5 litre capacity cans. The greywater did not include water from the kitchen. Samples are taken 5 days a week (excluding weekends). Greywater is used immediately after collection for filtration.

After filtration, the effluent of treated greywater is collected in borosilicate glass beakers and tested for water quality parameters. If required the effluent is preserved in covered beaker at 4^0C. However, the analysis of the effluent is performed within 24 hrs of the storage.

3.2.3 Column Design

Each column is cylindrical in shape and made of polypropylene plastic. The total height of the column is 42 cm and inner diameter 6.3 cm. There are two openings of 1cm diameter, one at the top for inlet of greywater and other at the bottom acting as an outlet for effluent. The sand columns are operated for 6 hrs a day.

30 cm of column height is used for filtration. The sand depth is kept as 23 cm, the rest 7 cm are well-graded gravels to support the sand and to restrict the flow of sand with the effluent. The gradation of gravel just underneath the sand bed is shown in the Table 3.3.

Size	Depth (cm)
600 µm-1.18 mm	1
1.18 mm-2.36 mm	1.5
2.36 mm-4.75 mm	2
1 cm-3 cm	2.5

Table 3.3 Gradation of gravels

The schematic diagram of the column is shown in Figure 3.3.

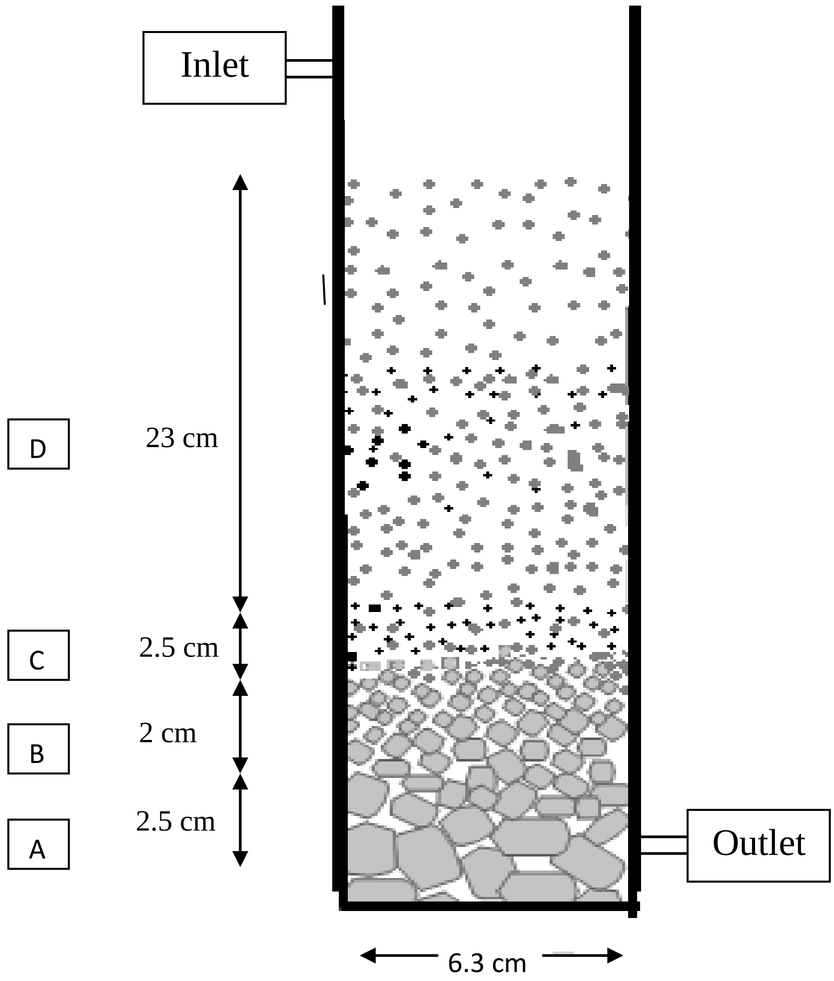


Figure 3.3 Schematic diagram of the column, where A, B, and C are the different gravel sizes lying in the range of 1-3 cm, 4.75-2.36 mm and 2.36 mm-600 µm respectively

Maintaining constant Rate of Filtration (Loading Rate)

Two columns are run at a constant filtration rate. One of the column **(Column 1)** at the rate of 20ml/min (filter loading rate 385l/m^2/hr) while the other **(Column 2)** at 10ml/min (192.5l/m^2/hr). The head is kept variable. The hydraulic loading rate is maintained from influent side by regulating the pump and overflow weir. The calculated HRT is 35 minutes and 70 minutes respectively for 20ml/min and 10ml/min.

Maintaining constant water column head above the sand bed

Two columns are run at constant head of 5cm **(Column 3)** and 3cm **(Column 4)**. Constant head is maintained by an overflow weir which carried the overflowing greywater back to the storage tank.

3.3 LABORATORY ANALYSIS

The characterisation of greywater is done for parameters COD, BOD, Conductivity, pH and Turbidity. The efficiency of the sand filtration is also checked for the above parameters. Hence, the parametric analysis of both raw and treated greywater is done simultaneously.

3.3.1 pH

pH of the raw and treated greywater sample is measured using the pH meter. pH meter is first calibrated with known solutions of pH 4 and 7.

3.3.2 Conductivity

Digital Conductivity Meter is the instrument used for measuring the conductivity of the sample. Conductivity meter consists of an electrode which when immersed in the sample gives reading in mS/cm. The conductivity meter works at a temperature of 27^{o}C. The readings are taken at room temperature. Hence, no temperature correction is required.

3.3.3 Chemical Oxygen Demand (COD)

COD is measured as per APHA, Standard methods for the examination of water and wastewater 1999. The method used is Closed Reflux, Colorimetric Method. In this method the sample is oxidized using potassium dichromate. The Dichromate ions get reduced to chromic ions. The increase in chromic ions is then measured using the principle of light absorbance. Chromic ions absorb light in the range of 600nm. This is measured in spectrophotometer. Calibration curves for absorbance and to known COD concentration are prepared. These standard curves are used to measure COD for corresponding absorbance, by interpolation and extrapolation.

3.3.4 Filtered Chemical Oxygen Demand

Filtered COD of only raw greywater is found out for characterisation. As all the suspended solids got retained by the filter, filtered COD of treated greywater is not found.

The sample is filtered with Whatman Filter- Grade 42 having pore size 2.5µm. The filtered sample is then tested for COD.

3.3.5 Biochemical Oxygen Demand (BOD)

BOD is measured as per APHA, Standard Methods for the Examination of Water and Wastewater 1999. 5-day BOD is found out for all the samples. Dilution water is prepared for diluting the sample. It is prepared by adding phosphate buffer, $CaCl_2$, $MgCl_2$ and $FeCl_3$ solutions to distilled water and then aerating by diffuser pumps overnight. These chemicals acted as nutrients. The diluted sample is prepared according to the expected BOD. The volume of sample added in the BOD is as shown in Table 3.4.

