Addis Ababa University
Addis Ababa Institute of Technology
School of Civil and Environmental Engineering
(Major in Water Supply and Environmental Engineering)

Greywater Treatment Using Banana Peel Biochar and Sand Filtration

By:

Biruktawit G/ Meskel

Addis Ababa,

Ethiopia

October, 2019

Addis Ababa University

Addis Ababa Institute of Technology

School of Civil and Environmental Engineering

Water Supply and Environmental Engineering (stream)

Greywater Treatment Using Banana Peel Biochar and Sand Filtration

By

Biruktawit G/Meskel

A thesis submitted to the School of Graduate Studies of Addis Ababa University in Partial fulfillment of the Degree of Master of Science in Water Supply and Environmental Engineering.

Advisor: Dr. Agizew Nigussie

Co-advisor: Mr. Zerihun

October, 2019

Greywater Treatment Using Banana Peel Biochar and Sand Filtration

By

Biruktawit G/meskel

Approved by The Board of Examiners

Dr. Agizew Nigusse	____________________	____________________
(Advisor)	Signature	Date
Dr. Mebruk Mohammed	____________________	____________________
(————————————)	Signature	Date
Dr. Ing. Geremwe Sahilu	____________________	____________________
(————————————)	Signature	Date
Dr. Mebruk Mohammed	____________________	____________________
(Dean, school of Civil and Environmental Engineering)	Signature	Date

Abstract

Sand has been used for long time to treat greywater. However, biochar might be an alternative to replace the sand for greywater treatment and also reduce the amount of organic waste disposed into the environment. In this study the biochar was produced from banana peel and the purpose was to evaluate and compare the performances of biochar, sand and sand with biochar in reducing turbidity, COD, N, P, fecal coliform and pH. The biochar and sand were packed to a depth of 27 cm into columns with a diameter of 7 cm but in case of sand with biochar the depth was 13.5 cm for sand and the remaining was filled by biochar. The columns were fed with synthetic and real greywater. Synthetic greywater was used for optimization of biochar particle size and pH. Real greywater was fed to the column by taking the optimum biochar particle size and pH and compared with, sand and sand with biochar for four days. Biochar was prepared in three different sizes: Fine, medium and coarse with a size of below 1mm, between 1-3 mm and above 3mm, respectively. Fine particle size of biochar showed more removal efficiency than medium and coarse sized particles. The average performance of fine medium and coarse particle size was 88%, 71.2% and 39.3% for turbidity 54.8%,36.5% and 23.1% for COD,62.2%, 23.4% and 12.6% for N and 52%,18.4% and 9.4% for P respectively. But in all particle sizes of biochar effluent pH and EC values were found to be more than that of the influent. For the optimization of pH values that varied from 5 to 10 were tested. The results of the analysis showed that the highest removals of turbidity (89%), COD (55%), N (94%) and P (78.8%) were achieved at pH value of 7. Fine biochar (FBC) showed better removal efficiency when compared to that of sand and biochar with sand (FBCS). The average performance efficiencies of FBC, sand and FBCS were 95%, 67%, and 79% for turbidity, 81%, 19% and 56% for ammonium, 71%, 28% and 50% for phosphate 50 %, 61% and 46% for COD and 90%, 80% and 87% for fecal coliform respectively. The findings of this paper indicate that transformation of banana peel into biochar has a double advantage of treating greywater and minimizing the amount of waste that is disposed into the environment.

Key words: *Greywater*, *Biochar*, *Sand*

Acknowledgment

First and foremost, I would like to thank God Almighty for giving me the strength, knowledge, ability and chance to undertake this research study and to persevere and to complete it. Without his blessings, this achievement would not have been possible. This thesis appears in its current form due to the assistance and guidance of several people. I would like to offer my sincere thanks to all of them.

I have great pleasure in acknowledging my advisor, Dr. Agizew N. and Mr. Zerihun G. to their insightful discussion, offering valuable advice, and support during the whole period of the study. Without them this paper will remain as an idea.

It would be inappropriate if I omit to mention the name of my dear friend Hiwot, she had helped me during the collection of greywater from different households and kept me going on my path to success by assisting on her abilities.

My acknowledgement would be incomplete without thanking the biggest source of my strength, my family mother, father, brother and my husband Fithialm, I thank them for putting up with me in difficult moments where I felt tired and for provoking me on to follow my goal. This would not have been possible without their unwavering and unselfish love and support given to me at all times.

Acronyms and Abbreviations

APHA = American Public Health Association

BOD = Biological Oxygen Demand

CBC = Coarse Biochar

COD = Chemical Oxygen Demand

CFU = Colony Forming Units

DO = Dissolved Oxygen

D_{10}/ D_{60} = Median grain size of sand or gravel.

E. coli = Escherichia coli

EC = Electrical Conductivity

FBC = Fine Biochar

FBCS = Fine Biochar with sand

NH_4-N = Ammonium Nitrogen

PO_4-P = Phosphate Phosphorus

P =Phosphorus

MBC = Medium Biochar

N = Nitrogen

RGW = Real Greywater

SS = Suspended solid

SGW = Synthetic Greywater

TDS =Total dissolved solids

Table of Contents

List of Figure

List of Tables

1. Introduction

1.1. Background

For century’s man built environment and quality of life has been closely predicated on the availability and sustainability of natural resources. As the common denominator for every ecosystem, water resources serve the cornerstone of human society and its sustenance (CSBE 2003). Nowadays stresses on freshwater resources grow throughout the world and new sources of supply become progressively more scarce, expensive, or politically controversial, different researchers and efforts are underway to identify new ways of meeting water needs. Among this potential greywater is the new source to overcome water supply problem (Allen 2010).

Greywater is a domestic wastewater, which may come from the shower, bath tub, spa bath, hand basin, laundry tub, clothes washing machine, kitchen sink and dishwasher, it excludes waste come from a toilet or urinal. (Morel and Diener 2006). Greywater gets its name from its cloudy appearance and from its status as being between fresh, potable water (known as "white water") and sewage water ("black water") (Pachkor and Parbat 2017).

The amount of greywater generated by any household will vary greatly according to the dynamics of the household and influenced by the number of occupants, the age distribution system, their lifestyle characteristics and water usage patterns (Huhn 2015). It accounts 50-80% of household wastewater (Nautiyal, et al. 2017).

The quality of grey water is highly variable due to the variability in household water use. It contains the same contaminants (organic compounds, nutrients and pathogens) as raw sewage water. However, greywater contains low concentrations of contaminants compared to those in raw sewage water or black water. The potential risks, as there is some concern that the high levels of organic load produced in kitchens might pose an unacceptable risk of pathogenic contamination in it (Nautiyal, et al. 2017, Pranati and Juverar 2015)

Recycling of greywater involves installing a system which treats to meet quality standard for non-potable uses (Nwajuaku 2015). Recycling grey water not only reduces the consumption of water, it also reduces the volume of water discharged into the sewerage system. And also, consumers with water meters could save money (Allen 2010). The other possible reuse options for the treated water are urinal and toilet flashing, irrigation of lawns (college campuses, athletic fields, cemeteries, parks and golf courses, domestic gardens), washing of vehicles and windows, fire protection, boiler feed water, concrete production, develop and preserve wetlands, infiltrate into the ground (for recharge of aquifers), agriculture and viticulture reuse (Jefferson, et al. 2004, Lambe and Chougule 2013)

A wide variety of technologies have been used or are being developed for greywater treatment and reuse including natural treatment systems, basic coarse filtration, chemical, physical, physio-chemical and biological processes. The exact selection of the most appropriate technology is dependent on many factors such as the scale of operation, end use of the water, socio-economic factors relating to cost of water and regional customs and practices (Jefferson, et al. 2004, Abdel-Shafy 2013). The cost and energy requirements of these systems vary and usually increase with higher levels of treatment. Thus, to reduce cost, treatment of greywater by natural system is gaining popularity in both developed and developing countries. These natural treatment systems such as sand/gravel filters, constructed wetlands (planted soil filters) and trickling filters are now competing with various conventional intensive technologies to treat grey water at household level and also, new technology is developed to use biochar as greywater treatment (Bhausaheb 2010)

Sand filtration is the oldest wastewater treatment technology. It has been used successfully in Europe since the early 1900s and still a popular method of treating municipal water supplies and wastewater (Sabbah, et al. 2003). It treating mechanism is filtration. Besides the physical filtration through the sand, an active biofilm develops. It is attached to the sand particle surfaces and mineralize organic matter from the wastewater (Rodgers, et al. 2004)

Biochar derived from biomass and defined as a carbonaceous residue from pyrolysis, including natural fires under limited oxygen. The application of biochar to the soil can improve its fertility and crop production, with the positive effect of mitigating the rising concentration of atmospheric carbon dioxide (Amutio, et al. 2012). Nowadays, biochar is recognized as an environmental-friendly adsorbent to abate organic pollutants (Chen and Chen 2009). Due to having a large surface area (100–1000 m^2/g), low density and high porosity (Downie 2009) which makes it an efficient adsorbent and good biofilm carrier. The unique properties of biochar, enhance water and wastewater quality in onsite systems.

Biochar is produced from wood and wood wastes, aquatic plants, agricultural crops and their waste by-products, and municipal and animal wastes (Angın and Sensoz 2014). In case of Ethiopia, there are many sources of potential to produce biochar, from this banana peel was selected in this research. Banana is the leading fruit crop in Ethiopia, in terms of consumption and production, among the horticultural crops. It covers about 86% (478,251 tones) of the total fruit production (Woldu 2015). From one banana an average 20 to 25% mass of banana peel produced. This large amount of solid waste can be recovered for further use as biochar rather than simply disposed by those impractical conventional methods. After treatment of greywater, the biochar will be used for soil amendment.

The aim of this research is to study the use of biochar from banana as a replacement/ alternative for sand to serve as a filter material for greywater purification.

1.2. Statement of Problem

Wastewater and solid waste management are big issues of concern in cities of the world. According to the fourth world water development report, only 20% of globally produced wastewater receives proper treatment (UNESCO 2012) and the solid waste generation rates are rising. In 2016, the worlds' cities generated 2.01 billion tons of solid waste, which is 0.74 kilograms per person per day. With rapid population growth and urbanization, annual waste generation is expected to increase by 70% from 2016 levels to 3.40 billion tones in 2050 (Williams 2008).

The waste composition in all region account for 50 percent on average of organic waste, but in developing countries it is up to 55-80 percent. However, solid waste management in most developing countries is very poor, with over 90% of the waste often disposed in unregulated dumps or openly burned (Maria 2018).

Wastewater is mainly managed by centralized treatment plant and it require transporting of wastewater to a central wastewater treatment plant. But, this practice is common in industrialized countries and in some large cities in less industrialized countries. Because it needs complex infrastructure, expensive investment cost to construct and operate. In low- and middle-income countries most of the wastewater discharged untreated due to lack of skilled man power, limited financial resources and prioritization of water supply over sanitation (Scott *et al.*, 2004).

According to (The Federal Democratic Republic of Ethiopia Ministry of Health 2016), the recent in-house wastewater service status assessment indicated that the sewerage service level in Addis Ababa and major cities remain to be in the range of 7% to 0.07%. About 49 million m^3 of wastewater is annually generated in the city of Addis Ababa, from this a large amount is contributed by domestic and industrial activities. Most of this greywater is disposed into streets, drainage lines, nearby open space, rivers and streams flowing through the city, like the Akaki River. According to the 2007 national census, 14.9% of the housing units of Addis Ababa has flush toilets, 70.7% pit toilets (both ventilated and unventilated), and 14.3% had no toilet facilities. It indicates that most of households are not connected to the central wastewater treatment plant.

According to (AASBPDA 2003) studies, daily solid waste generation in Addis Ababa is estimated to be 0.35kg/capita/day. The composition of organic waste in the city is about 70 percent of the waste generated from households (Cheru 2016). From these large solid wastes are uncollected and dumped in unauthorized areas such as open fields, ditches, sewers, streets and many other available spaces in the city (AASBPDA 2003)

Therefore, uncollected garbage and wastewater are serious environmental hazards for all, especially in areas where the roads are not accessible for collection by the municipality. These causes bad smells, attracts various disease vectors and deteriorates aesthetic quality of the city. (ENDA 2006). Also, when water bodies receive excess nutrients, especially nitrates and phosphates, these nutrients can stimulate excessive plant growth including algal blooms (which may release toxins to the water), leading to oxygen depletion, decreased biodiversity, changes in species composition and dominance, and a severe reduction in water quality. The other adverse impact on human health by unpleasant odor and diseases like typhoid and diarrhea (Mohamed 2013).

To overcome the above problem appropriate wastewater treatment technology and sustainable solid waste management practices should be used. The conventional wastewater management requires high investment cost and takes long time to implement. However, there are low-cost technologies that contribute to sustainable waste management and environmental pollution control. This study focuses on greywater treatment using organic biochar produced from banana peel. Decentralized greywater treatment using biochar can reduce environmental pollution from untreated wastewater discharge, and support waste recycling and reuse.

1.3. Objective

The general objective of this research was to study the use of banana peel biochar as alternative method for greywater treatment.

The study is expected to achieve the following specific objectives:

- To study the effect of particle sizes of banana peel biochar on greywater treatment performance.
- To optimize parameters that affect greywater treatment.
- To evaluate the performance biochar, sand filtration and biochar with sand.
- To identify the best isotherm model that represents the adsorption process for the efficient filter media?

1.4. Research Question

- What is the efficiency of fine, medium and large size of biochar on grey water treatment?
- What is the optimum pH and residence time for optimum size of banana peel biochar, sand and biochar with sand?
- What is performance of biochar, sand and biochar with sand for turbidity, pH, COD, N, P and fecal coliform?
- Which (Langmuir or Freundlich) isotherm model best describe adsorption process for the efficient filter media?

1.5. Scope of the study

This research was completed by preparing synthetic greywater at laboratory and collecting of real greywater from nearby households to AAiT. It was done for six parameter these were turbidity pH, COD, NH_4-N, PO_4-P and fecal coliform concentration and to characterize physical and chemical properties filter SEM bulk density specific surface area and elemental analysis were done.

1.6. Significance of the study

In this study banana peel biochar was used as a media, which is abundant and easily accessible by community. The biochar can be used as an appropriate technology to treat greywater. The study contributes to research endeavors in the area of greywater recycling using appropriate technologies. It enables to appreciate how solid waste management integrated with wastewater management and contribute to environment sustainability.

1.7. Organization of the thesis

The study has been divided into five chapters. The first chapter consists the introduction of the paper, statement of the problem, objectives, research questions, significance, scope and limitation of the study. The second chapter review previous literature on concept and works greywater treatment technology and method, characteristics and finding. The third chapter demonstrates material and method on experimental set-ups and procedures used to test the performance of different particle size of banana peel biochar and sand in treating synthetic and real greywater. And the next chapter results and discussion: which interpret the finding of the study and discuss by relating with previous studies. Finally, the last chapter is conclusions and recommendations in this section it summarize based on the findings of the studies and suggest for further research.

2. Literature Review

Greywater treatment and recycling prevent both water shortages and environmental pollution. An increasing of global population, scarcity of water resources, mismanagement and climate change, water shortage and water pollution have become a global issue (Bouwer 2000). Industrial and domestic wastewaters' constituents contribute to water resource and soil pollution (Metcalf and Eddy 1991). Greywater is any household wastewater with the exception of wastewater from toilets, which is known as blackwater. 50-80% of household wastewater is greywater from kitchen sinks, dishwashers, bathroom sinks, tubs and showers. Greywater release 9-14% N, 20-32%, P 18-22% and 29-62 % K. (Kujawa-Roeleveld 2006).

Greywater used with or without simple treatment (AlJ031). The first issue is recycling for indoor use such as flushing toilets, washing clothes and/or bathing (Cui and Ren 2005). The second issue is for outdoor use such as irrigating domestic gardens, lawns on college campuses, athletic fields, cemeteries, parks and golf courses, washing vehicles and windows, extinguishing fires, feeding boilers, developing and preserving wetlands and recharging ground water (AlJ031). The third issue is (standards) mainly related to health and social aspects in order to improve the control of the recycling process (Cui and Ren 2005). The fourth issue is obtaining affordable treatment technologies to cope with the quantity and quality variation of greywater sources (Cui and Ren 2005)

Knowledge of the pathogen content of greywater is limited. However, specific pathogens and significant numbers of indicator bacteria have been reported (Birks 2004,), indicating that the disinfection of greywater prior to reuse is essential to reduce the risk to public health. This review, therefore, examines various greywater treatment methods with the aim of coming up with an efficient, simple and affordable treatment method with safe effluent for use. A treatment method is considered efficient if it produces the required effluent quality, is simple in operation with minimum maintenance, and affordable due to its low energy.

2.1. Greywater composition

Greywater composition varies according to source. The first source is: greywater from bathroom, water used in hand washing and bathing generates around 50-60% of total greywater and is considered to be the least contaminated type of greywater. Common chemical contaminants include soap, shampoo, hair dye, toothpaste and cleaning products. It also has some fecal contamination (and the associated bacteria and viruses) through body washing. The second source is: greywater from kitchen contributes about 10% of the total greywater volume. It is contaminated with food particles, oils, fats and other wastes. It readily promotes and supports the growth of micro-organisms. Kitchen greywater also contains chemical pollutants such as detergents and cleaning agents which are alkaline in nature and contain various chemicals. The third source is: greywater from cloth washing, water used in cloth washing generates around 25-35% of total greywater. Wastewater from the cloth washing varies in quality from wash water to rinse water to second rinse water. Greywater generated due to cloth washing can contain, in addition to soap and detergent, a large amount of dyes and can also have fecal contamination with the associated pathogens and parasites such as bacteria.

The household's activities vary according to socio-economic status, cultural practices, cooking habits, cleaning agents used, as well as demography. For example, a household that uses phosphate-free laundry detergent will produce a greywater that is much lower in phosphate than one that does not. Greywater usually contains surfactants (anionic, cationic and amphoteric) which come from shampoos and detergent formulations (Eriksson, et al. 2002). Personal care products are usually found in bathroom greywaters while detergents are the main constituents of laundry greywaters.

2.2. Characteristics of grey wastewater

The characteristics of greywater depend on are quality of the water supply, lifestyle and water usage pattern, living standards, social and cultural habits (soaps, toothpaste, shampoos and detergent) and quality of household chemical used. The composition chemical will vary significantly in terms of both place and time due to the variations in water consumption in relation to the discharged amounts of substances. Furthermore, there could be chemical and biological degradation of the chemical compounds, within the transportation network and during storage (Eriksson, et al. 2002, Yahya, et al. 2008).

2.2.1. Physical parameter

The physical parameters include temperature, color, turbidity and suspended solids and electrical conductivity (EC). Food particles and raw animal fluids from kitchen sinks and solid particles, hair and fibers from laundry wastewater are examples of sources of solid material in the grey water. Measurements of turbidity and suspended solids give some information about the content of particles and colloids (Eriksson, et al. 2002, Yash 2013)

Electrical conductivity (EC) is a replacement measure for total dissolved solids, which provides a measure of the dissolved salt content or salinity including negative (Cl^-,NO_3^-) and positively charged ions(Ca^{++}, Na^+). The most common salt is sodium chloride- the conventional table salt. Other important sources of salts are sodium-based soaps, nitrates and phosphates present in detergents and washing powders. The EC of greywater is typically in the range of 300–1,500 µS cm-1, but can be as high as 2,700 µS cm-1 (Mahmoud 2005).

