



Addis Ababa University

Africa Center of Excellence for Water Management

Performance of Lab-Scale Filtration System for Greywater Treatment
and Reuse: A Case of Natural and Computational Science Campus,
Addis Ababa University, Ethiopia

By

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July, 2020, Addis Ababa



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and Reuse: A Case of College of Natural and Computational Science
Campus, Addis Ababa University, Ethiopia

By

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of Science in Water Management (Water Supply and Sanitation)

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July, 2020, Addis Ababa

DECLARATION

I, **TUSIIME ANNA**, declare that this is a result of my own original work, and to the best of my knowledge, the findings have never been previously presented to the Addis Ababa University or elsewhere for a ward of any academic qualification. Where assistance was sought, it has been accordingly acknowledged.

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APPROVAL

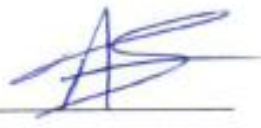
The undersigned certify that, they have read and approve for acceptance by the Africa Center of Excellence for Water Management, Addis Ababa university, this thesis entitled, 'Performance of a Lab- Scale Filtration System for Greywater Treatment and Reuse: A case of College of Natural and Computational Science Campus, Addis Ababa University, Ethiopia.'

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ABSTRACT

Greywater management through treatment using filtration systems and reuse is one way to achieve water security in Ethiopia. The College of Natural and Computational Sciences (CNCS) campus of AAU is facing the problem of water shortage especially in the evening hours when normal water supply is cut off resulting into poor sanitation. Reusing greywater (GW) that comes from dormitories for non-potable uses is one of the options to supplement water supply. The pollution levels of GW is quite low as compared to black water. This quality allows greywater to be treated by simple treatment technology like filtration. The aim of this study was to evaluate the performance of a lab-scale filtration system for greywater treatment and reuse using sand and granular activated carbon as filter media. The specific objectives of this study were to: 1) Characterize the raw greywater generated at CNCS campus; 2) Compare the treatment efficiency of lab-scale filtration systems that use gravel + sand and gravel + sand + GAC; and 3) Evaluate willingness to use treated greywater for selected non-potable uses. Raw greywater quality was characterized by determining its physico-chemical and microbiological parameters in the laboratory. The treatment efficiency was determined by comparing the mean values before filtration and with those after filtration. The systems were examined for their efficiencies at different hydraulic retention times (HRT) (12, 24, and 36 hrs) and at different filter columns, one with gravel + sand and the other with gravel + sand + GAC operating at constant HLR (0.15m/h). The willingness to use treated greywater for selected non-potable uses was evaluated through interviews (using questionnaire). Results showed that the raw greywater was polluted and was above reuse standards except nitrates and Total phosphorus, therefore treatment was necessary. For both filter columns, the treatment efficiency of the system increased with HRT at 12 h and 24 h and later on it decreased at 36 h, except for EC and NH₄-N, which decreased with increase in time. The removal of contaminants was significantly higher ($p < 0.05$) at 24 h and with no significant difference ($p > 0.05$) between filters except in removal of NH₄-N. The pollution reduction was from 60.8 % - 100 % for selected parameters (pH, turbidity, EC, BOD, COD, NH₄-N, NO₃, TP, TC, and FC) in filter column B and from 47.2 % - 100 % for filter column A. The results also indicated that over 80% of the respondents were willing to use the treated greywater for selected non-potable uses, for the fact that the treated greywater was meeting the reuse standards. Thus, a filtration system is efficient and can be employed to treat GW for non-potable uses at CNCS to improve hygiene, sanitation and water shortage.

Key words; greywater, filtration system, filter columns, hydraulic retention time.

ABBREVIATIONS

AAU	Addis Ababa University
AAWSA	Addis Ababa Water and Sewerage Authority
APHA	American Public Health Association
ASTM	American Society of Testing and Materials
CFU	Colony Forming Unit
CNCS	College of Natural and Computational Sciences
DN	Diameter Nominal
EPA	Environmental Protection Agency
FAO	Food and Agriculture Organization
FTU	Formazin Turbidity Unit
GWR	Greywater Reuse
HFCW	Horizontal Flow Constructed Wetland
HSD	Honest Significant Difference
pH	potential Hydrogen
PPr	polypropylene random copolymer
PVC	Poly Vinyl Chloride
RGW	Raw greywater
SD	Standard Deviation
SPPS	Statistical Package for Social Sciences
TGW	Treated Greywater
UK	United Kingdom
UNDP	United Nations Development Programme
USEPA	United States Environmental Protection Agency
VFCW	Vertical Flow Constructed Wetland
WHO	World Health Organization

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CHAPTER ONE: INTRODUCTION

1.1. Background

The human demands outweighs the volume of fresh water on earth. Of all water resources on Earth, about 97 % is found in the oceans while only 3 % remains available for direct exploitation (fresh water). However, out of this percentage of fresh water, the 2.7 % is comprised of glaciers and icecaps. The remaining little portion (0.3 %) is available as a surface and ground water for human consumption and to sustain all forms of life (Eakin and Sharman, 2010). Thus makes freshwater most vital yet it is spatially and temporal finite (Dessu *et al.*, 2014).

There is uneven distribution of freshwater in both space and time which causes the water scarcity worldwide. It has been found that many parts of the world are facing water shortage that resulted from over-exploitation and pollution of water bodies (Uddin *et al.*, 2014). According to UNDP (2017) estimated that 800 million people live under a threshold of water stress, and this number is projected to reach three billion by 2030. Water deficit have totally affected the economic development, and food availability worldwide (Boufaroua *et al.*, 2013).

Water demand is increasing at a higher rate in relation to the population growth, but water availability is reducing due to growing competing demands from various users (Jacobsen *et al.*, 2012). For instance, UN-INWEH (2017) projected that, the world will face a 40% water deficit by 2030. Ethiopia having a renewable water supplies less than 1700 m³ per capita per year and with an economic water scarcity (WWAP, 2016), it has been listed among the countries that are projected to fall below the water scarcity level by 2030.

In Ethiopia, it was found that the rapid expansion of the city, and inadequate wastewater treatment facilities coupled with poor governance make wastewater management complex and this leads to an increase of untreated wastewater point sources (Amare *et al.*, 2017). Water scarcity that could be the result of poor water quality and water-related disasters are the main concerns related to current and future water resources.

To improve the water quality and mitigating water scarcity are closely associated with greywater management through treatment and reuse for non-potable uses by filtration systems. Greywater is composed of domestic wastewater from the bathroom, laundry, and kitchen excluding toilet wastewater (Olanrewaju, 2015). The same author confirmed that greywater reuse (GWR) can reduce urban potable water demand by 30% - 70%.

Recently, Abdel-Shafy *et al.* (2014) studied the greywater treatment system applications of high-rate aerobic systems (Rotating Biological Contactor, Fluidized Bed, Aerobic Filter, and Membrane Bioreactor). These may have high capacity to produce superior quality of greywater than that generated from the traditional processes like physical processes (Wurochekke *et al.*, 2016). However, these are complex and require high technology to operate compared to the filtration system that use granular activated carbon (GAC) and sand as filter media (Allen *et al.*, 2010; Kariuki *et al.*, 2011). The GAC and sand have high efficiency on low strength wastewater, they are easily regenerated, and are available materials when compared to other filters like saw dust, pine barks and many others (Boyjoo *et al.*, 2013). Therefore, these are appropriate materials to use in filtration system. In their other hand, filtration system is a simple technology for developing countries in treating low strength wastewater.

1.2. Problem Statement

Supply of sufficient amount of water is one of the most challenges facing people residing in cities of developing countries. For instance, in Ethiopia, Addis Ababa City is one of the cities hit by acute water shortage due to industrialization, urbanization, and high population growth. The water demand is high and is expected to rise, making the existing water resources unsustainable (Mekonnen, 2015). To develop new fresh water sources does not meet these challenges in recent situation. Therefore, it is essential to supplement freshwater with other water sources by using reuse options. Among these alternatives, greywater can be used to meet the anticipated water scarcity. Water demand in Addis Ababa City exceeds water supply. The water demand in Addis Ababa City is about 866,540 m³/day, compared to water supply of about 618,000 m³/day (AAWSA, 2018). In this regard, water supply in the city is limited. For example, in the College of Natural and Computational Sciences campus (CNCS) of Addis Ababa University (AAU), water supply is cut off during evening hours, a situation that results into poor sanitation. Greywater reuse can help to bridge the water demand-supply deficit by filtration system. The pollution levels of GW is quite low when compared to black water. This quality allows greywater to be treated by simple treatment technology like filtration. However, though the possibility of reusing wastewater after treatment from filtration system has been explored in some areas, knowledge of its application in the AAU Science campus is limited. The greywater in the campus is collected in the combined system to the conventional treatment plant and some wastewater from laundry are discharged directly to the

environment. In other words, it doesn't have any existing treatment system of greywater for reuse purposes.

Therefore, evaluating the performance of a lab- scale filtration system for greywater treatment and reuse in AAU - CNCS Campus generates useful data that contributes to the introduction of appropriate simple technology at campus-level.

1.3. General objective

The aim of this study was to evaluate the performance of a lab- scale filtration system for greywater treatment and reuse at the College of Natural and Computational Sciences Campus, Addis Ababa University.

1.3.1. Specific objective

- i. To characterize the raw greywater generated at CNCS campus.
- ii. To compare the treatment efficiency of lab-scale filtration systems that use gravel + sand and gravel + sand+ GAC at varying HRT.
- iii. To evaluate the willingness to use treated greywater for non-potable purposes at CNCS campus.

1.4. Research questions

- i. What are the physico-chemical and microbiological characteristics of raw greywater generated from CNCS campus?
- ii. What is the treatment efficiency of lab-scale filtration systems that use gravel + sand and gravel + sand + GAC at varying HRT?
- iii. To what extent is the community of CNCS campus willing to use the treated greywater for non-potable purposes?

1.5. Significance of the study

The study will provide data to scale up the system to the college level and university at large. If scaled up there will be reduction of water demand and improved sanitation within the college. Furthermore, the scale up will reduce the hydraulic loads to the treatment plants and minimizing the underground and surface water pollution. The data generated from this study can be used by water engineers to implement similar technology elsewhere facing similar water challenge.

1.6. Scope of the Study

This study evaluated the performance of a lab- scale filtration system for greywater treatment and reuse to supplement water supply in CNCS campus, Addis Ababa University, Ethiopia. The study was a lab-based experiment, and it also involved a social survey of several CNCS staffs and students. The treated greywater would be used mainly for non-potable uses (toilet flushing, flower irrigation/watering and pavement washing).

CHAPTER TWO: LITERATURE REVIEW

2.1. Greywater definition

Greywater (GW) is household wastewater generated from bathrooms, kitchen, hand wash basins, laundry and it does not involve wastewater from toilets, urinals or any industrial process (Andarge, 2019). It constitutes 50-70% of domestic household (Kariuki *et al.*, 2011) and its characteristics normally vary in time and space. There are several aspects which influence that, namely the quality of water sources, the distribution network carrying the water and water related activities within the household (Olanrewaju 2015). The same author reported that the greywater reuse (GWR) system designs depends on the quality and quantity of greywater effluent.

2.2. Greywater generation

The low income areas can generate greywater volume from household that vary from 20 Liters per capita per day to several hundred per person per day. There are various factors that may contribute to the amount of greywater generated for example, geographical location, lifestyle, and type of infrastructure, climatic conditions, culture and habits. The volume of greywater produced from households is approximately 50-70 % of wastewater, which may increase to about 90 % if the toilets wastewater are included (Hernandez *et al.*, 2010).

The volume of greywater generated from poor countries of Africa that are facing water scarcity and with limited forms of water supply (e.g. community taps or wells) can be very low per person per day in households. However, households in middle- to high-income areas with piped water reticulation may generate significant volumes per person per day (Olanrewaju 2015). In estimation, the average typical GW generation in Addis Ababa households with piped water reticulation are likely to range between 40-60 l/p/d (approximately 50% of total water consumption) (AAWSA, 2019). The same author reported the volume of water used in household per day in Addis Ababa to be 100-110 l/c/d and more than half of this water can be collected and recycled from the greywater.

2.3. Sources of greywater

Bathroom greywater

The 50 % of total GW volume is contributed by the bathroom. This kind of GW can be contaminated with hair, dyes, shampoos, soaps, toothpaste, body fats and oils, nutrients and cleaning products (Andarge, 2019).

Laundry greywater

The 30 % of total greywater volume can be contributed by laundry greywater. The quality of laundry greywater differs from wash water of rinse water and second rinse water. Laundry GW may be contaminated with oils, grease, laundry detergents, chemicals, soaps, nutrients and other compounds (Andarge, 2019).

Kitchen wastewater

The kitchen can contribute 20 % of greywater. If a suitable treatment is not available, kitchen wastewater should not be considered as greywater because of its amount of contaminants (food particles, oil, grease, and many others.) it contains. However, kitchen greywater generates the smaller amount of the total greywater volume (Andarge, 2019).

2.4. Greywater characteristics

There are three factors which significantly affects greywater composition; water supply quality, the condition of the components conveying greywater from point of discharge, and the water related uses in the household (Eriksson *et al.*, 2002). It was found that the grey water characteristics of different categories of sources differ from each other in quality (Li *et al.*, 2009). Higher concentrations of both organics and physical pollutants originates from kitchen greywater and less from the bathroom and the mixed grey water as shown in Table 1. The greywater from the household have a good biodegradability of 2.5 in terms of the COD: BOD₅ ratios (Li *et al.*, 2009).

Table 1: The characteristics of grey water by different source categories.

Parameters	Bathroom	Laundry	Kitchen	Mixed
pH	6.4-8.1	7.1-10	5.9-7.4	6.3-8.1
TSS(mg/l)	7- 505	68-465	134-1300	25-183
Turbidity (NTU)	44-375	50-444	298.0	29-375
COD(mg/l)	100- 633	231- 2950	26-2050	100-700
TN(mg/l)	3.6-19.4	1.1- 40.3	11.4 - 74	1.7 – 34.3
TP(mg/l)	0.11 -171	ND -171	2.9 - 74	0.11- 22.3
TC (CFU/100ml)	10–2.4×10 ⁷	200.5–7×10 ⁵	> 2.4×10 ⁸	56–8.03×10 ⁸
FC (CFU/100ml)	0–3.4×10 ⁵	50–1.4×10 ³		0.1–1.5×10 ⁷

Source: Li *et al.* (2009)

2.4.1. Greywater composition

The biological and chemical degradations of wastewater compounds affects its composition. These may occurs during the transportation and storage. There could be high concentrations of organic compounds, chemical constituents and other constituents from household greywater which include nutrients, and biological microbes (fecal coliforms, and total coliforms) (Fatta-Kassinou *et al.*, 2011). Recent studies by Oteng-peprah *et al.* (2018) found pharmaceuticals, human care products, aerosols, pigments and heavy metals in the greywater.

2.4.2. Physical constituents

It is associated with the physical properties of greywater (temperature, turbidity, electrical conductivity and suspended solids). Greywater usually has a temperature ranging from 18 °C to 35 °C. The high range of temperature may be originating from bathroom and kitchen greywater Olanrewaju (2015) and this may favor microbiological growth which is undesirable. It can also cause precipitation of certain carbonates such as CaCO₃ which become less soluble at high temperatures (Oteng-peprah *et al.*, 2018).

Edwin *et al.* (2014) reported the range of 180–540 mg/L of total suspended solids (TSS) for greywater from house hold. The same author observed that greywater coming from the kitchen and laundry have high values of TSS, and this is because of washing clothes, shoes, vegetables, fruits, and tubers which may be containing sand, clay and other materials that could increase TSS.

The studies by Ciabatti *et al.*, (2009) reported the electrical conductivity of greywater in a range of 24 and 2500 µS/cm. The same author reported the turbidity in the range of 16 and 450 NTU which is mostly influenced by the water use activities that occur in the household.

2.4.3. Chemical contaminants

These kind of greywater contaminants could be from chemicals used for cleaning, cooking and bathing purposes. According to USEPA (2005) the allowable pH for water supply range between 5-9 and the pH of greywater to some extent depends on the acidity and alkalinity of it. The high pH found in greywater is the result of alkaline materials from detergents. Surfactants are among the chemical constituents found in greywater which are generated as a result of washing activities. Cationic surfactants are salt based, and are sources of ammonium in the greywater (Oteng-peprah *et al.*, 2018). Also nitrogen compounds and phosphorus compounds are the chemical constituents

found in greywater. Sodium is one of the constituent from Sodium-based soaps, cooking and preservation activities in the kitchen. Kitchen wastewater is the primary source of nitrogen in greywater and nitrogen concentrations that ranges from 4 to 74 mg/L (Olanrewaju, 2015).