Volume added	Expected BOD
3	200-560 mg/L
6	105-280
9	70-187
12	53-140
15	42-112
30	21-56
45	14-37
60	11-28
100	5-15
300	0-5

Table 3.4 Dilution for BOD test

After preparing the sample dissolved oxygen of both blank and diluted sample is determined by Winkler's method. The BOD bottles were then incubated at 20^0C for 5 days. BOD was calculated by:

BOD= (Initial DO – Final DO) * Dilution factor

Dilution factor = Total volume of BOD bottle/ Volume of sample taken

The sample is tested for BOD within 4hrs of the collection or after a maximum of 48hrs of preservation at $4^{o}C$.

3.3.6 Turbidity

Turbidity is measured using Digital Nephelometer. The instrument is first calibrated with known solution of 10 NTU and 0 NTU. The turbidity of the sample is then taken.

3.4 STATISTICAL ANALYSIS

The readings obtained from experimental results are used to find:

- **Mean**: The mean of the readings were found out by the formula

  $X_{mean} = \sum X_i / n$

- **Standard deviation**: standard deviation is calculated using formula

  $\sigma = \sqrt{\sum (X_i - X_{mean})^2 / n}$

- **Correlation coefficient**: To find correlation between two set of values

  Found using Statistical function "correl" in MS Excel.

- **Efficiency**: The percent removal of a parameter was obtained by

  $E\% = (C_{influent} - C_{effluent}) * 100 / C_{influent}$

CHAPTER FOUR
RESULTS AND DISCUSSION

4.1 General

Experimental study of greywater treatment by sand filtration is carried out. There is removal of organics, solids and nutrients. The water came out of filter quite clean in terms of turbidity as can be seen in Figure 4.1.1. The effluent coming out of filter is tested to check the efficiency of the filter. Filter efficiency regarding removal of chemical oxygen demand, biochemical oxygen demand, turbidity and conductivity is evaluated. Change in pH is also examined. The change in characteristics of greywater as a result of filtration and causes of the change are discussed in this chapter. Efficiency of the system is checked.

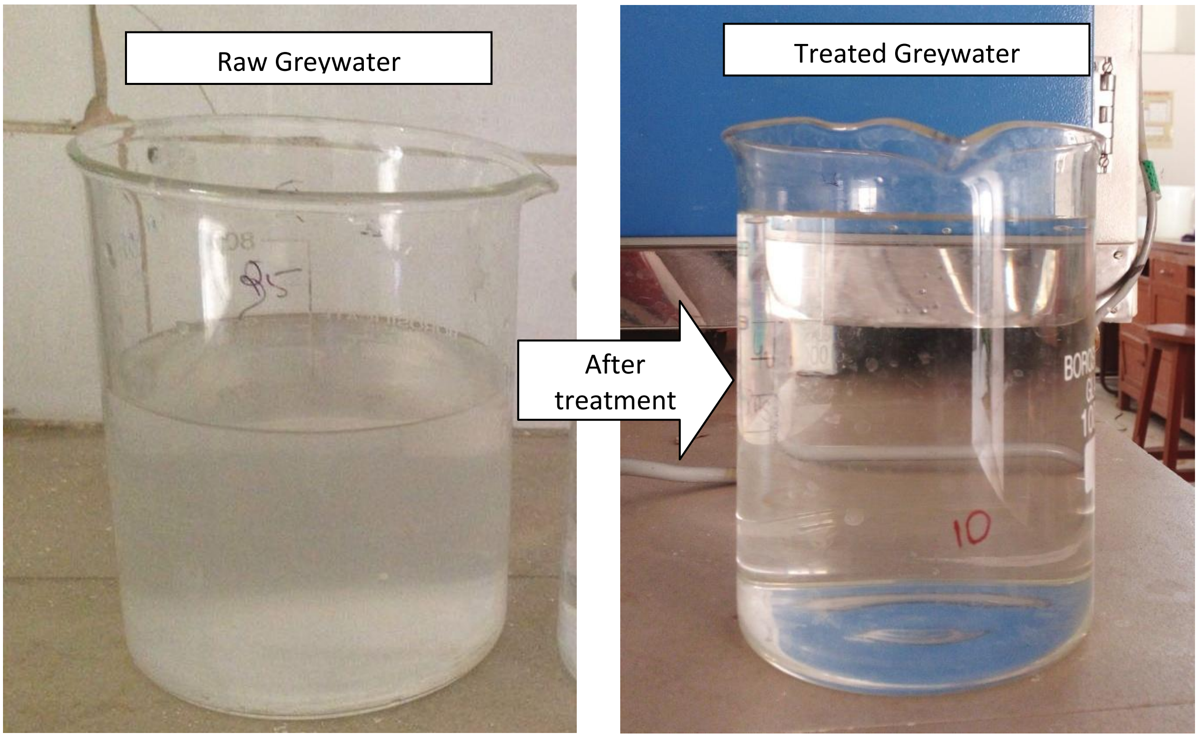


Figure 4.1.1 Greywater before and after treatment

4.2 Characteristics of Greywater

Characterization of greywater regarding Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD), Turbidity, Conductivity, and pH are shown below in the Table 4.2.1.

SR. NO.	PARAMETER	Mean ± S.D.
1	Chemical oxygen demand (COD) (mg/l)	98.88±20.63
2	Filtered Chemical oxygen demand (mg/l)	83.5±15
3	Biochemical oxygen demand (BOD) (mg/l)	51±10
4	BOD_5/COD	0.5 ± 0.08
5	Conductivity µS/cm	704 ± 100
6	Turbidity (NTU)	11 ± 2
7	pH	7.4

Table 4.2.1 Characteristics of Greywater

Greywater used in this experiment contained waters from wash basins, bathroom and laundry. However, laundries in hostels are used mostly on weekends and during working days it is used in afternoon. Hence, contribution of laundry to greywater quality can be considered as small.

These similar values have been reported in journal papers like that of C. Santos et al. (2012), Katell Chaillou et al. (2011) and Eva Eriksson et al. (2002) . The results show the low strength of greywater as compared to that of blackwater and greywater which contains kitchen wastewater. The BOD_5/COD ratio of 0.5, which is compatible with the findings of (H.I. Abdel-Shafya et al., 2014), indicate possibility for biological treatment (Metcalf & Eddy, 2015). The values show that simple treatment technologies could be sufficient to treat the water.

4.3 Working of Sand Filter Columns

Column 1 i.e. column working at filtration rate 20 ml/min operated for 12 days while Column 2 i.e. column working at filtration rate 10 ml/min for 10 days. Lower hydraulic loading rate causes more retaining of particles and early clogging of filter. The filtration rate, theoretical hydraulic retention time (HRT) and calculated initial head loss for the two columns are given in Table 4.3.1

Sr. No.	Parameters	20 ml/min	10 ml/min
1	Filtration rate	0.38 m/hr	0.2 m/hr
2	Hydraulic Retention Time	35 min	70 min
3	Initial head loss	0.12 cm	0.43 cm

Table 4.3.1 Parameters of filter column

The operational day for Column 3 i.e. column working in head 5 cm and Column 4 i.e. column working in head 3 cm are same (09 days) which shows the insignificant effect of water column depth on the filter life.