2.2.2. Chemical parameter

To identify the different chemical constituents in greywater, it is important to understand the sources of contaminants. Significant chemical constituents in greywater are from chemicals used for cleaning, cooking and bathing purposes. The pH in greywater to a large extent depends on the pH and alkalinity in the water supply and normally is within the range of 5–9. Greywater with most of its sources originating from the laundry will generally exhibit high pH due to the presence of alkaline materials used in detergents (37Lr). When sodium hydroxide-based soaps and bleach used for the purpose of laundry the PH rang of Grey water is increased within the range 9.3–10.

COD measures the amount of oxygen required to oxidize the organic material present in a water sample. The measured value of COD is usually higher than that of measured BOD in many waste streams because many organic substances can be oxidized chemically rather than biologically (36 MSC).Concentration of organic carbon exhibit a high variability among different sources of greywater. More specifically total COD average concentrations varied between 390 – 2072 mg/L whereas BOD_5 concentrations varied between 185-1363 mg/L. Laundry greywater exhibits the higher COD concentration with values equal to 2072±1401 which are almost two times greater than the respective ones from shower, handbasin and dish washer greywater samples and almost doubled of these of kitchen samples (4 Lr) (Noutsopoulos, et al. 2014). Kitchen greywater contains biodegradable dissolved drink and food residuals and dirt from vegetables particles which contribute to the BOD (16Lr) (Yash 2013). with values of 1119±476 mg/L and 831±358 mg/L for COD and BOD 5 respectively. On the other hand, lower organic carbon concentrations were recorded in bathroom.

Greywater has a significantly lower concentration of inorganic nutrients (N and P). The nitrogen and phosphorus deficiencies are to be expected as the majority of nitrogen compounds are excreted into the toilet bowl during urination and so not normally expected in greywater (Khalaphallah 2012). Kitchen wastewater is the main source of nitrogen in domestic greywater, the lowest nitrogen levels are generally observed in bathroom and laundry greywater. Nitrogen in greywater originates from ammonia and ammonia-containing cleansing products as well as from proteins in meats, vegetables, protein-containing shampoos, and other household products (Del Porto and Steinfeld 2000).Typical values of nitrogen in mixed household greywater are found within a range of 5–50 mg/l with extreme values of 76 mg/l, as observed by (Siegrist 1976)in kitchen greywater.

Similarly, most phosphorus originates in detergents used in washing powders and so will only be present if the laundry is included in the source waters. In countries where phosphorous-containing detergents have not been banned, dishwashing and laundry detergents are the main sources of phosphorous in greywater. Average phosphorous concentrations are typically found within a range of 4–14 mg/l in regions where non-phosphorous detergents are used (Eriksson, et al. 2002). However, they can be as high as 45–280 mg/l in households where phosphorous detergents are utilized, as in Israel (Friedler 2004).

2.2.3. Micro-organism

Greywater may pose a health risk given its contamination with pathogens. Pathogens are viruses, bacteria, protozoa, and intestinal parasites, are assumed to be present in partly high concentrations. These pathogens originate from excreta of infected persons. They can end up in greywater through hand washing after toilet use, washing of babies and children after defecation, diaper changes or diaper washing. Some pathogens may also enter the greywater system through washing of vegetables and raw meat, however, pathogens of fecal origin pose the main health risks (Ledin 2001).

Fecal contamination of greywater occurs from situations which include diaper laundry, childcare, anal cleansing and showering. Greywater has plenty of easily degradable organic compounds (Ottoson, Comparative analysis of pathogen occurrence in wastewater 2005). Ii is expressed by fecal indicators such as fecal coliforms, strongly depends on the age distribution of the household members. High contamination must be expected where babies and young children are present. Average concentrations are reported to be around 10^3 -10^6 cfu/100 ml. However, contamination can be as high as 10^7–10^8 cfu/100 ml in laundry or shower greywater, (Al-Jayyousi 2003, Dallas 2004.)

2.3. Greywater treatment methodology

Grey water treatment methodologies range from simple low-cost devices that divert grey water to direct reuse, such as in toilets or outdoor landscaping, to complex treatment processes incorporating sedimentation tanks, bioreactors, filters, pumps, and disinfection.

The factors that influence the selection of appropriate technology includes the volume of greywater, organic strength, energy requirement, reuse application, socio-economic factors, geographic location and public acceptance. The primary goal should be to prevent the need for treatment by reducing the volume of grey water generation through various water conservation techniques or by decreasing the pollutant load using environmentally friendly household products that are biodegradable and non-toxic (Ajit 2016, Golda 2014).

Therefore, there is no universally accepted design for greywater treatment (Friedler 2004). The treatment methods applied for greywater reuse included physical, chemical, and biological systems. Most of these methods are preceded by a solid-liquid separation step as pre-treatment and followed by a disinfection step as post treatment. To avoid the clogging of the subsequent treatment, the pre-treatments such as septic tank, filter bags, screen and filters are applied to reduce the number of particles and oil & grease (Metcalf and Eddy 1991) .

2.3.1. physical treatments

The physical treatments include coarse sand, soil, and membrane filtration followed mostly by a disinfection step. The coarse filter alone has limited effect on the removal of the pollutants present in the greywater.

Lab scale sand filter designed by (A. J. Assayed 2014) showed 90-95 % organic removal efficiency for synthetic grey water and an E. coli removal of 99% attributed to the straining of bacteria by the biofilm growth on the upper 10 cm of sand media. A similar study conducted by (Ushijima, et al. 2015) on unsorted soil media in slanted soil treatment system showed an average SS removal of 80% and COD removal of 75%. The E Coli removal rates achieved were of 4-5 log reductions. Considerable SS and organic matter removal could be achieved in these cases and hence if filtration is properly coupled with chlorination, water reuse standards by USEPA could be met.

The performance of a drawer compacted sand filter (DCSF) was evaluated (A. C. Assayed 2015). The system was designed to overcome the problems commonly found in traditional sand filter designs such as clogging, emission of bad odors and need for a large area to house the filter. Nine pilot DCSF plants were operated at different locations in Jordan for a period of 2 years and the results showed 78-96% of BOD_5 and 69-98% of TSS removal. However, the system was found to be maintenance intensive having large footprint (20 sqm to treat 142 L/day and 30g BOD5/m 2/day).

2.3.2. Chemical treatments

The chemical processes applied for grey water treatments include coagulation, photocatalytic oxidation, ion exchange and granular activated carbon.

Lin et al. (2005**)** reported a combined chemical grey water treatment system, in which electrocoagulation was followed by a disinfection step. The COD, the BOD, the turbidity and the SS in the lows strength grey water were reduced from 55 mg/l, 23 mg/l, 43 NTU and 29 mg/l in the influent to 22 mg/l, 9 mg/l, 4 NTU and 9 mg/l respectively in the effluent. The total coli forms were not detected in the reclaimed grey water. The effluent water quality meets the restricted grey water reuse standards proposed in this study. But the raw grey water fed into the treatment plant was low in organic strength.

(Šostar 2005)reported the treatment of low strength laundry grey water treatment process using a combination of coagulation, sand filter and granular activated carbon (GAC). This grey water treatment process reduced the COD, the BOD and the suspended solids from 280 mg/l, 195 mg/l and 35 mg/l in the influent to 20 mg/l, 10 mg/l and less than 5 mg/l respectively in the effluent and achieved a good treatment performance with the coagulation stage itself achieving 51% of the BOD removal and 100% of the suspended solids removal.

(Chang et al. 2007**)** investigated the flocculation process for grey water treatment (coagulation with aluminum salt). The COD and the anionic surfactant concentration were reduced by 70% and 90% respectively. The study showed that the flocculation process alone is not able to reduce the organic substances to the required reuse standard, thus necessitating the application of biological processes. In a study lead by (Jefferson, et al. 2008), the coagulation processes and the magnetic ion exchange resin process were applied for shower grey water treatment. At optimal conditions, coagulation with aluminum salt reduced the COD, the BOD, the turbidity, TN and $PO4^{3-}$ in from 791 mg/l, 205 mg/l, 46.6 NTU, 18 mg/l and 1.66 mg/l in the influent to 287 mg/l, 23 mg/l, 4.28 NTU, 15.7 mg/l and 0.09 mg/l respectively. The total coli forms, the E. coli and the faucal enterococci in the reclaimed grey water are all less than 1/100 ml. Coagulation with ferric salt achieved similar treatment efficiencies as that obtained with aluminum salt. The coagulation processes. In another study by the same research group (Jefferson, et al. 2008) they were able to reduce the BOD concentration to less than 30 mg/l but fail to decrease the turbidity to less than 5 NTU. The COD, BOD, turbidity, TN and $PO4^{3-}$ were decreased by the magnetic ion exchange resin to 272 mg/l, 33 mg/l, 8.14 NTU, 15.3 mg/l and 0.91 mg/l respectively. The total coliforms, the E. coli and the fecal enterococci in the reclaimed grey water are 59/100 ml, 8/100 ml and less than 1/ 100 ml. The magnetic ion exchange resin process failed to reduce the turbidity and the BOD to the levels required for both unrestricted and restricted reuses. The coagulation process and the magnetic ion exchange resin process have minor effects on the removals of both TN and $PO4^{3-.}$

2.3.3. Biological treatments

Several biological processes, including rotating biological contactor (RBC) sequencing batch reactor (SBR) anaerobic sludge blanket (UASB), constructed wetland (CW) and membrane bioreactors (MBR), have been applied for greywater treatment. The biological processes were often preceded by a physical pre-treatment step such as sedimentation, usage of septic tanks or screening.

(Nolde 1999) studied an RBC grey water treatment system. The process comprises a sedimentation tank followed by a four-stage RBC and a final UV disinfection stage. The BOD7 was reduced from the influent value of 50–250 mg/l to below 5 mg/l by the biological step. After the UV disinfection step, bacteriological effluent quality mostly meets water reuse standards. Similarly, (Eriksson et al. 2007) reported a pilot RBC low strength pilot grey water treatment plant. The grey water plant treats effluents from showers and hand basins from bathrooms in 84 apartments and the treated water is utilized for toilet flushing. The plant consists of a primary settling tank which is also used for equalizing the flow, biological treatment with 3 rotating biological contactors (RBC) in series, followed by secondary settling, a sand filter and UV treatment. The treated water is kept in two storage tanks. The pilot grey water treatment plant was able to reduce the COD, the BOD, the TOC, the NH4–N and the ortho-phosphate from 142 mg/l, 93 mg/l, 72 mg/l 5.2 mg/l and 0.66 mg/l in the influent to 25 mg/l, 6 mg/l, 13 mg/l, 0.031 mg/l and 0.26 mg/l in the final effluent respectively. Surprisingly the COD, the BOD and the TOC were increased from 20 mg/l, 1.6 mg/l and 0.5 mg/l in the effluent of the sand filter to 25 mg/l, 6 mg/l and 13 mg/l in the final effluent respectively. However, the study from Eriksson et al. (2007) also showed that the BOD can be reduced by the RBC step to below 5 mg/l. He also examined the removal efficiencies of 5 selected trace organic substances by the pilot grey water treatment plant. Their study showed that the five selected paraben biocides (methyl-, ethyl-, propyl-, butyl-, and iso-butyl-esters of Para hydroxy benzoic acid) can be removed effectively by the treatment plant showing that the micro-organisms has adapted to the parabens as a carbon source for their growth.

(Friedler et al. 2005) studied a low strength grey water treatment system, which combined Rotating Biological Contactors (RBC), sand filtration and chlorination. The RBC step was preceded by a fine screen for the removal of gross solids and hairs larger than 1 mm and followed by a sedimentation step in a sedimentation basin to separate sludge from the effluents. The TSS, Turbidity, COD, BOD and fecal coliform were reduced from 43 mg/l, 33 NTU, 158 mg/l, 59 mg/l and 5.6×105 /100 ml in the influent to 16 mg/l, 1.9 NTU, 46 mg/l, 6.6 mg/l and 9.7×103 /100 ml respectively in the effluent of the sedimentation basin. The sand filtration step, acting as a polishing stage, further reduced the TSS, turbidity, COD and BOD to 7.9 mg/l, 0.61 NTU, 40 mg/l and 2.3 mg/l respectively. Astonishingly, the fecal coliform level increased from 9.7×103 / 100 ml to 5.2×104\ /100 ml after the sand filtration, demanding a disinfection step thereafter. The fecal coliform level was reduced to 0.1/100ml by the disinfection step in the final effluent. The pilot plant successfully reduced the TP, TKN, ammonia and organic nitrogen from 4.8 mg/l, 8.1 mg/l, 4.9 mg/l and 3.2 mg/l in the influent to 2 mg/l, 1 mg/l, 0.16 mg/l and 0.97 mg/l respectively in the final effluent.

(Liu 2014) reported a submerged MBR from Mitsubishi Rayon (poly- ethylene, pore size 0.4 µm) for low strength bath grey water treatment. This study revealed that the COD was reduced from the influent value of 130–322 to 18 mg/l on average in permeate. NH4–N concentration was reported to have decreased from 0.6–1.0 mg/l in influent to less than 0.5 mg/l in the effluent. BOD5 was reduced from the influent value of 99–221 mg/l to less than 5 mg/l in the permeate. Anionic surfactants (AS) were reduced from 3.5–8.9 mg/l in the influent to less than 0.5mg/l in the effluent. The effluent was colorless and odorless and free of SS and fecal coliform concentrations were below the determination threshold. This study demonstrated that biological degradation removed most of the pollutants and membrane separation further eliminated the rest of the pollutants, thus ensuring a stable and excellent effluent water quality. (Lesjean 2006) studied a submerged plate and frame MBR grey water (including kitchen grey water) treatment unit was operated under low SRT (down to 4 d) and low HRT (set as 2 h) condition. The COD was reduced from the influent value of 493 mg/l to 24 mg/l in permeate and the elimination rate was greater than 85%. Nitrogen was decreased from 21 mg/l to 10 mg/l, but its elimination rate was not consistent (ranging from 20 to 80%). Phosphors was reduced by around 50%, decreasing from the influent value of 7.4 mg/l to 3.5mg/l in effluent. SS in permeate was reported to be less than 1 mg/l during the whole observation period. The stable permeate flux achieved in this study was 7 l/m^2. h.

(Merz 2007) studied a submerged MBR from Zeno (membrane pore size, 01 µm) for low strength grey water from a sports and leisure club. The turbidity, COD, BOD5, TKN, ammonia, TP, LAS and fecal coliforms were reduced from 29 NTU, 109 mg/l, 59 mg/l, 15.2 mg/l, 11.8 mg/l, 1.6 mg/l, 299 µg/l and 1.4×105/100 ml in the influent to 0.5mg/l, 15 mg/l, 5 mg/l, 5.7 mg/l, 3.3 mg/l, 1.3 mg/l, 10 µg/l and 68 /100 ml respectively in the effluent. The effluent was free of color and odorless. The detection of the fecal coliforms in the permeate was probably caused by the accidental contamination in the distribution system. The stable permeate flux obtained in this study ranged from 8 to 10 l/m^2h

(Gross 2007), studied a recycled vertical flow constructed wetland was applied for a high strength mixed grey water treatment. The TSS, BOD5, COD, TN, TP, anionic surfactants, boron and fecal coliform were reduced from 158 mg/l, 466 mg/l, 839 mg/l, 34.3 mg/l, 22.8 mg/l, 7.9 mg/l, 1.6 mg/l and 5×107 /100ml in the influent to 3mg/l, 0.7mg/l, 157mg/l, 10.8mg/l, 6.6 mg/l, 0.6 mg/l, 0.6 mg/l and 2×105 /100 ml respectively in the effluent. The constructed wetland reported in the literature showed good treatment performance to treat grey water.

(Hernandez 2007) used a sequencing batch reactor (SBR) for a high strength grey water treatment. The sludge retention time and hydraulic retention time were set as 15 days and 11.7 h respectively. The COD, TP, TN and ammonia was reduced from 830 mg/l, 7.7 mg/l, 53.6 mg/l and 1.2 mg/l in the influent tom91 mg/l, 6.5 mg/l, 34.4 mg/l and 0.41 mg/l respectively in the effluent. Another sequencing batch reactor (SBR) was operated for a high strength greywater treatment. During this period, the sludge retention time was increased to 378 days and the hydraulic retention time was reduced to 5.9 hours. The COD, TP, TN and ammonia was reduced from 827 mg/l, 8.5 mg/l, 29.9 mg/l and 0.8mg/l in the influent to 100mg/l, 5.8mg/l, 26.5mg/l and 0.44mg/l respectively in the effluent. The organic nitrogen in the effluent’s accounts for 90% and 74% of the TN, indicating that the transformation of particulate organic nitrogen to ammonia during the aerobic treatment was very limited.

2.4. Theoretical background on biochar

Biochar is pyrogenic Carbonaceous Material (PCM). It is an umbrella term used for all materials that contain organic carbon, and have been produced by thermochemical conversion. Biochar is produced by biomass pyrolysis, a process whereby organic substances are broken down at temperatures ranging from 350°C to 1000 °C (ebc guideline). Such materials include charcoal, soot, activated carbon and biochar. Charcoal is produced by thermochemical conversion of biomass, and most commonly to be used for energy production purposes. If charcoal is processed further and activated by steam or addition of chemicals, the term activated carbon is used. Biochar is the product of thermochemical conversion of biomass, in an environment with limited oxygen. (Joseph and Lehmann 2015). Pyrolysis technology can be distinguished by the residence time, pyrolytic temperature of the pyrolysis material (e.g., slow and fast pyrolysis process), pressure, size of adsorbent, and the heating rate (17).

Slow pyrolysis (heating for seconds or minutes) may be described as a continuous process, where purged (oxygen-free) feedstock biomass is transferred into an external heated kiln or furnace (gas flow removing volatile biochar emerging at the other end); “fast” pyrolysis on the other hand depends on very quick heat transfer, typically to fine biomass particles at less than 650°C with rapid heating rate (ca 100–1000°C/s) (17). The characteristics of the biochar product are heavily affected by the extent of pyrolysis (pyrolytic temperature and residence pressure) and entirely by biomass size and kiln or furnace residence time. The rate at which volatile and gases are removed in a kiln or furnace determines the vapor residence time(18).

Prolonged residence time results in secondary reactions, notably the reactions of tar on biochar surfaces and charring of the tar rather than additional combustion or processing outside the kiln or furnace For gasification in pyrolysis, the biomass feedstock to some extent is oxidized in the gasification chamber at a temperature of about 800°Cat atmospheric or elevated pressure (19). As already pointed out by its name, the main product of this process is gas; only few or no biochar, liquids, or the likes are formed.

The hydrothermal carbonization of biomass is obtained by applying high pyrolytic temperature (200–250°C) to a biomass in a suspension with liquid under high atmospheric pressure for several hours. It yields solid, liquid, and gaseous products (19).

On the other hand, with flash carbonization of biomass, a flash fire is lights up at an elevated pressure (at about 1–3 MPa) at the underneath of a packed bed biomass. The fire travels in an upward direction through the carbonization bed against the downward flow of air supplied to the process. A total of about 0.8–1.5 kg of air per kg of biomass is injected to the process. The residence time of the process is below 30 min, and the pyrolytic temperature in the reactor is in the range of 330–650°C (19). The process results mainly in gaseous and solid products such as biochar (19).