COD is defined as the amount oxygen required to chemically oxidize all organic matter found in greywater while BOD₅ is the amount oxygen used by microorganisms to decompose organic matter within 5 days. BOD₅ and COD concentrations in greywater is high when the quantity of water is low and products used in the household especially detergents, soaps, oils and fats are high (Oteng-peprah *et al.*, 2018). The COD/BOD₅ ratio below 2.5 indicates that greywater can be easily biodegraded. However, some studies have shown high greywater biodegradability with COD/BOD₅ ratios of 2.9-3.6 (Al-Jayyousi, 2003) because of high concentration of chemical compounds (detergents and the amount of oil and fat). The physico-chemical characteristics of greywater are summarized in Table 2.

Table 2: Physico-chemical Characteristic of raw greywater.

Parameters	N	Minimum value	Maximum value	Average
pH	15	5.77	7.96	6.71
EC (ms/cm)	10	520.6	906	688
Temperature (°C)	10	24.71	28.92	27.55
D.O. (mg O ₂ /L)	10	0.89	2.43	1.35
TDS (mg/L)	10	313	597	509.87
TSS (mg/L)	35	50	165	105
COD (mg O ₂ /L)	35	301	526	392
BOD ₅ (mg O ₂ /L)	35	240	410	298.6
Ca (mg/L)	15	151.41	437.61	290.36
Mg (mg/L)	15	83.22	140.01	105.64
Na (mg/L)	15	265	420	320.98
T.P. (mg/L)	15	8.4	12.1	10.54
Nitrates (mg/L)	15	0.39	0.48	0.40
Nitrites (mg/L)	15	-	-	-
TKN (mg/L)	15	18	32	28
Ammonia (mg/L)	15	7.5	9.2	8.4
Oil & grease (mg/L)	35	90	289	118.5

N = Number of samples, EC = Electrical Conductivity, D.O. = Dissolved Oxygen Concentration, TDS = Total Dissolved Solids, TSS = Total Suspended Solids, COD = Chemical Oxygen Demand, BOD = Biological Oxygen Demands, TP. = Total Phosphates, TKN = Total Kjeldahl Nitrogen

Source: Abdel-Shafy *et al.* (2014)

2.4.4. Biological characteristics

Greywater comprises of microorganisms (bacteria, protozoa and helminthes) that are introduced into body by contact. Maimon *et al.*(2014) observed that improper food handling in the kitchen and direct handling of contaminated food are the identified sources of pathogenic bacteria (Salmonella and Campylobacter) into the greywater. Fecal contamination in the greywater is from washing nappies containing fecal and poor personal hygiene (Oteng-peprah *et al.*, 2018). Table 3 summarizes the biological characteristics of greywater from various studies.

Table 3: Biological characteristic of raw greywater

Name of microbe	Concentration	Source
Total coliforms (counts/100 mL)	1.2×10^3 – 8.2×10^8	Oteng-Peprah <i>et al.</i> (2018)
E.coli	Up to 6.5×10^6	Oteng-Peprah <i>et al.</i> (2018)
Fecal coliforms	Up to 1×10^6	Mandal <i>et al.</i> (2011)
Pseudomonas aeruginosa	1.4×10^4	Benami <i>et al.</i> (2015a); Khalaphallah and Andres (2012)
Staphylococcus aureus	1.2×10^2 – 1.8×10^3	Benami <i>et al.</i> (2015b); Shoults and Ashbolt (2017)
Salmonella typhi	5.4×10^3	Kim <i>et al.</i> (2009)
Salmonella spp.	3.1×10^3	Oteng-Peprah <i>et al.</i> (2018)

2.5. Uses of treated greywater

Greywater can be used without treatment, or it can be treated to reduce the concentrations of pollutants and pathogens. The greywater depends on two appropriate uses; the source of GW and the level of treatment. Recycled water especially from greywater is most commonly used for non-potable uses (agriculture, landscape, car washing, and golf course irrigation). Other non-potable applications include; cooling of power plant and oil refineries, industrial process, toilet flushing, dust control, construction activities (concrete mixing) and ground water recharge (Giz, 2011).

2.6. Treatment technologies for reusing greywater

Considering the possible contents from GW sources there are reasons why GW should be treated, for example to remove substances that may be harmful to human health, plants, animals, environment and to prevent the clogging of irrigation system. The choice of the greywater treatment technology depends on the owner’s willingness to operate and maintain the facility (Mekonnen, 2015).

The concentrations of pollutants in GW can be reduced by applying treatment technologies before final disposal. The technologies are applied along the convectional wastewater treatment sequence which include pre - treatment, primary, secondary and tertiary treatment. These stages adopts either a physico-chemical or biological treatment processes and the methods of treatment include filtration, adsorption, reverse osmosis, UASB MBR, SBR, trickling filters, activated sludge, and CW. The greywater composition is determined by organics, nutrients and microbiological contamination. In the current situation, most greywater treatment technologies setups are based on septic tanks in combination with constructed wetlands, and sand filtration (Oteng-peprah *et al.*, 2018).

2.6.1. Four-barrel plastic greywater treatment system

The four barrel plastic greywater treatment system is an improvement of the two barrel plastic greywater treatment system. Two tanks each with 220 liters capacity, filled with gravel media that acts as anaerobic filters are inserted between the pretreatment tank and final storage tanks. The four barrels are lined up next to the other and interconnected with 50 mm PVC pipes (Mekonnen, 2015), as shown in Figure 2. As solids and floating materials settle in the first barrel, the relatively settled water from the first barrel enters in to the bottom of the second barrel. The process continues simultaneously in the three barrels up to the storage tank. Anaerobic microbes grows on the stone surface so that when the greywater passes through the stones, the microbes breaks down components of the organic material found in the greywater into biomass and gas. The last barrel is the storage tank for treated greywater. As soon as this barrel is filled, a floating device switches on a small water pump which then delivers the water through the drip irrigation network (Mekonnen, 2015). The retention time of 1 to 2 days in the 4-barrel treatment kit were used. The influent greywater under goes treatment level equivalent to primary and secondary treatment and it could meet the World Health Organization's guidelines for restricted irrigation (Al-Beirut, 2004).

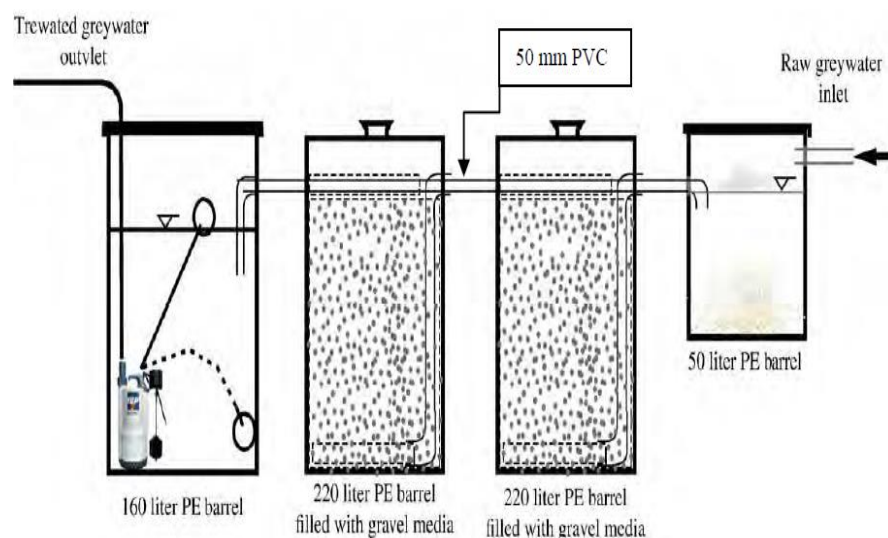


Figure 1: Four -barrel treatments units.

(Source: Al Beiruti, (2004))

2. 6.2. Filtration

Filtration process removes the pollutants which is not removed by primary processes. Physical and biological processes are the treatment processes that are used in filtration system to remove contaminants. The greywater treatment schemes mostly use physical methods to remove solids. Filtration media which are commonly used for filtration are in the form of sand, gravel, and fine mesh (Oteng-peprah *et al.*, 2018).

Studies was done by Dalahmeh *et al.* (2012) on the performance of different filter media in the filtration system which include activated charcoal, polyurethane foam, pine bark and sand as filter media in treating greywater. The filtration systems reviewed by Oteng-peprah *et al.* (2018), only bark filters were able to meet the pH criteria for reuse. The same author found that using bark and charcoal filters as filter media could meet the BOD₅ reuse standard and It was also observed that bark has high removal rates of total phosphorous compared to charcoal and sand filters. The performance of the filtration system is summarized in [Table 5](#) below. As a matter of fact, the monetary and health benefits of a GW treatment system in schools, filtration using (sponge filtration–sedimentation–gravel and sand filtration–aeration and chlorination) has encouraged the government of the state of Madhya Pradesh to build 412 similar GW reuse systems, out of which 200 have already been built in schools (Boyjoo *et al.*, 2013).

Chemical treatment such as electrocoagulation, coagulation, adsorption and AOPs seem attractive prospects for the future of GW treatment. Chemical treatments such as coagulation and adsorption are cheap, have short HRT and are simple to maintain but are mostly successful with GW with low pollutant loadings. Adsorbents such as GAC, are cheap, require low technology, and are easily regenerated. Additionally, GAC is a cheap alternative to ozone for the removal of micro pollutants (Hernandez *et al.*, 2010). The table below reports the treatment costs of typical greywater systems in Jordan.

Table 4: the treatment costs of typical greywater systems.

Treatment type	Systems	Capacity	Capital costs	Operating costs	Maintenance costs
Natural	Vertical-flow constructed wetland	210 m ³ /yr	US\$600	-	US\$100/yr
Biological	UASB	0.35 m ³ /d	US\$430	Zero	
	Septic tank	2.4 m ³ /d	US\$570	US\$28 /yr (Desludging)	
	SBR	-	>US\$1,420, ^d	Air blower power, sludge disposal	
	RBC	-	RBC (US\$) = 3,590Q ^{0.6776} , Chlorination unit (US\$) =1,670	Power (W) = 42.2e ^(2.51041) , Chlorine US\$/yr =62.11Q, Or Operating cost for large Systems=1.5 kWhm ⁻³	Labour = US\$1,040/yr
	MBR	-	Pump cost (US\$) = 594Q ^{0.0286} , MBR (US\$) =18,853 +17,945 lnQ	1–1.5 kWh m ⁻³ (small units), 0.5–0.75 kWhm ⁻³ (big units 650–10,000 m ³ d ⁻¹)	Labour = US\$1,040 yr ⁻¹ , Membrane treatment =US\$0.02–0.03m ⁻³ yr ⁻¹
Physical	Grease trap– Infiltration trench	30 L/p/ d	US\$121	-	US\$5.5
	Intermittent sand filter		US\$570	-	
	Ultrafiltration –Reverse osmosis	200 m ³ d ⁻¹	€0.63 per m ³	€0.56 per m ³	€0.16 per m ³
Chemical-physical					

	Flocculation– Sand filtration– GAC adsorption	200 m ³ d ⁻¹	€0.11 per m ³	€0.07 per m ³	€0.33 per m ³
Chemical	Coagulation	-	-	£0.0012–0.0048 per m ³	-
	Electrocoagul ation–	-	-	£0.0040–0.0185 per m ³	-

d – Required for air blowers, diffusers and pneumatic valves,

l – GW flowrate (m³ h⁻¹).

Source: Boyjoo *et al.* (2013)

2.6.3. Constructed Wetlands

Constructed wetlands (CWs) is the artificial wetlands constructed utilizing ecological technology to mimic conditions that occur in natural wetlands. The technology adopts special flora and fauna, soil and microorganisms to remove pollutants from the wastewater. They are normally classified into three main types such as subsurface flow, surface flow and floating treatment. The CW is categorized into two flow systems; vertical flow constructed wetland (VFCW) and horizontal flow. Each of them removes contaminants by different processes (physical, chemical and biological processes), and the treatment efficiency depends on operating conditions such as loading rate and the availability of electron acceptors (Oteng-peprah *et al.*, 2018). The system have high potential of removing BOD₅, suspended solids and some heavy metals (Pb, Zn, and Fe). The performance of HFCW in greywater treatment studied by Gross (2008) observed that, the quality of greywater effluent require pretreatment in order to be improved. In the same study, the average retention time used was about 30 h and it was realized that electrical conductivity increased from 160 to 200 mS/m, TN and TP reduced from 31 to 23 mg/L and 48 to 46 mg/L respectively. One major advantage of CW is its ability to run on its own without the attention of an operator. The removal rates of cations (Na²⁺, Ca²⁺ and Mg²⁺) are relatively low and these can lead to an increase in electrical conductivity (EC). The dissolution of organic matter in the treated water may lead to an increase of Total Dissolved Solids (TDS) and for this matter it affects the EC. The review by Oteng-peprah *et al.* (2018) observed that the CWs cannot completely remove microbes (*E. coli* and helminth eggs). The performance of the system is reported in Table 5 below.

Natural systems such as CWs are a cheap alternative and can be used to treat GW from all sources of the house and are well suited for middle-income countries since the raw materials are readily available and have ornamental properties. They are the cheapest to construct, maintain, operate, consume little energy (intermittent pumping) and are environmentally friendly since they can work as carbon sink (Dalahmeh *et al.*, 2012). However, CWs require large areas ($25 \text{ m}^2/2 \text{ m}^3$, $1\text{--}2 \text{ m}^2/200 \text{ L}$) which has an impact on the environment, have long HRTs and cannot be used in hot climates due to excessive evaporation. The poor removal of pathogens from natural systems also means that a disinfection stage is needed. CWs are not suitable for cities and other densely populated areas and do not guarantee a very good quality effluent (Boyjoo *et al.*, 2013).

2.6.4. Rotating Biological Contactors (RBCs)

These are attached growth reactors consisting of rotating disks which are mounted on a horizontal shaft. They are partially submerged and rotated as wastewater flows through it. The microbes grow over it that do the treatment. Alternatively, exposed part to the atmosphere favors the oxidation of dissolved organic pollutants and nutrients for degradation (Mekonnen, 2015). Friedler *et al.* (2011) studied the potential of RBC to remove indicator bacteria such as fecal coliforms, heterotrophic bacteria and specific pathogens (*Pseudomonas aeruginosa*, *Staphylococcus aureus*). The study reported that RBC removed 88.5–99 % of all bacteria groups. Performance of the system is presented in Table 5 below.

Advantages of RBCs

Being an attached growth system, RBC has a lot of similar advantages over the Trickling Filter (TF) system as described below;

- It is an open technology
- It is a simple and reliable biological process; the plant operators do not require expensive training or skilled qualifications to monitor the system,
- The operation cost of RBC system is much lower compared to activated sludge plants
- Short contact periods are required because of the large active surface, which means very small footprint compared to activated sludge systems;
- RBCs are capable of handling a wide range of flows, loads and have high resistance in toxic shocks. It can be applied for de-nitrification and phosphorus removal in order to meet strict discharge standards.

- It has low sludge production. The sludge has better settling characteristics because it is more dense and heavy and is easier to dewater than in activated systems.
- It is suitable for small to medium sized cities
- No flies issues are encountered and odor nuisance is lower than in TF systems (Mekonnen, 2015).

Disadvantages

- Potential failure of mechanical components with the system, such as the shafts, disks and bearings because of poor design regarding the weight of the attached biomass, or of poor maintenance
- Clogging risk is much higher than in TF system, but still remains as a potential. For this reason, primary settling tank may be required, thus making the system more complex (additional settling unit, Sludge treatment)
- The system is commonly installed in a concrete tank, which present difficulties for plant operators to monitor the system effectively within the tank.
- The shaft bearings and the mechanical drive units require frequent maintenance (Prashant, 2012).