4.4 COD Removal Results

The removal mechanisms of Chemical oxygen demand of greywater are straining, sedimentation, interception, adsorption and biological oxidation of the organic matter. However, biological oxidation may be limited due to low strength of greywater. Low quantity of nutrients i.e. nitrogen and phosphorous might not be sufficient enough for the growth of microorganisms. The flow in the filter is intermittent, which allowed diffusion of oxygen (Dalahmeh, 2013). Also the water pumped in the filter carried oxygen with it. There is no prominent formation of schmutzdecke layer. Figure 4.4.1 of top view of the column show absence of schmutzdecke layer.

Figure 4.4.1 Top view of the sand column

4.4.1 Filter working at constant flow rate

Average influent COD for Column 1 i.e. column working at filtration rate 20 ml/min is 93.6 mg/l, and average effluent COD is 42.8 mg/l which shows percent removal as 54.27%. The maximum percent removal is found to be 75.5% on the 8th day of commencement of running of the filter. After that, the removal efficiency declined to depict filter reaching its breakthrough. Rise in COD is attributed to shearing off the film of strained particles or biological layer around soil that came out with the effluent.

The average COD influent for column 2 i.e. column working at the filtration rate of 10ml/min is 96.78 mg/l, and the average effluent COD is 42.96 mg/l which shows percent removal of 56%. The highest removal is 80% observed on the 7th operational day. The decrease in efficiency on the 8th day can be due to the same reasons as of that for Column 1. However, the removal efficiency of 10 ml/min filter is higher than that of 20 ml/min filter. Lesser the filtration rate, higher the contact time between water and medium which aids in good filtration process.

Good correlation is observed between COD of influent and effluent, with a correlation coefficient of 0.65 and 0.6 for flow rates 20 ml/min and 10 ml/min, respectively. The Same correlation is seen by Elena Aizenchtadt et al. (2009).

The tables below show COD values for raw and treated greywater with loading rate 20 ml/min and 10 ml/min.

Date	Operational Day	Influent COD (Mg/L)	Effluent COD (Mg/L)	Percent Removal (%)
16.2.16	1	80.5	42.5	47
17.2.16	2	95	25.33	73
19.2.16	3	116.12	47	60
22.2.16	4	68.61	34.15	34.5
23.2.16	5	76.4	33.14	57
24.2.16	6	97.1	27.592	72
25.2.16	7	100	20.771	80 (Max.)
29.2.16	8	130	77.82	40
1.3.16	9	107.3	78.41	29

Table 4.4.1 Influent and effluent COD from column working with rate of filtration 10 ml/min

Date	Operational Day	Influent COD (mg/L)	Effluent COD (mg/L)	Percent Removal (%)
11.2.16	1	83	41.5	50
16.2.16	2	80.5	34.5	70
17.2.16	3	95	24.2	74.5
19.2.16	4	116.12	42.7	63
22.2.16	5	68.61	29.24	57
23.2.16	6	76.4	35.62	53.4
24.2.16	7	97.1	34.035	65
25.2.16	8	100	24.453	75.5 (Max.)
29.2.16	9	130	87.2	33
1.3.16	10	107.3	74	31
3.3.16	12	85.11	50.74	40
4.3.16	13	84.17	35.572	57.7

Table 4.4.2 Influent and effluent COD from column working with rate of filtration 20 ml/min

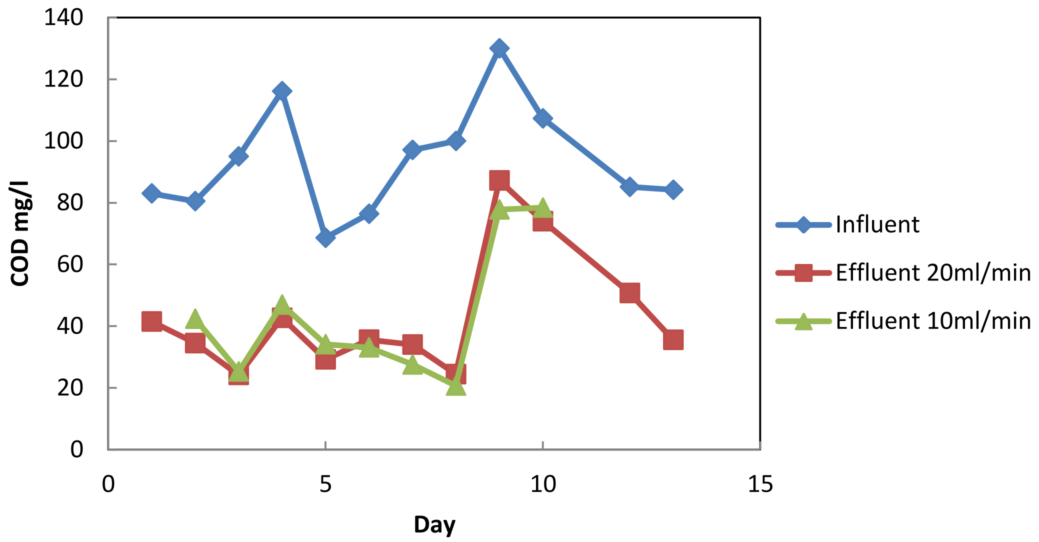
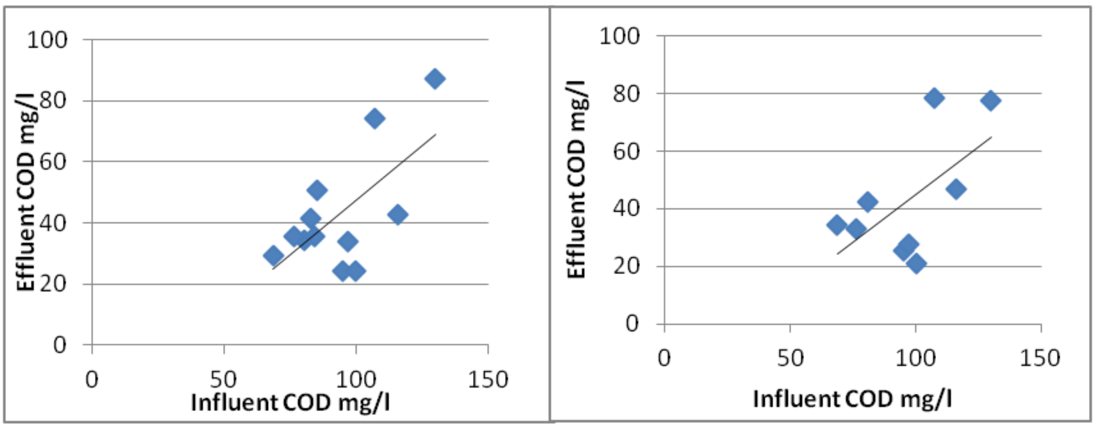


Figure 4.4.2 Graphical representation of influent and effluent COD at different filtration rates



(a) (b)

Figure 4.4.3 Graphs showing correlation between the influent and effluent COD for loading rates (a) 20 ml/min and (b) 10 ml/min

4.4.2 Filter working at constant head

The average influent and effluent COD for column 3 are 100.179 mg/l and 44.35 mg/l depicting 55.73% removal. The average influent and effluent COD for column 4 are 100.179mg/l and 39.6 mg/l depicting 60.5% removal. Less head means low flow velocity through the filter. Low velocity will allow greater contact time with the medium and better interception of particles. Here, the correlation between influent and effluent values is quite weak. The tables below show the influent and effluent COD for filter running with constant head 5cm and 3cm.