2.4.1. Biochar in wastewater treatment

Biochar is produced for the specific purpose of being used as an adsorbent in water treatment, both the raw material and the type of pyrolysis process needs to be selected in a way that provides the desired surface characteristics in the product. Specific surface area, the type and density of surface charge, elemental composition (carbon, nitrogen, hydrogen, Sulphur and oxygen), and functional groups on the surface are the characteristics that play a central role in the material's adsorption capacity (Lou 2016)).

The adsorbents need to have a very high specific surface area, and the surfaces should be relatively free from adsorbed material. The most commonly used adsorbent is activated charcoal. The surface of activated carbon is suitable for microbial activity, which also may improve adsorption. Bigger molecular weight of the solute and longer contact time increase adsorption. The pH value is also significant, as adsorption decreases with increasing pH value (Gray 2010).

The qualities of the biochar, such as cation exchange capacity, surface area and pH, can be optimized for nutrient removal by using the most appropriate pyrolysis method. (J. Lehmann 2007) suggests that 450-550˚C is probably the optimal production temperature. Due to its larger surface area, greater negative surface charge and charge density, biochar has a greater potential to adsorb cations. biochar is also able to adsorb phosphate anions.

The surface charge of biochar is usually negative. This consequently means that adsorption of phosphate anions by biochar is sometimes low. (Lou. 2016) suggest that despite its high surface area and oxygen functionality, biochar is rarely effective for the removal of phosphates or other anions. The surface charge of biochar is, however, pH dependent. When the net surface charge of any specific type of biochar is changed by lowering the pH, the pH value passes a so called point of zero charge. The pH value for reaching the point of zero charge is unique for each biochar type, and depends on the raw material, production temperature, and possible activation method used. The anion sorption capacity of biochar is at its greatest when the pH of the solution is below the pH_{PZC} value, and the capacity drops when the pH rises above it. The results of the experiments by Lou et al. reached only approximately 4% efficiency in phosphate removal by biochar, as the pH of the solution was above the pH_{PZC} of every biochar tested.

2.4.2. Findings of biochar in nutrient removal

(Lukkarinen 2016) carried out a series of column tests with biofilters, and when filtering bog water through them, found that columns that had both biochar and woodchips in them merely leached phosphorous throughout their experiment. Using biochar independently showed that it leached nitrogen as well as some zinc and copper into the influent. One of the biochar columns was leaching phosphorous, while the other one was removing it slightly. One explanation for this could be that the biofilm, which contributes to nutrient removal, was developing at different rates in the columns. Only moss filters were found to consistently reduce the chemical oxygen demand (COD) in water, while both woodchip and biochar filters were found to both decrease and increase the COD depending on the date of sampling. The influents had markedly lower concentrations of nutrients compared to the influent used in the laboratory experiment for this paper (Lukkarinen 2016)

The influent used by (Berger 2012) had the mean concentrations of 95 mg/l for Tot-N. In this study, biochar filters were able to reduce nitrogen efficiently from greywater. Total nitrogen was removed with the efficiency of 90.94%. Ammonium was reduced with 2.7% efficiency, and nitrate with 19.8% efficiency. Salix biochar performed better than activated carbon in phosphorous removal (89% and 78%, respectively), and biochar’s phosphate removal efficiency was 86%. According to these results, biochar’s ability to remove total phosphorous and phosphates increases with time. The total phosphorous content in the influent was 3.6 mg/l. The COD removal in this study was as high as 99.1%, with the average COD of the influent being 1389 mg/l (Berger 2012)

(Dalahmeh, et al. 2012) studied bark and charcoal filters for grey water treatment. In this study it revealed that grey water is a sustainable water source for recycling. Laboratory-scale pine bark, activated charcoal and sand filters were evaluated as regards their pollutant removal and interactions between medium properties, grey water, microbial activity and bacteria community structure. The effects of hydraulic and organic loading rates (HLR and OLR) were described by general regression models (GRM). A series of experiments examined treatment of artificial grey water in terms of lowering the biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), phosphorous (Tot-P), nitrogen (Tot-N) and pathogen indicators (total thermotolerant coliforms) and tracer microorganisms. The driving force shaping bacterial communities in bark material was its organic composition and low pH while the communities in the charcoal and sand filters were more influenced by the grey water. The organic matter content and surface and hydraulic properties of the bark filters resulted in high BOD_5 removal rates (94- 99%), even at increased HLR and OLR. High nitrification occurred in the bark filters in all loading regimes tested but with low Tot-N removal. The charcoal had large specific surface area, which provided the capacity for intermediate high removal of BOD_5 (83- 97%), Tot-N (50-98%), Tot-P ((64-98%), but removal of microorganisms was poor. Also, sand filters demonstrate low BOD removal 67-91 per cent and high nitrification, but low nitrogen removal.

(Gao 2015) tested the ammonium (NH_{4+}) sorption capacities of biochar produced from three different organic waste materials and using three pyrolysis temperatures. The highest biochar yield was gained at 300℃ (41.5% for peanut shells), and the lowest yield at 600℃ (22.6% for corncobs). The low temperature biochar was highly effective in ammonium adsorption, due to high adsorption capacities and fast adsorption kinetics. The effect of pH was tested by controlling the pH of the ammonium solution with NaOH and HCl solutions. The sorption of ammonium was high at all tested pH levels (1, 3, 5, 7, 9, 10 and 12), and peaked at pH=10, where the sorption capacity was 19.2 mg/g. Raising the temperature reduced ammonium adsorption, but even at 50℃ the adsorption capacity was close to 10 mg/g. The relationship between adsorption capacity and temperature indicates that exothermal reactions control the adsorption.

2.5. Adsorption

The Brownfields and Land Revitalization Technology Support Center (2009) reported that adsorption is the adhesion of atoms, ions, or molecules from a gas, liquid, or dissolved solid to a surface. This process creates a film of the adsorbate on the surface of the adsorbent. This process differs from absorption, in which a fluid (the absorbate) is dissolved by or permeates a liquid or solid (the absorbent), respectively. Adsorption is a surface-based process while absorption involves the whole volume of the material. The term adsorption encompasses both processes, while desorption is the reverse of it. Adsorption is a surface phenomenon. Similar to surface tension, adsorption is a consequence of surface energy.

According to (Ferrari, et al. 2010) revealed that the exact nature of the bonding depends on the details of the species involved, but the adsorption process is generally classified as physisorption (characteristic of weak van der Waals forces) or chemisorption (characteristic of covalent bonding). It may also occur due to electrostatic attraction. Adsorption, ion exchange, and chromatography are adsorption processes in which certain adsorbates are selectively transferred from the fluid phase to the surface of insoluble, rigid particles suspended in a vessel or packed in a column.

2.5.1. Mechanism of Adsorption

Adsorbents which are produced from agricultural wastes may act as a significant material for contaminant adsorption. The term adsorption was proposed by (McBain 1909) as a complete description of mass transport into a solid, encompassing surface adsorption, absorption by penetration into the solid and condensation within pore.

Adsorption is divided into the two sub-categories of physical adsorption (physisorption) or van der Waals adsorption and chemical adsorption (chemisorption) and the adsorption process can be determined whether chemical bonds are formed during the process. Physisorption is applicable to all adsorbate adsorbent systems provided the conditions of pressure and temperature are suitable whereas chemisorption may only occur if the system is capable of making a chemical bond (Park 2010)

2.5.2. Adsorption Kinetics

The study of adsorption kinetics describes the solute uptake rate and evidently this rate controls the residence time of adsorbate uptake at solid–solution interface. The kinetics of parameter adsorption onto the composite media was analyzed using the pseudo-first-order (Lagergren 1898) and pseudo-second-order equations (Ho and Mckay 2000)

Batch rate analysis can be used to recognize the practical application of adsorption and design of the batch reactor. Some kinetic models with varying degree of complexity are available to illustrate the kinetics of parameter adsorption in batch systems. The sorption kinetics are significant in the treatment of wastewater, as it provides valuable insights into the reaction pathways and mechanisms of sorption reactions. Since adsorption is a metabolism- independent process, it would be expected to be a very fast (Gupta 2010). Pseudo-first order and pseudo-second order was used in this study to understand the controlling mechanism of parameter adsorption.

Pseudo-first-order

Lagergren (1898) presented a first-order rate equation to describe the kinetic process of liquid-solid phase adsorption of oxalic acid and malonic acid onto charcoal, which is believed to be the earliest model pertaining to the adsorption rate based on the adsorption capacity.

To distinguish kinetic equations based on the adsorption capacity from solution concentration, Lagergren first order rate equation have been called pseudo-first-order. In recent years, it has been widely used to describe the adsorption of pollutants from wastewater in different fields, such as the adsorption of methylene blue from aqueous solution by broad bean peels and the removal of malachite green from aqueous solutions using oil palm trunk fiber (Tan 2008)

The pseudo-first order kinetic model assumes “adsorbate adsorption process is first order in nature as it is only dependent on the number of adsorbates present at the specific time in the solution” (Lagergren, 1898).

Pseudo-first order Lagergren can be presented as

$$Log(qe - qt) = Log\ qe - \frac{K1t}{2.303}$$

Where K_1 (min^{-1}) is the rate constant of pseudo-first order adsorption model,

qe and *qt* (mg/g) denote the amounts of adsorbed on F, C and FC at equilibrium and at any time *t* (min).

Pseudo-second-order

(Ho and Mckay 2000) described a kinetic process of the adsorption of divalent metal ions onto peat in which the chemical bonding among divalent metal ions and polar functional groups on peat, such as aldehydes, ketones, acids, and phenolics are responsible for the cation-exchange capacity of the peat. The main assumptions for the above two equations were that the adsorption may be second order, and the rate limiting step may be chemical adsorption involving valent forces through sharing or the exchange of electrons between the peat and divalent metal ions. In addition, the adsorption follows the Langmuir equation. Pseudo-second order kinetic model assumes that “the adsorption process is dependent on the number of adsorbates present in the solutions as well as the free adsorption sites on the adsorbent surface” .

The pseudo-second order equation is expressed as Eq. (2.2) :

$$\frac{t}{qt} = \frac{1}{k2qe^2} - \frac{t}{qe}$$

Where K_2 is the rate constant of pseudo-second order adsorption model (min^{-1}),

q_t is the amount of adsorption time t (min), and

q_e the amount of adsorption equilibrium (mg/g).

2.5.3. Adsorption Isotherm

According to (Hassan and Puteh 2007)revealed that adsorption process is usually studied through graphs known as adsorption isotherm. Adsorption is the amount of adsorbate on the adsorbent as a function if its pressure or concentration at constant temperature. The quantity adsorbed is nearly always normalized by the mass of the adsorbent to allow comparison of different materials. From the above, we can predict that after saturation pressure (Ps), adsorption does not occur anymore, that is there are limited numbers of vacancies on the surface of the adsorbent. At high pressure a stage is reached when all the sites are occupied and further increase in pressure does not cause any difference in adsorption process. At high pressure, adsorption is independent of pressure. The analysis of adsorption data is important for developing an equation which accurately represents the results and which could be used for design purposes. The linear regression was used to determine the most fitted models among all written isotherms (Gupta 2010). Several isotherm equations have been widely used for the equilibrium modeling of adsorption systems, there are Langmuir and Freundlich equations.

A. Langmuir Adsorption Isotherm

In 1916, Irving Langmuir published a new model isotherm for gases adsorbed to solids, which retained his name. It is a semi-empirical isotherm derived from a proposed kinetic mechanism. The Langmuir isotherm model is based on the assumption that there is a finite number of active sites which are homogeneously distributed over the surface of the adsorbent. These active sites have the same affinity for adsorption of a mono molecular layer and there is no interaction between adsorbed molecul. Based on his theory, Langmuir derived an equation which explained the relationship between the number of active sites of the surface undergoing adsorption and pressure. The Langmuir monolayer sorption isotherms are based on the following assumptions (Cruz, et al. 2004):

I. The solid surface presents a finite number of energetically uniform identical sites.
II. There is no interaction among adsorbed species
III. A monolayer is formed when the solid surface reaches saturation.

The linearized Langmuir equation (Langmuir, 1918) is given as :

$$\frac{Ce}{qe} = \frac{1}{qmax^{b}} + \frac{Ce}{qmax}$$

Where qe (mg/g) is equilibrium adsorption capacity and

Ce (mg L^{-1}) is equilibrium metal ion concentration,

qmax (mg g^{-1}) is the maximum amount of pollutant per unit weight of adsorbent to form a complete monolayer on the surface, and b is a constant related to the affinity of binding sites with the pollutant (L mg^{-1}).

B. Freundlich Adsorption Isotherm

In 1909, Freundlich expressed an empirical equation for representing the isothermal variation of adsorption of a quantity of gas adsorbed by unit mass of solid adsorbent with pressure. The Freundlich isotherm (Chiou and Li 2002)applies to adsorption on heterogeneous surfaces with interaction between the adsorbed molecules, and is not restricted to the formation of a monolayer. This model assumes that as the adsorbate concentration increases, the concentration of adsorbate on the adsorbent surface also increases and, correspondingly, the sorption energy exponentially decreases on completion of the sorption centers of the adsorbent. Though Freundlich Isotherm correctly established the relationship of adsorption with pressure at lower values, it failed to predict values of adsorption at higher pressure. This relation is called as the Freundlich adsorption isotherm. Freundlich (1906) created Freundlich equation and it is an empirical equation based on adsorption on heterogeneous surface and its linearized form can be given as

$$Log\ qe = Log\ Kf = \frac{1}{n} logCe$$

Log q_e = log K_F = 1 log C_e (2.4) n

Where K_F and $1/n$ are Freundlich constants related to adsorption capacity and intensity of adsorption, respectively.

2.6. Greywater Reuse in Other Countries

The reuse of greywater is being increasingly practiced in a number of countries, whose water crisis is less critical. A number of these countries have carried out assessments of greywater reuse practices and investigated the technical means of reuse as well as the health and environmental implications. The following are some influences where information on greywater reuse has been found, and where greywater reuse is currently being practiced.

Los Angeles has reused 13%–65% of greywater saved from domestic households for agricultural irrigation (B. Sheikh 1993)A residential household in Brazil has used processed greywater for toilet flushing and has cut water consumption by approximately 29%–35% (Ghisi and Ferreira 2007). In Malaysia, 67% of water consumption is for the domestic usage, and greywater reuse for toilet flushing has the potential of 30% saving in water demand (Ismail, et al. 2011). The operate rate of greywater facilities in South Korea is 26.5% through supply of two hundred million tons of greywater. In 2010, the Ministry of Environment announced a new law that enforced the installation of greywater reuse system for non-potable use, and people who need to build or remodel their buildings should install wastewater reclamation and reusing system which could reuse more than 10% of used water. In Japan, the government does not provide incentives for household residents to implement greywater systems. However, 70% of Japanese support the utilization of rainwater or recycled water as they are highly aware of the need to conserve water, and water costs are relatively high in urban areas. China’s rapid economic growth has created a water crisis that the government has addressed through a number of policies including regulation requiring greywater treatment and water reuse for large scale institutional buildings and residential developments (United Nation 2012)..

3. Material and Method

Laboratory column experiments were conducted at the wastewater treatment laboratory at Addis Ababa institute of Technology (AAiT).

3.1. Biochar preparation

The biochar used in this study was produced from banana peel and prepared in the laboratory using pyrolysis process. The peel was collected from local juice bar and dried in the sun for days. After drying, it crushed with a blender to prepare three different sizes of biochar; (Berger 2012, Beven and Germann 1982) the first was coarse biochar (CBC) which is > 3mm, second biochar size was medium biochar (MBC) with size of 1-3mm, and the last particle size was < 1mm which is named as fine biochar (FBC). Then the three different size was carbonized by an electric muffle furnace at temperature of 450°C (Antal and Grønli 2003, Masek, et al. 2013) for 1.5 hour and cooled at room temperature. The prepared biochar washed with distilled water to remove the very fine particle and oven dried at temperature of 100°C for 3 hours.

a b c d e

Figure 3.1 a) Banana peel b) Dried banana peel c) CBC d) MBC e) FBC

3.2. Biochar characterization

According to (Novak, et al. 2009) biochar pH and (EC) were measured in 1:10 biochar to distilled water mass ratio after shaking for 30 min. After this, samples were allowed to stand for 30 min and then pH and EC was measured. The pH reading was taken using HI 8010 model Electric conductivity (EC) was also measured using JENWAY 4330 conductivity meter and using the same samples prepared for pH analysis.

Elemental analysis also performed using a CHNS elemental analyzer (FlashEA 1112) to analyze the elemental content of carbon, hydrogen, nitrogen, and Sulphur present in the banana peels;

the oxygen content was obtained by mass difference (O = (100 - C - H - N -S) (Jamaluddin, et al. 2013).

The morphological properties of biochar were analyzed by Scanning Electron Microscopic (SEM) imaging. A range of SEM images (Magnification: 500× to 2000×) were captured with a JEOL JSM-6490 operating at 20KV at Ethiopian Leather Institute, Addis Ababa. Image analysis was done with ImageJ version 2.0 with appropriate threshold and size range values.

The specific surface area of biochar was done using air permeability apparatus and also bulk density was determined by dividing the dry weight of the filter medium by the volume occupied by the medium.

$$\rho = \frac{Ms}{Vs}$$

ρ g cm^{-3} bulk density

Ms g mass of solids

Vs cm^3 volume of solids

3.3. Sand preparation and characterization

sand was purchased from a local building material supplier and washed by distilled water to remove very fine particles and dissolved organic matter, it was left to air to remove excess water then it was put into the oven at 105^oc.

The particle-size distribution of the sands on a weight basis was analyzed in triplicate by conventional dry-sieving techniques (Day 1965). The grain-size distribution plots were used to estimate d_{10} (10% of the sand by weight is smaller than d_{10}) and d_{60} (60% of the sand by weight is smaller than d_{60}). The uniformity of the particle-size distribution (the uniformity coefficient) was calculated as the ratio between d_{60} and d_{10}.

To determine effective size and uniform coefficient of particle, three homogeneous and representative 1000 g samples were taken at each sampling event, dried and sieved through seven stainless steel screens ranging from 0.075 to 4.75 mm pores. Then, each screen was weighed to determine the retained sand and the particle size distribution curve, which allowed the computation of UC.

In addition to characterize the sand SEM, bulk density and specific surface area was analyzed.

3.4. Experimental Setup

The experimental setup consisted of six plastic cylinders with diameter of 7 cm and a total height of 36 cm each. The bottom of each column had with a small 0.5 cm diameter outlet. Each filter cylinder is filled with three layers. These were gravel and biochar or sand. The depth was fixed by taking the proportional of (Berger 2012) research. Based on that, the gravel filled with 1.4 cm at the bottom, then 27 cm of depth were filled by biochar or sand and added to the column spoon by spoon in order to pack them as densely as possible, but in case of FBCS the 13.5cm depth is filled by FBC and the rest depth is filled by sand media. For the same reason, the outside of the column was knocked after each spoon. A layer of 1.4 cm top gravel was added and finally the whole column was packed into aluminum foil in order to prevent light penetration to avoid the growth of algal.