2.6.5. Sequencing Batch Reactor

It is the biological treatment process used in wastewater treatment. Processes in the reactor takes place in batches for all treatment. The batch is sequenced through a series of treatment stages in a single tank which include fill, react, settle, decant, and idle (Oteng-peprah *et al.*, 2018).The performance of the system is reported in [Table 5](#) below. Hernandez *et al.* (2010) demonstrated the use of SBR in the Netherlands to treat greywater from 32 houses. The same author observed that SBRs have removal efficiencies of up to 98 % for BOD₅ and COD, 85 % TN and 99 % for NH₄-N. The limiting factor found in the performance of SBRs was Hydraulic Retention Time (HRT). Mekonnen (2015) noted some of the advantages and disadvantages of SBR system in relation to activated sludge as shown below:

Advantages

- Well proven process.
- Open source technology.
- The system requires lower proportion electro-mechanical plant and therefore has likely low construction and maintenance costs.

- Smaller foot print because of biological and clarification functions in one tank.
- Same level of resistance to variations in the flows and loads as the biomass can adapt to these loads up to a degree.
- Potential energy recovery (biogas utilization from anaerobic sludge digestion) which may increase the cost efficiency of the process.

Disadvantages

- The process is complex and requires high capital cost and very skilled personnel for its operation and maintenance and has relatively poor resistance to toxic shocks:
- Difficulty in decanting the treated effluent without drifting solids from the sludge blanket.

2.6.6. Membrane Bioreactor

A membrane bioreactor (MBR) is the suspended growth process integrated with a biological process for treating greywater. It operates in combination of biological, microfiltration and ultrafiltration systems during treatment. This is the best technology that can be used on greywater treatment in densely urbanized areas. Performance of this system is presented in Table 5 (Oteng-peprah *et al.*, 2018).

Membrane installment results is greater in operational and process complexity. The complexity is mostly associated with the maintenance and membrane cleanliness. Membranes tend to foul (clogging of pores by organics and inorganics) with time. It is necessary to provide various operational strategies as well as processes to mitigate the fouling propensity of membranes (park *et al.*, 2015).

Biological systems such as MBR have small footprints and give good quality effluents. MBRs consistently give excellent permeate quality, and are stable and robust, whilst RBCs are similarly efficient. The biggest disadvantage of the MBR and RBC is their capital costs, which make them economically feasible either for tall buildings (for RBC) or clusters of buildings (for MBR) only. Also the requirement for well-trained professional staff does not make these options favorable in developing countries (Boyjoo *et al.*, 2013).

2.6.7. Up-flow Anaerobic Sludge Blanket

The Up flow Anaerobic Sludge Blanket (UASB) is the suspended growth reactor used in various wastewater for treatment. It is anaerobic process and maintains a high concentration of active suspended biomass and produces better settle able sludge when compared with other treatment technologies (Oteng-peprah *et al.*, 2018). The study of Abdel-Shafy *et al.* (2014) on investigating

the efficiency of UASB in greywater treatment for unrestricted use in Egypt reported the removal efficiencies of 20 % for TSS, 58.8% for COD, 68.5% for BOD₅ and 85 % for oil and grease after treatment. The performance of UASBs increases when they are integrated with other treatment systems. The performance of the system is presented in Table 6 below. According to Chong *et al.* (2015) observed that wastewater treated by UASB may need post treatment since pathogens are not fully removed except for helminthes eggs that are entrapped in the sludge.

Anaerobic treatment using UASB is cheap, simple and proficient at removing suspended COD and is recommended for countries that produce low quantity, and concentrated greywater. However, since high sludge age is undesirable, the sludge will have to be discharged regularly. Conversely, disposal of sludge is of concern following biological treatment since XOCs do not readily degrade but instead remain adsorbed together with some heavy metals onto the sludge. This can be of concern if the sludge is disposed in to landfills (Fatta-Kassinos *et al.*, 2011). Conventional biological systems (UASB) are much cheaper to construct and maintain compared to the MBR or RBC (Boyjoo *et al.*, 2013).

The efficiencies of various greywater treatment technologies described above are summarized in Table 5.

Table 5: Efficiencies of some selected greywater treatment systems

Parameter	Filtration ^a	Wetlands ^b	SBR ^c	RBC ^d	MBR ^e	UASB ^f
Turbidity(NTU)	-	-	-	-	98-99%	-
EC(μs/m)	-	-	-	-	-	-
TSS(mg/l)	53–93%	90–98%	-	9–12%	100%	-
TDS (mg/l)	-	-	-	-	-	-
BOD ₅ (mg/l)	89–98%	99%	90–98%	27–53%	93–97%	67%
COD(mg/l)	37–94%	81–82%	90–98%	21–61%	86–99%	38–79%
Oil and grease(mg/l)	97%	95.45	-	-	-	83.7%
NO ₃ (mg/l)	17–73%	-	-	-	6–72%	-
TN (mg/l)	5–98%	26–82%	80%	-	52–63%	24 - 58%
TP (mg/l)	100%	71%	-	-	19%	10 -39%
FC				88.5–99.9%	99%	-
E.Coli	100%			88.5–99.9%		-
Ca (mg/l)	100%	-	-	-	-	-
Mg (mg/l)	100%	-	-	-	-	-
Na(mg/l)	47%	-	-	-	-	-
Cl (mg/l)	-	92- 94%	-	-	-	-

Source: ^aAl-Hamaiedeh and Bino (2010); Dalahmeh *et al.* (2012); Parjane and Sane (2011)

^bGross (2008); Travis *et al.* (2010); ^cHernandez *et al.* (2010); ^dFriedler *et al.* (2011)

^eAbdel-Shafy *et al.* (2014); Hernandez *et al.* (2010)

2.7. Naturally Occurring Greywater Treatment Media

The naturally occurring materials are mostly used media in some of available conventional greywater systems. The following in Table 6 are the studies of many researchers for treatment offered by different media.

Table 6: Performance of different media in treatment

Type of material	Target pollutant removal	Percentage removal	Mode of removal	Source
Activated carbon	BOD ₅	97	Adsorption	Sahar <i>et al.</i> (2012)
	COD	94		
	TN	98		
	TP	91		
Activated charcoal	EC	12	Adsorption	Dalahmeh <i>et al.</i> (2012)
	BOD ₅	97		
Peat moss and lime	COD	90	Filtration	Parjane and Sane (2011)
	BOD ₅	95		
pebbles	E. coli	100	Adsorption	Sahar et al. (2012)
	Pine bark	BOD ₅		
Moringa oleifera	COD	74		
	TN	19		
	TP	97		
	COD	64	Coagulation	Yuliastri <i>et al.</i> (2016)
	EC	11		
BOD ₅	12			
Turbidity	96			
TSS	88			
Sawdust	TSS	83	Filtration	Parjane and Sane (2011)
	TDS	70		
	O&G	97		
	COD	82		

2.8. Grey water reuse guidelines

The treated GW to be allowed for reuse should be hygienic safety, aesthetic and environmental friendly and economic feasibility. However, water quality standards that would guide the reuse of treated grey water in most of the countries is not appropriate (Lazarova *et al.*, 2003). Li *et al.* (2009) noted that different reuse applications require different water quality standards and it demands

different treatments from simple processes to advanced ones. In many cases, the national water reuse guidelines vary from nations to nations as shown in [Tables 7 and 8](#)

Table 7: Water quality criteria of different countries for toilet flushing.

Parameter	Toilet flushing						
	US	Japan	WHO	USEP A	Australi a	UK	German y
pH	6-9	5.8-8.6		6.9			6-9
BOD5 (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	ND	≤ 10 (e- coli)		≤ 10	≤ 4		10
Residual chlorine (mg/l)	1						
odor	odor less						

ND –Not Detectable, (m) – mandatory (g) – guideline

Source: Lazarova (2003)

Table 8: Greywater reuse standards

a) UK greywater reuse standards (BS 8525) ^(*)				
Parameter	Car washing	WC flushin;	Garden watering	Washing machine use
<i>E. coli</i> (number/100ml)	Not detected	250	250	Not detected
Intestinal enterococci (number/100ml)	Not detected	100	100	Not detected
Turbidity NTU	<10	< 10	Not available	<10
pH	5-9.5	5-9.5	5-9.5	5-9.5
Residual Chlorine (mg L-1)	<2.0	<2.0	<5.0	<2.0
Residual bromine (mg L-1)	0.0	0.0	0.0	0.0
b) Japan ^(**)				
Parameter	Toilet flushing	Landscape irrigation	Environmental (aesthetic settling)	Environmental (limited public contact)
pH	5.8-8.6	5.8-8.6	5.8-8.6	5.8-8.6

Turbidity NTU	Not unpleasant	Not unpleasant	≤10	≤5
BOD5 (mg L-1)	≤ 20	≤ 20	≤10	≤ 3
Residual Chlorine (mg L-1)		≤ 0.4		
Total Coliform (number/100ml)	≤ 1000	≤ 50	≤ 1000	≤ 50
c) Jordanian greywater standards (JS1767:2008) ^(***)				
Irrigation parameter	Trees and fodder irrigation “restricted irrigation”	Landscape and vegetables to be eaten cooked	vegetables to be eaten uncooked	Toilet flushing
BOD5 (mg L-1)	300	60	60	≤ 10
COD (mg L-1)	500	120	120	≤ 20
TSS (mg L-1)	150	100	50	≤ 10
pH	6-9	6-9	6-9	6-9
NO3 (mg L-1)	50	70	70	70
TN (mg L-1)	70	50	50	50
Turbidity (NTU)	25	Not available	Not available	≤ 5
E.coli (number/100ml)	Not specified	10	10	< 10
Egg nematodes (number/1L)	≤ 1	≤ 1	≤ 1	≤ 1

Source: (*) (Agency-UK, 2011); (**) (Maeda *et al.*, 1996); (***) (JSMO, 2008)

2.9. Socio-technical issues of greywater reuse

The high willingness among university students to accept recycled water systems for non-potable use reveals an opportunity to substitute water sources with recycled greywater. University students appear to be very supportive of using recycled water for non-potable purpose. The opportunity for source substitution is particularly significant with regards to water use for toilet flushing given that the survey carried out by (Stoakley, 2013) showed that 97% of university students would approve of using recycling water for this purpose. Approximately 63% of the water used in public environments or offices is for flushing toilets. Replacing the current potable water stream with reused water would significantly reduce the demand for potable water on university campus (Mekonnen, 2015). Over all, survey revealed a broad willingness to accept urban recycling as long as public health is not compromised. The percentage of respondents willing to recycle was 88% for toilet flushing, whereas 12% of the survey revealed a willingness to accept for drinking (Mekonnen, 2015).

2.10. Public acceptance related to greywater reuse

The successful implementation of any reuse project hinges on public acceptance. The factors that can influence public acceptance towards GW treatment are socio-demographic, age, level of education, religion, water availability, cost, source of the influent, use of the effluent, environmental awareness, health risks and income. The implementation of GW treatment should not be a difficult feat since the degree of acceptance from the public is higher for recycled GW reuse than for domestic wastewater reuse (Mekonnen, 2015). Before implementation of any reuse project, the media should be used to increase the public awareness regarding the science and benefits involved with recycling as well as successful past projects. Public trust could be done by building demonstration sites that can be open to the public prior to the full-scale implementation of a GW reuse technology (Boyjoo *et al.*, 2013).

In summary of the literature, the treatment technologies which had higher efficiency on grey water treatment requires higher capital, operational cost, technical skills, enough land and many others. The filtration system using sand and GAC are cheap, require low technology, and are easily regenerated. The intermittent sand filter requires the capital of about 570 US\$, CW (600 US\$), RBC, MBR, SBR (>130,098) for 200 m³per day, Additionally, GAC is a cheap alternative to ozone for the removal of micro pollutants (Boyjoo *et al.*, 2013).The sand and GAC are efficient in removal of ammonia, turbidity, BOD, COD and total phosphorus. The filtration system using activated carbon and sand filter media are efficient, simple and require low technology when compared with other filter media (Al-Beirut, 2004). The CWs which is also simple to operate require large areas (25 m²/ 2 m³, 1–2 m²/200 L) which has an impact on the environment.

3.2. Study Design

The study was carried out to evaluate the performance of a lab- scale filtration system for greywater treatment and reuse. The study began in October 2019 to June 2020. It was conducted by experimental design, sampling, laboratory analysis, and use of questionnaires for social data collection.

3.2.1. Sample Size

A total of 36 greywater (GW) samples of triplicated experiments, were collected at generation sources, before filtration and after filtration. Eighteen (18) samples were collected from each treatment. The treatments had two experimental setups, one with gravel + sand media and the other containing gravel, sand media and granular activated charcoal.

For the social part, the sample size of respondents (students, gardeners, cleaners and other staff) was calculated using Cochran’s (1977) formula (1) and (2) below.

$$N_1 = \frac{z^2 \times P(1-P)}{d^2} \dots \dots \dots (1)$$

$$N_2 = \left[\frac{Z^2 \times P(1-P)}{d^2} \right] / 1 + \left[\frac{Z^2 \times P(1-P)}{d^2 N} \right] \dots \dots \dots (2)$$

Where, N₁ = desired sample size when population is greater than 10000, N₂ = desired sample size when population is small or moderate, N = population size, P = Standard of deviation, Z = Z-score of confidence level chosen; d = margin of error. Assuming the maximum variability, which is equal to 50 % (p = 0.5) and taking a 90 % confidence level with ±10 % precision.

The above formula gave the following sample sizes for the various respondents:

Students

$$N = \frac{(1.65)^2 \times 0.5 \times (1-0.5)}{(0.1)^2} = 68 \text{ respondents}$$

Other Staff

$$N = \left[\frac{(1.65)^2 \times 0.5 \times (1-0.5)}{(0.1)^2} \right] / 1 + \left[\frac{(1.65)^2 \times 0.5 \times (1-0.5)}{(0.1)^2 \times 500} \right] = 60 \text{ respondents}$$

Cleaners

$$N = \left[\frac{(1.65)^2 \times 0.5 \times (1-0.5)}{(0.1)^2} \right] / 1 + \left[\frac{(1.65)^2 \times 0.5 \times (1-0.5)}{(0.1)^2 \times 90} \right] = 39 \text{ respondents}$$

Gardeners

There were nine flower gardeners at CNCS and all were interviewed.

In total, the number of respondents who participated for interview were 176.

3.2.2. Raw greywater collection

Grey water was collected from the regional student hostel at CNCS, AAU. Equal proportions of 10 liters of grey water were collected from kitchen, bathroom, and washing machine using 15-liter buckets ([Annex 3](#)). The greywater was collected once per week for three weeks and transported by buckets to ACEWM laboratory for treatment in the filter column set-ups during the period of Feb to March 2020. The grey water was collected in the morning and afternoon by composite sampling. The wastewater from bathroom and washing machine were collected in the morning while for the kitchen were collected in the afternoon.

3.2.3. Experimental set up

Two 30 liter barrels (settling tank) were interconnected with 25 mm diameter PPr pipe in parallel to two filter columns made up of PVC pipe DN150 mm of 1.3 m length ([Figure 4](#)). The gate valve was connected between the settling tank and the filter columns to control the flows. The two filter columns were packed with different filter media. One with gravel and sand (named filter column A) while the other (named filter column B) had gravel, sand, and Granular Activated Charcoal (GAC). Both of them had a perforated pipe at the bottom to drain out the treated GW ([Figure 4](#)). During packing, one filter column (A) was filled to 30 cm mark with tap water to allow uniform media packing, also to prevent air binding. The filter column A was manually packed to a depth of 20 cm with a gravel layer (media support with grain size 10-20 mm) for drainage followed by 30 cm of media grains (0.8-2 mm) then sand media grain of size 0.425-8 mm with thickness of 70 cm. The second filter column (B) was packed in the same way as first column, only that between layer of media size (0.8 – 2 mm) and 0.425-0.8 mm, it was packed with 20 cm layer of Granular Activated Charcoal (GAC) (0.8-1 mm grain size) as shown in [figure 4](#) below (EPA,1995)

In this system, pretreatments (screening, fats and oils skimming, sedimentation) were considered to reduce the organic loading rate and clogging of the filter media. A screen of 1.2 mm size was

used during the pouring of GW to the settling tank to reduce the solid materials from entering into the system. The tee junction (baffle) connected at the outlet of settling tank was used to stop the scum, fats and oils from entering into the filter column (Figure 4). The following are the processes that were used in the treatment system.

1. Sedimentation

Sedimentation is the physical separation of suspended material from wastewater by gravity. In this study, 1 day was considered for the settling of suspended solids from greywater basing on the study of Al-beiruti (2004) and sedimentation was used as a pretreatment process. Abdel-Shafy *et al.* (2013) emphasized that the wastewater should be pretreated (by sedimentation) to increase the effectiveness of sand filter during filtration.