Date	Operational Day	Influent COD (mg/L)	Effluent COD (mg/L)	Percent Removal (%)
29.3.16	1	108.67	41.35	62
30.3.16	2	88.023	38.47	56.3
31.3.16	3	90.2	52.3	42.11
4.4.16	4	131.792	52	60.5
5.4.16	5	103.22	33	68 (Max.)
6.4.16	6	83.279	48.34	42
7.4.16	7	120.77	43.26	64.18
8.4.16	8	101.57	35.64	54.46
9.4.16	9	74.087	34.82	53

Table 4.4.3 Influent and effluent COD from column with head 5 cm

Date	Operational Day	Influent COD (mg/L)	Effluent COD (mg/L)	Percent Removal (%)
29.3.16	1	108.67	40	63.2
30.3.16	2	88.023	34.74	60.53
31.3.16	3	90.2	46.6	48.44
4.4.16	4	131.792	60.63	54
5.4.16	5	103.22	25.79	75 (Max.)
6.4.16	6	83.279	49.376	40.7
7.4.16	7	120.77	41.847	65.35
8.4.16	8	101.57	30	70
9.4.16	9	74.087	27.42	63

Table 4.4.4 Influent and effluent COD from column with head 3 cm

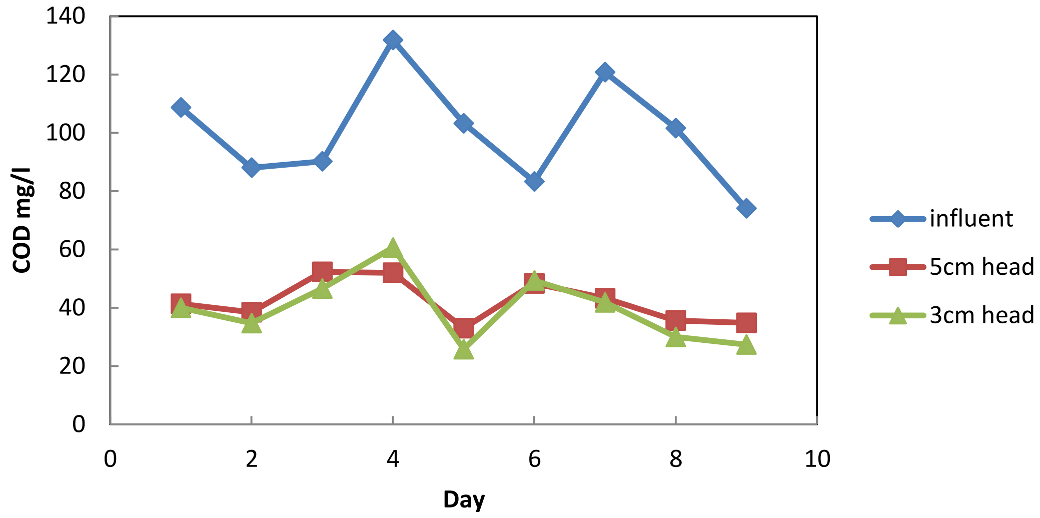
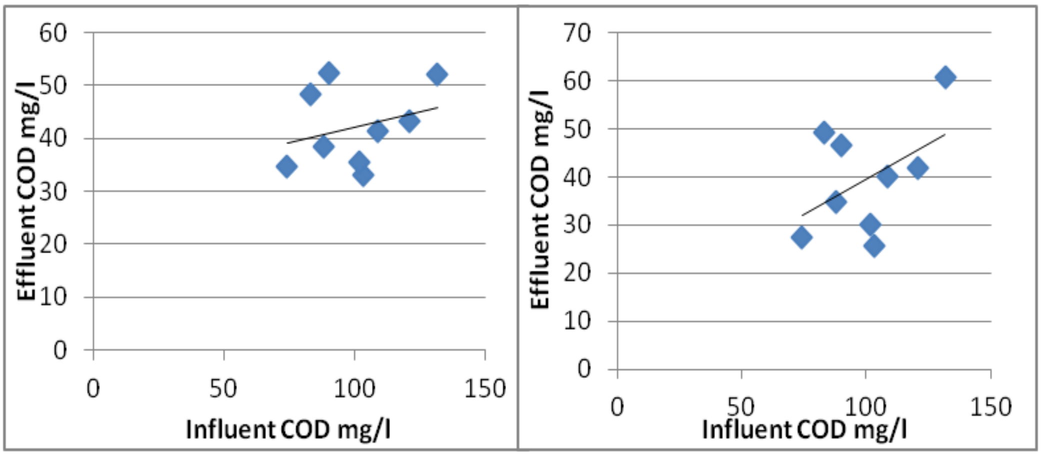


Figure 4.4.4: Graphical representation of influent and effluent COD for the constant head.



(a) (b)

Figure 4.4.5 Graphs showing correlation between the influent and effluent COD for heads (a) 5 cm and (b) 3 cm

4.5 BOD REMOVAL

4.5.1. Filter working at constant flow rate

The average raw and treated greywater BOD is 49.35 mg/l and 21.4 mg/l for column 1 and, 49.17 mg/l and 12.33 mg/l for column 2. The removal percentages respectively are 72% and 75%. The remaining BOD concentration after filtration is probably in soluble form and is not retained by the filter (C. Santos et al., 2012). It can be clearly seen that the BOD_5/COD ratio has decreased from 0.5 to 0.3 which shows the presence of slowly degradable and non-biodegradable matter in greywater which could not be removed by filtration (C. Santos et al., 2012 and H.I. Abdel-Shafy et al.,2014). Here too, there is a positive correlation between influent and effluent BOD values. A line at 10 mg/l in the graph 4.5.1 shows the allowable BOD in water for use in horticulture and toilet flushing. The results, however, could not fulfil the criteria of reuse for toilet flushing and horticulture. Nevertheless, this water can be used for growing crops which allow 20 mg/l of BOD in water (CPHEEO Manual).

The table below show the influent and effluent BOD for column1 and column 2.

Date	Operational Day	Influent BOD (mg/l)	Effluent BOD (mg/l)	Percent removal (%)
11.2.16	1	50	10	80
16.2.16	2	49.5	15.18	69.33
17.2.16	3	42.75	7.5	82.4
19.2.16	4	56.89	14.94	73
23.2.16	6	53.75	11.25	79
24.2.16	7	39	9	76.9
25.2.16	8	52.3	9.53	82 (Max.)
29.2.16	9	50	35	30

Table 4.5.1 Influent and effluent BOD from column working with rate of filtration 20 ml/min

Date	Operational Day	Influent BOD (mg/l)	Effluent BOD (mg/l)	Percent removal (%)
16.2.16	1	49.5	11.25	77.27
17.2.16	2	42.75	6	85.96
19.2.16	3	56.89	16.45	71.08
23.2.16	4	53.75	20	62.8
24.2.16	5	39	5	87.18
25.2.16	6	52.3	5.2	90 (Max.)
29.2.16	7	50	22.4	43
1.3.16	8	50	10	80

Table 4.5.2 Influent and effluent BOD from column working with rate of filtration 10ml/min

