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Performance of lab-scale filtration system for grey water treatment and reuse



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ABSTRACT

In this study, we evaluate the performance of a lab-scale filtration system for greywater treatment and reuse using sand and granular activated carbon as filter media. Using a laboratory, Physico-chemical and microbiological parameters are determined. The treatment efficiency comparison is made between lab-scale filtration systems that use gravel + sand and gravel + sand + GAC using pre-filtration and post-filtration mean values at different hydraulic retention times (HRT) and different filter columns. For both filter columns used, the treatment efficiency of the system increased with HRT at 12 h and 24 h and later on it decreased at 36 h. The pollution reduction was from 60.8% - 100% for selected parameters (pH, turbidity, BOD, COD, TC, and FC) in filter column B and from 47.2% - 100% for filter column A. Thus, filtration systems are efficient at improving hygiene, and water shortage at the university. Also, the results of the willingness to use the treated greywater (TGW) revealed that on the average, about 84.75%, 91.75%, and 100% of the respondents are willing to adopt the TGW for toilet flushing, pavement washing, and flower garden watering respectively.

1. Introduction

Water demand is increasing at a higher rate with population growth, yet water availability is reducing due to growing competing demands from various users (Alemu and Dioha, 2020; Edwin et al., 2013; Filali et al., 2022). According to UNDP, 2017 report estimated that 800 million people live under a threshold of water stress currently, and will reach three billion by 2030. Water is needed for replenishment of the fluids lost through normal physiological activities such as respiration, perspiration, and urination (Solihu and Bilewu, 2022; Shallom et al., 2011).

Water deficits have affected economic development, and food availability globally (Ahmad and Li 2021). The acute 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 (Alemu and Dioha, 2020). Solihu and Bilewu, 2021, established that there was water supply scarcity in Oyo State, Nigeria, and groundwater was the preponderate potable water supply source. Similarly, Adegoke et al., 2022 reported that there was water scarcity in the southern part of Ondo State, Nigeria, and this had a direct impact on the access to improved sanitation and waterborne disease occurrence in the State.

Ethiopia having renewable water supplies of less than 1700 m^3 per capita per year and with economic water scarcity (UN-Water, 2016), has been listed among the countries that are projected to fall below the water scarcity level by 2030. In Addis Ababa, inadequate wastewater treatment facilities and poor wastewater management lead to an increase in untreated wastewater point sources (Amare et al., 2017). The volume of water used in households per day in Addis Ababa is 100-110 L/c/d and more than half of this water can be collected and recycled from the greywater (Frade, 2019).

One of the challenges in most cities of developing countries is the supply of adequate water. Water demand in Addis Ababa City exceeds the water supply due to industrialization, urbanization, and high population growth. The water demand is high and is expected to rise, making the existing water resources unsustainable (Admaise, 2015). Developing new freshwater sources does not meet these challenges in the 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.

Evaluating the performance of a lab-scale filtration system for greywater treatment and reuse serves as the rationale for this study. Thus, this study characterized the raw greywater generated at the College of Natural and Computational Sciences (CNCS) campus; compared the treatment efficiency of lab-scale filtration systems that use gravel + sand and gravel + sand+ GAC at varying HRT, and evaluated the willingness to use treated greywater for non-potable purposes at CNCS campus.

The study provided the data to scale up the system to the college level and university at large. If successfully scaled up there will be a reduc-

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tion in water demand and improved sanitation within the college. Also, there would reduction in the hydraulic loads to the treatment plants, and minimized underground and surface water pollution. The treated greywater would be used mainly for non-potable uses (toilet flushing, flower irrigation/watering, and pavement washing). The data generated from this study and the methodological procedure could be replicated elsewhere with similar water challenges.

2. Literature review

Grey water management through treatment and reuse for non-potable uses by filtration systems offers opportunities of mitigating water scarcity. However, it becomes a complex venture when necessary technologies and procedures are not well researched (Patil et al., 2022). Greywater (GW) is household wastewater generated from bathrooms, kitchens, hand wash basins, and laundry and it does not involve wastewater from toilets, urinals, or any industrial process (Albalawneh and Chang, 2015; Andarge, 2019; Rakesh et al., 2020). In estimation, the average typical GW generation in Addis Ababa households with piped water reticulation is likely to range between 40-60 l/p/d (approximately 50% of total water consumption) (Frade, 2019). GW reuse system designs depend on the quality and quantity of greywater effluent.

According to Abdel-Shafy et al., (2014), greywater treatment system applications of high-rate aerobic setup may have a high capacity to produce superior quality of greywater than that generated from traditional processes like physical processes (Wurochekke et al., 2016). However, there are complex and require high technology to operate compared to the filtration system that uses granular activated carbon (GAC) and sand as filter media (Allen et al., 2010; Kariuki et al., 2011).

Pine bark, activated charcoal, and sand were used by Dalahmeh, 2013. In a similar study, (Dalahmeh et al., 2012) used GAC, pine bark, sand, and polyurethane form as treatment media. Niwagaba et al. 2014 used earthworms, gravel, mulch; wood shavings, geotextile polymer, charcoal, and bottom gravel for a pilot greywater treatment scheme in Uganda. Nagar et al., 2021 used sand, gravels, M seal cement, Sieves, and two baffle sheets to set up his grey water treatment with the filter unit utilizing 2 mm galvanized iron sheets.

Also, Patil et al., (2022) utilized in order of filter assembly; fine sand, banana peels, wood chips, Coconut husks, small-sized gravel, crushed fly-ash bricks, small and medium-sized gravel, and large-sized gravel. As can be seen, sand filtration is a recognized technique for wastewater treatment and is well suited for greywater treatment (Rakesh et al., 2020), but treatment can be done with or without sand. Also, many of the initiatives to treat grey water involve filtration (Oteng-Peprah et al., 2018; Patil et al., 2022).

