COMPARATIVE STUDIES OF THE PERFORMANCE OF FILTER MEDIA MADE USING BIOCHAR AND ACTIVATED CARBON IN GREYWATER REMEDIATION

BY

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ZARIA, NIGERIA

MAY, 2017

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B.ENG AGRIC & ENV. RES (UNIMAID, 2010)

M.Sc/ENG/41914/12-13

A THESIS SUBMITTED TO THE SCHOOL OF POSTGRADUATE STUDIES, AHMADU BELLO UNIVERISTY, ZARIA

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTER OF SCIENCE DEGREE IN WATER RESOURCES AND ENVIRONMENTAL ENGINEERING

DEPARTMENT OF WATER RESOURCES AND ENVIRONMENTAL ENGINEERING,

AHMADU BELLO UNIVERSITY,

ZARIA, NIGERIA

MAY, 2017

DECLARATION

I declare that the work in this dissertation titled "COMPARATIVE STUDIES OF THE PERFORMANCE OF FILTER MEDIA MADE USING BIOCHAR AND ACTIVATED CARBON IN GREYWATER REMEDIATION" is the result of my own investigation.

The information derived from the literature has been duly acknowledged in the text and a list of references provided.

SalihuWamdeo SAMUEL

(M.Sc/ENG/41914/2012-2013) Signature Date

CERTIFICATION

This dissertation titled "COMPARATIVE STUDIES OF THE PERFORMANCE OF FILTER MEDIA MADE USING BIOCHAR AND ACTIVATED CARBON IN GREYWATER REMEDIATION" By SalihuWamdeo SAMUELmeets the regulations governing the award of the degree of Master of Sciences (M.Sc) of Ahmadu Bello University, Zaria, and approved for its contribution to knowledge and literary presentation.

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DEDICATION

This dissertation is dedicated to the loving memory of my late father Mr. Samuel S. Wamdeo.

ACKNOWLEDGEMENT

First and foremost I will like to thank my God for His grace on me throughout the duration of this programme.

My sincere gratitude goes to my research supervisors; Dr. E.M. Shaibu-Imodagbe and Prof. C. AOkuofu for their tireless contribution during the course of this dissertation. Without your efforts, this would have not been a success.

Much gratitude also goes to the Head, Department of Water Resources and Environmental Engineering; Prof. Ismail Abubakar and all the staff of the department: Prof. J.A Otun, Dr. D.B Adie,Dr. U.A Umar,Dr. S.BIgboro, Dr. F.B Ibrahim, Dr.SalihuLukman, Dr.M.A Ajibike and many others for their contributions during my study. My appreciation also goes to the Staff of Industrial Development Centre (IDC) Zaria for their help during my construction stage. MusaSamaila of Hayin Dan Yaro is not left out for his invaluable help during my laboratory work. I am also grateful to Mr. P.C Alika, Mr.AmehGeofery and Mal. YahayaYakubu of the departmental Laboratory for their help and guide during my laboratory work.

Finally my appreciation goes to my mum; Mrs. Rhoda S. Wamdeo, my Uncle; Mr.HabilaNjidafor their unquantifiable effort in seeing me complete this dissertation. My heartfelt gratitude also goes to my family, course mates, friends especially Nathan Issac, Ibrahim Hena, Matthew Kure, Benjamin Bako, BarkaSamboand so many others who helped me in one way or the other. May God Bless you all.