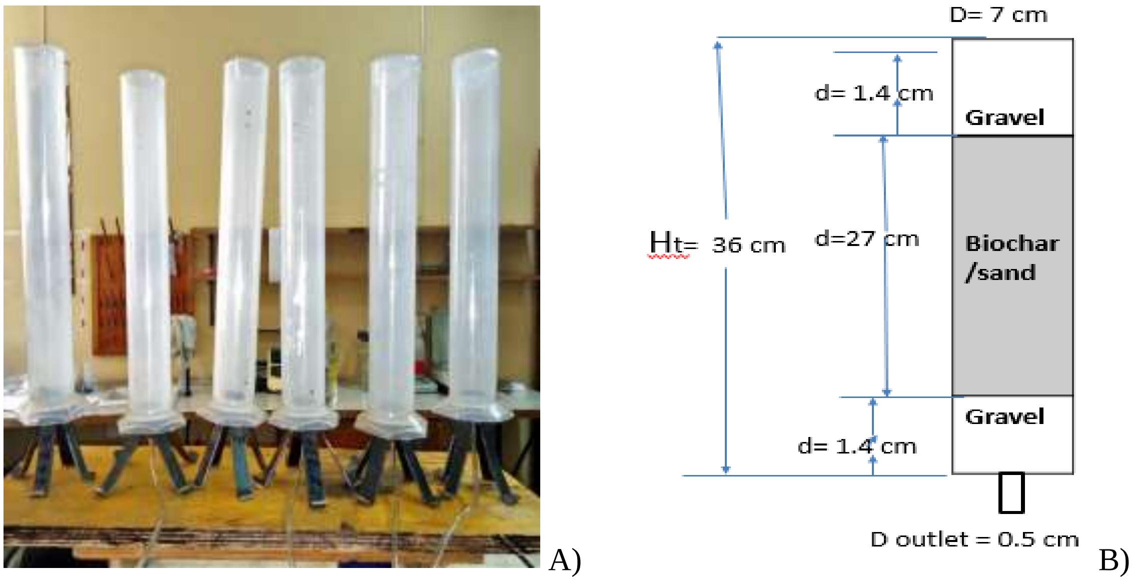


Figure 3.2A) columns used to fill with biochar and sand **B**) schematic drawing of column

3.5. Research Design

In this study, the research design involved in preparation of synthetic greywater (SGW) and collection of real greywaters (RGW) from different households which was near to laboratory.

3.5.1. Synthetic Greywater Preparation and Composition

The synthetic greywater (SGW) was used in order to control the quality of the test of greywater, to ensure repeatability of the quality, and to optimize different parameters. The ingredients used for SGW (Berger 2012) were used 0.4 g/l sunflower oil (Tena, Ethiopia),0.16 g/l shampoo (Organza, rose flowers, U.S.A), 0.16 g/l dishwashing gel (SHAGAN, U.S.A), 0.16 g/l washing powder (Ariel, Germany) and 2.5g nutrient broth. But nutrient broth was prepared at laboratory because the ingredient was not available on market. It was prepared according to (Vanderzant and Splittstoesser 1992) by using 10g/l of beef extract, 10g/l of peptone and 5g/l of sodium chloride. Then mix it by flocculator in 1L of distilled water.

Figure 3.3 Ingredients used for the preparation of the synthetic greywater

The ingredients were dissolved one after the other in the above figure 3.3 listed order, this order was chosen since the first ingredient being in powder form, it needed more time to dissolve. The next two ingredients and nutrient broth were weighted and then each dissolved with 10 ml of distilled water in a small beaker and mixed by flocculator. The sunflower oil and 10 ml of water were put directly into a big beaker in order to prevent oil losses. Then 950 ml of distilled were used to rinse the small beakers with the dissolved ingredients into the big beaker. The mix of all the ingredients and the one liter of water (50 ml+ 950 ml) were placed on the flocculator for another 10 minutes. The prepared 1L of SGW was used only for one day of sample test.

3.5.2. Real greywater

Greywater with a volume of 5 L was collected at working days from kebele house which was near to AAiT. Sample was collected directly from the shower or bathtub, and the laundry from the manual washing areas while the kitchen water was collected from the kitchen sink and it was analyzed on the day of production for a maximum of 24 hours.

3.6. Effect of particle size on adsorption process

To identify the effect of particle size, three different size of biochar was prepared. Which was CBC, MBC and FBC and it was filled in three columns. Then 3 L of SGW was prepared for one day of experiment and feed to the columns.

3.7. Effect of pH on adsorption process

The effect pH on adsorption was investigated by preparing 6 L of SGW for one day of experiment and fill in six glass bottles with volume of 1000 cm^3 each. The pH of the SGW was adjusted over the range of pH 5-10 by using 0.5 M HCl and 20 M NaOH solutions. The adjusted SGW was added in to six columns which was filled by the optimum of biochar particle size.

3.8. Performance of FBC, FBCS and sand

After the optimum particle size of biochar and optimum pH was obtained, the next step was compression of FBC, sand and FBCS by using RGW. The procedure was first filling filter materials into column and feeding of RGW to it. Finally, physiochemical and biological parameters were analyzed.

3.9. Residence time

The residence time of water in the filter was determined after 15 days from start-up by adding a 100 mL pulse of NaCl tracer solution (10 g L −1) to the filters and then monitoring the electrical conductivity (EC) of the effluent as a function of time. The mean residence time in the filter was defined as the time when 50% of the total tracer recovered (Dalahmeh, et al. 2012).

3.10. Adsorption Isotherms

Study and comparison of Freundlich and Langmuir adsorption isotherms for COD and P parameters are carried out, the concentration was high.

Langmuir Adsorption Isotherm:

The Langmuir adsorption isotherm is proposed by Langmuir, in 1918. The Langmuir equation is given as:

$$qe = \frac{Qo * KCe}{1 + K * Ce}$$

$$\frac{1}{qe} = \frac{1}{Qo} + \frac{1}{K * Qo} * \frac{1}{Ce}$$

where 'Ce' is the equilibrium concentration and 'qe' is the amount of adsorbate adsorbed per gram of adsorbent at equilibrium (mg/g), Q_O is the quantity of adsorbate required to form a single monolayer on unit mass of adsorbent, K is adsorption equilibrium constant that is related to the apparent energy of adsorption.

Freundlich Adsorption Isotherm

The Freundlich adsorption equation

$$qe = KF * ce^{\frac{1}{n}}$$

$$\log(qe) = \log(KF) + \frac{1}{n}\log(Ce)$$

Where 'qe' is equilibrium adsorption capacity (mg/g), 'Ce' is the equilibrium concentration of the adsorbate in solution, 'Kf', and 'n' are constants related to the adsorption process such as adsorption capacity and intensity respectively.

3.11. Sampling and Analysis

Physio-chemical and biological analyses of RGW and SGW were determined for the selected parameters: pH, turbidity, COD, N, P and fecal coliform. All analysis carried out in the laboratory of AAiT but, COD was analyzed in EPA and fecal coliform also analyzed at AAU (4 kilo campus) because the reagent was not available on the market. Samples of inflow greywater were taken at the time of feeding and outflow samples were taken immediately after enough water had accumulated in the outlet recipient. The analysis was done for four days and run in triplicate then the average values were taken.

The pH, conductivity and turbidity were determined in situ using a calibrated Hanna educational pH meter- HI 8010, JENWAY 4330 conductivity meter and Hanna HI 93102 turbidity meter respectively. And both N and P was analyzed by Palintest photometer 7100 (UK).

The effectiveness of a filter (removal efficiency) was computed as a measure of the ability of the media filter to remove particles from the inlet effluent. Filter removal efficiency was determined for all pH, conductivity, turbidity, COD, N, P and FC using the formula:

$$E = \left(\frac{C\ in - C\ out}{C\ in}\right) * 100$$

Where

E efficiency (percent),

C in influent concentration (mg/l) and C out effluent concentration mg/l.

3.12. Quality control and assurance

All chemicals and reagents used in the laboratory test procedures were of analytical grade and standard approved make. The glassware, containers, bottles and column used for the sampling and analysis were initially cleaned with tap water followed by nitric acid before rinsing with distilled water. Standard solutions and necessary reagents were prepared on a regular basis to achieve the best possible results.

Samples were vigorously shaken to obtain homogeneous quality before they were feed in to column. Instrumental calibrations were performed on a regular basis. All experimental development, calibrations, standard preparations, experimental methods, data generation, and documentation of activities were conducted on the guidelines of APHA.

500 ml of greywater samples were collected in labeled plastic sampling bags from an aerobic holding tank from household, at two-hour production. The greywater in the holding tank was not mixed before sampling but it is thought that discharges might create disturbance and resuspension of settled solids in the tank. Sampling bags were filled without air bubbles and kept in an icebox below 4^oC during transportation to the laboratory. E. coli were rapidly measured.

Particle size of biochar for optimization of biochar particle size, pH and comparison between biochar with sand, the filter media used in one optimization parameter never used for other experiment.

4. Result and Discussion

4.1. Greywater characterization

Characteristics of the sample greywaters are presented in Table 4-1 and the findings are compared with relevant literature values.

Table 4-1 Characteristics of SGW and RGW

Parameter	SGW		RGW	
	Average	Range	Average	Range
Turbidity (NTU)	133.73	53 – 169	229.17	195– 314
pH	8.7	7.7 – 9.2	7.5	6.78 – 8.21
COD (mg/l)	934.5	801 – 1102	2004	1482 - 2640
N (mg/l)	0.78	0.36 – 1.26	1.02	0.74 – 1.26
P (mg/l)	22.2	19.6 – 27.7	16.9	13.6 –22.4
Fecal coliform (CFU/100 ml)	–	–		2.88×10^3 –3.76×10^3

The values of turbidity varied between 195–314 NTU for RGW and 53 – 169 NTU for SGW. (Edwin 2014) and (Oteng-Peprah 2018) were reported that turbidity is mostly influenced by the water use activities. Greywater with much of the water originating from the kitchen and laundry accounts for relatively high values of turbidity, and this may be due to washing of clothes, shoes, vegetables, fruits, tubers and many others which may contain sand, clay and other materials.

The pH of greywater was found to be slightly basic, ranging between the value of 6.78–8.21 and 7.7 – 9.2 for RGW and SGW respectively. This is close to values reported in the literature such as (Casanova 2001) who indicated greywater pH in the range of 6.7 – 7.6. Greywater that originates from the laundry is alkaline and has generally pH-values in the range of 8–10 due to the use of soap and detergents (Chaillou, et al. 2011)

Nitrogen concentration varied between 0.74mg/l–1.26mg/l and 0.36mg/l – 1.26mg/l for RGW and SGW, respectively. According to (Boyjoo 2013) greywater N concentration ranges between 4 and 74 mg/L. The values of nitrogen found to be in the range of 5–50 mg/l (Hong, et al. 2003). But ammonia values ranged between 0.05 and 6.4 mg/L, with an average of 2.9 mg/L as reported by (Alsulaili and Hamoda 2015). In this study, the sample greywaters exhibited smaller nitrogen concentrations. According to (Del Porto and Steinfeld 2000) levels of nitrogen in greywater are relatively low (urine being the main nitrogen contributor to domestic wastewater). Kitchen wastewater is the main source of nitrogen in domestic greywater, and, the lowest nitrogen levels are generally observed in bathroom and laundry greywaters.

Phosphorus concentrations in RGW and SGW ranged between 13.6–22.4mg/l and 19.6 – 27.7mg/l, respectively. Phosphorous concentrations are typically found within a range of 4–14 mg/l in regions where non-phosphorous detergents are used (Eriksson, et al. 2002). However, they can be as high as 45–280 mg/l in households where phosphorous detergents are utilized. as observed in Thailand (Schouw et al., 2002) and Israel (Friedler 2004). Data reported from Australia revealed P concentration in greywater in the range of 0.6 – 27.3 mg/l (Ottoson and Stenstro¨m 2003). PO_4 – P were found to be in average concentration of 7.76 mg/l for raw greywater from Morocco (Sadani, et al. 2002). The organic matter content in SGW and RGW ranged between 801-1102 mg/l and 1482-2640 mg/l, respectively and this is within the range reported by (Eriksson, et al. 2002), i.e. 13 - 8000 mg COD /l.

Fecal concentration in RGW was around 2.0 x10^3 to 7.4 x 10^6 CFU/100 ml. However, the level can be as high as 2.51x 10^7–3.94 x 10^8 CFU/100 ml in shower greywater as reported in (Al-Jayyousiy 2002, Dallas 2004.)

In general, the values of SGW is not represent fully RGW. This is due to the ingredients of SGW which have less turbidity, null suspended solids and the lower limit of P and on SGW was higher than RGW also lower and upper limit of COD on was higher than from SGW. This causes variation of result on efficiency of SGW and RGW on removal of turbidity P COD

4.2. Biochar characterization

The elemental analysis of banana peel biochar as shown in Table 4-2 had high carbon percentage whereas hydrogen was detected in low concentration. Nitrogen and Sulphur were not detected in the peel. The other physical and chemical characteristics of biochar were EC 3.36 µS/cm and pH - 9.93.

Table 4-2 Elemental composition of biochar

Elemental composition %				
Banana peel	N	C	H	S
	-	69.99	2.33	-

According to (Ahmadvand 2018) report the contents of N, H and O decreased as pyrolysis temperature increased from 400 to 700°C, whereas carbon increased with higher pyrolysis temperatures. At this stage, some of the nitrogen oxidized into nitrogen oxides and Sulfur volatilized and his finding concluded that carbonization was promoted with increasing pyrolysis temperature. Hydrogen and oxygen losses at high pyrolysis temperature were due to the cleavage and breakage of weak bonds within the biochar structure. As finding of (Hesas, et al. 2013) adsorbents containing higher carbon content have given better performance in purification of water and wastewater.

In the finding of (J. Lehmann 2007) biochar pH values ranging between 3.1 and 12.0. Biochar produced under high temperatures (>400°C), it is likely to have greater pH values than the low temperature (<400°C) biochar (Hossain, et al. 2011, Jindarom, et al. 2007, Yao, et al. 2011). During high temperature of carbonization, acidic functional groups are removed and salts of alkali elements remain (Ueno *et al*. 2008; Fuertes *et al*. 2010) also, biochar EC values ranging from 0.04 dS m^{-1} (Rajkovich, et al. 2012) to 54.2 dS m^{-1} (Smider and Singh 2014) but it is dependent on the feedstock and the pyrolysis temperature.

4.3. Physical properties of FBC compared with sand

The physical characteristics of biochar were 400kg/m^3 and 118 m^2 /g for bulk density and specific surface area respectively. It reveals that biochar were lighter and had high specific surface area compared to sand (1600 kg/m^3 bulk density and 0.156 m^2/g specific surface area). According to (Perez-Mercado, et al. 2018) findings from willow biochar with density of 320 kg/m^3 and sand 1690 kg/m^3 and the specific surface area also related to (Dalahmeh, et al. 2012) 105 m^2 /g and 0.136 m^2/g to biochar and sand respectively.

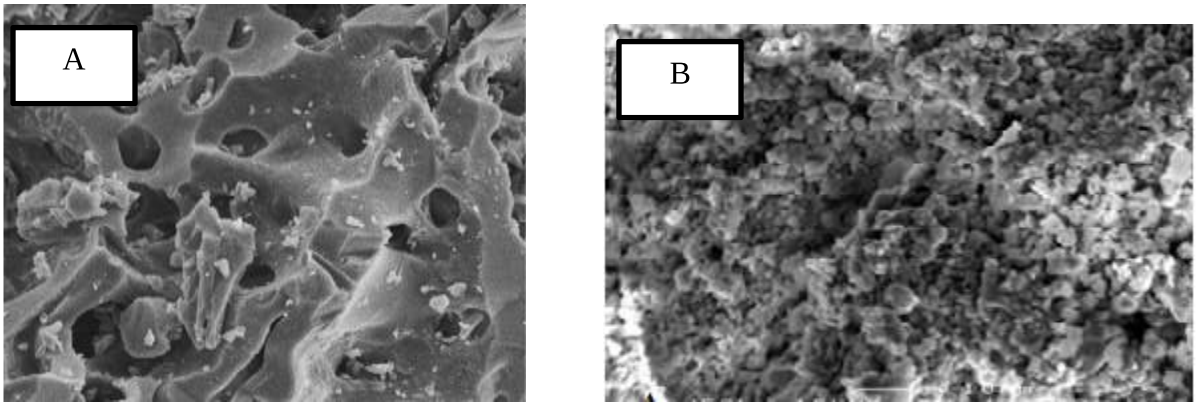


Figure 4.1 SEM image of A) FBC and B) sand

The other physical characteristics of biochar and sand was SEM analysis. As shown on figure 4.1 SEM image of biochar had random pore structure on the surface and pore appeared over the surface but sand particles had solid structure with limited occurrence of micropores. This means that a filter made of biochar would have better capacity to hold water in macropores than a sand filter also better capacity to form biofilm in the pores without clogging. Therefore, biochar can be more suitable surface conditions for bacterial attachment and biofilm development than, which lead to an efficient biological degradation of organic matter and nitrification (Huggins, et al. 2016).

4.4. Sand characterization

The sand selected for the experiment had effective grain size (d_{10}) and d_{60} of sand was 0.35 mm and of 0.9mm respectively as shown in Figure 4.2. According to Danish EPA guidelines (EPA 1999), d_{10} and d_{60} should be in range of 0.3–2.0 mm and 0.5 and 8 mm respectively, and uniformity coefficient (d_{60}/d_{10}) should be less than four, in order to secure an adequate hydraulic conductivity and to minimize clogging and (USEPA 2002) also recommended that UC less than four used for wastewater treatment. In this research the uniformity coefficient was 2.57, which had good hydraulic conductivity and stay for longtime without clogging. The larger the UC_s, the less uniform the sand, and the smaller sand particles can fill the spaces between the larger particles, making filter clogging easier at higher loading rates (Darby, et al. 1996).

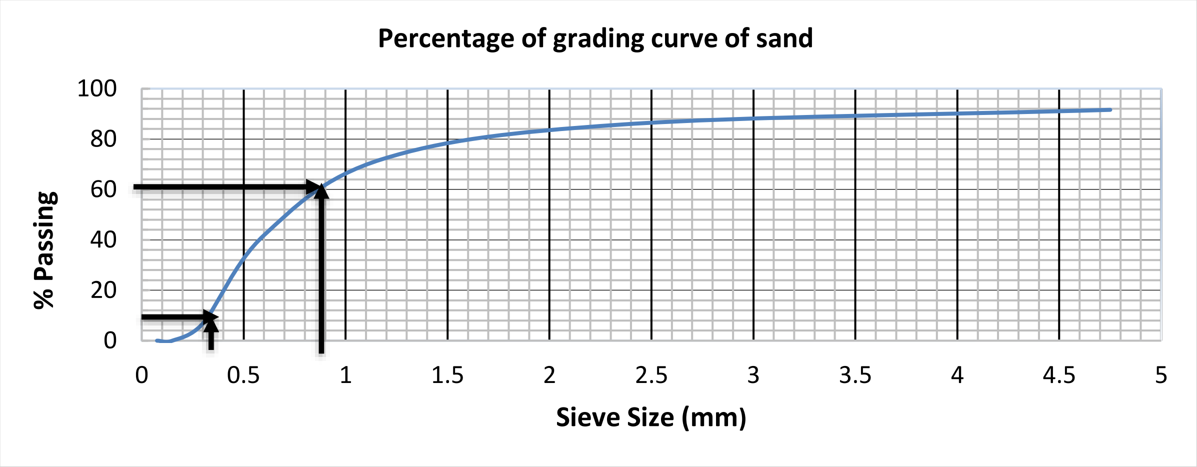


Figure 4.2 Particle size distribution curve of sand

4.5. Performance of FBC, MBC and CBC using SGW

The efficiency COD and turbidity by FBC, MBC and CBC at the last day of experiment were 84.1%, 53.8% and 48.3% and 84%, 82% and 66% respectively and recovery of N and P from SGW was 98 % ,24% and 19% and 75%, 32% and 18% for FBC, MBC and CBC respectively.