The GAC and sand have a high efficiency on low-strength wastewater, there are easily regenerated, and are available materials when compared to other filters like sawdust, pine barks, and many others (Boyjoo et al., 2013). Therefore, there are appropriate materials to use in the filtration system.

Sources of greywater by average percentage are; 50% bathroom greywater, 30% laundry greywater, and 20% kitchen wastewater (Andarge, 2019; Boano et al., 2020). Bathroom greywater is always contaminated with hair, dyes, shampoos, soaps, toothpaste, body fats and oils, nutrients, and cleaning products. Laundry GW may be contaminated with oils, grease, laundry detergents, chemicals, soaps, nutrients, and other compounds according to (Andarge, 2019).

The characteristics are different because the sources differ from each other in quality (Bakare et al., 2017), as shown in Table 1. The greywater from the household has a good biodegradability of 2.5 in terms of the COD: BOD_5 ratios (Ghaly et al., 2021).

The biological and chemical degradations of wastewater compounds affect their composition. These may occur during 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-Kassinos et al., 2011). Recent studies by (Oteng-peprah et al., 2018) found pharmaceuticals, human care products, aerosols, pigments, and heavy metals in the greywater.

Physically, the constituents of GW are 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 and Ilemobade, 2015) and this may favor microbiological growth which is undesirable. It can also cause precipitation of certain carbonates such as $CaCO_3$ 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 the household. The same author observed that greywater coming from the kitchen and laundry has high values of TSS, and this is because washing clothes, shoes, vegetables, fruits, and tubers may be containing sand, clay, and other materials that could increase TSS. The study by (Ciabattia et al., 2009) reported the turbidity of grey water in the range of 16 and 450 NTU which is mostly influenced by the water use activities that occur in the household.

Chemically, the contaminants of GW 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 its 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 greywater (Oteng-Peprah et al., 2018).

Also, nitrogen compounds and phosphorus compounds are among the chemical constituents found in greywater. Sodium 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 and Ilemobade, 2015).

COD (the amount of oxygen required to chemically oxidize all organic matter found in greywater), and BOD_5 (the amount of oxygen used by microorganisms to decompose organic matter within 5 days) concentrations in greywater are 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/BOD_5 ratio below 2.5 indicates that greywater can be easily biodegraded.

However, some studies have shown high greywater biodegradability with COD/BOD_5 ratios of 2.9-3.6 (Al-Jayyousi, 2003) because of the high concentration of chemical compounds (detergents and the amount of oil and fat). The Physico-chemical characteristics of greywater are summarized in Table 2.

Biologically, Greywater comprises microorganisms (bacteria, protozoa, and helminths) that are introduced into the body by contact. (Maimon et al., 2014) observed that pathogenic bacteria (Salmonella and Campylobacter) in the greywater are from improper handling of contaminated food. 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.

In treatment technologies, the choice of greywater treatment technology depends on the owner's willingness to operate and maintain the facility (Admaise, 2015a). 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 includes pre-treatment, primary, secondary and tertiary treatment.

These stages adopt either Physico-chemical or biological treatment processes and the methods of treatment include filtration, adsorption, reverse osmosis, up-flow Anaerobic Sludge Blanket (UASB), membrane bioreactor (MBR), Sequencing Batch Reactor (SBR), trickling filters, ac-

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)

Table 2
Physico-chemical characteristics of raw greywater

Parameters	N	Minimum value	Maximum value	Average
pH	15	5.77	7.96	6.71
EC (ms/cm)	10	520.60	906.00	688.00
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	313.00	597.00	509.87
TSS (mg/L)	35	50.00	165.00	105.00
COD (mg O_2/L)	35	301.00	526.00	392.00
BOD_5 (mg O_2/L)	35	240.00	410.00	298.60
Ca (mg/L)	15	151.41	437.61	290.36
Mg (mg/L)	15	83.22	140.01	105.64
Na (mg/L	15	265.00	420.00	320.98
T.P. (mg/L)	15	8.40	12.10	10.54
Nitrates (mg/L)	15	0.39	0.48	0.40
Nitrites (mg/L)	15	-	-	-
TKN (mg/L)	15	18.00	32.00	28.00
Ammonia (mg/L)	15	7.50	9.20	8.40
Oil and grease (mg/L)	35	90.00	289.00	118.50

Source: (Abdel-Shafy and Al-Sulaiman, 2014)
Where 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

tivated sludge, and CW. 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).

The filtration process uses Physical and biological processes to remove pollutants that are not removed by primary processes. Filtration media that are commonly used for filtration are in the form of sand, gravel, and fine mesh (Oteng-peprah et al., 2018). Studies were done by (Dalahmeh et al., 2012) on the performance of different filter media in the filtration system which includes activated charcoal, polyurethane foam, pine bark, and sand as filter media in treating greywater.

In 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 BOD_5 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 4.

3. Materials and methods

3.1. Study area description

The College of Natural and Computational Sciences (CNCS) campus is under Addis Ababa University (AAU), located in Arat Kilo, Arada Sub City, and Addis Ababa City, Ethiopia. CNCS is located at coordinates of $38^0 45^I 55.05^{II}$ E longitude, $9^0 02^I 04.27^{II}$ N latitude, and an elevation of 8036 ft. above mean sea level. The map of the study area location is shown in Fig. 1.

3.2. Study period, design, and sample size

The study began in October 2019 to June 2020. It was conducted by experimental design, sampling, laboratory analysis, and the use of questionnaires for social data collection. A total of 36 greywaters (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.

3.3. Material procurement

3.3.1. Grey water

Grey water was collected once per week for three weeks, in the morning and afternoon by composite sampling from the regional student hostel at CNCS, AAU. Equal proportions of 10 liters of grey water were collected from the kitchen, bathroom, and washing machine using 15-liter buckets and transported by buckets to the ACEWM laboratory for treatment in the filter column set-ups. The wastewater from the bathroom and washing machine was collected in the morning while the kitchen was collected in the afternoon. Fig. 2 shows the greywater sample collection process.