2. Filtration

Following the design criteria in the wastewater treatment design manual of EPA (1995), the wastewater down flow filter bed of grain size of 0.425 -2 mm and 0.7 m filter bed thickness was used.

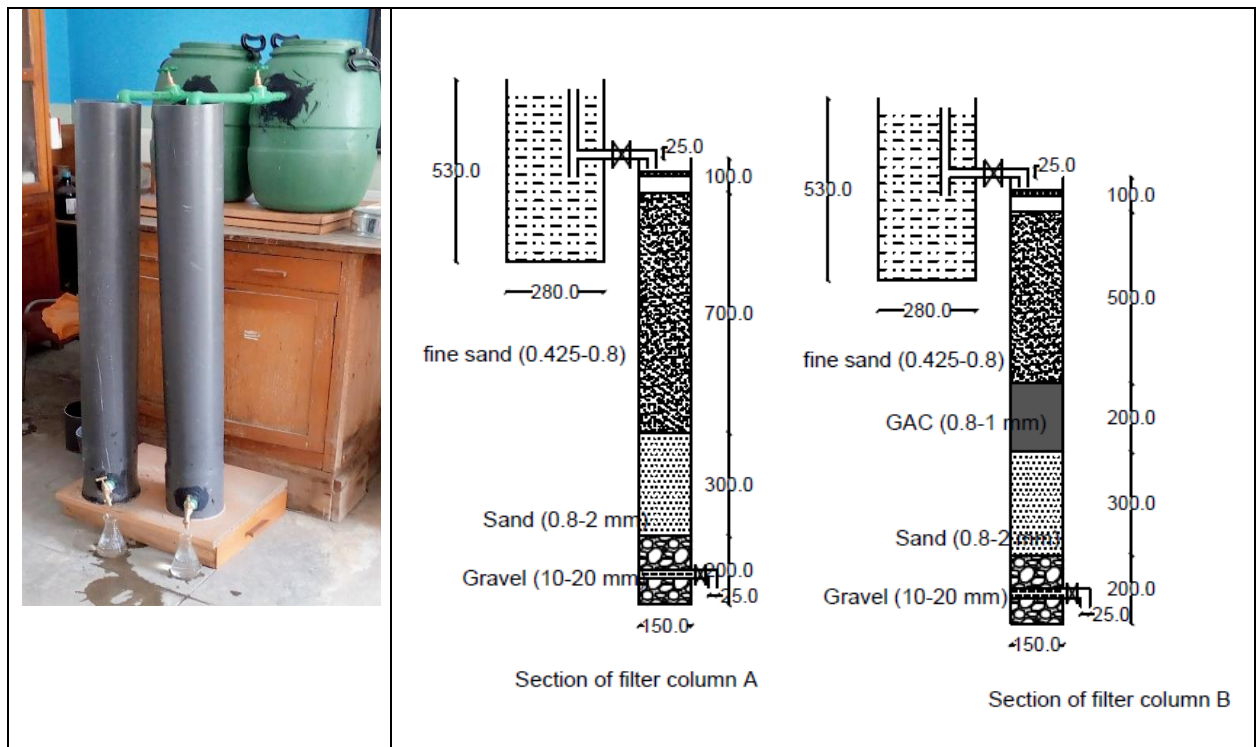


Figure 3: Experimental set up of the filtration system

3.2.5. Operating conditions

The two filter columns were operated parallel at constant hydraulic loading rate (HLR) of 0.15 m/h. The HLR was determined basing on previous column studies on treating synthetic greywater (Dalahmeh *et al.*, 2012) and design criteria in the EPA (1995) manual. The system was first run for two weeks to ripen the filter until steady state conditions were attained, i.e. when the differences between successive measurements of both COD and BOD was below $\pm 1\%$ (Abel *et al.*, 2012). The flow rate used in the experiment was determined using equation (3) (EPA, 1995):

$$\text{HLR} = Q/A \dots\dots\dots (3)$$

where Q is the flow and A is the surface area.

Hydraulic retention time of 12, 24, and 36 h were optimized at constant HLR. This retention time was maintained by holding grey water in the system before the effluent was allowed to flow out. These retention times was considered basing on the literature, where retention time for physical treatment systems averaged to 16 hours were used but those systems were not applied in Africa (Li *et al.*, 2009).

The filtration system was operated in continuous process during treatment of GW. Equal volumes (10 liter) of grey water types were mixed uniformly in a 30 L plastic tank (see Figure 3 above) using a stirrer and then allowed to settle in the tank/ barrel. The settled wastewater was allowed to flow into the filter column by adjusting the gate valve, where it was distributed uniformly on filter bed using the percolated plate. The influent infiltrates into the intermittent filter bed as different mechanism was taking place.

3.2.6. Filtration media

Sand and gravel media; It was obtained from a sand collection point in Sedest kilo of Arada Sub city. It was washed before use with tap water until the clear water was observed from it (See Annex 3). The gravel was used purposely for drainage. The sand was selected because of its availability and its high efficiency in removal of pollutants from low strength wastewater when compared to other filter media like pine barks, rice husks, and saw dust (Dalahmeh *et al.*, 2012). To obtain the effective size (D_{10} , D_{30} and D_{60}) of the sand and gravel media, Sieve analysis was carried out according to ASTM (1998). The coefficient of uniformity (Cu) of 2.0 and coefficient of curvature (Cc) of 1.63 were then obtained using the equations (4) and (5):

$$C_u = D_{60}/D_{10} \dots \dots \dots (4)$$

$$C_c = (D_{30})^2 / (D_{60} * D_{10}) \dots \dots \dots (5)$$

where; C_u is the coefficient of uniformity, C_c is the coefficient of curvature, and D_{10} , D_{30} and D_{60} are the sizes of the sieve through which 10%, 30% and 60% respectively of the media would pass.

Granular Activated Carbon (GAC); It was obtained from chemical suppliers in Cherkos of Addis Ababa city. It was chemically activated charcoal of size 0.8- 1 mm diameter and was selected because of its high treatment efficiency compared to other filter media like pine barks, rice husks, and saw dust (Dalahmeh et al., 2012).

3.2.7. Operation and maintenance

The sand filter columns were backwashed every after 36 h to refresh the system using tap water.

3.3. Data collection methods

3.3.1. Characterization of the physico-chemical and microbiological quality of raw greywater

The quality of raw greywater (RGW) at generation were characterized by determining the physico-chemical parameters (turbidity, pH, Electrical Conductivity, BOD, COD, TDS, NO_3 , NH_4-N , and TP) and microbiological parameters (Total Coliform and Fecal coliform). The composite RGW samples collected from kitchen sinks, bathrooms, washing machine were analyzed in the Environmental Science Laboratory for physico-chemical parameters, while microbiological parameters were analyzed in the Insect and Bio-instrumentation laboratory of CNCS campus. The samples were triplicated for the effective results during analysis.

3.3.2 Sample collection

Before sampling, the plastic sample bottles were cleaned using a detergent, triple rinsed with distilled water and during sampling the bottles were triple rinsed again with the wastewater as suggested by Fatoki and Mathabatha (2001). Bottles for collections of bacteriological samples were first sterilized. Wastewater samples like for pH, Turbidity and Electrical Conductivity were analyzed in-situ while BOD₅, COD, Total Phosphorus, Ammonia – Nitrogen, Total Coliform and Fecal Coliform were not analyzed immediately. They were stored at 4°C and warmed to room temperature before tests were carried out and all the samples were labeled with dates and collection stations (APHA, 1998). Safety was taken serious by wearing protective clothes, gloves and nose mask as stated in WHO guideline (WHO, 2006).

3.3.3. Greywater Sample Analysis

Physico-chemical and microbiological characteristics of the Greywater (GW) were analyzed for selected parameters: pH, Electrical conductivity (EC), Turbidity, Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD₅), Nitrates (NO₃), Ammonia-Nitrogen (NH₄-N), Total Phosphorus (TP), Total coliform (TC) and Fecal coliform (FC). Samples were analysed following APHA (1998), and WHO (2006) standard methods for examination of wastewater.

Before any analysis of samples, instruments were calibrated using standard solutions. The EC meter was calibrated first with 12.88 µS/cm EC solution. The probe was dipped into the solution and adjusted to 13.40 µS/cm. The EC electrode or probe was dipped into the sample after rinsing with deionized water. The value was read and recorded in µS/cm after a time lapse of about 30 secs (APHA, 1998).

PH was measured in situ where, the pH meter was calibrated with buffer solution of 6.864 and 4.003 following the APHA (1998) standards.

Turbidity was measured as soon as the samples were taken to the laboratory using turbid meter. The equipment was calibrated and zeroed. The original sample container was shaken and the sample was filled in a 10 mL clean curette and placed in the cell chamber. The lid was covered and the concentration was read on the screen and recorded in Formazin Turbidity Unit (FTU) (APHA, 1998).

Chemical Oxygen Demand (COD)

The chemical oxygen demand of wastewater means the quantity of oxygen, in milligram, required to oxidize or stabilize the oxidizable chemicals present in one liter of wastewater under specific condition. It was determined using the Closed Reflux, colorimetric method (APHA, 1998).

Biochemical Oxygen Demand (BOD₅)

Biochemical oxygen demand of wastewater is the milligram of oxygen required to biologically stabilize one liter of wastewater in 5 days at 20°C. It was determined by using APHA (1998) methods and the following formula (6) was applied.

$$\text{BOD}_5 \text{ concentration (mg/L)} = (\text{DO}_1 - \text{DO}_2) / \rho \dots\dots\dots (6)$$

where; DO₁ is the initial dissolved oxygen, DO₂ is the final dissolved oxygen, ρ is the fraction of sample to total combined volume.

Nutrient content (TP, NH₄-N, NO₃)

The total phosphorus was analyzed by ascorbic acid method after per sulfate digestion, and ammonia-nitrogen and nitrates were analyzed using phenate, and sodium salicylate method respectively (APHA, 1998).

Fecal coliforms

Fecal coliforms were determined using the APHA, (1998) and the following formula (7) was applied in fecal coliform count.

$$\text{CFU/ml} = (\text{Average count/ volume of sample filtered}) \times 100 \dots\dots\dots (7)$$

where CFU is the Colony Forming Unit

Total coliforms

The GW samples were too polluted with microorganisms, and for that case they were subjected to serial dilution to isolate the bacteria for easy counting. The dilution up to 10⁻⁶ and 10⁻³ for raw RGW and treated GW sample respectively were used (APHA, 1998). The equation (8) below was used to calculate total coliform count.

$$\text{CFU/ml} = (\# \text{ of colonies} \times \text{dilution factor})/\text{volume of culture plate} \dots\dots\dots (8)$$

where CFU is the Colony Forming Unit

3.3.2. Comparison of the treatment efficiency of lab-scale filtration systems that use gravel + sand and gravel + sand+ GAC at varying HRT

The treatment efficiency depends on several parameters like the filter media used, the depth, hydraulic retention time, wastewater characteristics (Khan *et al.* 2015). These were considered in designing the filtration systems.

The performance of a lab- scale filtration systems that use sand +gravel and sand +gravel + GAC were compared for the removal of pH, EC, Turbidity, COD, BOD₅, NO₃, NH₄-N, TP, TC, and FC. The performance of the systems was determined after pretreatment processes (screening and sedimentation for one day).The treatment efficiency was determined between the concentration of influent (before filtration) and effluent (after filtration) of different parameters in the systems at different Hydraulic Retention Time (HRT) under constant Hydraulic Loading Rate (HLR).

Efficiency of the filtration systems was determined from the difference in pollutants concentration in the influent and effluent of the system, using the following formula (9) (Enitan *et al.*, 2015):

$$\text{Treatment Efficiency (\%)} = [(C_i - C_e)/C_i] \times 100 \dots\dots\dots (9)$$

where, C_i = is the concentration of the pollutants in the influent; C_e = is the concentration of the pollutants in the effluent.

3.3.2. Evaluation of willingness to use treated greywater for selected purposes

It was evaluated using the questionnaires (Annex 1). The questions were asked to the students, cleaners, gardeners and other staffs, in CNCS campus to determine the extent they were willing to accept to use treated greywater for selected non-potable uses. A total of 176 respondents were interviewed, of which 68 were students, 39 were cleaners and 9 were gardeners and 60 were other staffs (teaching and non-teaching staff excluding cleaners and gardeners). The questions used were semi-structured and were asked to the respondents face to face. The questions were written in English and translated by field assistant to the local language (Amharic) especially for cleaners and gardeners who didn't understand well the English language. For the questionnaire-based study, voluntary participants were fully informed about the study and its purpose. The participants were first requested to participate in the questionnaire survey before being interviewed.

3.3.3. Data Analysis

The data was subjected to normality test using the SPSS-IPM version 20 to test if data is normally distributed. One-way analysis of variance (ANOVA) at 95% confidence level was used to test significance of the mean influent and effluent wastewater qualities in both columns, and at different HRT. In cases where a statistically significant difference was found in mean wastewater quality values at different HRT, a Post Hoc analysis was carried out using Tukey -Honestly Significant Difference (HSD).

CHAPTER 4: RESULTS AND DISCUSSION

4.1. Characterization of the physicochemical and microbiological quality of raw greywater

4.1.1. Physico-chemical characteristics

PH

The pH of raw greywater (RGW) samples was in the range of 9 to 9.5 with mean value of 9.2 (Table 9). This was high when compared to the study by Kariuki *et al.* (2011) on RGW collected from Jomo Kenyatta university hostel where it reported the range of 6.8- 9.34. The other study by Oteng-peprah *et al.* (2018) on comparing the characteristics of RGW from high income countries and low income countries reported the range of 6 to 8.1. High pH was due to the presence of alkaline based detergents, soap, and sodium chloride from the kitchen wastewater. Surfactants is the common chemical constituent in greywater because of its main active agent in cleaning products. This constituent cationic which is generally a salt based that is the source of ammonium in greywater (Jakobi and Lohr, 1987).

Electrical conductivity

It was recorded with the mean values of 1460 $\mu\text{S}/\text{cm}$ (Table 9). This value was within the range of 14 to 3000 $\mu\text{S}/\text{cm}$ as reported from study of Ciabatti *et al.* (2009) on industry laundry wastewater. The study by Kariuki *et al.* (2011) on RGW collected from Jomo Kenyatta university hostel reported the range of 326 to 1950 $\mu\text{S}/\text{cm}$ which is not far from this study. The observed EC in RGW is associated with dissolved materials like salts and inorganics. Also old plumbing materials can contribute to an increase of electrical conductivity (Oteng-peprah *et al.*, 2018).

Turbidity

In this study, the mean value for turbidity was 473.5 FTU which was high when compared with other studies (Table 9). The turbidity viewed by Oteng-peprah *et al.* (2018) ranged between 133 to 444 NTU on the study of industrial laundry wastewater in Italy. The study of Ciabatti *et al.* (2009) on greywater treatment using the sample collected from household of Oman ranged from 40 to 150 NTU which could be influenced by the water use activities. The presence of turbid could be due to the suspended particles from the kitchen, hair and fibers from the laundry.

Chemical Oxygen Demand (COD) and Biochemical Oxygen Demand (BOD₅)

Chemical Oxygen Demand and Biochemical Oxygen Demand of RGW had the mean values of 476.5 mg/l and 187 mg/l respectively (Table 9). These mean values showed that the organic strength of the RGW from CNCS was not high, when compared to other studies on RGW from slum households, the values ranging from 5662 to 8658 mg/l and 2445 to 7447 mg/l for COD and BOD₅ respectively were reported (Niwaqaba *et al.*, 2014). Another study from the literature by Chaillou *et al.*, (2011) on RGW reported the range of 55 mg/L to 633 for COD and the range of 20 mg/L to 633 mg/L for BOD₅ from the house hold in Oman. The low values of organic strength of this study was the result of high dilution of wastewater. The observed values of BOD₅ and COD could be due to the presence of organic compounds such as fats and oils, substances used for cooking, and residues from soap and detergents. For this study the RGW showed good biodegradability of the average BOD₅/COD ratio of 0.4 and thus it required physical and chemical or biological treatment processes. This makes media (sand, gravel, and GAC) filter based systems appropriate for COD and BOD₅ removal from grey water. Oteng-peprah *et al.* (2018) reported the RGW biodegradability in the range of 0.31 and 0.71. However, the key issue to be noted with regard to biodegradation of organic matter is the nutrient balance. The relative proportion of BOD₅: N: P for the GW was observed to be 94:7:1 and an ideal value 100:5:1 was reported by (Metcalf and Eddy, 2003). The result indicates that there is slight imbalance between carbonaceous matter and nutrients.