CBC and MBC particle sizes had lowest efficiency when compared to with FBC, due to large macropores in the filter. Under this condition, greywater passing through the filter media quickly (0.20cm^3/s and 0.17cm^3/s for CBC and MBC) without enough contact time between the filter media but in FBC filter media the average discharge was 0.17cm^3/s. Smaller size particle efficient in removing pollutants, due to high micropore which is used retain water for longer time (Mohanty and Boehm 2014, Kołodyńska, et al. 2012) and surface area of the biochar also key factor. Smaller particle size has large surface area which adsorption capacity effect (Fengfeng 2015) additionally, water path through media is shortened and it provides a better opportunity to make the absorbed ions penetrate all internal pore structure (Demirbas 2004).

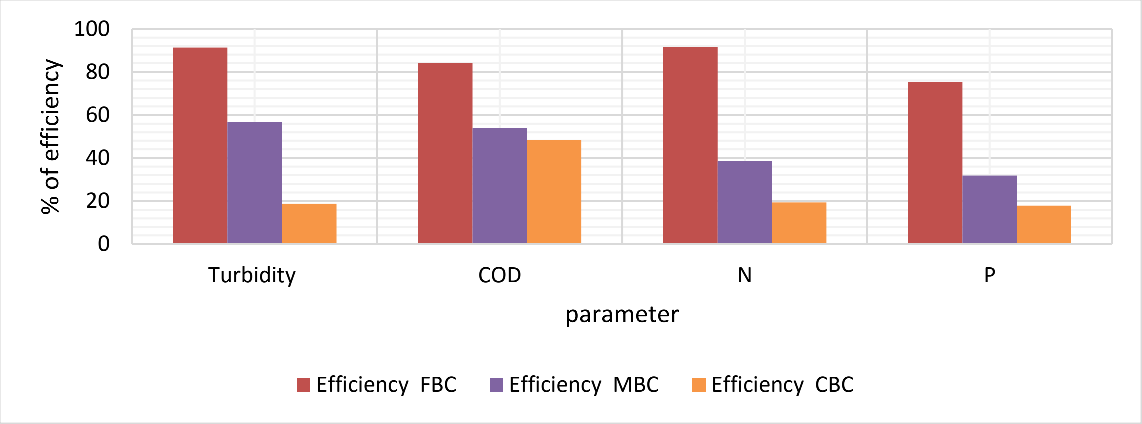


Figure 4.3 Efficiency of FBC, MBC and CBC using SGW

Table 4-3 Treatment of SGW by FBC MBC CBC size of banana peel biochar

parameter	SGW	after treatment		
		FBC	MBC	CBC
EC (µs/cm)	3.313	4.33	4.21	3.63
pH	9.01	9.87	9.37	9.14

As shown in Table 4-3 pH and EC value was 9.01 and 3.31µS/cm respectively, but after treatment of SGW by FBC, MBC and CBC the pH showed higher alkalinity; the pH values were 9.87 ,9.37 and 9.14 also, EC value rise 4.33 µS/cm,4.21 µS/cm and 3.63 µS/cm. This finding is related to with findings of (Streubel 2012, Amma 2017) who reported higher pH and EC value of effluent is due to the characteristics of biochar of the filter media and also smaller biomass particle size of biochar had higher pH and EC than other particles due to the residence time was longer.

4.6. Effect of pH on adsorption process using SGW

4.6.1. Effect of pH for N and P recovery

As shown on Figure 4.4 N removal increased within pH 5 - 7 (from 88 to 98.4%) and declined after pH 8(from 97.6% to 80.2%). high N removal was achieved when pH was 7.

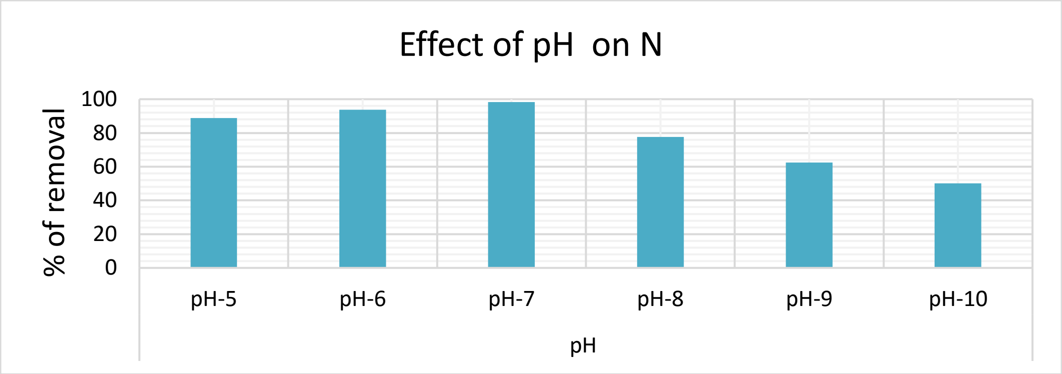


Figure 4.4 Effect of pH on N for SGW

This result was similar by (Godinia, et al. 2017) due to the absorbent surface has a negative charge and since N-ammonium is a cationic compound, results in electrostatic binding between absorbent and the pollutant would increase removal efficiency. On the other hand, the removal percentage efficiency for pH values of 5-7 increasing whereas the efficiency was less than for pH values of 8-10 this is due to absorbent surface creates a repellent force between the FBC and cationic pollutant and consequently decreases the efficiency.

In a study which was conducted by (Zheng, et al. 2008) on ammonium nitrogen absorption, using composite hydrogel, highest absorption capacity observed in pH 4-8. (Shi 2013) studied the N ammonium removal, using activated carbon modified with sodium (Na+) and concluded that an optimum NH_4-N removal efficiency obtained in neutral pH conditions.

According to (Chen K 2013, Meng S 2013) report While the amount of NH_4^+ in the solution was depended on the pH of the solution. When pH is below 8, NH_4^+ ion concentration in solution rose with decrease of pH value, while H^+ concentration increased with the drop in the pH which would have a negative influence on the NH_4^+ exchange (Saltalı 2007) When pH is over 8, NH_4^+ was converted into NH_3 which is gaseous form of N. And also, this result of N was similar to (Saltalı 2007) they reported that the optimum NH_4^+ N remove efficiency was achieved at pH 8.

Therefore, the removal of NH_4^+ is supposed to be higher at low pH, and vice versa, due to the cation exchange mechanism in aqueous solution However, ammonium removal dramatically decreases at pH < 5 because of H^+ competition (Demir 2002).

Phosphate removal by biochar was observed at pH values ranging between 5 and 10. Figure 4.5 shows that as the solution pH increases in the range of 5–7, the removal efficiency of phosphate increased gradually and attains a maximum value (82.7%) when the pH value was 7. However, when the pH increases to between 8 and 10, the removal efficiency drops to 63.6%

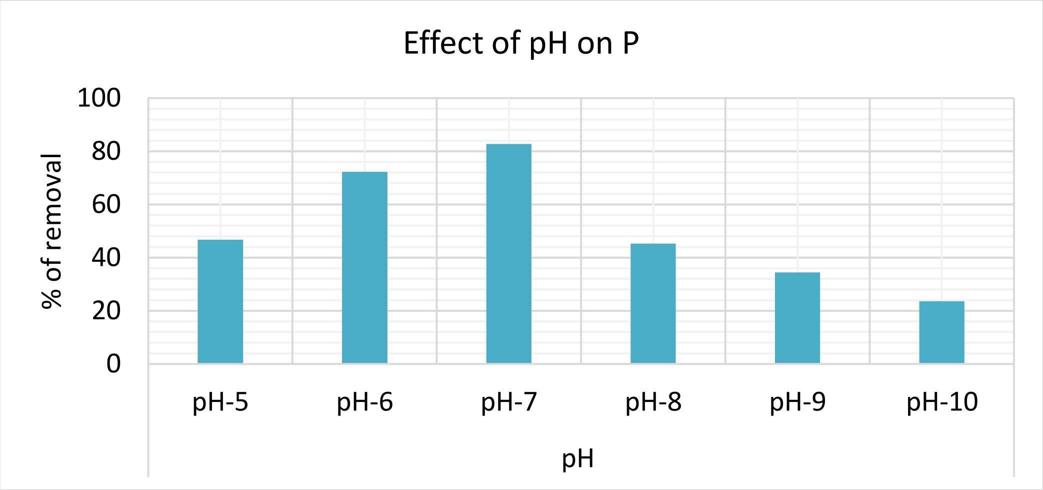


Figure 4.5 Effect of pH on P for SGW

Similar results were reported by (Zhou 2005), the absorption of anions like phosphate decreases with the increase of pH and surface charge becomes more negative. The surface of the adsorbent became positively charged in acidic medium and negatively charged in alkaline medium. Phosphate ions are negatively charged and it appears that there are repulsion forces between ions and the negatively charged adsorbent surface in alkaline medium because of that abundance of (OH)- ions and it appears that there are repulsion forces between phosphate ions($H_2PO_4^-$, HPO_4^{2-} and PO_4^{3-}) and the negatively charged adsorbent surface (Subha 2015, Yao, et al. 2011, Zhang, et al. 2009, Zhang, et al. 2010).

As shown on Figure 4. 5 the phosphate adsorption was low at pH 5 (46.7%); when the pH increased from 5 to 7. According to (Berkessa 2019) finding low phosphate removal at pH< 5 could be due to predominant H_3PO_4, which is attached to the sites of the adsorbent and disable the adsorbent to attach on surface.

4.6.2. Effect of pH on COD

Figure 4.6 depicts the effect of pH on COD removal. The COD removal capacity of FBC had achieved high at pH value of 5 up to 7 then decreased as the pH was increased from 8 up to 10. At pH 7 high percentage uptake of COD with the value of 88% removal was achieved.

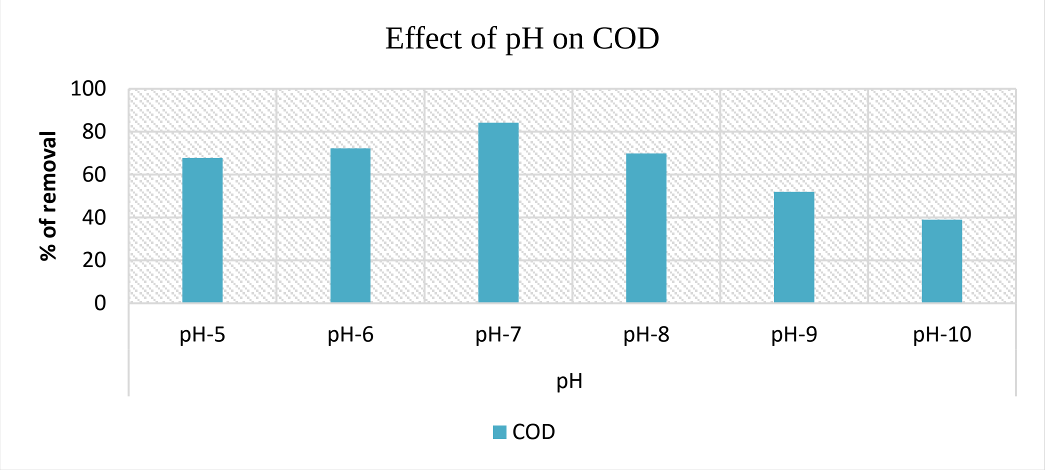


Figure 4.6 Effect of pH on COD for SGW

Similar result found optimum pH at 7 and a fall in removal capacity afterwards was observed in the COD from wastewater of coffee processing plant (Ashok 2008, Rani 2010) and sugar industrial effluent (Parande, et al. 2009) . However, a slight enhancement in COD adsorption for pH values ranging from 7.5 to 8 was observed (Muftah, et al. 2010) and also, maximum COD removal was observed at pH 5.5 – 7.0 using activated coconut shell and industrial grade granular activated carbon respectively (Mahesh et al., 1999).

According to (Andal and Charulatha 2014) one the removal of COD at lower pH levels, was sharply increased because the positively charged functional groups of organic molecules bind through electrostatic attraction to the negatively charged of the surface of the adsorbent. On another hand, at higher pH the reduction in adsorption due to the increase of hindrance to organic ions diffusion because of that the abundance of (OH)- ions leads to repulsion between the organic molecules and the surface of the adsorbent. Similar observations have also been reported by the researchers (Ghodale and Kankal 2014, Miranda 2017, Sarkar 2006, Yakout, et al. 2017).

4.6.3. Effect of pH on turbidity removal

Figure 4.7 shows the graphical representation of turbidity removal percentage, it was observed that the removal of turbidity was increased with the increase in solution pH. After the pH of 7 the removal of turbidity was decreased with the increase in solution pH. The maximum removal efficiency of turbidity at pH 7 was 86.8%.

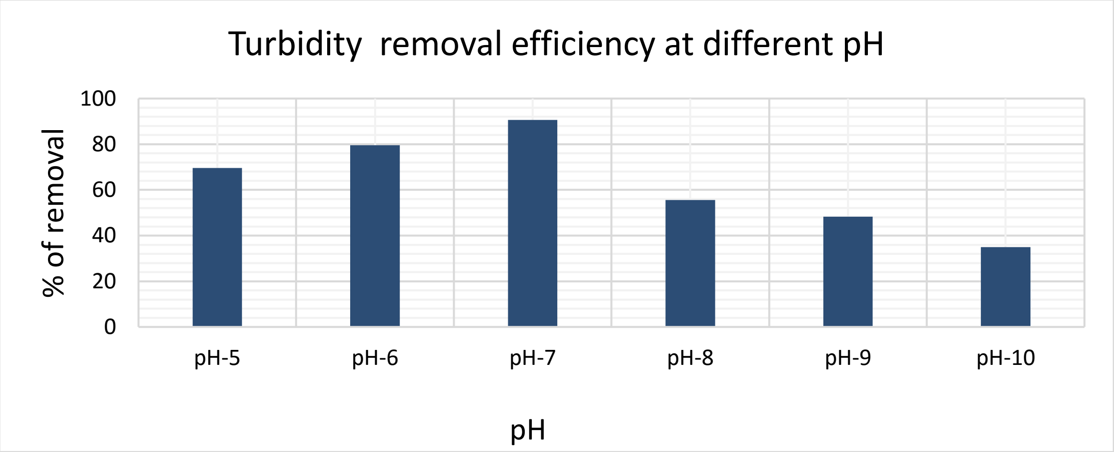
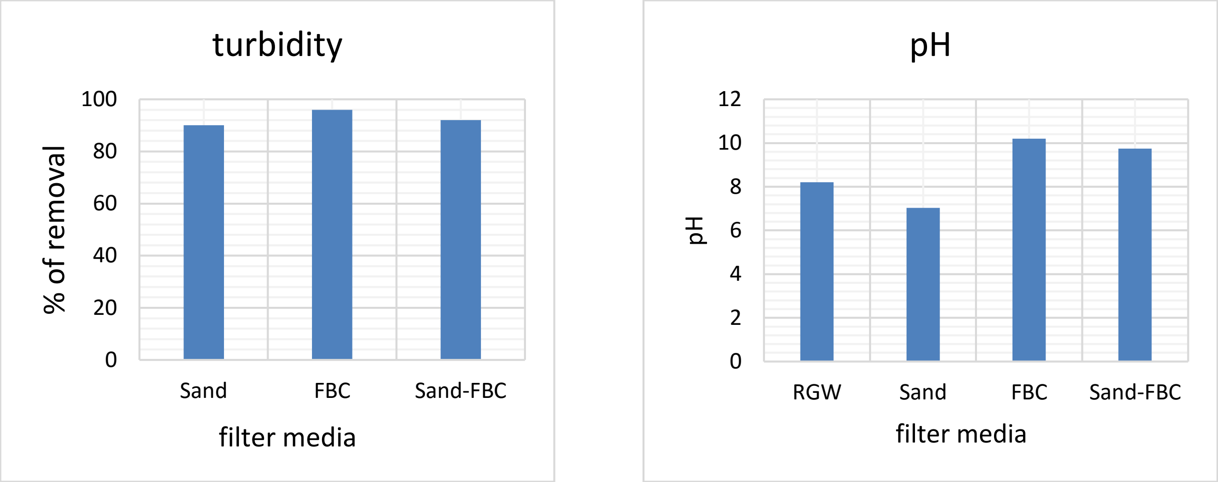


Figure 4.7 Effect of pH on turbidity removal for SGW

This result was similar with (Kumar, et al. 2018) at low pH, the less removal was observed because of the competition between the hydronium ions and the ions in the water samples towards the surface of the adsorbent. When the pH was increased from the lower value then the competition between the hydronium ions and the ions in the solution was found to be less which makes more ions in the solution move towards the surface of the adsorbent due to the electrostatic attraction. At higher pH, the electrostatic repulsion between the ions in the solution and the functional groups on the surface of the biochar was observed.

4.7. Comparison of FBC, FBCS and sand using RGW

Turbidity reduction was 96%, 90% and 92% for FBC sand and FBCS respectively and pH value of RGW effluent was declining for sand filter but it rises by FBC and FBCS. The reduction percentage of pH for sand was 14% but the pH of effluent was rise up to was 24% and 19% FBC and FBCS respectively.



(a) (b)

Figure 4.8 (a) percentage removal of turbidity, (b) pH from RGW

The removal efficiency of N as ammonium in each media are shown Figure 4.9. The results show that the ammonium concentration in the effluent from three media were vary. The recovery of FBC, sand and FBCS was 99%, 32% and 72% respectively.

Figure 4.9 shown the recovery of phosphate from RGW by using FBC, sand and FBCS filter media. Effluent from sand and FBCS had higher phosphate concentration than that from the FBC media. The recovery of phosphate was 85%, 66% and 67% respectively. And the COD removal during experiment were71%, 58% and 47% and fecal coliform removal was 90%, 80% and 87% for FBC, sand and FBCS respectively.

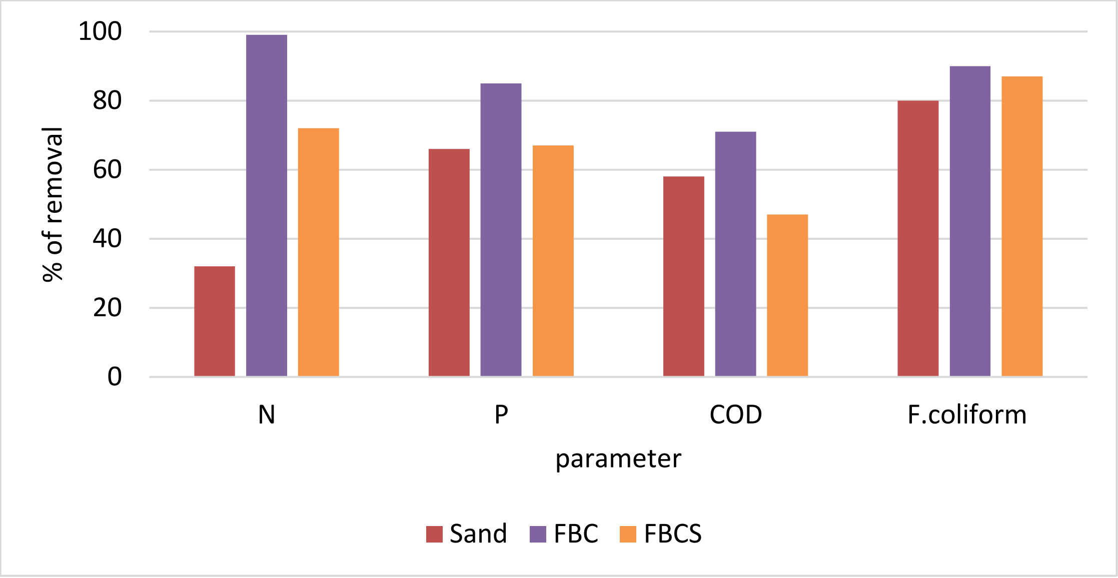


Figure 4.9 removal percentage of N, P, COD and fecal coliform from RGW

Sand filtration systems are biofilm driven processes that create conditions suitable for the biodegradation and mineralization of organic matter and the assimilation of nutrients by diverse microbial populations. Various researchers investigated the effectiveness of sand filters for treatment of wastewater at laboratory scale, and suggest that sand filters are capable of removing turbidity up to 88%. (Farooq and Al-yousef 1993) conducted a pilot study using slow sand filtration with effective sand sizes of 0.31 and 0.56 mm for the treatment of secondary chlorinated effluents, and achieved 50-67% COD removal, this paper of finding is not far from the above literature, the turbidity removal is 90% and COD removal was 58%. The COD reduction by the biochar filter was 73% and sand 58% reported by (Kaetzl, et al. 2018) by biochar made from coconut shells with column experiment.