3.4. Experimental setup

Two 30-liter barrels (settling tank) were interconnected with a 25 mm diameter PPr pipe in parallel to two filter columns made up of PVC pipe DN150 mm of 1.3 m in length (Fig. 3). The gate valve was connected between the settling tank and the filter columns to control

Table 3
Biological characteristics of raw greywater

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

Table 4
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)	-	-	-	-	-	-
BOD5(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/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%	-	-	-	-

[a] Al-Hamaiedeh and Bino, (2010); Dalahmeh et al., (2012); Parjane and Sane, (2011)
[b] Gross et al., (2008); Travis et al., (2010)
[c] Leal et al., (2010)
[d] Friedler et al., (2011)
[e] (Abdel-Shafy and Al-Sulaiman, (2014)

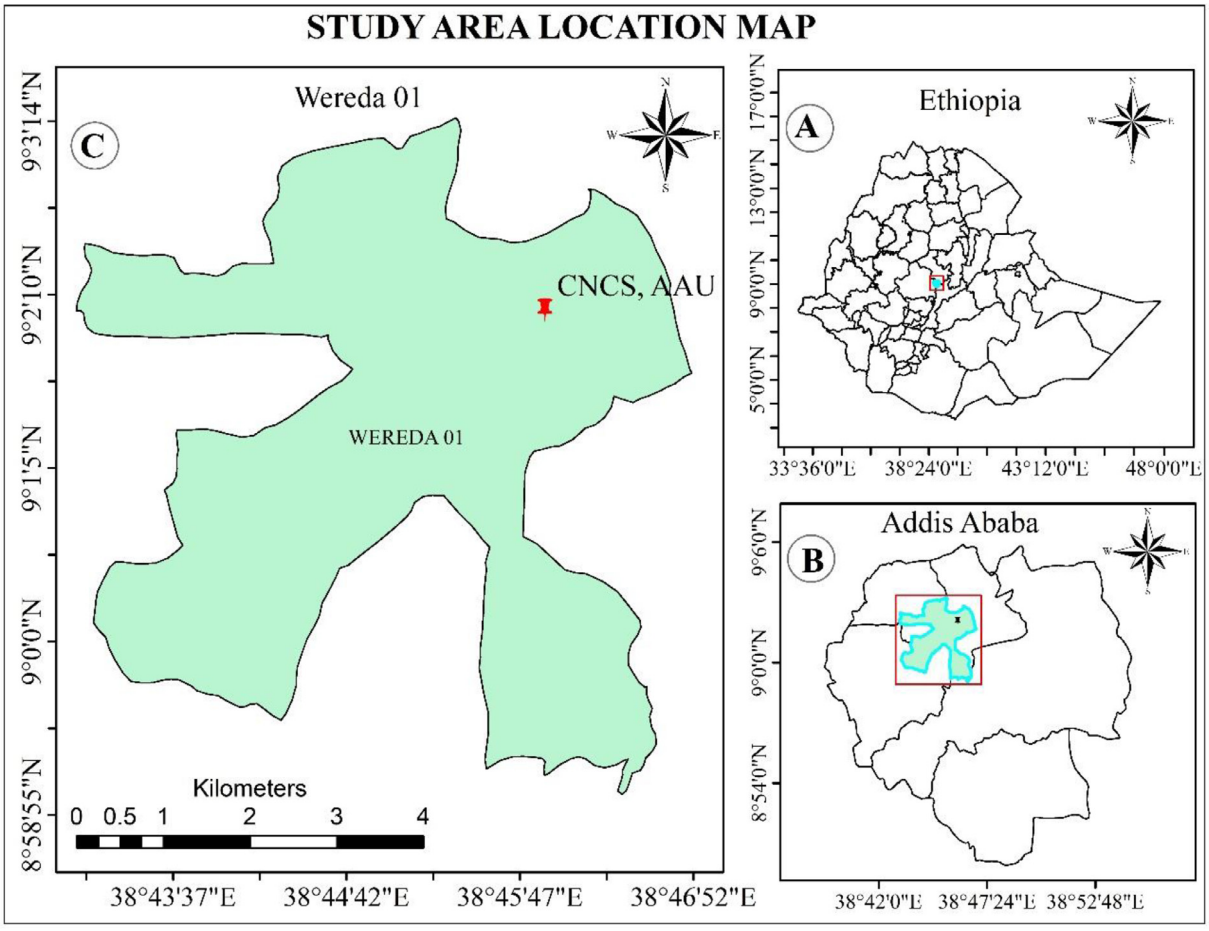


Fig. 1. Study Area Geographical Location Map

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 (Fig. 3).

During packing, one filter column (A) was filled to the 30 cm mark with tap water to allow uniform media packing and 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 the thickness of 70 cm. The second filter