Nutrient content of the raw grey water

The Results of nutrient analysis of wastewater showed that the average concentrations of NO₃, NH₄-N and TP were 0.13 mg/L, 14.5 mg/L and 1.4 mg/L, respectively (Table 9).

Proteinaceous substances from food particle and detergents in the wastewater could be sources of nitrogen forms which are sourced from the kitchen. According to Kariuki *et al.* (2011) food particles from the kitchen can also be the source of phosphorous in the greywater. Polyphosphates from detergents, animal, and human excreta into the wastewater, are the main source of phosphates. The nutrient content of RGW in this study was within the range when compared to the research by Oteng-Peprah *et al.*, (2018) which ranged from 0.012 -1.1 mg/L, 4.3-26 mg/L, and 0.67-16.1 mg/L for NO₃, NH₄-N, and TP respectively. Low mean value of TP observed in this study indicates that the animal and human excreta were also minimal for mostly GW sourced from the kitchen and bathroom after comparing the results reported by Niwaqaba *et al.* (2014) ranging from 16.1 to 34.2 from the related study.

Microbiological characteristics

For this study, the RGW had the mean value of 8.05×10^7 cfu/100 ml of total coliform and 1.21×10^3 cfu/100 ml of fecal coliforms (Table 9). The study showed high values of TC and low values for FC when compared to the study by Kariuki *et al.* (2011). This author studied on potential of the low cost technology for greywater treatment of samples collected from Jomo Kenyatta Hostel in Kenya and TC count of 7.3×10^6 cfu/100 ml and FC at 5.4×10^5 cfu/100 ml of RGW was reported. The TC of this study was as high as the study by Katukiza *et al.* (2014) on greywater treatment in urban slum areas of Uganda. The author reported the TC count of 7.5×10^7 cfu/100 ml and 8.4×10^4 cfu/100 ml of FC. The high value of TC were largely associated with poor personal hygiene, old and highly contaminated drainage systems. The presence of FC resulted by washing of fecally contaminated laundry and it indicated human bacterial contamination. Fecal coliforms were studied as they are an indicator of fecal pollution source of pathogens in grey water (Kotut *et al.*, 2011). The high variability of Total coliform counts was also due to the; fact that grey water favors their growth, the hygiene conditions, too dirty clothes, and the time in which items to be cleaned had been left soaked in the water (Niwagaba *et al.*, 2014).

Table 9: The physico-chemical and Microbiological characteristics of raw greywater sampled from CNCS Campus, Addis Ababa University.

Parameters	Unit	Mean \pm Sd
pH		9.2 ± 0.3
Turbidity	FTU	473.5 ± 9.2
Electrical Conductivity(EC)	$\mu\text{s/cm}$	1460 ± 597
BOD ₅	mg/l	187 ± 1.4
COD	mg/l	476 ± 4.9
Total Phosphorus (TP)	mg/l	1.4 ± 0.9
Ammonia-nitrogen	mg/l	14.5 ± 0.7
Nitrates	mg/l	0.13 ± 0.0
Fecal Coliform	cfu/100ml	$1.21 \times 10^3 \pm 14$
Total Coliform	cfu/100ml	$8.05 \times 10^7 \pm 7.1 \times 10^4$

4.2. Comparison of the treatment efficiency of lab-scale filtration systems that use gravel + sand and gravel + sand+ GAC at varying HRT

pH in the filtered effluent

The pH of the influent ranged from 7.3 - 7.6 with the average value of 7.5 ± 0.18 (SD) which had decreased from the range of 9 – 9.5 after settlement of RGW for 24 hrs. The pH of effluent was varying in two filter columns at different HRT and it ranged from 7 to 8.5 with recorded mean values of 7.4 ± 0.32 , 7.3 ± 0.21 , 7.3 ± 0.15 for filter column A (sand only) and 8.0 ± 0.25 , 7.8 ± 0.44 , 8.1 ± 0.61 for filter column B (sand with GAC) at 12, 24, and 36 hrs respectively (Figure 5). The pH was insignificant different between influent and effluent ($p = 0.05$) at all HRT in both filter columns. The system reduced the pH by 1.3 %, 2.7 %, and 2.7 % for filter column A and increased by 6.6 %, 4 %, and 8 % for filter column B at 12, 24 and 36 hrs respectively. The increase of pH in filter column B could be the result of chemical reactions influenced by functional group of activated carbon. The decrease of pH after settling tank could be due to nitrification that took place in settling tank. The pH of the influent favors the physical treatment by sedimentation and adsorption on to the filter media. The study by Samayamanthula *et al.* (2019) reported the optimum pH (6.5 to 8.5) favors the biological wastewater treatment of wastewater and also (Fernando *et al.* (2009) reported that the same ranges of pH increases the adsorption rate.

It was observed that there was no significant difference in pH between the influents and effluents (Figure 5). This could be due to the chemical reaction like nitrification and denitrification that took place in the system. Also during adsorption (Vander Waal forces of attraction) there is possibility of cations and anions being released in to the system, keeping pH in the range of 7.3 – 8.1 (effluent). The studies by Samayamanthula *et al.* (2019) from Kuwait on GWT reported similar range (7.3-8.4) after treatment. The effluents from the filtration system was in the allowable limits (WHO, 2001) for reuse of selected non-portable uses (Annex 2). It is recommended that, for easier treatment and to avoid negative impacts on soil and plants when reused, GW should show a pH in the range of 6.5–8.4 [FAO, 1985; USEPA, 2004].

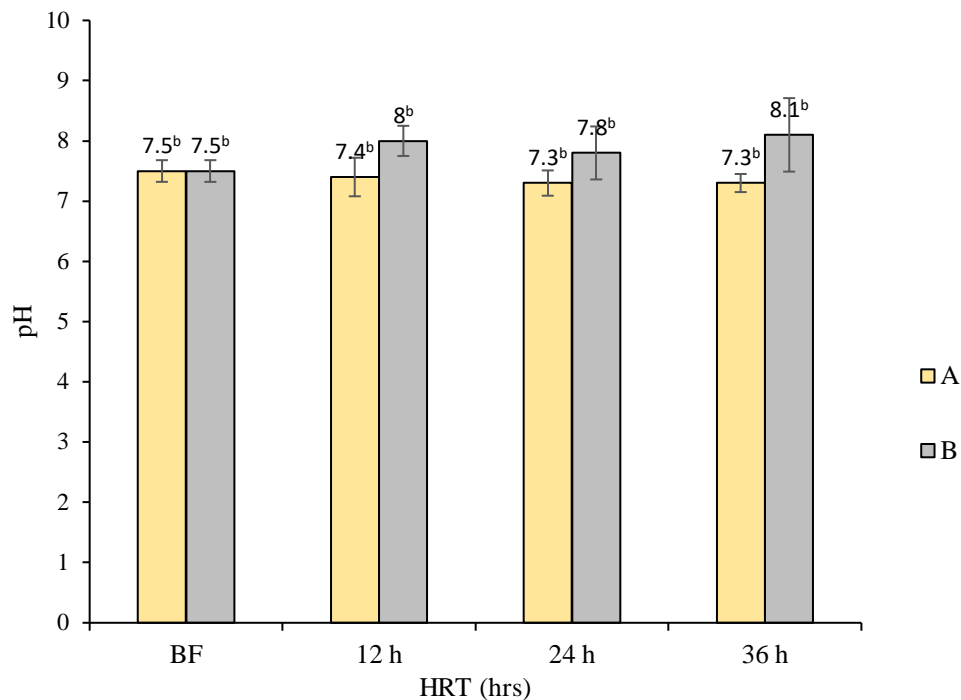


Figure 4: Variation of pH in the influent and effluent at different HRT in filter columns A and B. Error bars are standard deviation of means.

b- No statistical significant different ($p > 0.05$)

BF- before filtration

A- Filter column A

B- Filter column B

Turbidity in the filtered effluent

The turbidity of the effluent varied at different HRT (12, 24, and 36 hrs) through the filtration system. The influent recorded was 257.5 ± 7.64 FTU which significantly decreased ($p < 0.05$) to 2 ± 3.46 , 0.0 ± 0.0 , and 7.3 ± 4.16 FTU for column A and 0 ± 0.0 , 0 ± 0.0 , 2.7 ± 1.15 FTU for column B at 12, 24, and 36 hrs respectively (Figure 6). The system showed a significant decrease in both filter columns at 12 h and 24 h then a significant increase at 36 h for filter column A ($p < 0.05$; Figure 6 below). The treatment system achieved the efficiencies of 99.2%, 100% and 97.10% for filter column A and 100%, 100% and 99% for filter column B at 12, 24, and 36 hrs respectively as

shown in [Table 10](#). The studies by (Hernandez *et al.* (2010) and Oteng-Peprah *et al.* (2018) reported the range of 98 – 99 % when they used membrane bioreactor.

The system showed a high efficiency for the removal of turbidity in both filter columns because of the mechanisms that occurs within the sand filter and GAC like straining, physical adsorption and intra-particle diffusion into the GAC. This reduces the suspended, Colloidal, dissolved solids and fine dispersions of pollutants that cause turbidity in the influent. The pathogenic micro-organisms flourished in turbid water may result in to epidemics (Sehar *et al.*, 2011). Therefore Removal of turbidity in the greywater is a key in wastewater treatment. In this study it was observed that the decrease of turbidity was decreasing with the TC and its increase also increased the TC in the system. It was also observed that efficiency for turbidity removal decreased at 36 h because of desorption which may occur after long contact time in the filter.

Filter column B was more efficient in removal of turbidity than filter column A, because of the adsorptive properties (active sites) of GAC that would attract the turbid in wastewater. Khalaphallah (2012) and Saad *et al.* (2016) reported that the sand filtration using activated carbon can reduce turbidity when the wastewater passes through it. The turbidity of the filtration system after treatment was within the allowable standards, USEPA (1992) (≤ 5) for reuse of selected non portable uses except in column A at 36 h which showed value of 7.3 that was beyond the reuse standards ([Annex 2](#)).

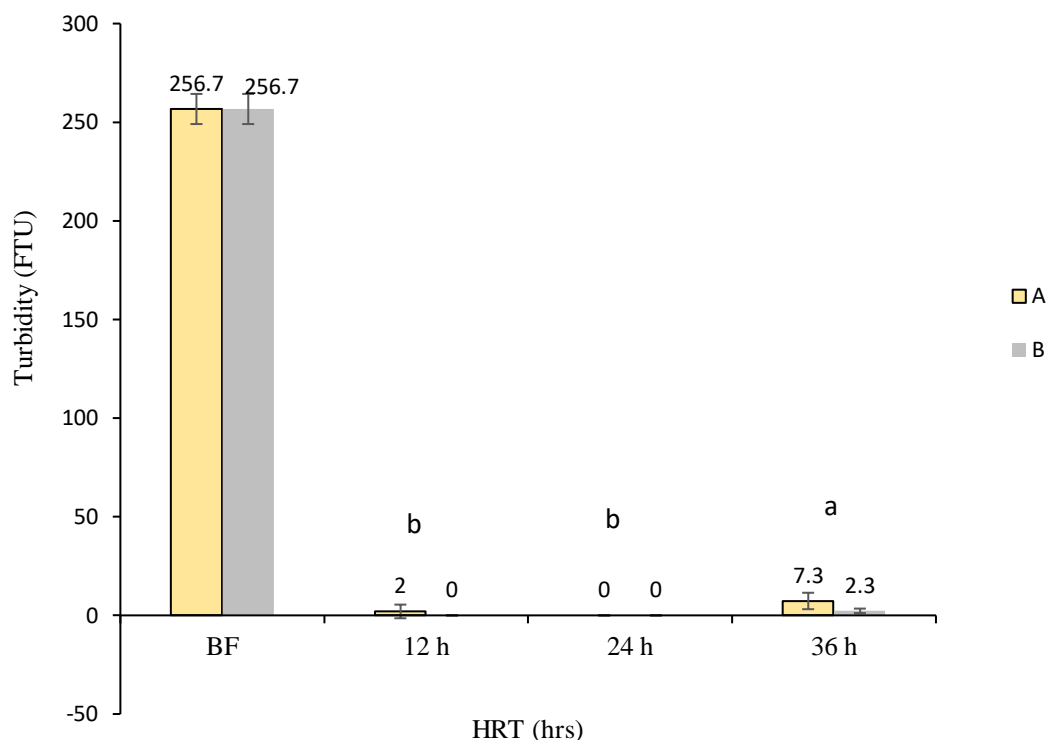


Figure 5: Variation of turbidity in the influent and effluent at different HRT in filter columns A and B. Error bars are standard deviation of means.

a- Statistical significant different ($p < 0.05$)

b - No statistical significant different ($p > 0.05$)

Electrical Conductivity (EC) in the filtered effluent

The Electrical Conductivity of the effluent varied at different HRT (12, 24, and 36 hrs) with the mean values of 313 ± 2.08 , 576.33 ± 90 , and 601.67 ± 10.60 $\mu\text{s/cm}$ for filter column A and 316 ± 1.53 , $67,427.67 \pm 13.65$, and 712.33 ± 25.81 $\mu\text{s/cm}$ for filter column B respectively of which had significantly reduced ($p < 0.05$) from the influent of $1091 \pm 167.17(\text{SD})$ $\mu\text{s/cm}$ (Figure 7). In this study, it was observed that EC of the effluent was increasing with increase in HRT in both filter column but with no significant difference when effluent is compared between the two columns at all HRT ($p > 0.05$, Figure 7). The system achieved the efficiencies of 71.3 %, 47.2%, and 44.9 % for filter column A and 71%, 60.8 % and 34.7% for filter column B at 12, 24, and 36 hrs respectively (Table 10). The study showed a decrease in efficiency for EC removal with increase in retention time (24 h and 36 h) (Figure 7). This was opposing the literature where the efficiency for EC removal was increasing with time (Niwa-gaba *et al.*, 2014). At 12 h it showed significant decrease

when compared influent with effluent. The decrease of efficiency could be due detergents with bulking agents and salts contained in the greywater. When the greywater degrades, the salts breaks down and are released in to the effluents. Also it might be due to the dissolution of organic nitrogen to ammonium. The increase for the efficiency of EC removal at 12 h could be due to conversion of nitrate (NO₃) into diatomic molecular nitrogen (N₂) (Khan *et al.* (2015), and chemical adsorption of dissolved compounds onto filter media and absorption of phosphorus by microorganisms. The degradation and salt disintegration processes were also still limited at 12 h. EC of TGW of both columns were meeting the WHO (2006) standards for reuse for selected non-portable uses at all HRT except filter column B at 36 h that would meet only for flower irrigation (Annex 2). EC is associated with salinity. High salinity have negative impact on soil which in turn affects the flower growth.