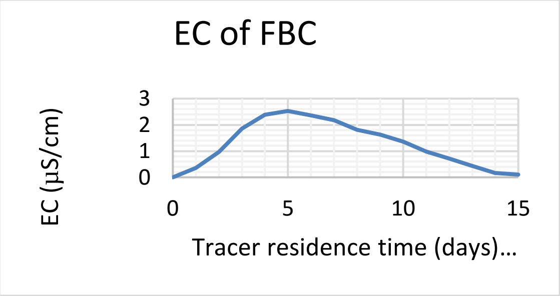
The concentration turbidity, N and P in the effluent from the FBCS media was consistently lower that in the sand media which indicates that as the finding of (Hanandeh 2017) the addition of biochar had positive effect on the capacity of the media to remove phosphate and ammonium. But in case of COD that the addition of biochar to sand did not have adverse effect on the media. fecal coliform obtained by (Yogafanny 2014) ranged between 87.6 – 89.9%%by sand having UC coefficient of 2 and biochar remove fecal coliform up to 90-99% as finding of (Berger 2012).

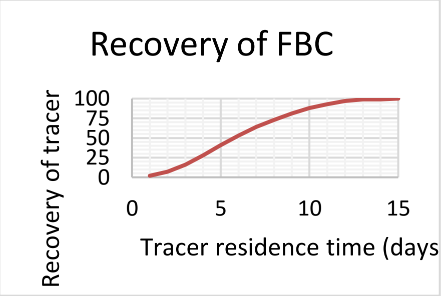
In general, FBC had high efficiency than FBCS and sand except the rising of pH. This is due to different characteristics such as porosity, specific surface area and reactivity, adsorption capacity and ability to promote biofilm development for biological breakdown of organics (Rolland et al., 2009). Biochar filters are characterized by large specific surface and high porosity, which provides better absorption capacity and thus achieves a greater reduction of pollutants from start-up compared with sand. FBC had a specific surface area of 118 m^2/g and sand had small surface area of 0.156 m^2/g. This indicate that the velocity trough FBC is slow than sand, and it had higher residence time, this resulted high efficiency for FBC filter.

In addition, filtration mechanism of biochar depend the characteristics of large specific surface areas and rich pore structures enhance the physical adsorption capacity of biochar, and the rich pore structures help to adsorb the organic matter with the same molecular weight. And also, electrostatic attraction ability on the surface of biochar plays a very important role in the adsorption of pollutants (Demirbas 2004). The surface electricity of biochar is negative, so it has a good adsorption performance for positive ions (Cantrell, et al. 2012). But in case of sand media filter physical filtration is the main removing mechanism of impurities by mechanical straining and chemical filtration also happen when oxidation of organic matter by aerobic bacteria also biological filtration happen when biofilm occurred (Weber-Shirk and Dick 1997).

4.8. Residence time

The biochar filters had the longest mean hydraulic residence time among sand and FBCS filters (biochar 6.1 days, sand 3.6 days and FBCS filters 5.1 days). The longer retention time in the biochar can be attributed to its high water-holding capacity and high porosity. A long hydraulic residence time extends the duration of contact between wastewater and biofilm, which in turn increases the probability of organic matter degradation or nitrification.





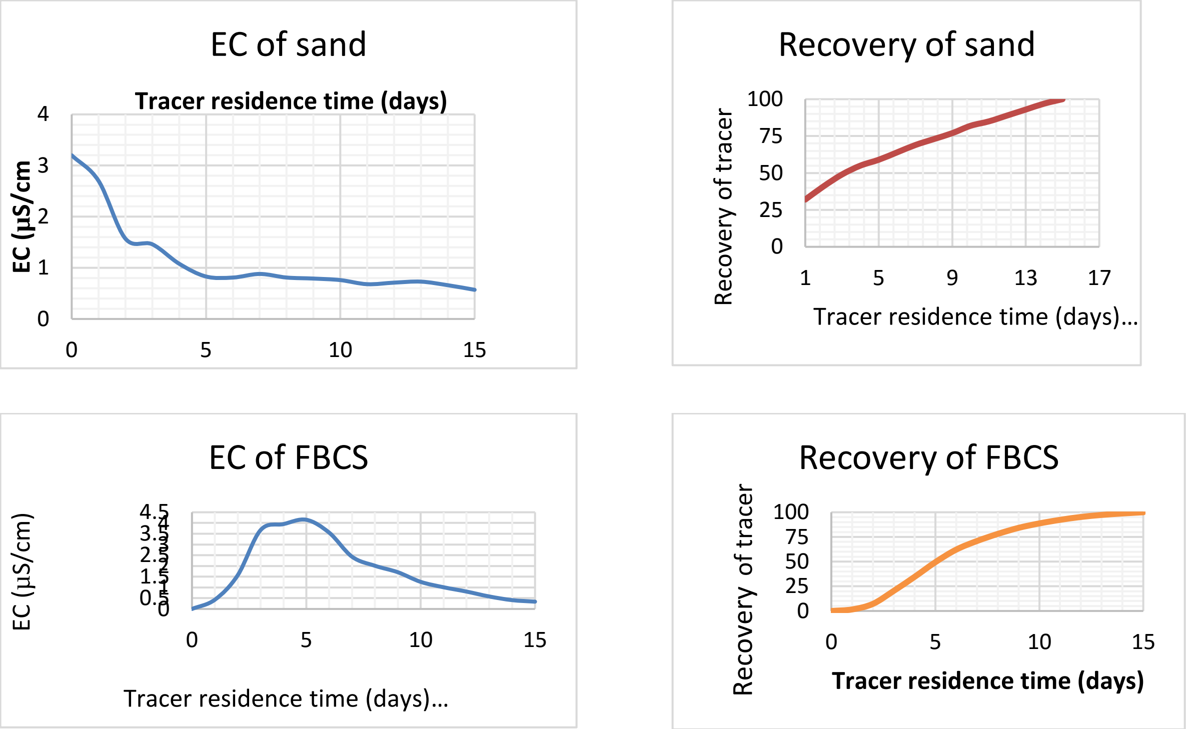
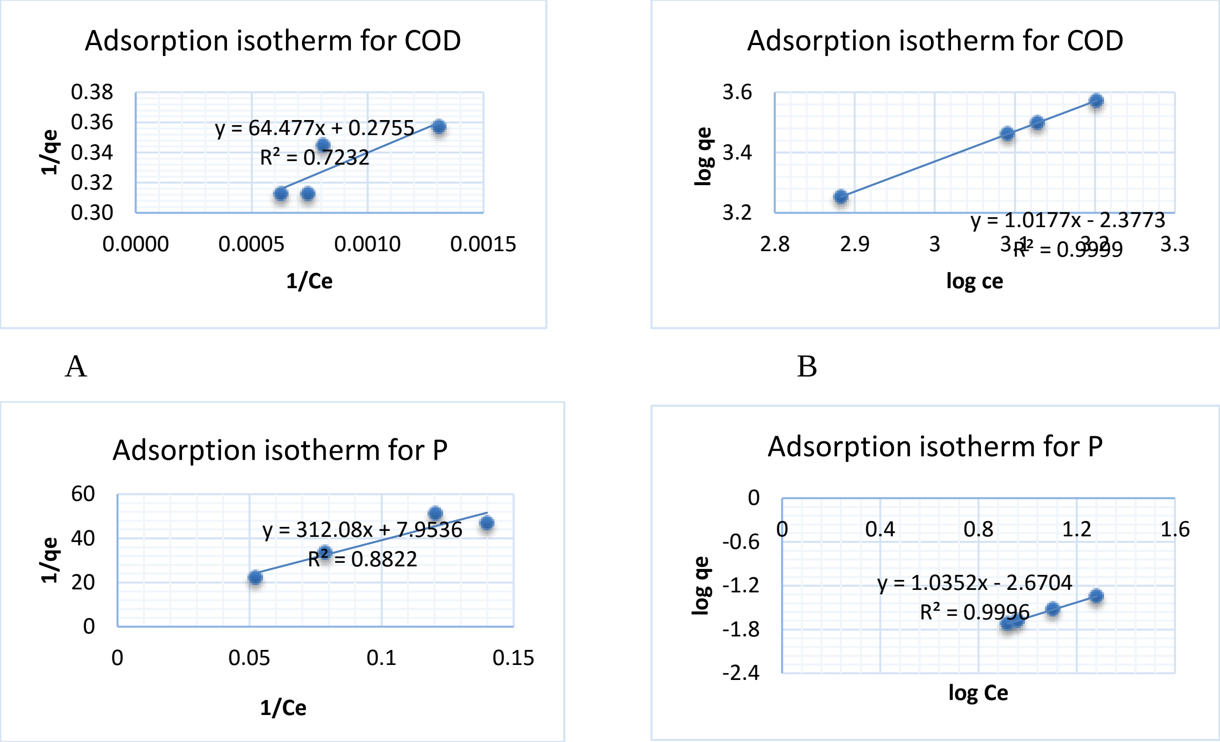


Figure 4.10 Response curves of FBC, sand and FBCS to addition of NaCl measured as electric conductivity (EC) in the filter effluent and hydraulic residence time and percentage recovery of tracer (mean value) after adding a pulse of NaCl tracer

In this study, FBC have a higher proportion of micropores than sand as shown on SEM image and also the specific surface area of FBC were higher than sand. This was supported by the observed differences in hydraulic retention time between the materials. Water flow takes place mainly in the smallest pores, reducing the water velocity and increasing the retention time. Higher specific surface and retention time increase the contact opportunities between contaminants and biofilm/adsorption sites, leading to better pollutant removal performance than in other materials with less specific surface and porosity (Stevik, et al. 2004).

4.9. Adsorption Isotherms

Figure 4.11 show Langmuir and Freundlich adsorption isotherms for COD and P parameters from RGW and also Table 4-4 shows the values of corresponding isotherm parameters, their correlation coefficients (R^2) for each parameter. In Figure 4.11 high R ^{2} value were obtained by fitting experimental data into the Freundlich isotherm model both for COD and P ($R^2 > 0.999$ for COD and $R^2 > 0.9996$ for P). Therefore, the mechanism of COD and P uptake by biochar as adsorbent process at the active sites are well distributed throughout the banana peel with a maximum adsorbed capacity of 4.1 mg/ g of COD and 0.046 of mg/ g of P



A

B

C

D

Figure 4.11 (A) Langmuir isotherm model for COD (B) Freundlich isotherm model for COD (C) Langmuir isotherm model for P and (D) Freundlich isotherm model for P

Table 4-4 Langmuir and Freundlich adsorption parameters for COD and P

	Model					
	Langmuir			Freundlich		
parameter	qm (mg g-1)	KL (L/mg)	R^2	KF (mg/ g)	1/n (L/ mg)	R^2
COD	2.9	3.629	0.7232	4.1	0.98	0.99
P	0.038	0.126	0.8822	0.046	0.96	0.99

5. Conclusion and Recommendation

5.1. Conclusion

Greywater accounts large volume of domestic wastewater. In many developing countries, it is disposed into the environment without treatment and this might cause ecological problems. There are different methods for treatment of greywater. Sand has been used for long time in central treatment plant however it requires high investment cost, biochar from banana peel can be an alternative which is abundant and easily accessible by community.

In this study SGW and RGW had been used and the biochar was produced from banana peel with three different particle size and FBC had showed good efficiency in removing an average performance of 88% for turbidity 54.8% for COD,62.2% for N and 52% for P respectively but in three particle size EC and pH was rising from the SGW influent. The effect of pH on FBC was investigated by changing pH value of SGW and the result showed that the highest removal of turbidity (89%), COD (55%), N (94%) and P (78.8%) were achieved at pH value of 7. In comparison of FBC, FBCS and sand using RGW in different parameters, FBC has been effective with an average reduction of, 95% for turbidity, 81% for N 71% for P, 61% for COD and 90%, 80% and 87%for fecal coliform

Over the entire experiment, effectiveness of the FBC, FBCS and sand filters in turbidity, COD, nitrogen and phosphorus reduction improved during the experiment, however removal efficiency of FBC filter was high due to the high adsorption capacity, it is also potentially able to remove organic and inorganic substances from greywater and contribute to a safer environment by reduction of organic waste and improved greywater quality.

5.2. Recommendation

This study was done at laboratory scale using vertical columns using banana peel biochar. However, the work reported in this paper has some limitation to show the full profile of the effectiveness of banana peel biochar. Therefore, it is recommended that further studies to be done, by increasing the working time of laboratory for several weeks and check the removal efficiency and to analyze the effect of depth on treatment process. It is also recommended that to scale up the laboratory test to pilot scale and on-site treatment. Further studies have to be done for the contaminants, such as $BOD_{5,}$ TDS and pathogen indicators in regards to how long the cleaning capacity of biochar lasts and how the performance of the filter changes under this time using high loaded greywater. And also compare the performance different biomass of biochar used for filter materials.

References

AASBPDA, Addis Ababa City Sanitation, Beautification and Park Development Agency. 2003. "Current Status of Dry Waste Management in Addis Ababa." *Unpublished material.*

Abdel-Shafy, H.I. El-Khateeb,M.A. Shehata, M. 2013. "Desalination and Water Treatment : Greywater treatment using different designs of sand filters."

Ahmadvand, m., Soltani, J., Garmdareh, S.E.H., Varavipour, M. 2018. "The relationship between the characteristics of Biochar produced at different temperatures and its impact on the uptake of NO3-N." *Environmental Health Engineering and Management Journal* 5: 67-75.

Ajit, K. 2016. "A Review on Grey Water Treatment and Reuse." *International Research Journal of Engineering and Technology (IRJET)* 3 (05).

Al-Jayyousi, OR. 2003. "Greywater reuse: towards sustainable water management." *Desalination* 156: 181-192.

Al-Jayyousiy, O.R. 2002. "Focused environmental assessment of greywater reuse in Jordan. Environmental Engineering Policy." 67–73.

Allen, L. Christian,S.J. Palaniappan,M. 2010. *Overview of Grey water Reuse: The Potential of Grey water Systems to Aid Sustainable Water Management.*

Almoayied Assayed, Jonathan Chenoweth and Steven Pedley. n.d. *Drawer compacted sand filter: A new and.*

Alsulaili, A. D., and M. F. Hamoda. 2015. "Quantification and characterization of greywater from schools." *Water Science & Technology* 1973-1980.

Amma, A.,Gharaibeh, Hanandeh, A. 2017. "Phosphorus removal from wastewater in biofilters with biochar augmented geomedium: Effect of biochar particle size."

Amutio, M,, G. Lopez, M. Artetxe, G. Elordi, M. Olazar, and J. Bilbao. 2012. " Influence of temperature onbiomass pyrolysis in a conical spouted bed reactor." *Resour Conserv Recy 59* 59: 23–31.

Andal, N.M., and S Charulatha. 2014. " Efficacy of Agricultural Wastes in the Removal of Hexavalent Chromium- A Review." *Research and Reviews Journal of Chemistry* 2: 1 - 5.

Angın, D., and S. Sensoz. 2014. "Effect Of Pyrolysis Temperature On Chemical And Surface Properties Of Biochar Of Rapeseed (Brassica Napus L.)." *International Journal of Phytoremediation* 16: 684-693.

Antal, MJ., and M. Grønli. 2003. " The art, science and technology of charcoal production." *Industrial and Engineering Chemistry Research* 42: 1619–1640.

Arias, C. A., Del, B. M., Brix, H. 2001. " (2001). Phosphorus removal by sands for use as media in subsurface flow constructed reed beds." *Water Research, 35(5),* 35: 1159–1168.

Ashok, K.,Rani, Vijender,. 2008. "COD and BOD reduction from coffee processing wastewater using Avacado peel carbon." *Bioresource Techn* 99: 1853–1860.

Assayed, A. Chenoweth J., and Pedley S. 2015. "Assessing the efficacy of an innovative method for onsite greywater treatment: Drawer compacted sand filter - A case study in Jordan.)." *Ecological Engineering* 81: 525-533.

Assayed, A., Jonathan, C. Pedley, S. 2014. "Drawer compacted sand filter: A new andinnovative method for on-site grey water traetment." *Environmental Technology* 35: 2435-2446.

Balakrishnan, B., and M.R. Rahman. 2018. "Bod And Cod Reduction From Synthetic Sugar Industry Wastewater." *International Research Journal of Engineering and Technology (IRJET)* 4: 444-453.

Berger, C. 2012. "Biochar and activated carbon filters for greywater treatment – comparison of organic matter and nutrients removal." *Thesis for a Master's degree in EnvEURO. Swedish University of Agricultural Sciences, Department of Energy and Technology, Uppsala.* (Swedish University of Agricultural Sciences).

Berkessa, Y., Mereta,S. Feyisa,F. 2019. "Simultaneous removal of nitrate and phosphate from wastewater using solid waste from factory ." *Applied Water Science* 1-10 .

Beven, K., and P. Germann. 1982. "Macropores and water flow in soils." *Water Resources Research* 18: 1311-1325.

Bhausaheb, L. Pangarkar, Saroj, B. , Parjane, Sane M.G. 2010. "Design and Economical Performance of Gray Water Treatment Plant in Rural Region." *International Journal of Civil and Environmental Engineering.*

Birks, R. Colbourne, J. Hills, S. Hobson, R. 2004,. "Microbiological water quality in a large in-building, water recycling facility." *Water Science and Technology* 50 (2): 165-172.

Boller, M., Schwager, A., Eugster, J., V, M. 1993. "Dynamic bahavior of intermittent buried filters." *Water Science & Technology* 28: 99-107.

Bouwer. 2000. "Integrated water management: emerging issues and challenges." *Agricultural Water Management* 45: 217–228.

Boyjoo, Y., Pareek, V. K., Ang, M. 2013. " A review of greywater characteristics and treatment processes." *Water Science and Technology* 67: 1403–1424.

Cantrell, KB., PG. Hunt, M. Uchimiya, JM. Novak, and KS. Ro. 2012. " Impact of pyrolysis temperature and manure source on physicochemical characteristics of biochar." *Bioresource Technology* 10: 419–428.

Casanova, L.M., Gerba, C.P. ,Karpiscak, M.,. 2001. " Chemical and microbial characterization of household graywater." *J. Environ. Science Health* 36: 395 – 401.