Fig. 2. Greywater collection

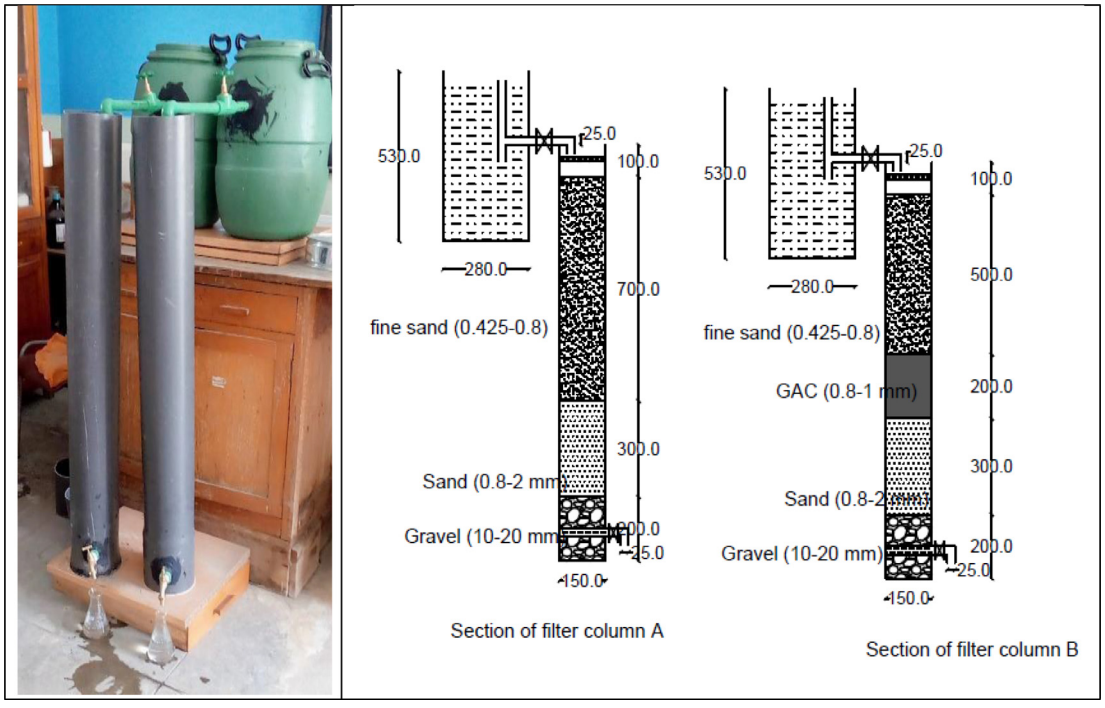


Fig. 3. Experimental setup of the filtration system

column (B) was packed in the same way as the first column, only that between the layer of media size (0.8 – 2 mm) and 0.425-0.8 mm, it was packed with a 20 cm layer of Granular Activated Charcoal (GAC) (0.8-1 mm grain size) as shown in Fig. 3 (EPA, 1995).

In this system, pre-treatments (screening, fats, and oils skimming, sedimentation) were considered to reduce the organic loading rate and clogging of the filter media. (Abdel-Shafy et al., 2013) emphasized that the wastewater should be pre-treated (by sedimentation) to increase the effectiveness of the sand filters during filtration. A screen of 1.2 mm size was used during the pouring of GW into the settling tank to reduce the solid materials from entering the system. The Tee junction (baffle) connected to the outlet of the settling tank was used to stop the scum, fats, and oils from entering the filter column (Fig. 3). The following are the processes that were used in the treatment system.

3.5. Sand and gravel media

Sand and gravel for the filtration media were obtained from a sand collection point in Sedest Kilo of Arada Sub-City. It was washed before use with tap water until clear water was observed from it. The gravel was used purposely for drainage. The sand was selected because of its availability and its high efficiency in the removal of pollutants from low-strength wastewater when compared to other filter media like pine barks, rice husks, and sawdust (Dalahmeh et al., 2012).

To obtain the effective size (D10, D30, and D60) of the sand and gravel media, a Sieve analysis was carried out according to Pope and Ward, 2008). The coefficient of uniformity (Cu) of 2.0 and coefficient of curvature (Cc) of 1.63 was then obtained using Equations (1) and ((2) respectively. The materials processing is shown in Fig. 4.



Fig. 4. Preparation of Local Materials for Filtration; Sand Sieving (left), Graded Sand and Gravel (middle), Washing Sand (right)

$$C_u = \frac{D60}{D10} \quad (1)$$

$$C_c = \frac{(D30)^2}{D60 * D30} \quad (2)$$

Where; Cu is the coefficient of uniformity, Cc 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.

3.6. Granular activated carbon (GAC)

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

3.7. Operating conditions

The two filter columns were operated parallel at a constant hydraulic loading rate (HLR) of 0.15 m/h. The HLR was determined based on previous column studies on treating synthetic greywater (Dalahmeh et al., 2012) and design criteria in the EPA, (1995) manual. The system was first to 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 were below ±1% (Abdelhay and Abunaser, 2021). The flow rate used in the experiment was determined using Equation 3 (EPA, 1995).

$$HLR = Q/A \quad (3)$$

Where Q is the flow and A is the surface area. The hydraulic retention times of 12, 24, and 36 h was 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 were considered based on the literature, where retention time for physical treatment systems averaged 16 hours was used but those systems were not applied in Africa (Xin et al., 2010).

The filtration system was operated in a continuous process during the treatment of GW. Equal volumes (10 liters) of grey water types were mixed uniformly in a 30 L plastic tank (Fig. 3) 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 the filter bed using the percolated plate. The influent infiltrates into the intermittent filter bed as a different mechanism was taking place.

3.8. 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. As a means of operation and maintenance, the sand filter columns were backwashed every 36 h to refresh the system using tap water.

3.9. Sample collection

Before sampling, the plastic sample bottles were cleaned using a detergent, and 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 for pH and turbidity were analysed in situ while BOD_5, COD, Total Phosphorus, Ammonia – Nitrogen, Total Coliform, and Faecal Coliform were not analysed immediately.

They were stored at 4°C and warmed to room temperature before tests were carried out and all the samples were labelled with dates and collection stations (American Public Health Association, American Water Works Association, and Water Environment Federation, 1992). Safety was taken seriously by wearing protective clothes, gloves, and a nose mask as stated in the WHO guidelines (World Health Organization, 2006).

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

The quality of raw greywater (RGW) at generation was characterized by determining the physicochemical parameters (turbidity, BOD, COD, and TDS,) and microbiological parameters (Total Coliform and Fecal coliform). The composite RGW samples collected from kitchen sinks,



Fig. 5. Analysis of greywater parameters

bathrooms, and washing machines were analyzed in the Environmental Science Laboratory for physicochemical parameters, while microbiological parameters were analyzed in the Insect and Bio-instrumentation laboratory of the CNCS campus as shown in Fig. 5. The samples were triplicated for effective results during analysis.