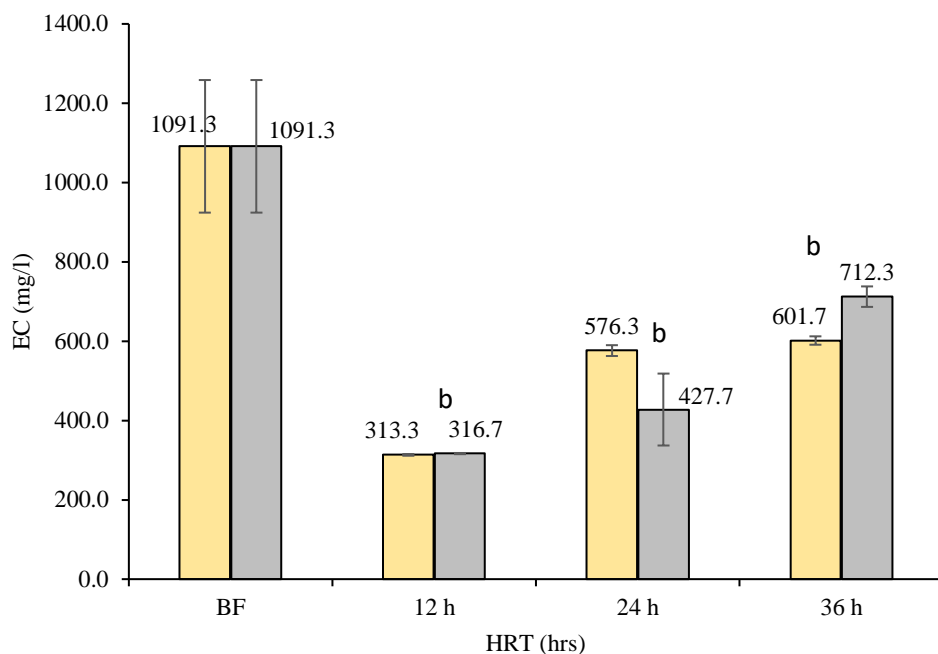


Figure 6: Variation of Electrical Conductivity in the influent and effluent at different HRT in filter columns A and B. Error bars are standard deviation of means.

b - No statistical significant different ($p > 0.05$)

Chemical Oxygen Demand (COD) in the filtered effluent

In this study, COD before filtration was 397.3 ± 4.9 mg/l which significantly decreased ($p < 0.05$) to 16.3 ± 1.6 , 4.1 ± 0.3 , and 15 ± 1.0 for filter column A, and 5.7 ± 1.2 , 2.3 ± 0.3 , and 5.0 ± 1.0 for filter column B at 12, 24, and 36 hrs respectively (Figure 8). It was observed that COD removal of

filter column B was significantly different ($p < 0.05$) than that of filter column A at 12 h and 36 h but no significant difference at 24 h. At 36h, both filter columns showed a significant increase in COD values ($p < 0.05$; Figure 8). The system achieved the removal efficiencies of 95.91%, 98.98% and 96.22% for filter column A, 98.57%, 99.43%, and 98.74% for filter column B at 12, 24, and 36 hrs respectively (Table 10). The system showed a significant higher removal of COD at 24 h in both filters.

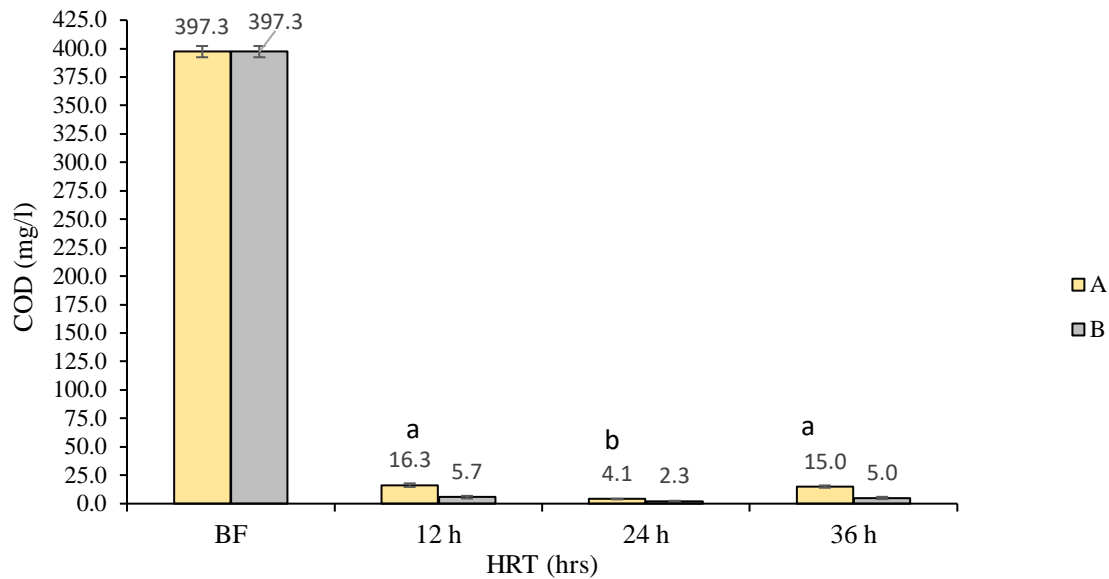


Figure 7: Variation of COD in the influent and effluent at different HRT in filter columns A and B. Error bars are standard deviation of means.

a- Statistical significant different ($p < 0.05$)

b - No statistical significant different ($p > 0.05$)

Biochemical Oxygen Demand (BOD₅) in the filtered effluent

The initial mean value before filtration of BOD₅ was 184 ± 22.9 mg/l and it reduced significantly ($p < 0.05$) to 6.5 ± 0.6 , 1.5 ± 0.1 , and 6.0 ± 0.4 for filter column A, and 2.3 ± 0.5 , 1 ± 0.1 , and 2.0 ± 0.4 for filter column B at 12, 24 and 36 hrs respectively. It was observed that BOD₅ removal of filter column B was significantly different ($p < 0.05$) from that of filter column A at 12 h and 36 h but not significantly different at 24 h ($p > 0.05$). At 36h, both filter columns showed a significant increase ($p < 0.05$) (Figure 9). The system achieved the removal efficiencies of 96.5 %, 99.1 % and

96.8 % for filter column A and 98.8 %, 99.5%, and 98.9 % for filter column B at 12, 24, and 36 hrs respectively (Table 10). The system showed a significant higher removal of BOD₅ at 24 h in both filters. The removal efficiency of the filtration system was as high as that reported in the literature when concentration of BOD₅ and COD in the influent were compared. In studies of treating grey water through optimization of filter media by Katukiza *et al.* (2014) achieved 90.5 % COD removal efficiency at constant HLR and Hernandez *et al.* (2010) achieved 90 to 98 % by using membrane bioreactors (MBR) and sequencing batch reactors (SBR). Table 10 shows a large variability of percentage removal of BOD₅ and COD at different HRT. It was observed that the efficiency increased with increase in retention time (12 and 24h) and later on it decrease at 36 h. Niwagaba *et al.* (2014) revealed in the literature that retention time of GW in the filtration system plays a significant role in the BOD₅ and COD reduction. The system significantly reduced BOD₅ and COD (> 90 %) due to dissolved organic and inorganic matter adsorption on the filter media, intra particle diffusion into the GAC and chemical oxidation of organic matter (Niwagaba *et al.*, 2014).

The study by Nema and Christianc (2017) on effect of retention time on primary media (marble chips, rice husk, pine wood and coir jute rope) without sand and GAC for greywater treatment in India also reported that removal efficiency increased with retention time (6, 8, 12, and 16 hrs) and started to decrease after 18 h in terms of COD. It was also observed that filter column B was more efficient than filter column A, due to molecular structure of GAC with active site that oxidizes organic matter. Khalaphallah (2012); Wurochekke *et al.* (2014); Saad *et al.* (2016) reported that the sand filtration using activated carbon is the best method and reduces COD and BOD₅ when the wastewater flows over it. BOD₅ and COD of both filter columns were meeting the USEPA (1992) standards for reuse of all selected non-portable uses (Annex 2). These means that the amount of oxygen in the filtration system was sufficient for microbes to degrade organic matter in wastewater. Thus, the heterotrophic bacteria could rapidly oxidize the organic matters into biomass and gas.

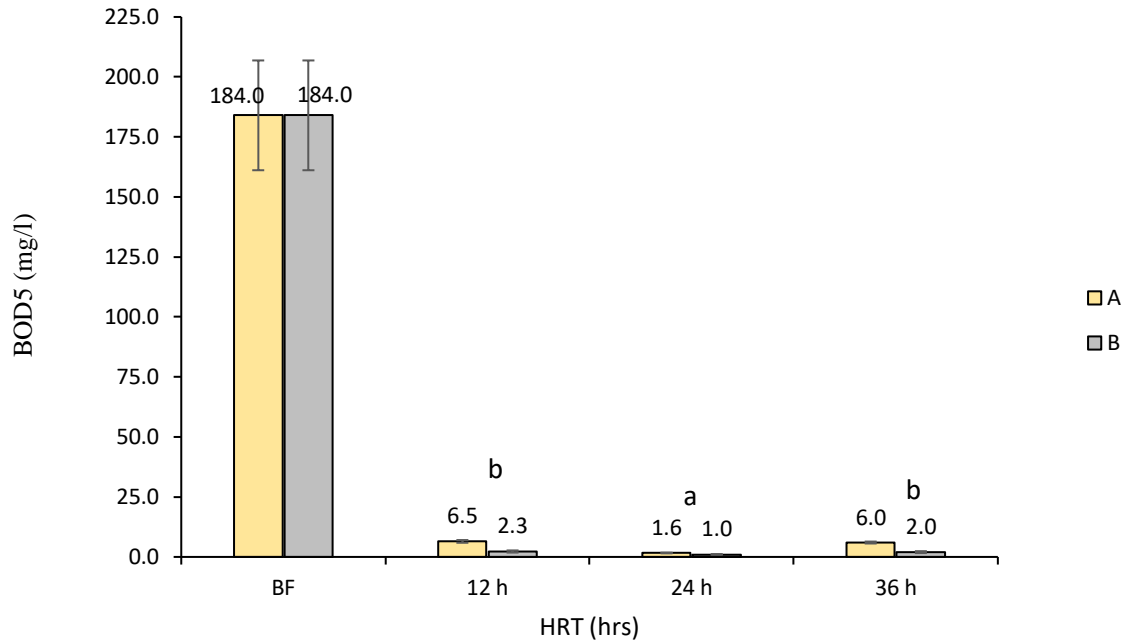


Figure 8: Variation of BOD₅ in the influent and effluent at different HRT in filter columns A and B. Error bars are standard deviation of means.

a- Statistical significant different ($p < 0.05$)

b - No statistical significant different ($p > 0.05$)

Total phosphorus (TP) in the filtered effluent

The TP of the effluent varied at different HRT (12, 24, and 36 hrs) through the filtration system. The recorded influent mean value was 1.71 ± 0.87 mg/l which significantly decreased ($p < 0.05$) to 0.22 ± 0.02 , 0.16 ± 0.01 and 0.18 ± 0.01 mg/l for filter column A and 0.27 ± 0.03 , 0.13 ± 0.02 and 0.15 ± 0.01 mg/l for filter column B at 12, 24, and 36 hrs respectively (Figure 10). The study showed a decrease at 24 h then an increase at 36 h in both filter columns. When the two filter columns were compared, no significant difference was observed at all retention time. The system achieved TP removal efficiencies of 87.1 %, 90.6 %, and 89.5 % for filter column A and 84 %, 92.2 %, and 91.2 % for filter column B at the HRT of 12 h, 24 h, and 36 h respectively (Table 10). It was observed that, at 24 h the TP removal was more efficient due to reduction of TC at the similar retention time.

The removal efficiency of TP removal could be due to the assimilation of phosphorus into microbial biomass in addition to adsorption. Also it could be the result of microbial reduction in the system since phosphate is stored in its cells. The reduction of efficiency at 36 h could be the

result of desorption but it was not significant. The researcher, Dalahmeh *et al.* (2013) reported that desorption of previously sorbed phosphate occurred due to the occurrence of anoxic conditions. The removal efficiency of Tot-P in the study was much higher than for other researchers (Dalahmeh *et al.* (2013); Niwagaba *et al.* (2014) which was in range of 30-83% and this could be due to low concentration of greywater influent. All in all the effluent of TP from the system was meeting the Jordan, (2002) standard for non- portable reuse shown in Annex 2. However, Ghunmi *et al.* (2011) emphasized that where the treated grey water is to be used for irrigation, NO₃ and Tot-P should be monitored but not removed.

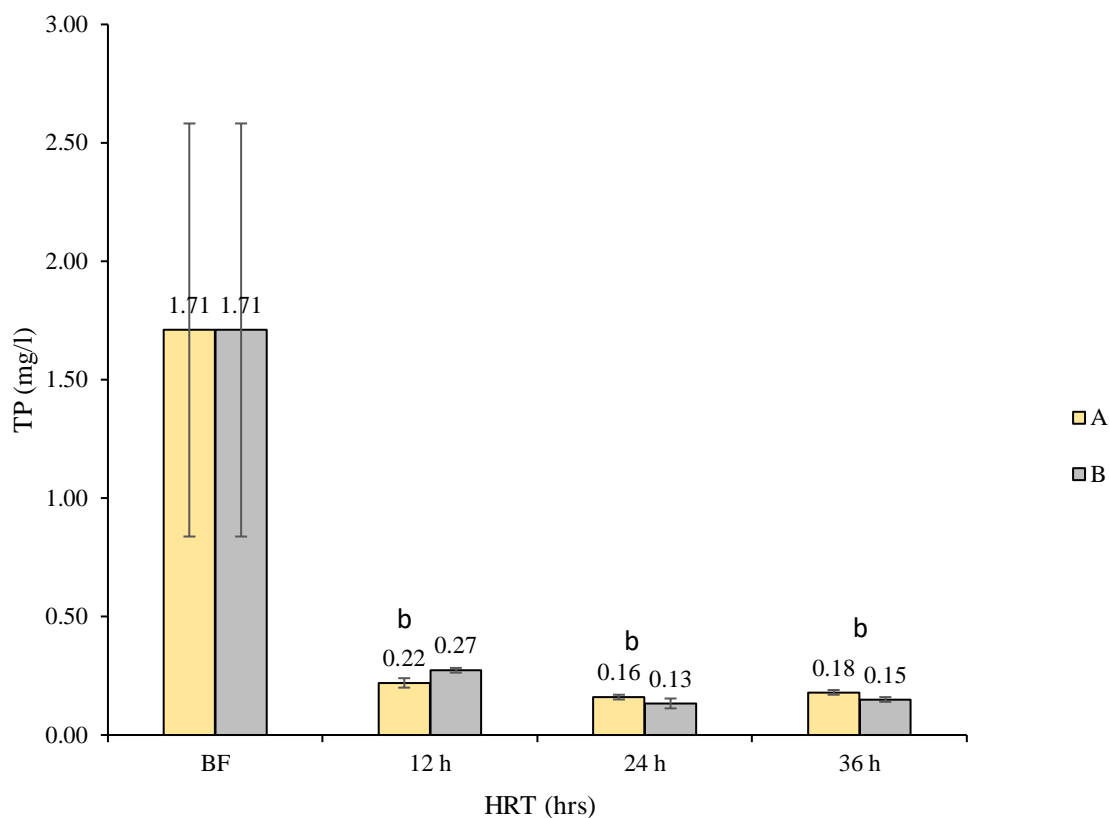


Figure 9: Variation of TP in the influent and effluent at different HRT in filter columns A and B. Error bars are standard deviation of means.

b - No significant different ($p > 0.05$)

Ammonia – nitrogen (NH₄-N) in the filtered effluent

The ammonia-nitrogen of the effluent varied at different HRT (12, 24, and 36 hrs) through the filtration system. The influent recorded was 4.22 ± 0.13 mg/l which significantly decreased ($p < 0.05$) to 0.16 ± 0.01 , 0.21 ± 0.03 and 0.36 ± 0.03 mg/l for filter column A and 0.24 ± 0.03 , 0.08 ± 0.01 and 0.18 ± 0.05 mg/l for filter column B at 12, 24, and 36 hrs respectively (Figure 11). The study showed an increase of NH₄-N concentration with increase in HRT for filter column A and a decrease at 12, and 24 h then an increase at 36 h in filter column B. When the two filter columns were compared, it was observed that there was significant different ($p < 0.05$) at 24 h and 36 h but no difference at 12 h. The system achieved NH₄-N removal efficiencies of 96.2 %, 94.9 %, and 91.6 % for filter column A and 94.3 %, 98.1 %, and 95.7 % for filter column B at the HRT of 12 h, 24 h, and 36 h respectively (Table 10). It was observed that filter column B at 24 h was more efficient in removal of ionized ammonia from the system.

The decrease of NH₄ - N in TGW could be due to the breakdown of ammonia to NO₃ by nitrifying bacteria. They could have also reduced due to adsorption on to the filter media.

The increase of efficiency for ammonia- nitrogen removal with time was observed in only filter column B at 12 h and 24 h (Figure 11) because of molecular structure of GAC that could adsorb NH₄⁺. The decrease of efficiency for the removal of ammonia- nitrogen with time was observed in filter column A (24 h and 36 h) and filter column B at 36 h only (Figure 11). This could be due to hydrolysis of proteinaceous substances to ammonia and desorption when the filter media had reached equilibrium state. The reported literature ranged from 61.8 – 96 % when treated with sand filter and 88.3- 97 % when treated with GAC (Dalahmeh *et al.*, 2012; Katukiza *et al.*, 2014; Wurochekke *et al.* 2014). Hernandez *et al.* (2010) reported 72 % by using MBR and are comparable to results of this study.