Cengeloglu, Y., A. Tor, M, Ersoz, and G. Arslan. 2006. "Removal of nitrate from aqueous solution by using red mud." *Sep Purif Technol* 51: 374–378.

Chaillou, K., C. Gérente, Y. Andres, and D. Wolbert. 2011. "Bathroom Greywater Characterization and Potential Treatments for Reuse." *Water, Air, & Soil Pollution* 215: 31-42.

Chen K, Zhao K, Zhang H, Sun Q, Wu Z, Zhou Y,. 2013. "Phosphorus removal from aqueous solutions using a synthesized adsorbent prepared from mineralized refuse and sewage sludge." *Environmental Technology :* 34: 1489–1496.

Chen, B., and Z. Chen. 2009. "Sorption of naphthalene and 1-naphthol by biochars of orange peels with different pyrolytic temperatures." *Chemosphere* 76: 127–133.

Cheru, M. 2016. "Solid Waste Management in Addis Ababa A new approach to improving the waste management system." *Thesis for Bachelor of Engineering Degree Program in Environmental Engineering, Helsinki Metropolitan University of Applied Sciences.*

Chiou, M. S., and H. Y. Li. 2002. "Equilibrium and kinetic modeling ofadsorption of reactive dye on crosslinked chitosan beads." *Journal of Hazardous Materials* 64: 231-241.

Cruz, C. C. V., A. C. A. Da Costa, C. A. Henriques, and A. S. Luna. 2004. "Kinetic modeling and equilibrium studies during cadmium biosorption by dead Sargassum sp. biomass." *Bioresources Technology* 913: 249-257.

CSBE, Centre for the Study of the Built Environment. 2003. *Graywater Reuse in Other Countries and its Applicability to Jordan.*

Cui, and G., Ren. 2005. "Pilot study of process of bathing wastewater treatment for reuse."

Dalahmeh, S., P. Mikael, V. Bj örn, D. Lars, I. Ander, and O. Jönsson. 2012. "Efficiency of Bark, Activated Charcoal, Foam and Sand Filters in Reducing Pollutants from Greywater." *Water Air Soil Pollut.*

Dallas, S. Scheffe, B. Ho, G. 2004. "Reedbeds for greywater treatment – Case study in Santa Elena-Monteverde, Costa Rica, Central America." *Ecological Engineering* 23(1): 55-61.

Darby, J., G. Tchobanoglous, M. Asri Nor, and D. Maciolek. 1996. "Shallow intermittent sand filtration:performance evaluation." *Small Flows Journal* 2: 3-15.

Day, P.R. 1965. " Particle fractionation and particle-size analysis. In Methods of Soil Analysis." 545–567.

Del Porto, D. and Steinfeld, C. 2000. "What about Graywater, The composting toilet system book. Massachusetts The Center for Ecological Pollution Prevention (CEPP)." 167-193.

Del Porto, D., and C. Steinfeld. 2000. "What about Graywater, The composting toilet system book. Massachusetts The Center for Ecological Pollution Prevention (CEPP),." 3: 167-19.

Demir, A., Günay, A. & Debik, E. 2002. "Ammonium removal from aqueous solution by ion-exchange using packed bed natural zeolite." *Water SA 28(3),* . 28: 329–336.

Demirbas. 2004. "Effects of temperature and particle size on bio-char yield from pyrolysis of agricultural residues." *J. J Anal Apply Pyrolysis* 8-243.

Demirbas, A., and G. Arin. 2002. "An Overview of Biomass Pyrolysis." *Energy Sources* 25 (5): 471 –482.

Downie, A., Krosky, A., Munroe, P. 2009. "Physical Properties of Biochar." *In Biochar for Environmental Management Science and Technology.*

EBC, European Biochar Certificate. 2018. "European Biochar Foundation—European Biochar Certificate—Guidelines for a Sustainable Production of Biochar." *European Biochar Certificate (EBC):Arbaz* 1-27.

Edwin, G. A., Gopalsamy, P., Muthu, N. 2014. "Characterization of domestic gray water from point source to determine the potential for urban residential reuse: a short review." *Applied Water Science* 4: 39–49.

Environment Agency. 2011. *Greywater for domestic users: an information guide.*

EPA. 1999. "Rodzoneanlæg op til 30 PE. Environ Guidelines."

EPA, United States Environmental Protection Agency. 2007. "Membrane Bioreactors, Wastewater Management Fact Sheet."

Eriksson, E., K. Auffarth, M. Henze, and A. Ledin. 2002. "Characteristics of grey wastewater. Urban Water." 4(1): 85-104.

Farooq, S., and A.K. Al-yousef. 1993. "Slow sand filtration of secondary effluent." *J. Environ. EngASCE.* 119: 615–630.

Fengfeng, M., Baowei,Z., Jingru, D. 2015. " Ammonium Adsorption Characteristics in Aqueous Solution by Dairy Manure Biochar." *J. Environmental Science* 36: 1678-1685.

Ferrari, L., J. Kaufmann, F. Winnefeld, and J. Plank. 2010. "Interaction of cement model systems with superplasticizers investigated by atomic force microscopy, zeta potential, and adsorption measurements." *J Colloid Interface Sci* 347: 15–24.

Friedler. 2004. "Quality of individual domestic gray water streams and its implication for on-site treatment and reuse possibilities." *Environ Technol* 25(9): 997–1008.

Gao, F Y. Xue, P. Deng, X. Cheng Yang. 2015. "Removal of aqueous ammonium by biochars derived from agricultural residues at different pyrolysis temperatures." *Chemical Speciation and bioavailability* 27: 92-97.

Ghisi, E., and D.F. Ferreira. 2007. "Potential for potable water savings by using rainwater and greywater in a multi-storey residential building in southern Brazil." 42: 2512–2522.

Ghodale, M., and S. Kankal. 2014. "Investigation of Optimum Operating Parameters for BOD and COD Removal using Activated Carbon." *IJRDET* 2: 38-43.

Glaser, B., Lehmann, J. and Zech, W. 2002. "Ameliorating physical and chemical properties of highly weathered soils in the tropics with charcoal - A Review." 35 (4): 219–230.

Godinia, H., A. Dargahib, M. Mohammadic, GS. Khorramabadid, A, Azizie, L. Tabandehc, and Z. Jaliliand. 2017. "Efficiency of Powdery Activated carbon in Ammonia-Nitrogen Removal from Aqueous Environments (Response Surface Methodology)." *Arch Hyg Sci* 6: 111 -120.

Golda, A. Edwin, Poyyamoli, G. Nandhivarman, M. 2014. "Characterization of domestic gray water from point source to determine the potential for urban residential reuse: a short review." 4: 39–49.

Gray, N.F. 2010. "an Introduction to Environmental Scientists and Engineers, 3rd ed." London: Elsevier.

Gross, A., Kaplan, D., and Bake, K. 2007. "Removal of chemical and microbiological contaminants from domestic grey water using a recycled vertical flow bioreactor (RVFB)." *Ecological Engineering* 31: 107–114.

Gupta, V. K., Rastogi, A., Nayak, A. 2010. "Biosorption of nickel onto treated alga (Oedogonium hatei): Application of isotherm and kinetics models." *Journal of Colloid and Interface Science* 342: 533-539.

Hanandeh, Bhuvaneswaran, Rozari. 2017. "Removal of nitrate, ammonia and phosphate from aqueous solutions in packed bed filter using biochar augmented sand media." *MATEC Web of Conferences 120 , 05004* 1-7.

Hassan, M. A. A., and M. H. Puteh. 2007. " Pre-Treatment of Palm Oil Mill Effluent (Pome): A Comparison Study Using Chitosan and Alum." *Malaysian Journal of Civil Engineering* 19: 38-51.

Hernandez, L., Zeeman, G., Temmink, H., Buisman, C,. 2007. "Characterisation and biological treatment of greywater." *Water Sci. Technol* 56: 193–200.

Hesas, Rh., A. Arami-Niya, D. Wmaw, and Jn. Sahu. 2013. "Preparation And Characterization Of Activated Carbon From Apple Waste By Microwave-Assisted Phosphoric Acid Activation: Application In Methylene Blue Adsorption." *Bioresources* 8: 2950-2966.

Ho, Y. S., and G. Mckay. 2000. "The kinetics of sorption of divalent metal ions onto sphagnum moss peat." *Water Resources,* 34: 735-742.

Hong, D,A., M. Berg, H.H Minh, V. Pham, G. Hervé, W. Walter, and V.U Urs. 2003. "Trihalomethane Formation by Chlorination of Ammonium- and Bromide-Containing Groundwater in Water Supplies of Hanoi, Vietnam." *Water research* 37: 3242-3252.

Hossain, M.K., Strezov. V., KY. Chan, A. Ziolkowski, and PF. Nelson. 2011. "Influence of pyrolysis temperature on production and nutrient properties of wastewater sludge biochar." *J Environ Manage* 92: 223–228.

Huggins, T.M., A. Haeger, J.C. Biffinger, and Z.J Ren. 2016. "Granular biochar compared with activated carbon for wastewater treatment and resource recovery." *Water Res.* 94: 225–232.

Huhn, L. 2015. *GREYWATER TREATMENT IN SAND AND GRAVEL FILTERS Low Tech Solution for Sustainable Wastewater Management Manual for Design, Construction, Operation and Maintenance.*

Ismail, Z., S. Ellias, R.M. Tajuddin, I. Atan, Y. Ashaari, I.R. Endut, and A. Baki. 2011. "Alternative Water Resources or Sustainable Buildings."

Jamaluddin, M.A., K. Ismail, M.A. Mohd Ishak, Z. Ab Ghani, M.F. Abdullah, M.T. u. Safian, S.S. dris, S. Tahiruddin, M.F. Mohammed Yunus, and N.I.N., Mohd Hakimi. 2013. "Microwave assisted pyrolysis of palm kernel shell: optimization using response surface methdology (RSM)." *Renew Energy* 55: 357-365.

Jefferson, B., A. Palmer, P. Jeffrey, R. Stuetz, and S. Judd. 2004. "Grey water characterisation and its impact on the selection and operation of technologies for urban reuse." *Water Science and Technology* 50: 157-164.

Jefferson, Pedol, F. Memon, T. Stephenson, and P. Jeffrey. 2008. "Grey water recycling: Treatment options and applications. Proceedings of the Institution of Civil Engineers Engineering Sustainability." 160: 119–131.

Jindarom, C., V. Meeyoo, B. Kitiyanan, T. Rirksomboon, and P. Rangsunvigit. 2007. " Surface characterization and dye adsorptive capacities of char obtained from pyrolysis/gasification of sewage sludge." *Chem Eng J* 133: 239–246.

Joseph, J., and S. Lehmann. 2015. "Biochar for environmental management: an introduction Biochar for environmental management: Science, technology and implementation." 2-11.

Kaetzl, K, M. Lübken, T. Gehring, and M. Wichern. 2018. "Efficient Low-Cost Anaerobic Treatment of Wastewater Using Biochar and Woodchip Filters." *Water* 10: 1-17.

Katal, R., MS. Baei, HT. Rahmati, and H. Esfandian. 2012. " Kinetic, isotherm and thermodynamic study of nitrate adsorption from aqueous solution using modifed rice husk." *J Ind Eng Chem* 18: 295–302.

Khalaphallah, Rafat. 2012. "Greywater treatment for reuse by slow sand fitration :study of pathogenic microorganisms and phage survival."

Kołodyńska, D., R. Wnętrzak, J. J. Leahy, M. H. B. Hayes, W. Kwapiński, and Z. Hubicki. 2012. "Kinetic and adsorptive characterization of biochar in metal ions removal." *Chem. Eng. J* 197: 295-305.

Kujawa-Roeleveld, K. And Zeeman, G. 2006. "Anaerobic treatment in decentralized and ource-separation-based sanitation concepts. ." *Reviews in Env. Science and Bio Technology (RESB)* 5: 115-139.

Kumar, D.T., M.A. Hasan, S. Paul, B Islam, and Y. Akanda. 2018. "Performance Evaluation And Effectiveness Of Different Natural Bioadsorbents For Wastewater Treatment." *International Journal of Current Engineering and Technology* 8.

Lagergren, S. K. 1898. " About the theory of so-called adsorption of soluble substances. Kungliga Svenska Vetenskapsakademiens." *Handlingar* 24: 1- 39.

Laird, D., Fleming, P., Wang, B., Horton, R. and Karlen, D. 2010. "Biochar impact on nutrient leaching from a Midwestern agricultural soil." 158: 436– 442.

Lambe, J. S., and R. S. Chougule. 2013. "Greywater - Treatment and Reuse." *IOSR-JMCE* 20-26.

Ledin, A., Eriksson, E. and Henze, M.,. 2001. "Aspects of groundwater recharge using grey wastewater." 650-673.

Lehmann, J. 2007. "“Bioenergy in the black”, Frontiers in Ecology and in the Environment." 5 (7): 381-387.

Lehmann, J., Kern, D. C., Glaser, B. and Woods, W. I. 2003. "mazonian Dark Earths: Origin, Properties, Management." *Springer.*

Lesjean, B., and Gnirss, R. 2006. "Grey water treamtne with a membrane bioreactor operated at low SRT and HRT." *Desalination* 199: 432–334.

Liu, S., Song, H., Wei, S., Yang, F., Li, X. 2014. "Bio-cathode materials evaluation and configuration optimization for power output of vertical subsurface flow constructed wetland—Microbial fuel cell systems." *Bioresour. Technol* 575–583.

Lou, K. Rajapaksha,A.U. Ok Y.S. and S.X.Chang,. 2016. "Pyrolysis temperature and steam activation effects on sorption of phosphate on pine sawdust biochar in aqueous solutions." 28 : 42-50.

Lou., Rajapakshal A.U Ok Y.S. and .Chang, S.X. 2016. "Pyrolysis temperature and steam activation effects on sorption of phosphate on pine sawdust biochars in aqueous solutions." *Chemical Speciation & Bioavailability* 28: 42-50.

Lukkarinen, L T. Ranta-Korhonen, S. Seppäläinen and H. Soininen,. 2016. "Valumavesien käsittelyyn soveltuvat biosuodatinmateriaalit ja niiden laboratoriotestaukset." *Biosuodattimet metsätalouden vesiensuojelussa* 37-53.

Mahmoud, J. M. Y. Burnat and N. 2005. "Evaluation of On-Site Gray Wastewater Treatment Plants Performance in Bilien and Biet-Diko Villages/Palestine." (Environment Protection Committee (EPC)).

Main J. S. & Ingavale B.C. 2012. "Sequencing batch reactor for greywater treatment, International journal of multidisciplinary management studies." 2: 88-107.

Manderso, Temesgen Mekuriaw. 2018. "Overview of Existing Wastewater Management System in Case of Debre Markos Town, Ethiopia." *Engineering Mathematics* 2(2): 107-118.

Maria, F., Lovat,E., Caniato,M. 2018. "Waste Management in Developed And Developing Countries: The Case Study Of Umbria (Italy) and The West Bank (Palestine)." *Journal for Waste and Residues* 03: 171-180.

Masek, O., P. Brownsort, A. Cross, and S. Sohi. 2013. "Influence of production conditions on the yield and environmental stability of biochar." *Fuel* 130: 151–155.

McBain, J. 1909. "Sorption of a Penetrant by a Solid." *Phil Mag* 18: 916–925.

Meng S, Li Y, Zhang T, Chen J, Xu P, Song C,. 2013. "Influences of Environmental Factors on Lanthanum/Aluminum-Modified Zeolite Adsorbent (La/Al-ZA) for Phosphorus Adsorption from Wastewater." *Water Air & Soil Pollution* 224: 1–8.

Merz, C., Scheumann, R., El Hamouri B.,Kraume M. 2007. "Membrane bioreactor technology for the treatment of grey water from a sports and leisure club." *Desalination* 215: 37–43.

Metcalf, and Eddy. 1991. *Waste Water Engineering: Treatment and Reuse in Tchobanoglous.* Vol. Fourth Edition., in *McGraw-Hill series in water resources and environmental engineering*, edited by F.L. G. and Burton.

Miranda, Devaki R. M.Tech Lima, R. 2017. "INDUSTRIAL EFFLUENT TREATMENT BY ADSORPTION." *ejpmr* 4: 293-298.

Mohamed, R.M.S.R. Chan, C.M. Ghani, H. Yasin, M.A.M. Kassim, A.H.M. 2013. "Application of Peat Filter Media in Treating Kitchen Wastewater." *International Journal of Zero Waste Generation* 1 (1): 11 -16.

Mohanty, S. K., and A. B. Boehm. 2014. "Escherichia coli Removal in Biochar-Augmented Biofilter: Effect of Infiltration Rate, Initial Bacterial Concentration, Biochar Particle Size, and Presence of Compost,." *Environ. Sci.Technol* 48: 11535-11542.

Morel, A., and S. Diener. 2006. "Greywater Management in Low and Middle-Income Countries, Review of Different Treatment Systems for Households or Neighbourhoods." *Swiss Federal Institute of Aquatic Science and Technology (Eawag).*

Muftah, H., El-Naas, Sulaiman, Al-Zuhair, and A. A Manal. 2010. "Reduction of COD in refinery wastewater through adsorption on date-pit activated carbon." *J. Hazrd. Mater* 173: 750–757.

Nautiyal, R., S. Uliana, I . Raj, B. Shah, K. Rathore, and A. Singh. 2017. "Decentralized Treatment of Grey Water by Natural Coagulants in the Presence of Coagulation Aid."

Nguyen, N. T. 2015. "Adsorption Of Phosphorus From Wastewater Onto Biochar: Batch And Fixed-bed Column Studies." *Helsinki Metropolia University of Applied Sciences, masters thesis Environmental Engineering.*

Nolde. 1999. "Greywater reuse systems for toilet flshing in multi-storey buildings over ten years experience in Berlin." *Urban Water* 275-284.

Noutsopoulos, C., A. Andreadakis, N. Kouris, D. Charchousi, A. Mendrinou, P. Galani, and I. Mantziaras. 2014. "Greywater characteristics and loadings – treatment to."

Novak, J. F., W. J. Busscher, D. L. Laird, M. Ahmedna, D. W. Watts, and M. A. S. Niandou. 2009. "Impact of biochar amendment on fertility of a Southeastern coastal plain soil,”." *Soil Science* 174: 105-112.

Nwajuaku, I. I. Ekenta,O. E. Nwajuaku,A. I. 2015. "Treatment of Greywater for Non-Potable Applications." *ASRJETS* 11: 32-41.

Oteng-Peprah, M., de Vries, N. K., Acheampong, M. A. 2018. "Greywater characterization and generation rates in a periurban municipality of a developing country." *Journal of Environmental Management* 206: 498–506.

Ottoson, J. 2005. "Comparative analysis of pathogen occurrence in wastewater."

Ottoson, J., and T.A. Stenstro¨m. 2003. "Faecal contamination of greywater and associated microbial risks." *Water Research* 37: 645 – 655.

Pachkor, R. T., and D.K. Parbat. 2017. "A Literature Review on Integrated Approach for Grey Water Treatment." *International Journal for Research in Applied Science & Engineering Technology.*

Pajupojat Oy. 2017. Accessed January 29, 2019. http://pajupojat.fi/paju/biohiili/.

Parande, A.K., A. Sivashanmugam, H. Beulah, and N. Palaniswamy. 2009. "Performance evaluation of low cost adsorbents in reduction of COD in sugar industrial effluent." *J Hazard Mater.* 168: 800-805.