3.11. Greywater sample analysis

Physico-chemical and microbiological characteristics of the Greywater (GW) were analyzed for selected parameters with the aid of instruments calibrated using standard solutions: pH, Turbidity, Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD_5), Total coliform (TC), and Fecal coliform (FC). Samples were analyzed by following (American Public Health Association, American Water Works Association, and Water Environment Federation, 1992), and (World Health Organization, 2006) standard methods for the examination of wastewater.

3.12. 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, and wastewater characteristics (Khan et al., 2015). These were considered in designing the filtration systems.

The performance of a lab-scale filtration system that uses sand +gravel and sand +gravel + GAC was compared for the removal of pH, Turbidity, COD, BOD_5, 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 Times (HRT) under a constant Hydraulic Loading Rate (HLR). The comparison among the raw water; treated greywater from filter column A, and treated greywater from column B are shown in Fig. 6.

The efficiency of the filtration systems was determined by the difference in pollutants concentration in the influent and effluent of the system, using Equation 4 (Enitan et al., 2015).

$$Treatment\ Efficiency\ (\%) = \left[(Ci - Ce)/Ci\right] x\ 100 \quad (4)$$

Where, Ci = is the concentration of the pollutants in the influent; Ce = is the concentration of the pollutants in the effluent.

3.13. Willingness evaluation to use TGW for non-potable purposes

For the social part, the sample size of respondents (students, gardeners, cleaners, and other staff) was estimated using Cochran' formula (Cochran, 1977) as expressed in Equations 5 and 6.

$$N_1 = \frac{Z^2 x P(1-P)}{d^2} \quad (5)$$

$$N_2 = \left[\frac{Z^2 x P(1-P)}{d^2}\right] / 1 + \left[\frac{Z^2 x P(1-P)}{d^2 N}\right] \quad (6)$$

Where, N_1 = desired sample size when population is greater than 10000, N_2 = 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 68 students, 39 cleaners, and 60 other respondents for the study, in addition to the nine (9) flower gardeners at CNCS, and all were interviewed leading to 176 respondents in total who participated in the study.

3.14. Data analysis

The data were subjected to a normality test using the SPSS-IPM version 25 to test if data is normally distributed. One-way analysis of variance (ANOVA) at a 95% confidence level was used to test the 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).

4. Results and discussions

Tables 5 and 6 show the results of the greywater quality analyses before filtration, after filtration at different Hydraulic Retention Times (HRT), and their respective treatment efficiencies (%) through Columns A and B respectively.

4.1. 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



Fig. 6. The left is the raw water; the middle is treated greywater from filter Column A; the Right is the treated greywater from column B.

Table 5
Greywater Quality Analysis Results before and after Filtration through Column A

Column A Parameter	Unit	Before Filtration Mean±Std	After filtration at 24 hr Mean±Std	After filtration at 36 hr Mean±Std	After filtration at 48 hr Mean±Std	24 hr, Eff., %	36 hr, Eff., %	48hr, Eff., %
pH	–	7.46 ± 0.2	7.3 ± 0.4	7.35 ± 0.2	7.5 ± 0.1	–	–	–
Turbidity	FTU	257.5 ± 10.6	12 ± 0.0	12 ± 0.0	21 ± 12.7	95.3	95.3	91.8
EC	µs/cm	1108.5 ± 232.6	426.5 ± 19.1	733.5 ± 33.2	684 ± 190.9	61.5	33.8	38.3
(TDS)	Mg/l	538.5 ± 117	196 ± 1.4	368 ± 38.2	341.5 ± 118.1	63.6	31.7	36.6
BOD5	Mg/l	75.25 ± 1.8	20.7 ± 1.0	62.2 ± 1.4	71.5 ± 2.1	72.5	66.8	5.0
COD	Mg/l	123.5 ± 4.9	34 ± 1.4	232 ± 2.1	123 ± 4.2	72.5	66.4	0.4
TP	Mg/l	9± 4.9	3.1 ± 0.1	3.6 ± 0.1	3.65 ± 0.2	43.6	34.5	33.6
Ammonia	Mg/l	15.8 ± 0.4	2.35 ± 0.2	5.5 ± 0.7	6.75 ± 0.4	85.1	65.1	57.1
Nitrates	Mg/l	87.5 ± 2.5	11 ± 1.4	19 ± 1.4	31.65 ± 2.3	87.4	78.3	63.8
Fecal Coliform	CFU/100ml	1070 ± 70.1	89 ± 4.2	53 ± 4.2	195 ± 7.1	91.7	95.0	81.8
Total Coliform	CFU/100ml	6.95×10^7 ± 707107	5800 ± 283	43000 ± 4242.6	477500 ± 3535.5	100.0	99.9	99.3

Table 6
Greywater Quality Analysis Results before and after Filtration through Column B