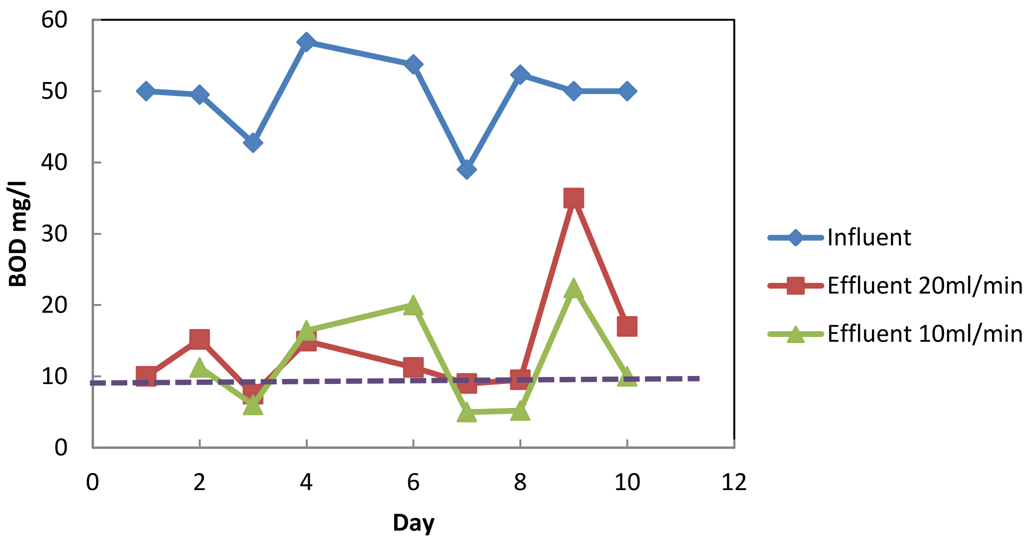
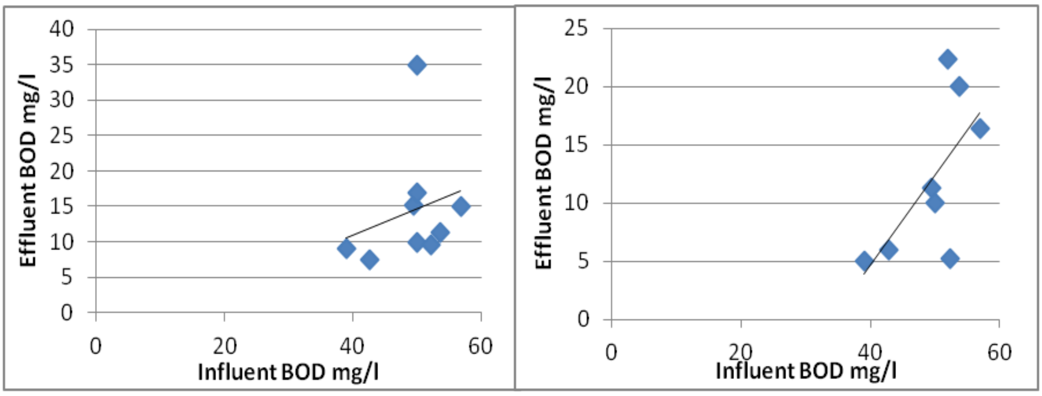


Figure 4.5.1 Graphical representation of the influent and effluent BOD at different filtration rates



(a) (b)

Figure 4.5.2 Graphs showing correlation between the influent and effluent BOD for loading rates (a) 20 ml/min and (b) 10 ml/min

4.5.2 Filter working at constant head

The average BOD_5 for raw greywater is 50.61mg/l which reduced to an average of 21.4 mg/l and 18.14mg/l for heads 5 cm and 3 cm. The corresponding percent removal is 57.7% and 64.15%. The removal for the 3 cm head is higher due to the same reasons as explained for COD removal. Here again, effluent could not meet the toilet flushing and horticulture requirements although, it can be used for irrigation.

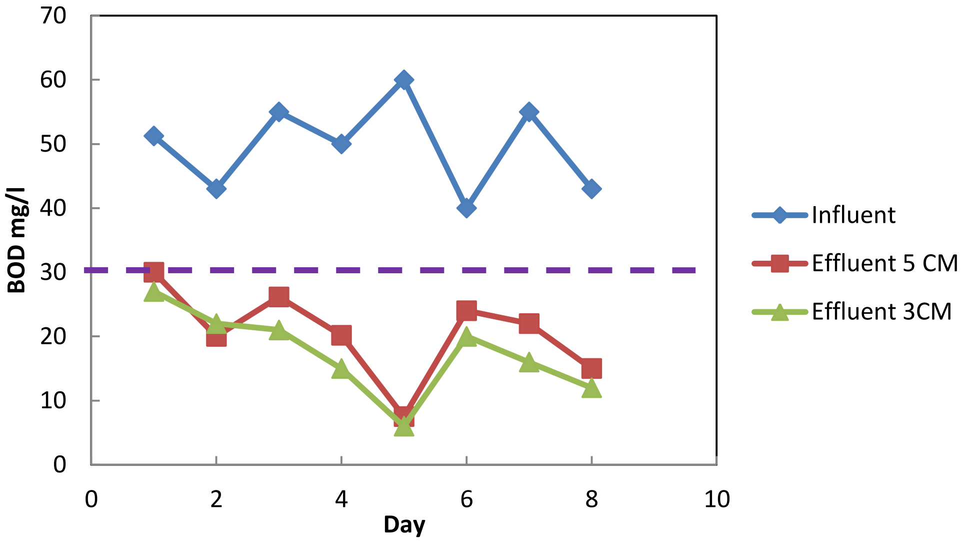
The table below shows the influent and effluent BOD for column 3 and column 4.

Date	Operational Day	Influent BOD (mg/L)	Effluent BOD (mg/L)	Percent Removal (%)
29.3.16	1	51.25	30	41.4
30.3.16	2	43	20	53.5
31.3.16	3	55	26.15	52.5
4.4.16	4	50	20.17	60
5.4.16	5	60	7.5	87.5
6.4.16	6	40	24	40
7.4.16	7	55	22	60

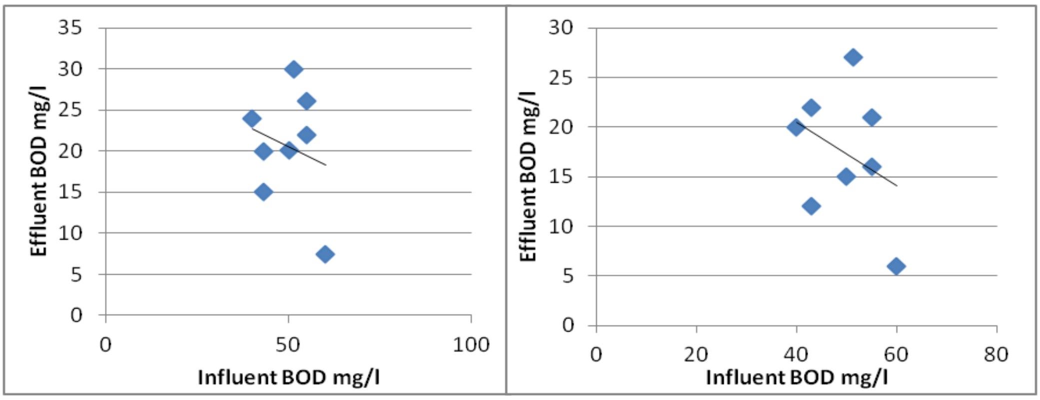
Table 4.5.3 Influent and effluent BOD from column with head 5 cm