The pH of (7.0–8.0) plays an important role in nitrification and denitrification (Li *et al.*, 2009; Wurochekke *et al.*, 2014) by increasing the biological process. The NH₄-N of both filter columns after treatment were meeting the selected non - portable reuse standards (WHO, 2006; Jordan, 2002 and Agency UK, 2011) (Annex 2).

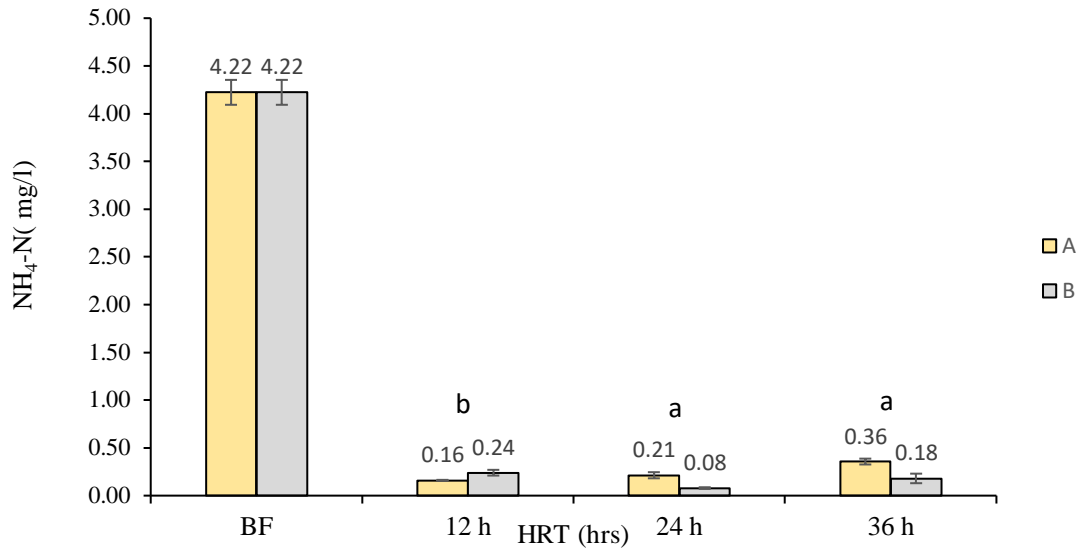


Figure 10: Variation of $\text{NH}_4\text{-N}$ in the influent and effluent at different HRT in filter columns A and B. Error bars are standard deviation of means.

a- Statistical significant different ($p < 0.05$)

b - No statistical significant different ($p > 0.05$)

Nitrates in the filtered effluent

The NO_3 of the influent varied at different HRT (12, 24, and 36 hrs) through the filtration system. The influent recorded was 0.058 ± 0.007 mg/l which significantly decreased ($p < 0.05$) to 0.029 ± 0.004 , 0.004 ± 0.00 and 0.001 ± 0.00 mg/l for filter column A and 0.045 ± 0.003 , 0.005 ± 0.00 and 0.001 ± 0.00 mg/l for filter column B at 12, 24, and 36 hrs respectively (Figure 12). The study showed a decrease of NO_3 concentration with increase in HRT for both filter columns. When the two filter columns were compared, it was observed that there was no significant different ($p > 0.05$) at 24 h and 36 h but a difference at 12 h. The system achieved NO_3 removal efficiency of 50.6 %, 92.5 %, and 98.9 % for filter column A and 21.8 %, 91.6 %, and 99.0 % for filter column B at the HRT of 12 h, 24 h, and 36 h respectively (Table 10) below. It was observed that the system was efficient in removal of nitrates.

The decrease of NO_3 could be due to the breakdown of nitrate to N_2 by denitrifying bacteria.

The NO_3 removal in both filters were less efficient at 12 h but more at 36 h. The studies by Dalahmeh *et al.* (2012) and Katukiza *et al.* (2014) on GWT reported the removal efficiency ranging

from 40 – 97.1% which was not far from this study. The similar results was reported by Mohamed *et al.*, (2014) on natural filtration system for grey water in Malaysia.

At longer HRT, there could be regrowth of bacteria which could break nitrates into free nitrogen and autotrophic nitrifiers grow much slowly than heterotrophic therefore it requires longer HRT. Dalahmeh *et al.* (2013) reported that Increasing amounts of influent organic matter probably cause a thick and homogeneously distributed biofilm to develop. This in turn created more anoxic sites, providing favorable conditions for denitrification, the reason for decrease of nitrates in the system. The pH of (7.0–8.0) plays an important role in denitrification (Li *et al.*, 2009; Wurochekke *et al.*, 2014) by increasing the biological process. The NO₃ of both filter columns after treatment were meeting the selected non - portable reuse standards (WHO, 2006; Jordan, 2002 and Agency UK, 2011) ([Annex 2](#)).

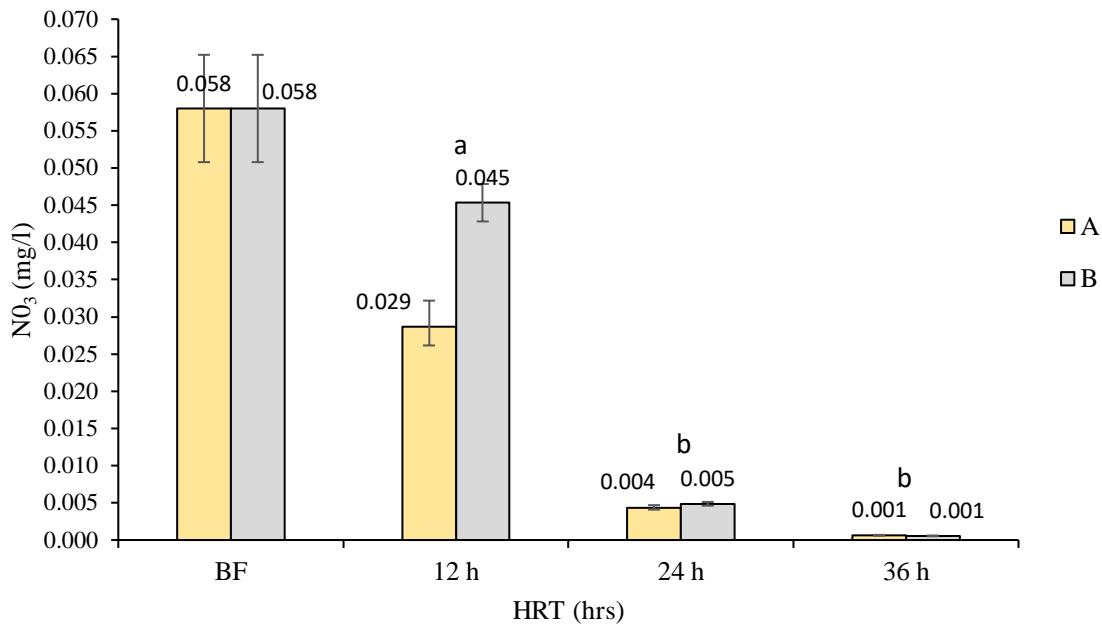


Figure 11: Variation of NO₃ in the influent and effluent at different HRT in filter columns A and B. Error bars are standard deviation of means.

a- Statistical significant different ($p < 0.05$)

b - No statistical significant different ($p > 0.05$)

Fecal Coliform (FC) in the filtered effluent

The FC of the effluent varied at different HRT (12, 24, and 36 hrs) through the filtration system. The influent had fecal coliform of $1.1 \times 10^3 \pm 90.2$ CFU/100 ml which significantly decreased ($p < 0.05$) to 86 ± 6.0 , 51.3 ± 4.2 , and 66.7 ± 4.7 CFU/100ml in filter column A and 82.7 ± 4.6 , 42.0 ± 2.0 , 54 ± 1.5 in filter column B at 12, 24, and 36 hrs respectively (Figure 13). This study showed a decrease in count at 12 h and 24 h then an increase at 36 hr as shown in the Figure 13 below. In comparing the means, FC count indicated no significant decrease ($p > 0.05$) between filter column A and B. The system achieved the efficiency for the removal of FC count at 92.3 %, 95.4 %, and 94% for filter column A and 93.3 %, 97.1 %, 95.8 % for column B at 12, 24 and 36 h respectively (Table 10).

Total Coliform (TC) in the filtered effluent

The TC of the effluent varied at different HRT (12, 24, and 36 hrs) through the filtration system. The influent had total coliform count of $6.6 \times 10^7 \pm 5.5 \times 10^6$ CFU/100 ml which significantly decreased ($p < 0.05$) to 5033.3 ± 550.8 , 4133.3 ± 152.8 , 4300 ± 264.6 CFU/100ml in filter column A and 4633.3 ± 152.8 , 3300.0 ± 300 , 5100.0 in filter column B at all retention time (Figure 13). This study showed a decrease in count at 12 h and 24 h then an increase at 36 hr as shown in the Figure 13 below. In comparing the means, TC count indicated no significant decrease ($p > 0.05$) between filter column A and B. The system achieved the efficiency for the removal of TC count at 99.99 %, 99.99 %, 99.99% for both filter column A and B at 12, 24 and 36 h respectively. (Table 10).

The significant decrease of TC and FC count in both filter columns at different HRT (12, 24, 36 h) could be due to natural die off, oxidation, predation, adhesion to biofilms, mechanical filtration of micro-organism present in the influent and adsorption on to filter media.

The results of the effluent were in the range of other studies done by Niwagaba *et al.*, (2014) and katukiza *et al.* (2014) on GWT in Uganda. At 36 h the removal efficiency started showing a decrease. This could be the increase of organic matter resulted by desorption in the system after long HRT that enhanced the regrowth of microorganisms in the system. Khan *et al.* (2015) reported that decrease of COD and BOD supports nitrifying bacteria to use dissolved oxygen for new biomass growth.

It was observed that there was no significant difference in removal of FC and TC count in both filter columns but had good efficiency of more than 95%. A study by Dalahmeh *et al.* (2013) in

comparing GAC, bark, and sand filters also reported no significant difference between these filters. The same author reported that bacteria can be found in the effluent when the micro pores of the media is clogged due to overgrowth of bacteria on the large specific surface of the GAC (Scholz and Martin, 1997). This could also explain the cause of increase of FC and TC at 36 h.

Nnaji *et al.* (2013) reported that, filtration process contributes significant reduction of bacterial load. The same authors demonstrated that more than 99 % of coliform bacteria can be reduced by filtration process using constructed wetland and sand filtration in treating GW

The studies by Kariuki *et al.* (2011) on low cost GWT using conventional system in Jomo Kenyatta university reported that the system reduced total and fecal coli forms from 7.3×10^6 and 5.4×10^5 to 10^4 cfu/100 ml, and 2.0×10^2 cfu/100 ml respectively where the system of this study was much better for GWT.

Total Coliform of TGW for both filter columns were above the permissible level for reuse of selected non portable uses at all HRT used in this study and fecal coliform was only meeting the WHO (2000) standards for flower watering ([Annex 2](#)).

Total and fecal coliform were above the permissible level. For this case it required further treatment like disinfection to meet the standards for reuse. Katukiza *et al.* (2014) on optimizing the sand filters found the microorganisms in the final effluent not meeting the WHO standards for reuse and the author concluded that there is a need for adding a tertiary treatment step to increase the removal of these microorganisms.

A study by Yogafanny *et al.* (2014) reported that sand filtration techniques are effective in reducing the microbes only if the post treatment is applied using disinfection.

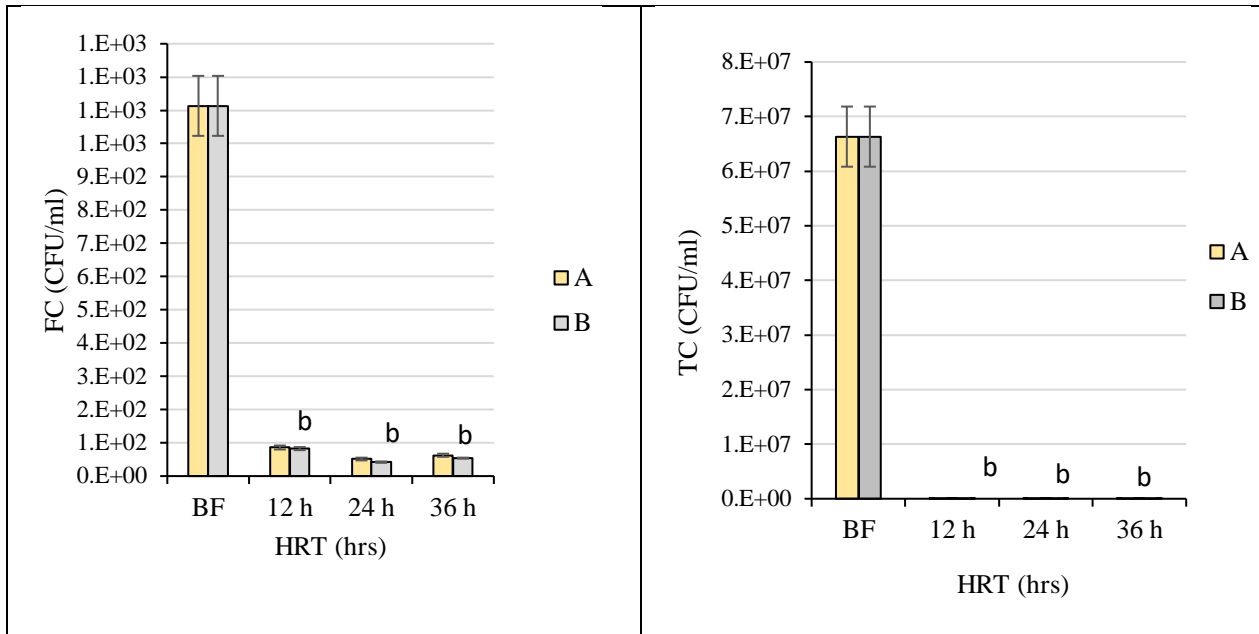


Figure 12: Variation of FC (left) and TC (right) in the influent and effluent at different HRT in filter columns A and B. Error bars are standard deviation of means.

b – No significant different ($p > 0.05$)

Table 10: The Summary of mean values of the influent, effluents and efficiencies of the treatment system of both filter columns.