Column B Parameters	Unit	Before Filtration Mean±Std	After filtration at 24 hr Mean±Std	After filtration at 36 hr Mean±Std	After filtration at 48 hr Mean±Std	24 hr, Eff., %	36 hr, Eff., %	48hr, Eff., %
pH	–	7.46 ± 0.2	7.85 ± 0.6	7.95 ± 0.4	8.15 ± 0.1			
Turbidity	FTU	257.5 ± 10.6	2 ± 2.8	2 ± 2.8	1 ±1.4	99.2	99.2	99.6
EC	µs/cm	1108.5 ± 232.6	553.5 ± 210	718.5 ± 33.2	692 ± 251.7	50.1	35.2	37.6
TDS	Mg/l	538.5 ± 117	264 ± 100	344.5 ± 17.7	297 ± 80.6	51.0	36.0	44.8
BOD5	Mg/l	75.25 ± 1.8	2.35 ± 0.1	1.75 ± 0.4	4.55 ± 0.1	96.9	97.7	94.0
COD	Mg/l	123.5 ± 4.9	4.4 ± 0.8	2.75 ± 0.4	11 ± 1.4	96.4	97.8	91.1
TP	Mg/l	2.15 ± 0.2	5.5 ± 0.1	2.6 ± 0.3	3.05 ± 0.1	52.7	49.1	44.5
Ammonia	Mg/l	22 ± 4.2	15.75 ± 0.1	1.9 ± 0.2	2.95 ± 0.2	87.9	81.9	81.3
Nitrates	Mg/l	2.65 ± 0.4	87.5 ± 0.1	1.95 ± 0.4	2.95 ± 0.1	97.8	96.6	96.6
Fecal Coliform	CFU/100ml	1070 ± 70.1	80 ± 1.4	48.5 ± 0.7	163 ± 4.2	92.5	95.5	84.8
Total Coliform	CFU/100ml	6.95 × 107 ± 707107	5300 ± 424.3	33000 ± 4242.6	78000 ± 4848.4	100.0	100.0	99.9

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 (Fig. 7).

The pH was insignificantly different between influent and effluent 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 in-

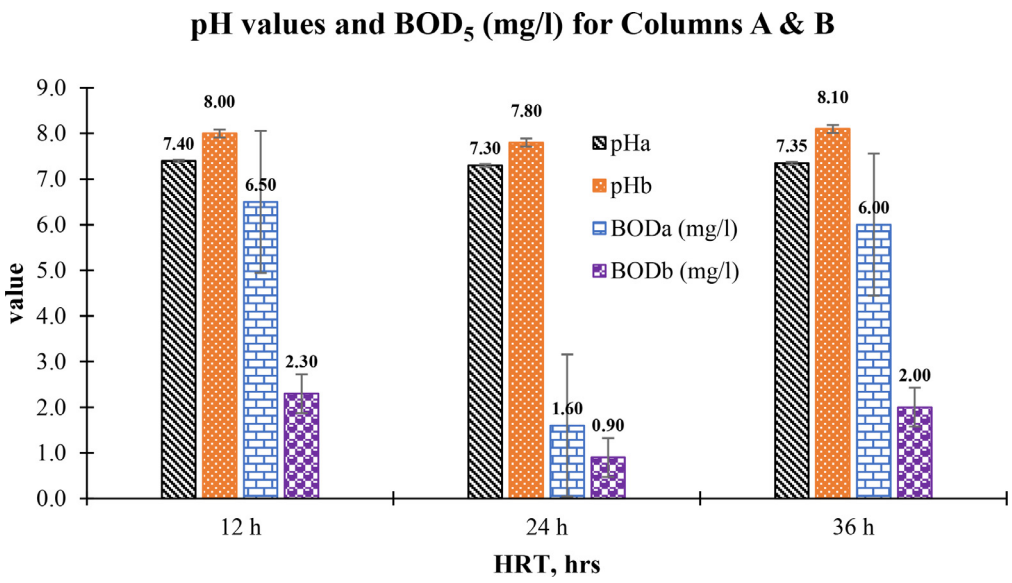


Fig. 7. Variation of pH and BOD5 in the influent and effluent at different HRT in filter columns A and B

fluenced by a functional group of activated carbon. The decrease of pH after the settling tank could be due to nitrification that took place in the settling tank. The pH of the influent favors the physical treatment by sedimentation and adsorption onto 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 increase the adsorption rate.

It was observed that there was no significant difference in pH between the influents and effluents (Fig. 7). This could be due to the chemical reaction like nitrification and denitrification that took place in the system. Also, during adsorption (Vader Waal forces of attraction) there is the possibility of cations and anions being released into 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 a similar range (7.3 - 8.4) after treatment.

The effluents from the filtration system were within the allowable limits (WHO, 2001) for reuse of selected non-portable uses. 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 (Ayers and Westcot 1985; USEPA 2005).

4.2. Biochemical Oxygen Demand (BOD_5) in the filtered effluent

The initial mean value before filtration of BOD_5 was 184 ± 22.9 mg/l and it reduced significantly 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 as shown in Fig. 7.

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. The system showed significantly higher removal of BOD_5 at 24 h in both filters. The removal efficiency of the filtration system was as high as that reported in the literature when the concentration of BOD_5 and COD in the influent were compared. 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 (Leal et al., 2010) achieved 90 to 98 % by using membrane bioreactors (MBR) and sequencing batch reactors (SBR). There exist a large variability in the percentage removal of BOD5 and COD at different HRT.

It was observed that the efficiency increased with an increase in retention time (12 and 24h) and later on it decrease to 36 h. (Niwagaba et al., 2014) revealed in the literature that the retention time of GW in the filtration system plays a significant role in the BOD_5 and COD reduction. The system significantly reduced BOD_5 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 et al., 2017) on the 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 the molecular structure of GAC with an active site that oxidizes organic matter.

Khalaphallah, (2012); Wurochekke et al., (2016); Saad et al., (2016), reported that sand filtration using activated carbon is the best method and reduces COD and BOD_5 when the wastewater flows over it. BOD_5 and COD of both filter columns were meeting the (USEPA, 2005) standards for reuse of all selected non-portable uses. This 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 matter into biomass and gas.

4.3. Chemical Oxygen Demand (COD) in the filtered effluent

In this study, COD before filtration was 397.3 ± 4.9 mg/l which significantly decreased 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 (Fig. 8). The system achieved 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. The system showed significantly higher removal of COD at 24 h in both filters.

4.4. 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 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 (Table 7). 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.