Date	Operational Day	Influent BOD (mg/L)	Effluent BOD (mg/L)	Percent Removal (%)
29.3.16	1	51.25	27	47.32
30.3.16	2	43	22	48.8
31.3.16	3	55	21	62
4.4.16	4	50	15	70
5.4.16	5	60	6	90
6.4.16	6	40	20	50
7.4.16	7	55	16	71

Table 4.5.4 Influent and effluent BOD from column with head 3 cm



. Figure 4.5.3 Graphical representation of the influent and effluent BOD for the constant head



(a) (b)

Figure 4.5.4 Graphs showing correlation between the influent and effluent BOD for head (a) 5 cm and (b) 3 cm

4.6 pH

pH increases after greywater passes through the sand medium. This might be due to the some biological processes going on in the filter. The pH is not too high to cause hardness in water. The mean pH of the greywater incoming the filter is 7.35 and that of treated water is 7.63. The increase in pH is still in the acceptable range of 6.5-8.3 (CPHEEO Manual) for toilet flushing, horticulture and irrigation of crops.

4.6.1 Filter working at constant flow rate

pH value fluctuated throughout the experiment. The tables below show pH changes after treatment by sand filtration for flow rates 20 ml/min and 10 ml/min.

Dates	Operational day	Influent pH	Effluent pH
11.2.16	1	7.19	8.06
16.2.16	2	7.76	7.71
17.2.16	3	7.60	7.80
19.2.16	4	7.20	8.04
22.2.16	5	7.53	7.67
23.2.16	6	7.00	7.58
24.2.16	7	7.39	7.76
25.2.16	8	7.33	7.46
29.2.16	9	7.46	7.34
1.3.16	10	7.00	7.39
2.3.16	12	7.36	7.39
3.3.16	13	7.30	7.73

Table 4.6.1 Influent and effluent pH from column working with filtration rate 20 ml/min

Dates	Operational day	Influent pH	Effluent pH
16.2.16	1	7.76	8.12
17.2.16	2	7.60	8.25
19.2.16	3	7.20	8.00
22.2.16	4	7.53	7.94
23.2.16	5	7.00	7.91
24.2.16	6	7.39	7.87
25.2.16	7	7.33	7.29
29.2.16	8	7.46	7.68
1.3.16	9	7.00	8.00
2.3.16	10	7.36	7.55

Table 4.6.2 Influent and effluent pH from column working with filtration rate 10 ml/min

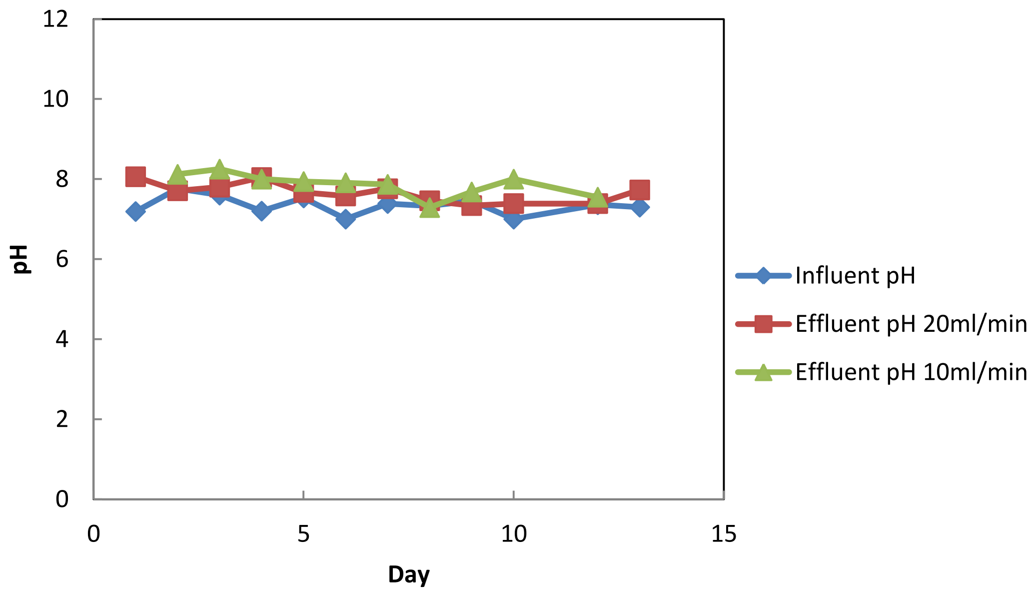


Figure 4.6.1 Graphical representation of the influent and effluent pH for the different filtration rates

4.6.2 Filter working at constant head

The tables below show pH changes after treatment at constant head.

Date	Operational Day	Influent pH	Effluent pH At Head 5 cm	Effluent pH At Head 3 cm
29.3.16	1	7.72	7.51	7.45
30.3.16	2	7.43	7.00	7
31.3.16	3	7.39	7.28	7.85
4.4.16	4	6.39	7.7	7.65
5.4.16	5	7.46	7.69	7.47
6.4.16	6	7.83	7.46	7.42
7.4.16	7	7.32	7.75	7.79
8.4.16	8	7.27	7.53	7.53
9.4.16	9	7.41	7.46	7.58

Table 4.6.3 Influent and effluent pH from column working with heads 5 cm and 3 cm

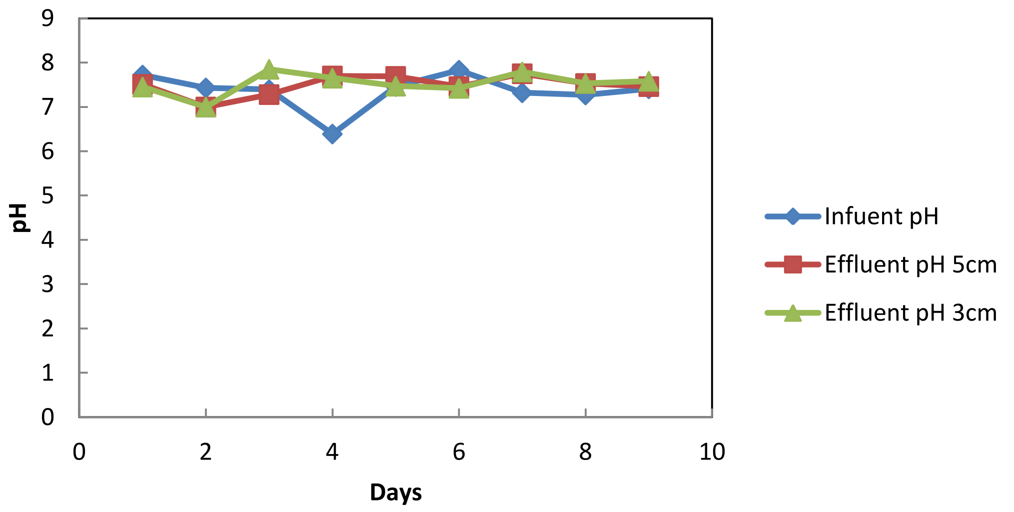


Figure 4.6.2 Graphical representation of the influent and effluent pH for the different heads

4.7 CONDUCTIVITY

The conductivity of the greywater is not too high, making it good quality water for irrigation purpose. The conductivity of the effluent increased during initial four hours due to leaching of nitrates from the soil.