Park, D., Yun, Y. S. & Park, J. M. 2010. " The past, present and future trends of biosorption." *Biotechnology and Bioprocess Engineering, 15(1), 86-102.* 15: 86-102.

Perez-Mercado, L.A., Lalander, Berger,C. C, and S. Dalahmeh. 2018. "Potential of Biochar Filters for Onsite Wastewater Treatment: Effects of Biochar Type, Physical Properties and Operating Conditions." *Water* 10: 1-18.

Pranati, and Juverar. 2015. " Design of Small Scale Waste Water (Grey Water) Treatment Plant."

Rajkovich, S., A. Enders, K. Hanley, C. Hyland, AR. Zimmerman, and J. Lehmann. 2012. " (2012) Corn growth and nitrogen nutrition af er additions of biochars with varying properties to a temperate soil." *Biology and Fertility of Soils* 4: 271–284.

Rani. 2010. "Innovative Technology of COD and BOD reduction from coffee processing wastewater using avocado seed carbon (ASC)." *Water Air Soil Pollut* 207: 299–306.

Rehrah, D., MR. Reddy, JM. Novak, RR. Bansode, KA. Schimmel, Yu., DW. Watts, and M. Ahmedna. 2014. "Production and characterization of biochars from agricultural byproducts for use in soil quality enhancement." *Journal of Analytical and Applied Pyrolysis* 10: 301.

Retrieved from United States Environmental AgencY:. 2013. "Water Recycling and Reuse: The Environmental Benefits." http://www.epa.gov/region9/water/recycling/).

Rodgers, M., Mulqueen, J., Healy, and M.G. 2004. "Surface clogging in an intermittent stratified sand filter." *Soil Science Society of America Journal* 68: 1827-1832.

Rose, J.B., G. Sun, C.P. Gerba, and N.A., Sinclair. 1991. " Microbial quality and persistence of enteric pathogens in greywater from various household sources." *Water Research* 25: 37 – 42.

Sabbah, I., B. Ghattas, A. Hayeek, J. Omari, Y. Haj, S. Admon, and M. Green. 2003. "Intermittent sand filteration for wastewater treatment in rural area of the Middel Easta— Pilot study." *Water Sci. Technology* 48: 147–152.

Sadani, M., N.N. Ouazzani, L. Mandy, and M. Meybeck. 2002. "Impact of urban water discharge on the water and sediment quality of a river in the south of Morocco (Ouarzazate region), in First World Wide Workshop for Junior Environmental Scientists, 2002."

Saltalı, K. Sarı ,A., Aydın, M. 2007. "Removal of ammonium ion from aqueous solution by natural Turkish (Yıldızeli) zeolite for environmental quality." *Journal of Hazardous Materials* 141: 258–263.

Sarkar, B., Chakrabarti, P., Vijaykumar, A. 2006. "Wastewater treatment in dairy industries— possibility of reuse." *Desalination* 195: 141–152.

Sebastián, D. Rafael, V. Enrique, G. Miriam, M. 2011. "Aerobic Membrane Bioreactor for Wastewater Treatment – Performance Under Substrate-Limited Conditions Biomass Detection, Production and Usage,."

Sheikh, B. 1993. "The city of Los Angeles grey water pilot project shows safe use of grey water is possible.In Water Management in the 90s: A Time for Innovation; American Society of Civil Engineers."

Sheikh, B. n.d. "The city of Los Angeles grey water pilot project shows safe use of grey water is possible."

Shi, M., Wang, Z., Zheng, Z. 2013. "Effect of Na+ impregnated activated carbon on the adsorption of NH+4-N from aqueous solution." *J Environ Sci* 25: 1501 -1510.

Siegrist, R., Witt, M. Boyle, W.C. 1976. "Characteristics of Rural Household Wastewater." *Journal of the Environmental Engineering Division-Asce* 102(3): 533-548.

Smider, B., and B. Singh. 2014. "Agronomic performance of a high ash biochar in two contrasting soils." *Agriculture, Ecosystems and Environment* 191: 99–107.

Šostar, Sonja, P. Irena, S.M. 2005. *Laundry Wastewater Treatment Using Coagulation and Membrane Filtration.* Vol. 44.

Stevik, T.K., K. Aa, G. Ausland, and J.F. Hanssen. 2004. " Retention and removal of pathogenic bacteria in wastewater percolating through porous media: A review." *Water Res.* 6: 1355–1367.

Streubel, J. D. Collins, H. P. Tarara, J. M. Cochran, R. L. 2012. "Biochar Produced from Anaerobically Digested Fiber Reduces Phosphorus in Dairy Lagoons." *J. Environ. Qual* 41 : 1166--1174.

Subha, E. Sasikala, S. Muthuraman, G. 2015. " Removal of Phosphate from wastewater using natural adsorbents." *International Journal of ChemTech Research* 1: 3095–3099.

Tan, I. A. W., A. L. Ahmad, B. H. Hameed. 2008. "Adsorption of basic dye using activated carbon prepared from oil palm shell: batch and fixed bed studies." *Desalination* 225: 13-28.

The Federal Democratic Republic of Ethiopia Ministry of Healthy, T. 2016. "National Sanitation and Hygiene Strategic Action plan." Addis Ababa, Ethiopia.

UNESCO. 2012. "Managing water under uncertainty and risk. The United Nations World Water Development Report 4. United Nations Educational, Scientific and Cultural Organization, Paris."

United Nation. 2012. "Economic and Social Commission for Asia and the Pacific. Water Resource Management: Policy Recommendations for the Development of Eco-Efficient Infrastructure." Accessed April 18, 2019. http://www.unescap.org/sites/default/files/8.%20Water-Resource-Management.pdf .

USEPA, United States Environmental Protection Agency. 2002. "Onsite Wastewater Treatment System Manual." 53–59.

Ushijima, K., E. Tanaka, L. Y. Suzuki, N Hijikata, N. Funamizu, and I. Ryusei. 2015. "Grey water treatment by slanted soil system with unsorted soil media." *Environmental Technology* 36(20): 2603- 2609.

Vanderzant, C., and D. F. Splittstoesser. 1992. " Compendium of methods for the microbiological examination of foods." *3rd ed. American Public Health Association, Washington, D.C.*

Verheijen, F. Jeffery, S. Bastos, A. C. Velde, M. v. d. Diafas, I. 2010. "Biochar Application to Soils - A Critical Scientific Review of Effects on Soil Properties, Processes and Functions." *European Commission.*

Wada, Y., Flörke, M., Hanasaki, N., Eisner, S., Fischer, G., Tramberend, S., Satoh, Y., Van Vliet, M. T. H., Yillia, P., Ringler, C., Burek, P. and Wiberg. D. 2016. "Modeling global water use for the 21st century: the Water Futures and Solutions (WFaS) initiative and its approaches." *Geoscientific Model Development* 9: 175–222.

Wang, Y., J. Jorge, S. Aviles, R. Furlan, and I. Ramos. 2003. "Pyrolysis Temperature and Time Dependence of Electrical Conductivity Evolution for Electrostatically Generated Carbon Nanofibers." 2: 39-43.

Weber-Shirk, and R. I. Dick. 1997. "Physical-Chemical mechanism in slow sand filters." *Journal of American Water Works Associations* 89: 87-100.

Williams, P. 2008. *Waste Treatment and Disposal.*

Woldu, Z., Mohammed, A., Belew, D., Shumeta, Z. and Bekele, A. 2015. " Assessment of Banana Production and Marketing in Ethiopia." *International Journal of Sciences: Basic and Applied Research* 24: 283-307.

Yahya, S., Al-Degs, I. Musa, a. El-Barghouthi, H. Amjad, a. El-Sheikh, M. Gavin, and Walker. 2008. "Effect of solution pH, ionic strength, and temperature on adsorption." 77: 16-23.

Yakout, A. Abd ElAziz, A. Nayl Reda, E. Tamer, El Mal, and M. Sobhy. 2017. "Adsorption studies on the removal of COD and BOD from treated sewage using activated carbon prepared from date palm waste." *Environ Sci Pollut Res* 22284-22293.

Yao, Y., B. Gao, M. Inyang, A.R. Zimmerman, X. Cao, P. Pullammanappallil, and L. Yang. 2011. " Biochar derived from anaerobically digested sugar beet tailings: Characterization and phosphate removal potential ." *Bioresour Technol* 102: 6273–6278.

Yash, B, Vishnu K. Pareek, Ming, A. 2013. "A review of greywater characteristics and treatment process." *Water Science & Technology* 67.7: 1403-1424.

Yogafanny, E.,Fuchs,S, Obst,A. 2014. "Study of Slow Sand Filtration in Removing Total Coliforms and E.Coli." *Jurnal Sains dan Teknologi Lingkungan* 6: 1 07-1 1 6.

Zhang, G., H. Liu, R. Liu, and J. Qu. 2009. "Removal of phosphate from water by a Fe–Mn binary oxide adsorbent." *J Colloid Interface Sci* 335: 168–174.

Zhang, J., Z. Shen, W. Shan, Z. Chen, Z. Mei, Y. Lei, and W. Wang. 2010. " Adsorption behavior of phosphate on Lanthanum(III) doped mesoporous silicates material." *J Environ Sci* 22: 507–511.

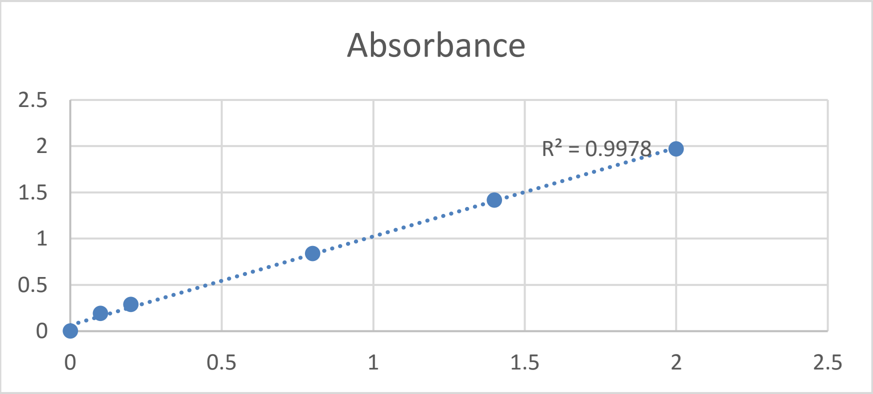
Zheng, H., L. Han, H. Ma, Y. Zheng, H. Zhang, and D. Liu. 2008. "Adsorption characteristics of ammonium ion by zeolite 13X." *J Hazard Mater* 158: 577-584.

Zhou, A., Tang, H., Wang, D. 2005. "Phosphorus adsorption on natural sediments: modeling and effects of pH and sediment composition." *Water Res* 39: 1245–1254.

Appendix

Appendix **A** Concentration against absorbance for calibration of Photometer

Concentration (mg/l)	Absorbance
2	1.97
1.4	1.417
0.8	0.839
0.2	0.29
0.1	0.191
0	0.00



Appendix **B** Measurements of Nitrogen and Phosphorus using pilentest

I. **Method** for Nitrogen

The plaintest Ammonia test is based on indophenols method. Ammonia reacts with alkaline salicylate in the presence of chlorine to form a green blue indophenols complex. Catalysts are provided in the form of two tablets for maximum convenience. The test is simply carried out by adding one of each tablet to a sample of the water. The intensity of the color produced in the test is proportional to the ammonia concentration and is measured using palintest photometer.

ii. Test instructions

1. Fill the tube with sample to the 10m mark

2. Add one ammonia number 1 tablet and one ammonia number 2 tablets, crush and mix to dissolve.
3. Stand for ten minutes to allow color development
4. Select phot 004 on photometer to measure Ammonia mg/ N or select phot 062 on photometer to measure Ammonium mg/ NH4.

NB: 1. At low temperature the rate of color development in the test may be slower. If the sample temperature is below 200c allow 15 minutes for the color to develop. 2. Ammonia concentration can be expressed in a number of different ways. The following factors may be used for the conversion of readings:

- To convert from N to NH4 multiply N reading by 1.3
- To convert from N to NH3 multiply N reading by 1.2

II. **Method** for phosphors

The palintest phosphate HR test is based on the Vanadom Olybdate method. In the test phosphate react with ammonium molybdate, in the presence of ammonium vanadate, to form the yellow phosphovanado molybdate. The intensity of the color produced in the test is proportional to the phosphate concentration and is measured using palintest photometer number 029.

Test Instruction

1. Fill test tube with sample to the 10m mark
2. Add one photometer high range tablet, crush and mix to dissolve
3. Stand for 10 minutes to allow full color development
4. Select phot029 on photometer
5. Take photometer reading in usual manner
6. The result is displayed as mg/ PO_4

Appendix C Laboratory Equipment used during experiment

A) Palintest photometer 7100 0

B) Hanna educational pH meter- HI 8010

C) Hanna HI 93102 turbidity meter

D) JENWAY 4330 conductivity and pH meter

E) Air permeability apparatus

F) sieve analysis

F) grinding machine

Annex

Annex A: performance of different particle size of biochar

Day 1 performance of different particle size of biochar

parameter	Raw SGW	after treatment			Efficiency		
		FBC	MBC	CBC	FBC	MBC	CBC
Turbidity (NTU)	159.08	24.8	46.75	91.05	84.41	70.6	42.76
EC (ms/cm)	0.301	0.425	0.382	0.338			
pH	9.1	9.31	9.29	9.23			
COD (mg/l)	957	635	785	912	33.65	18.0	4.70
N (mg/l)	0.87	0.771	0.79	0.81	11.38	9.2	6.90
P (mg/l)	6.2	5.72	5.8	6	7.74	6.5	3.23

Day 2 performance of different particle size of biochar

parameter	Raw SGW	after treatment			Efficiency		
		FBC	MBC	CBC	FBC	MBC	CBC
Turbidity (NTU)	89.646	11.79	15.88	30.88	86.85	82.3	65.6
EC (ms/cm)	0.378	4.35	4.26	3.45			
pH	9.2	9.31	9.43	9.1			
COD (mg/l)	852	525	690	800	38.4	19.0	6.1
N (mg/l)	0.4	0.14	0.34	0.36	65	15.0	10.0
P (mg/l)	8.9	3.6	8.04	8.53	59.6	9.7	4.2

Day 3 performance of different particle size of biochar

parameter	Raw SGW	after treatment			Efficiency		
		FBC	MBC	CBC	FBC	MBC	CBC
Turbidity (NTU)	114.08	12	28.49	80	89.5	75.0	29.9
EC (ms/cm)	0.313	4.33	4.21	3.63			
pH	9.01	9.87	9.37	9.14			
COD (mg/l)	801	296	359	535	63.0	55.2	33.2
N (mg/l)	1.14	0.22	0.79	0.98	80.7	30.7	14.0
P (mg/l)	14.84	5.1	11.04	13.04	65.6	25.6	12.1

Day 4 performance of different particle size of biochar

parameter	Raw SGW	after treatment			Efficiency		
		FBC	MBC	CBC	FBC	MBC	CBC
Turbidity (NTU)	53.34	4.6	34.01	43.32	91.4	56.8	18.8
EC (ms/cm)	0.236	0.367	0.26	0.238			
pH	7.7	9.84	9.35	8.92			
COD (mg/l)	1128	179	521	583	84.1	53.8	48.3
N (mg/l)	0.36	0.03	0.26	0.29	91.7	38.5	19.4
P (mg/l)	8.12	2.01	5.53	6.67	75.2	31.9	17.9

Annex B: Effect of pH on greywater treatment

Day 1 Effect of pH on different parameters

parameter	Raw SGW	after treatment					
		pH-5	pH-6	pH-7	pH-8	pH-9	pH-10
Turbidity (NTU)	159.08	46.75	32.5	21.05	97.25	117.00	148.50
EC (ms/cm)							
COD (mg/l)	979	957	916	814	862	879	923
N (mg/l)	0.64	0.4	0.19	0.1	0.11	0.15	0.17
P (mg/l)	20.7	14	20.7	5.28	5.59	6.72	7.12

Day 2 Effect of pH on different parameters

parameter	Raw SGW	after treatment					
		pH-5	pH-6	pH-7	pH-8	pH-9	pH-10
Turbidity (NTU)	168.6	47.48	37.71	14.19	106.50	139.86	153.21
EC (ms/cm)							
COD (mg/l)	566	543	409	381	438.00	455.00	498.00
N (mg/l)	0.6	0.24	0.12	0.03	0.04	0.10	0.22
P (mg/l)	27.7	13.9	27.7	6.12	10.14	10.51	10.81

Day 3 Effect of pH on different parameters

parameter	Raw SGW	after treatment					
		pH-5	pH-6	pH-7	pH-8	pH-9	pH-10
Turbidity (NTU)	158.6	45.64	37.26	18.63	99.50	117.00	134.49
EC (ms/cm)							
COD (mg/l)	1408	454	391	222	284	396	438.00
N (mg/l)	0.99	0.6	0.12	0.02	0.03	0.21	0.23
P (mg/l)	22.3	14.6	22.3	4.47	8.20	8.62	8.97

Day 4 Effect of pH on different parameters

parameter	Raw SGW	after treatment					
		pH-5	pH-6	pH-7	pH-8	pH-9	pH-10
Turbidity (NTU)	167.76	51.05	34.2	15.52	108.06	120.295	142.53
EC (ms/cm)							
COD (mg/l)	963	370	362	116	364.00	375.00	382.00
N (mg/l)	1.26	0.14	0.08	0.02	0.03	0.22	0.25
P (mg/l)	19.6	12.4	19.6	3.4	6.80	6.96	7.14

Annex C: Comparison of FBC, FBCS And Sand

Day 1 Comparison of FBC, FBCS And Sand

parameter	SGW	after treatment		
		Sand	FBC	Sand-FBC
Turbidity (NTU)	120	70.8	9.72	43.2
EC (ms/cm)				
COD (mg/l)	6.78	6.54	10.26	9.91
N (mg/l)				
P (mg/l)	1.26	0.52	0.29	0.48
Turbidity (NTU)	14.3	13.2	6	8.6

Day 2 Comparison of FBC, FBCS And Sand

parameter	SGW	after treatment		
		Sand	FBC	Sand-FBC
Turbidity (NTU)	286.5	129.5	10.7	74.1
EC (ms/cm)				
COD (mg/l)	7.27	6.81	10.28	9.71

N (mg/l)				
P (mg/l)	0.74	0.61	0.01	0.57
Turbidity (NTU)	13.6	13.1	4.5	8.3

Day 3 Comparison of FBC, FBCS And Sand

parameter	SGW	after treatment		
		Sand	FBC	Sand-FBC
Turbidity (NTU)	314.9	73.4	15.0	44.1
EC (ms/cm)	0.0			
COD (mg/l)	7.8	6.8	10.2	9.8
N (mg/l)	0.0			
P (mg/l)	1.2	0.6	0.1	0.4
Turbidity (NTU)	17.3	11.3	4.6	8.1

Day 4 Comparison of FBC, FBCS And Sand

parameter	SGW	after treatment		
		Sand	FBC	Sand-FBC
Turbidity (NTU)	195.3	19.8	8.4	15.0
EC (ms/cm)				
COD (mg/l)	8.21	7.03	10.2	9.75
N (mg/l)				
P (mg/l)	0.88	0.6	0.01	0.25
Turbidity (NTU)	22.4	7.7	3.3	7.5

Annex D: Fractions of the sieved biochar

Biochar sieving: three fractions (<1 mm; 1-3mm and >3 mm)