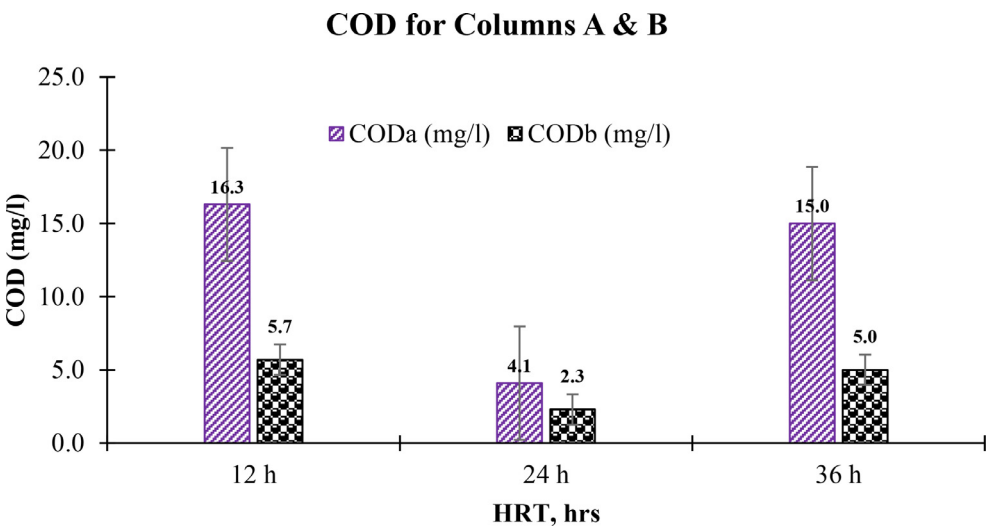


Fig. 8. Variation of COD in the influent and effluent at different HRT in filter columns A and B

Table 7
Variation of turbidity in the influent and effluent at different HRT in Filter columns A and B

Parameters	BF	12 h	24 h	36 h
Turbidity_a (NTU)	257.5 ± 7.64	2.0	0.0	7.3
Turbidity_b (NTU)	257.5 ± 7.65	0.0	0.0	2.7

The treatment system achieved 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. The studies by (Leal et al., 2010) and (Oteng-Peprah et al., 2018a) reported the range of 98 – 99 % when they used membrane bioreactors.

The system showed high efficiency for the removal of turbidity in both filter columns because of the mechanisms that occur 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 that flourished in turbid water may result in epidemics (Naz et al., 2011).

Therefore, the Removal of turbidity in 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 a long contact time in the filter.

Filter column B was more efficient in the removal of turbidity than filter column A, because of the adsorptive properties (active sites) of GAC that would attract the turbidity in wastewater. (Khalaphallah, 2012; Saad et al., 2016) reported that 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-potable uses except in column A at 36 h which showed a value of 7.3 that was beyond the reuse standards.

4.5. Feacal 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 × 103 ± 90.2 CFU/100 ml which significantly decreased to 86 ± 6.0, 51.3 ± 4.2, and 66.7 ± 4.7 CFU/100ml in column A and 82.7± 4.6, 42.0 ± 2.0, 54 ± I.5 in filter column B at 12, 24, and 36 hrs respectively as shown in Fig. 9.

This study showed a decrease in the count at 12 h and 24 h and then an increase at 36 hr as shown in Fig. 9. In comparing the means, FC count indicated no significant decrease between filter columns A and B. The system achieved efficiency for the removal of FC count at 92.3%, 95.4%, and 94% for filter column A and 93.3%, 97.1%, and 95.8% for column B at 12, 24, and 36 h respectively.

4.6. 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 a total coliform count of $6.6 \times 10^7 \pm 5.5 \times 10^6$ CFU/100 ml which significantly decreased to 5033.3 ± 550.8, 4133.3 ± 152.8, 4300 ± 264.6 CFU/100ml in the filter column A and 4633.3 ±152.8, 3300.0 ± 300, 5100.0 in filter column B at all retention time (Fig. 10). This study showed a decrease in the count at 12 hr and 24 hr then an increase at 36 hr as shown in Fig. 10.

In comparing the means, TC count indicated no significant decrease between filter columns A and B. The system achieved efficiency for the removal of TC count at 99.99%, 99.99%, and 99.99% for both filter columns A and B at 12, 24, and 36 hr respectively. The significant decrease of TC and FC count in both filter columns at different HRT (12, 24, 36 hr) could be due to natural die-off, oxidation, predation, adhesion to biofilms, mechanical filtration of micro-organisms present in the influent and adsorption on to filter media.

The results of the effluent were in the range of other studies were 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 resulting from desorption in the system after long HRT that enhanced the regrowth of microorganisms in the system. (Khan et al., 2015) reported that a decrease in 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, 2013) 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 are clogged due to the overgrowth of bacteria on the large specific surface of the GAC (Scholz and Martin, 1997). This could also explain the cause of the increase of FC and TC at 36 h.

Nnaji et al., (2013) reported that the 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 the conventional system at Jomo Kenyatta university reported that the system

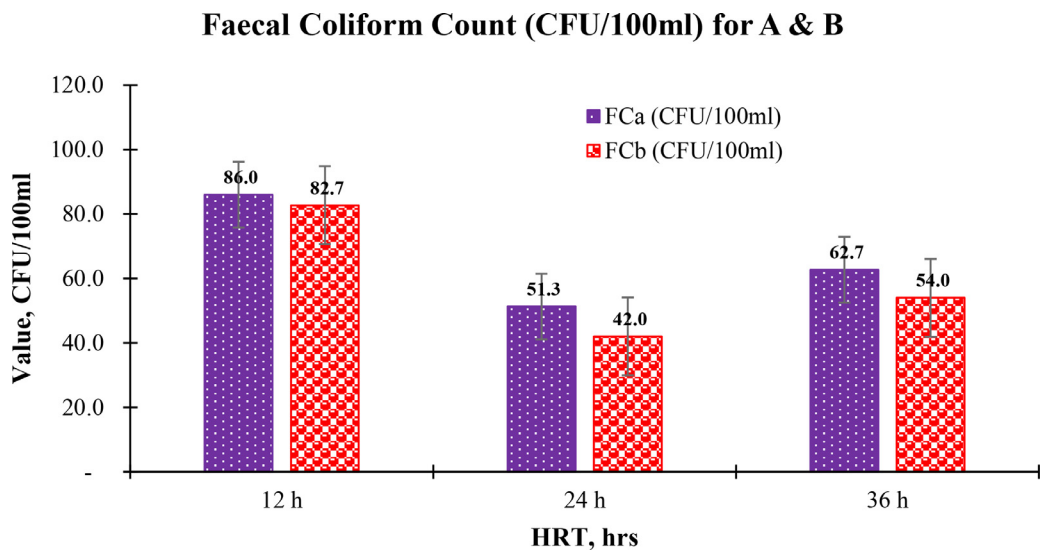


Fig. 9. Variation of FC in the influent and effluent at different HRT in filter columns A and B