4.7.1 Filter working at constant flow rate

The influent conductivity is 707.1µS/cm, and the effluent conductivity is 688.78µS/cm for filtration rate 10 ml/min while the influent and the effluent conductivity for filtration rate of 20ml/min are 697.33µS/cm and 667µS/cm, respectively. The observed decrease in conductivity shows absorption of ions by the sand.

The tables show the influent and effluent conductivity of greywater for these flow rates:

Date	Operational Day	Influent Conductivity (µs/cm)	Effluent Conductivity (µs/cm)
11.2.16	1	690	664
16.2.16	2	637	654
17.2.16	3	654	669
19.2.16	4	686	631
22.2.16	5	1000	778
23.2.16	6	690	676
24.2.16	7	716	663
25.2.16	8	683	670
29.2.16	9	651	646
1.3.16	10	647	653
3.3.16	12	647	640
4.3.16	13	667	660

Table 4.7.1 Influent and effluent Conductivity from column working with filtration rate 20 ml/min

Date	Operational Day	Influent Conductivity (µs/cm)	Effluent Conductivity (µs/cm)
16.2.16	1	637	680
17.2.16	2	654	680
19.2.16	3	686	668
22.2.16	4	1000	779
23.2.16	5	690	687
24.2.16	6	716	695
25.2.16	7	683	677
29.2.16	8	651	656
1.3.16	9	647	677

Table 4.7.2 Influent and effluent Conductivity from column working with filtration rate 10 ml/min

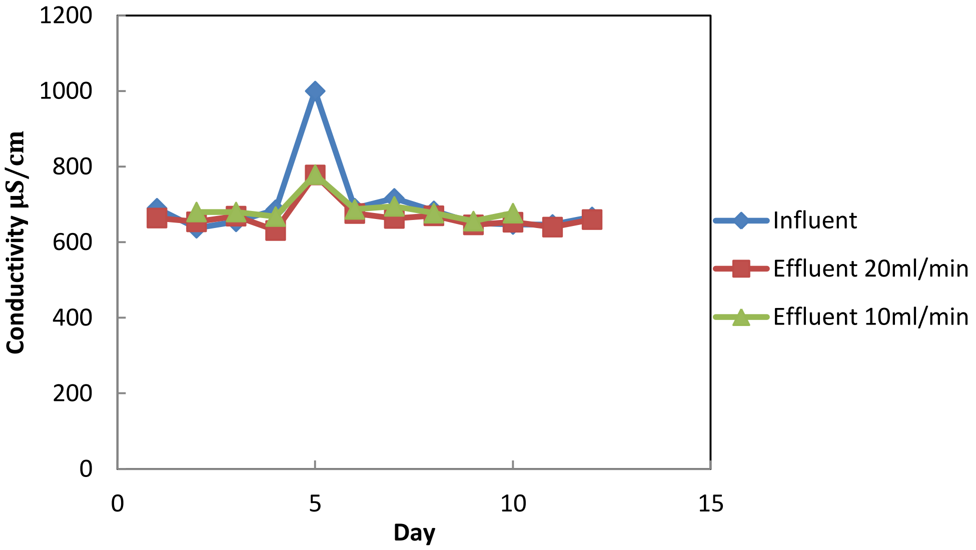


Figure 4.7.1 Graphical representation of conductivity for different filtration rates.

4.7.2 Filter working at constant head

Here too, there is little difference in conductivity with influent conductivity as 721.25µS/cm and effluent as 717µS/cm and 735µS/cm for water column height 5cm and 3cm respectively. However, there is an increase in conductivity for head 3cm indicating ions from sand bed coming along with effluent.

The tables show the influent and effluent COD of greywater for filter running with constant head 5cm and 3cm.

Date	Operational Day	Influent Conductivity (µs/cm)	Effluent Conductivity (µs/cm)
29.3.16	1	689	730
30.3.16	2	691	735
31.3.16	3	730	700
4.4.16	4	710	699
5.4.16	5	760	700
6.4.16	6	700	710
7.4.16	7	750	730
8.4.16	8	740	732

Table 4.7.3 Influent and effluent Conductivity from column working with head 5 cm

Date	Operational Day	Influent Conductivity (µsc/m)	Effluent Conductivity (µs/cm)
29.3.16	1	689	720
30.3.16	2	691	730
31.3.16	3	730	710
4.4.16	4	710	700
5.4.16	5	760	710
6.4.16	6	700	730
7.4.16	7	750	740
8.4.16	8	740	735

Table 4.7.4 Influent and effluent Conductivity from column working with head 3 cm

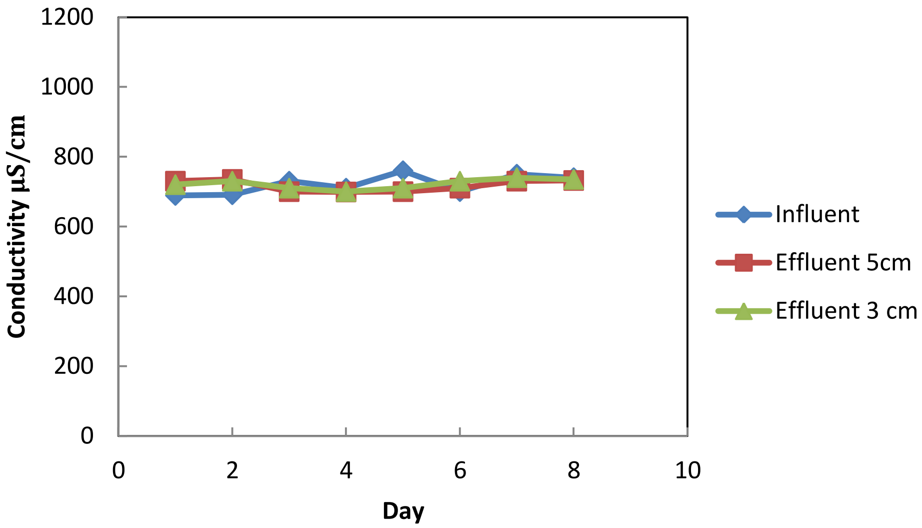


Figure 4.7.2 Graphical representation of conductivity for heads 5cm and 3cm

4.8 Turbidity

Turbidity removal through the filter is purely by physical filtration. As the sand particle size is fine, it can retain all the suspended particles, thereby attaining above 95% turbidity removal. After operating filter for few days, the effluent started appearing yellow-brown and high particle concentration can be observed. This increased the turbidity of the effluent. At this point the effluent can be said to have reached its breakthrough limit. The line in the Figure 4.7.1 at 2 NTU is the allowable Turbidity in water for use in toilet flushing and horticulture (CPHEEO Manual). Filtration is efficient in turbidity removal,thereby fulfilling the reuse requirements. It is also obsereved that a strong correlation of 0.739 exist between BOD and turbidity, which indicate that turbidity is contributing to the biochemical oxygen demand.