Filter column A									
			Before filtration	After filtration			Efficiency (%)		
#	Parameters	Unit	Mean ± SD	12 h (Mean ± SD)	24 h (Mean ± SD)	36 h (Mean ± SD)	12 h	24 h	36 h
1	pH		7.5 ± 0.18	7.4 ± 0.32	7.3 ± 0.21	7.3 ± 0.15			
2	Turbidity	FTU	256.67 ± 7.6	2 ± 3.5	0 ± 0.0	7.3 ± 4.2	99.22	100	97.14
3	EC	µs/cm	1091.33 ± 167	313 ± 2.1	427 ± 13.7	601 ± 10.6	71.3	60.8	44.9
4	BOD ₅	Mg/l	184 ± 22.9	6.4 ± 0.6	1.6 ± 0.14	6.0 ± 0.4	96.5	99.1	96.7
5	COD	Mg/l	397 ± 4.9	16.3 ± 1.6	4.1 ± 0.3	15 ± 1	95.91	98.98	96.22
6	TP	Mg/l	1.71 ± 0.87	0.22 ± 0.02	0.16 ± 0.01	0.18 ± 0.01	87.1	90.6	89.5
7	NH ₄ -N	Mg/l	4.22 ± 0.13	0.16 ± 0.01	0.21 ± 0.03	0.36 ± 0.03	96.2	94.9	91.6
8	NO ₃	Mg/l	0.058 ± 0.00721	0.029 ± 0.004	0.004 ± 0.0004	0.001 ± 0.001	50.6	92.5	98.9
9	FC	CFU/100ml	1.1 × 10 ³ ± 90.2	86 ± 6.0	51.33 ± 4.2	62.67 ± 4.7	92.3	95.4	94.8
10	TC	CFU/100ml	6.6 × 10 ⁷ ± 5.5 × 10 ⁶	5033 ± 550.8	4133 ± 152	4300 ± 264.6	99.99	99.99	99.99
Filter column B									
			Before filtration	After filtration			Efficiency (%)		
#	Parameters	Unit	Mean ± SD	12 h (Mean ± SD)	24 h (Mean ± SD)	36 h (Mean ± SD)	12 h	24 h	36 h
1	pH		7.5 ± 0.18	8 ± 0.25	7.8 ± 0.44	8.1 ± 0.61			
2	Turbidity	FTU	256.67 ± 7.6	0.0 ± 0.0	0.0 ± 0.0	2.7 ± 1.2	100	100	98.96
3	EC	µs/cm	1091.33 ± 167	316.67 ± 1.5	576 ± 90.7	712 ± 25.8	70.98	47.2	34.7
4	BOD ₅	Mg/l	184 ± 22.9	2.3 ± 0.5	0.9 ± 0.1	2.0 ± 0.4	98.8	99.5	98.9
5	COD	Mg/l	397 ± 4.9	5.7 ± 1.2	2.3 ± 0.3	5.0 ± 1.0	98.57	99.43	98.74
6	TP	Mg/l	1.71 ± 0.87	0.27 ± 0.03	0.13 ± 0.02	0.15 ± 0.01	84.0	92.2	91.2
7	NH ₄ -N	Mg/l	4.22 ± 0.13	0.24 ± 0.03	0.08 ± 0.01	0.18 ± 0.05	94.3	98.1	95.7
8	NO ₃	Mg/l	0.058 ± 0.00721	0.045 ± 0.003	0.005 ± 0.00	0.001 ± 0.00	21.8	91.6	99.0
9	FC	CFU/100ml	1.1 × 10 ³ ± 90.2	82.67 ± 4.6	42 ± 2.0	54 ± 1.5	92.6	96.2	95.1
10	TC	CFU/100ml	6.6 × 10 ⁷ ± 5.5 × 10 ⁶	4633 ± 152	3300 ± 300	5100 ± 360	99.99	99.99	99.99

4.3. Evaluation of willingness to use treated greywater for selected purposes

4.3.1. Demographic characteristics of respondents

A total of 176 respondents were interviewed, and all provided responses. Most of the respondents were students (39%), followed by other staffs (34%), then the cleaners (22%), and the gardeners (5%). Female respondents were more than male counterparts (55% compared to 45% respectively). The Undergraduate respondents (56%) were more than post graduates (17%) and other or with no qualification (27%). Singles were more than married respondents (52% compared to 48% respectively) as shown in [Table 11](#)

Table 11: Demographic characteristics of the respondents

Demographic characteristics		Number	Percentage (%)
Position at the college	Other Staffs	60	34
	Students	68	39
	Cleaners	39	22
	Gardeners	9	5
	Total	176	100
Gender	Male	79	45
	Female	97	55
	Total	176	100
Education level	Post graduate	30	17
	Undergraduate	98	56
	Other	48	27
	Total	176	100
Marital status	Married	84	48
	Single	92	52
	Total	176	100

4.3.2. Willingness to use treated greywater (TGW) for selected non- portable purposes

Respondents were asked if they were willing to use the TGW for selected purposes, namely; toilet flushing, pavement washing and watering flowers. Their willingness to use the TGW varied, as described in the following sections.

Toilet flushing

The extent of public willingness to use TGW for toilet flushing varied among different respondents ([Figure 15](#)). For other staffs, majority (92%) were willing to use TGW while only a few of them (8%) disagreed. For students, as high as 87% were willing to use TGW to flush toilets, compared

to only 13% who indicated that they could not use the water for this purpose. Most cleaners (85%) showed willingness to use TGW for this purpose, compared to 15% of them who rejected. For gardeners, majority (78%) were in agreement with the use of TGW for flushing toilets, while the rest (22%) opposed this idea.

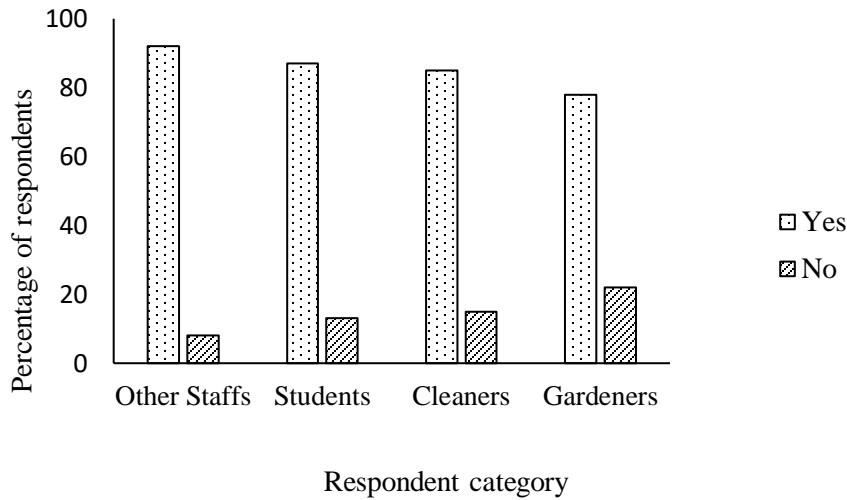


Figure 13: Willingness to use TGW for toilet flushing among various respondent categories

Pavement washing

The extent of public willing to use TGW for pavement washing also varied among different respondents (Figure 16). For instance, all most all other staffs (97%) were willing to use TGW for washing pavements, though a few of them (3%) were in disagreement. The biggest percentage (94%) of students also welcomed the use of TGW for pavement washing as compared to their few colleagues (6%) who expressed reservations for use of TGW for this purpose. Similarly, most cleaners (87%) and gardeners (89%) indicated their willingness to use TGW for this purpose, whereas 13% and 11% made a rejection.

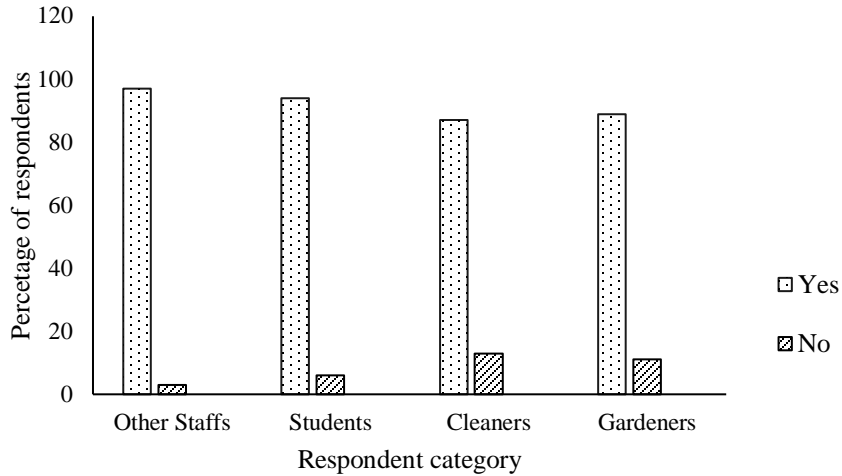


Figure 14: Willingness to use TGW for pavement washing among various respondent categories

Watering flower gardens

Unlike toilet flushing and pavement washing where respondents expressed different reactions, all (100%) respondents were willing to use treated TGW for watering flower gardens (Figure 17).

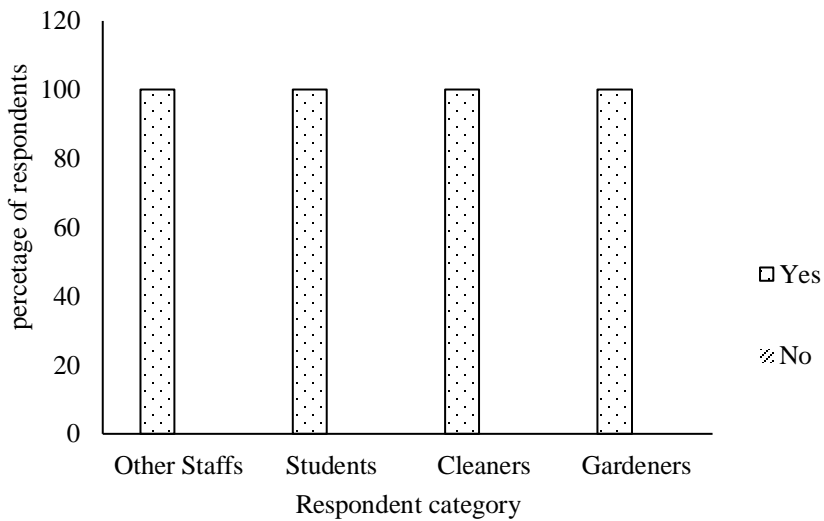


Figure 15 Willingness to use TGW for watering flower gardens among various respondent categories

Most of the respondents agreed to reuse the TGW for non- portable uses; toilet flushing, flower watering and pavement washing because it was aesthetic and meeting the WHO, (2006); USEPA, (1992); and Jordan, (2002) standards especially the treated water at 24 h. Also to cope up with the

water shortage in the college. The few who disagreed had the following reasons; health, fear, psychological, beliefs, distrust and lack of knowledge. The past studies on public perception of wastewater reuse in Kuwait University reported the related reasons (Alhumoud & Madzikanda, 2010). The respondents who disagreed for the mentioned reasons gave alternative choice to reuse it for flower watering. Similarly, in this study no one rejected reuse of TGW for watering flowers. The study on public perception of reusing TGW in Pretoria university of South Africa also reported the same finding (Stoakley, 2013).

A study by Oteng-Pepurah *et al.* (2018) on perception of GW reuse reported that most users would want to reuse GW for activities where personal contact is not involved. Thus, all respondents were are willing to reuse TGW for flower watering because chance of contact are limited. In England, (Mekonnen, (2015) observed public perception on willing to recycle GW for toilet flushing at 90%.

The extent of other staffs and students' willingness to use TGW was not different from the other but was greater than for cleaners and gardeners. This happened because the other staffs and students were familiar with the treatment system and they could easily understand after demonstration. The TGW were demonstrated to the respondents in comparison with raw greywater as shown in [Annex 2](#). The demonstrations were done by showing the videos and images of the experiment operation while explaining to them. The TGW for both filter columns were meeting the standards for non –portable uses for almost all parameters tested. This also convinced most of the respondents to accept to reuse TGW.

Approximately 60-70 % of the wastewater from AAU campuses is greywater (Mekonnen, 2015). Replacing the current potable water supply with treated GW would significantly reduce the demand for potable water in the campus. So far, CNCS student's hostels produces approximately 119 m³/day of greywater. If treated with this filtration system when scaled up it can save approximately 101 m³ of water from normal water supply to the CNCS which is equal to 2323 ETB/ day. Also basing on the system treatment efficiency and the willingness of CNCS community to use the treated greywater, it gives a high potential to the system to reduce water shortage if scaled up to the college level.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

Greywater reuse is one of the technique that can meet water demand in Ethiopia. This study is an attempt to evaluate the performance of lab- scale filtration system for GWT and reuse. The study determines RGW characteristics, efficiency of the filtration system, and the willingness of community to reuse TGW for selected non portable uses.

The parameters tested showed that GW from regional students' hostel, CNCS was not highly polluted in terms of physico-chemical characteristics when compared with the results of other researchers. All the parameters except TP and Nitrates were above the standards for non-portable uses therefore treatment was very necessary. Microbiological parameters showed that GW was highly polluted with microorganisms, similar to greywater characteristics from highly polluted areas like slum areas.

Using a filtration system for the treatment of greywater was found to be promising, simple and efficient technology. The GWT for both filter columns were inferred to be effective in removal of contaminants at 24 h though the sand with GAC was more effective. The filters were not significant different in removal of pollutants at 24 h except for $\text{NH}_4\text{-N}$ were filter column B was more effective. The system was less effective in removal of Electrical Conductivity.

In comparing TGW with the standards, all physico-chemical parameters tested were meeting the standards for reuse of selected non portable and for microbiological parameters were meeting the standards for only flower watering /irrigation. Therefore the system required the post treatment like disinfection to kill or further reduce microbial count for reuse of selected non portable uses (toilet flushing, flower watering, and pavement cleaning).

It was observed that above 80 % of respondents were are willing to use TGW for selected non portable use. The literature indicates that the opportunity for source substitution is particularly significant with regards to water use for toilet flushing, flower watering, and pavement washing given that the survey showed 80 % of respondents in the campus willing to use TGW. Therefore the TGW of this study can be reused for selected non portable uses.

5.2. Recommendations

All the above results and findings of the research full fill the gap of water demand and deficiencies related to water shortage in CNCS through reuse of TGW for non-portable uses.

1. The study can be scaled up in selective areas of Addis Ababa. This demonstrates its advantages to the authorities in implementing greywater reuse system using filtration technology. Thus, reducing water demand in Addis Ababa city and narrow the gap between the current water supply and water demand in Addis Ababa.
2. It was observed that the system does not fully remove the bacteria therefore, the post treatment should be implemented like disinfection using chemicals or other methods.
3. The filtration system requires substantial maintenance as its effectiveness is highly affected by clogging. Thus, system should be back washed at least once in a week.

5.3. Research limitations

1. The breakdown of pandemic disease (convid-19) was an interruption during my data collection. This caused the closure of schools in the country and the laboratory I was using for data analysis was affected.
2. Interaction during interview with the respondents was difficult because of language barrier especially to cleaners and gardeners. The translator himself knew little English he could not understand some of the words.

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ANNEX 1: QUESTIONNAIRE

Dear Respondent;

I am TUSIIME ANNA, a student at Africa Center of Excellence for Water Management, Addis Ababa University pursuing a Master of Science in Water Supply and Sanitation. Am carrying out a research on “Evaluating the Performance of a lab-scale filtration system for greywater treatment and reuse in CNCS campus, Addis Ababa University”. The purpose of this Questionnaire is to get your views on willingness to use treated water for non-potable uses. You have been selected to participate in this study. The information you provide will be treated with high level of confidentiality and shall not be used for any other purpose except for academic purposes. Please feel free to answer the questions to the best of your knowledge.

Yours faithfully,

Tusiime Anna

Please, fill this Questionnaire by ticking in the boxes where appropriate.

SECTION A: BIO DATA (Please tick the appropriate box)

1. Gender

Male Female

2. Marital status

Single Married

3. Levels of education

Under graduate
 Post graduate others

4. Position in the area

Flower gardeners Student
 Staffs Cleaner

SECTION E: EVALUATION OF WILLINGNESS TO USE THE TREATED GREYWATER FOR NON-POTABLE PURPOSES

How do you agree about reuse of treated greywater for the following non-potable purposes?

	Non-potable purposes		
		disagree	Agree
1	Flushing toilet		
2	Pavement washing		
3	Flower/compound irrigation/watering		

If disagree, give the reasons.

Disagree

.....

ANNEX 2: Table of treated greywater in comparison with standards of selected non-portable uses

Parameters	A			B			Toilet flushing	Land scaping/ flower watering	Pavement washing	Reuse standards
	12 h	24 h	36 h	12 h	24 h	36 h				
pH	7.4	7.3	7.35	8.0	7.8	8.1	6 - 8.5	6 - 9	6 - 8.5	WHO,2001
BOD (mg/l)	6.5	1.6	6.0	2.3	0.9	2.0	≤ 10	≤ 20	≤ 20	USEPA, 1992
COD (mg/l)	16.3	4.1	15	5.7	2.3	5.0	≤ 20	≤ 100	≤ 20	USEPA, 1992
Turbidity (NTU)	2	0	7.3	0	0	2.7	≤ 5	≤ 10	≤ 5	WHO, 2001
EC (μS/cm)	313.3 3	427.6 7	601.7	316.7	576.3	712.3	≤ 700	≤ 1000	≤ 700	WHO,2006
TP (mg/l)	0.22	0.16	0.18	0.27	0.13	0.15	≤ 6	≤ 30	≤ 30	Jordan, 2002
NO3 (mg/l)	0.029	0.004	0.001	0.045	0.005	0.001	≤ 30	≤ 50	≤ 30	Jordan, 2002 , AgencyUK,2011
NH ₄ -N (mg/l)	0.16	0.21	0.36	0.24	0.08	0.18	≤ 2.5	≤ 2.5	≤ 2.5	WHO,2006
FC(CFU/100ml)	86	51.3	62.7	82.7	42	54	≤ 10	≤ 200	≤ 10	USEPA,1992 UK,2011
TC(CFU/100ml)	5033.3	4133.3	4300	4633	3300	5100	≤ 1000	≤ 1000	≤ 50	WHO,2000 UK,2011

ANNEX 3: Pictorial



Preparation of local materials for filtration; Sand sieving (left), graded sand and gravel (middle), washing sand (right)



Greywater collection:



Analysis of greywater parameters



The left is the raw water; middle treated greywater from filter column A; Right is the treated greywater from column B.