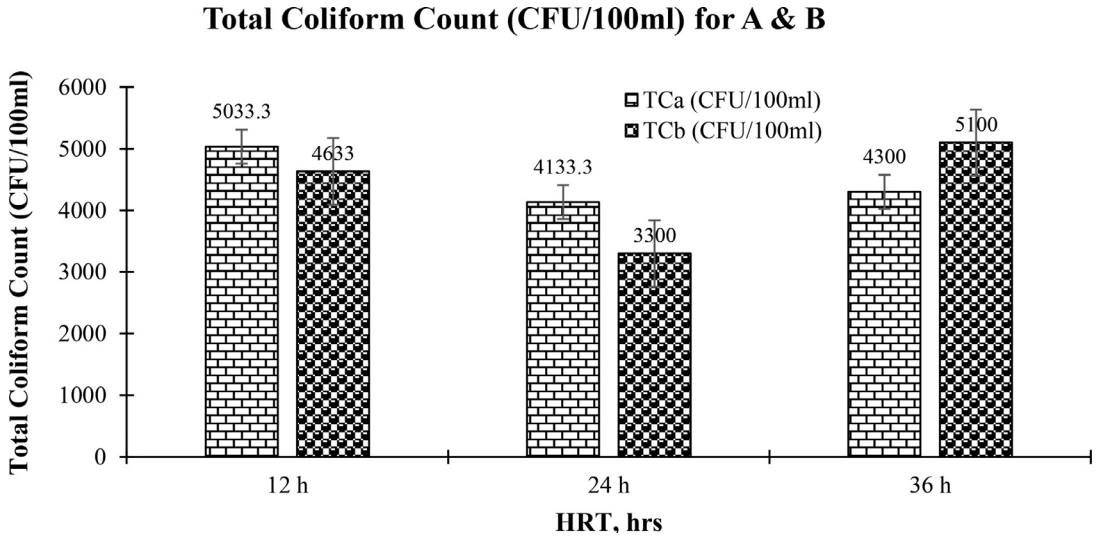


Fig. 10. Variation of TC in the influent and effluent at different HRT in filter columns A and B

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 was 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 (World Health Organization, 2006) standards for flower watering.

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 did not meet the WHO standards for reuse and the authors 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.

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

A total of 176 respondents were interviewed through the administered questionnaire, and all responded. Most of the respondents were students (39%), followed by other staff (34%), then the cleaners (22%), and the gardeners (5%). Female respondents were more than their male counterparts (55% compared to 45% respectively). The Undergraduate respondents (56%) were more than postgraduates (17%) and other or with no qualification (27%). Singles were more than married respondents (52% compared to 48% respectively).

On average, about 84.75%, 91.75%, and 100% of the respondents were willing to adopt the TGW for toilet flushing, pavement washing, and flower garden watering respectively. The past studies on public perception of wastewater reuse in Kuwait University reported the related reasons (Alhumoud and Madzikanda, 2010). The respondents who disagreed with the mentioned reasons gave the choice to reuse it for flower watering. Similarly, in this study, no one rejected the reuse of TGW for watering flowers. The study on public perception of reusing TGW at the Pretoria University of South Africa also reported the same finding (Stoakley, 2013).

5. Conclusions

This study evaluated the performance of lab-scale filtration systems for GWT and reuse. Microbiological parameters showed that GW was highly polluted with microorganisms, similar to greywater characteristics from highly polluted areas like slum areas. All filter columns were effective in the removal of contaminants at 24 hr through the sand with

GAC more effective. In comparing TGW with the standards, all physico-chemical parameters tested met the standards for reuse of selected non-portable, and microbiological parameters were meeting the standards for only flower watering/irrigation.

Therefore, the system required 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 willing to use TGW for selected non-portable use. This provides an opportunity for source substitution particularly significant concerning water use for toilet flushing, flower watering, and pavement washing given that the survey showed that 80 % of respondents on the campus are willing to use TGW. Therefore, the TGW of this study can be reused for selected non-portable uses.

This study is different as it offers a full treatment of grey water for reuse using locally available materials of GAC sand and gravel only, while many available technologies have been designed to remove specific pollutants. It is recommended that the study can be scaled up in selective areas of Addis Ababa and other developing cities. This demonstrates its advantages to the authorities in implementing a greywater reuse system using filtration technology. Thus, reducing water demand in cities and narrowing the gap between the current water supply and water demand in Addis Ababa. On limitations, the filtration system requires substantial maintenance as its effectiveness is highly affected by clogging. Thus, the system should be back-washed at least once a week.

6. Author contribution statement

Greywater sample collection and laboratory analyses were carried out by A.T., while data analysis such as tables and figures were generated by H.M.E. The manuscript was devolved by H.S. and J. S. All authors have proofread this manuscript before submission.

7. Data availability

The datasets analyzed during the current study are available from the corresponding author upon reasonable request

Declaration of competing interest

The author(s) declare no conflict of interest in the study arising from the subject matter, materials discussed or tests conducted during this study from any known person or organization.

Data Availability

Data will be made available on request.

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