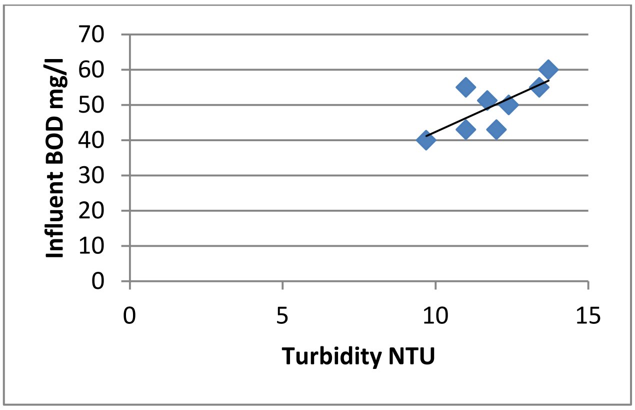


Figure 4.8.1 Graph of correlation between BOD and turbidity

Turbidity of influent and effluent greywater for filter column 3 and column 4 is

Date	Operational Days	Influent Turbidity (NTU)	Effluent Turbidity (NTU)	Percent Removal (%)
29.3.16	1	11.7	0	100 (max.)
30.3.16	2	12	0.6	95
31.3.16	3	11	0.1	99.1
4.4.16	4	12.4	0.7	94.35
5.4.16	5	13.7	0.3	97.8
6.4.16	6	9.7	0.5	94.8
7.4.16	7	13.4	0.6	95.52
8.4.16	8	11	1.2	89.09

Table 4.8.1 Influent and effluent Turbidity from column with head 5 cm

Date	Operational Days	Influent Turbidity (NTU)	Effluent Turbidity (NTU)	Percent Removal (%)
29.3.16	1	11.7	0	100
30.3.16	2	12	0.2	98.33
31.3.16	3	11	0	100
4.4.16	4	12.4	0.6	95.16
5.4.16	5	13.7	0.3	97.8
6.4.16	6	9.7	0.9	94.85
7.4.16	7	13.4	1	92.53
8.4.16	8	11	1.8	83.63

Table 4.8.2 Influent and effluent Turbidity from column with head 3cm

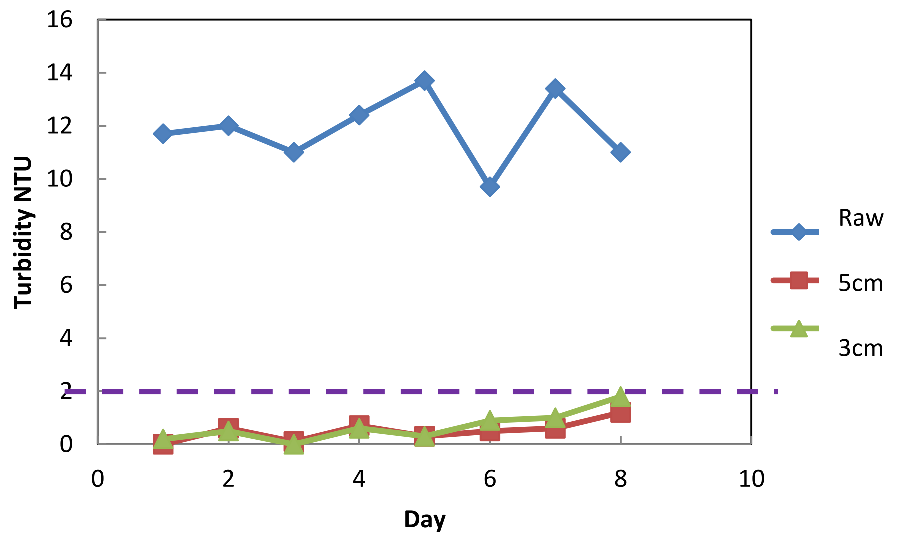


Figure 4.8.2 Graphical representation of turbidity removal

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CHAPTER FIVE
CONCLUSION AND FUTURE RECOMMENDATION

5.1 CONCLUSION

The research on examining the efficiency of locally available sand for the removal of COD, BOD_5, Turbidity and conductivity from greywater through filtration shows the potential for treatment. The main mechanism of pollutant removal is physical filtration. As the results show, there is a good removal of turbidity but average removal of BOD_5 and COD. The sand filter is tested at constant flow rate (20ml/min and 10ml/min) and constant head (5cm and 3cm). COD and BOD_5 removal for columns operating at constant filtration rate are better than those running at the constant head. Between the two filtration rate, 10ml/min flow rate gave good results. Too high filtration rate and too high water column head both decrease the efficiency of the filter. The sand used is too fine, and the filter got choked just in two weeks. This will demand frequent backwashing and renewing of the filter.

The reuse standards are confirmed from CPHEEO Manual. Although the treated greywater complies with reuse standards of irrigation yet it does not abide by the guidelines provided for use in toilet flushing or horticulture for which the treatment is intended.

5.2 FUTURE RECOMMENDATION

Greywater reuse is a very good water saving strategy. Methods must be found to treat it properly before use. In this research sand filtration is opted as a technique for treatment. But it could not fully treat the water. Further study can be carried to determine optimum depth of filter and find a suitable post treatment process. Filtration using other media like charcoal, other type of sand can be tested.

Some of the alternatives that can be applied to treat greywater to achieve good results are mixing of kitchen waste, so that other biological processes can be applied for treatment and treatment by chemical processes.

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APPENDIX 1

CPHEEO water reuse standards

Parameter	Toilet Flushing	Fire Protection	Vehicle exterior Washing	Non-contact impoundments	Landscaping, Horticulture and agriculture			
					Horticulture, Golf course	Crops		
						Non-edible crops	Crops which are eaten	
							raw	cooked
Turbidity(NTU)	<2	<2	<2	<2	<2	AA	<2	AA
SS	NIL	NIL	NIL	NIL	NIL	30	NIL	30
TDS	2100							
pH	6.5-8.3							
Temperature	Ambient							
Oil and Grease	10	Nil	Nil	Nil	10	10	Nil	Nil
Minimum residual chlorine	1	1	1	0.5	1	Nil	Nil	Nil
TKN	10	10	10	10	10	10	10	10
BOD	10	10	10	10	10	20	10	20
COD	AA	AA	AA	AA	AA	30	AA	30
Dissolved Phosphorous as P	1	1	1	1	2	5	2	5
Nitrate Nitrogen as N	10	10	10	5	10	10	10	10
Faecal Coliform in 100 ml	NIL	NIL	NIL	NIL	NIL	230	NIL	230
Colour						AA		
Odour	No foul odour							

INSTRUMENTS USED

S.No.	Instrument	Company	Model
1.	COD Digester	CHINO scientific instruments mfg.	
2.	UV- Spectrophotometer	Shimadzu, UV-1800	UV-1800
3.	Digital Nephelometer	EI	Model 341
4.	Incubator	Toshniwal	
5.	Microwave	Samsung	MW73BD
6.	pH Meter	Labtronics	LT-11
7.	Oven	Scientronic	SIM65
8.	Weighing Balance	CAS	CAUW220D
9.	Conductivity meter	Lutron	CD-4302