ABSTRACT

The problem of water Scarcity, water pollution and cost of accessing water for domestic needs have become growing concerns to the ever increasing global population. Waterwaterremediation has long been accepted as a viable option to mitigate water scarcity. This research examines the potentials of an environmentally friendly technique of using local but modified tropical plant materials in remediation of greywater for re-use. Column adsorption experiment was conducted using synthesized and characterized Biochar and Activated Carbon made from Shea tree (*Vitellariaparadoxa*), African Mahogany tree (*KhayaSenegalenses*) and the Fig tree (*FicusSycomous*) as filter media in constructed filter columns made from polyvinyl chloride pipes. Greywater Samples from Ahmadu Bello University Zaria's student hostel were passed through these filters at a hydraulic loading rate of $0.033m^3/m^2$/day for a period of 21 days. The parameters assessed in this experiment were Electrical Conductivity (EC), Biological and Chemical Oxygen Demand (BOD and COD), Ammonium Nitrogen (NH_4-N), Nitrate Nitrogen (NO_3-N), Total Nitrogen (Tot-N), available Phosphate (PO_4-P), Total Phosphorus (Tot-P) and pH. The results obtained showed high treatment efficiencies for both Activated Carbon and Biochar on all tested parameters except for NH_4-N in which AC had a low efficiency of 49% at one instance. Activated Carbon had (85 – 95%) in remediating organic matter, (61 -81%) in remediating EC, (39 – 89%) in remediating NH_4-N, (93 – 100%) for NO_3-N, 92 – 99% for Total Phosphorus. Biochar showed 88 – 92% efficiency in remediating Total Phosphorus, 91 – 99% for NO_3-N, 68 – 89% for NH_4-N, 85 – 90% for EC and 76 – 90% for organic matter removal. The factors of time, particle size, activation status and parent material used in the filters were used to determine the efficiency of the filters and the results showed that time, parent material used, and activated status of the filters had significant effect on the performance of the filters while differences in particle sizes had little effect on the performance. It could be concluded therefore that biochar compared favourably with activated carbon in the remediation of greywater, which is more complex to synthesize and cost more to produce. In addition, because of the ease of production and availability of raw materials in the tropics, biochar can be used to remediate greywater and replace Activated Carbon in some water treatment systems.

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LIST OF ABBREVIATIONS AND ACRONYMS

ABU	-	Ahmadu Bello University
AC	-	Activated Carbon
ANOVA	-	Analysis of Variance
BOD	-	Biological Oxygen Demand
CEC	-	Cation Exchange Capacity
COD	-	Chemical Oxygen Demand
DOS	-	Department of Statistics
EC	-	Electrical Conductivity
MCM	-	Million Cubic Meters
NA	-	Not Available
NH_4-N	-	Ammonium Nitrogen
NS	-	Not Significant
NO_3-N	-	Nitrate Nitrogen
PO_4-P	-	Phosphate Phosphorus
PPRC	-	Pollution Prevention Resource Centre
PS	-	Particle Size
PVC	-	Poly Vinyl Chloride
SOC	-	Synthetic Organic Compounds
TOT-N	-	Total Nitrogen
UN	-	United Nations
VOC	-	Volatile Organic Compounds
WREE	-	Water Resources and Environmental Engineering
WHO	-	World Health Organisation

CHAPTER ONE

INTRODUCTION

1.1 Background of the study

With the continuous annual increase in the world population (lowest increase being 1.1%) there is need to manage our natural resources. Water, which is one of these basic resources for human survival and socioeconomic development, needs to be managed efficiently. The United Nations has estimated that the use of water has increased six fold in the 20^{th} century and that by the year 2025, about 1.8 billion people will have absolute water scarcity conditions (with an annual water supply of less than $500m^3$ per capita) and also that two third (2/3) of the world population will live under water stress (with an annual water supply of less than $1700m^3$ per capita) (U.N-Water Report, 2006). This population increase will have adverse effects on developing countries where 82% of the world live and experience water scarcity (Dalahmeh, 2013). There is therefore need to properly manage and utilize existing water resources especially in the developing countries.

The reality of water scarcity, coupled with the increased potential health risk posed by greywater pollution necessitates a swift solution hence the idea of using locally available materials like biochar as a means of improving water quality, sanitation and reducing environmental problems has become attractive.This study seeks to find simple inexpensive and locally available materials like charcoal and sand to solve environmental problems posed by water scarcity and water pollution.

Wood from locally available tropical trees waspyrolyzed at a temperature of 650^oC and the biochar derived wascharacterized and treated. Its ability to adsorb certain major pollutants from the collected greywater was determined.

Greywater or sullage is defined as wastewater generated from kitchens and wash-hand basins, showers and baths, which, because it is nearly as clean as potable water, can be recycled onsite for uses such as toilet flushing, landscape irrigation and constructed wetlands (Barker and English, 2011).Biochar refers to biomass-derived char product most often used as cooking fuel (Kearns*et al*, 2014). It is a name for charcoal when it is used for a particular purpose such as soil amendment, water treatment, etc. (Kearns, 2012).Pyrolysis is a thermochemical decomposition of organic materials at elevated temperature in the absence of oxygen. It involves the simultaneous change in both chemical and physical compositions of the organic materials. The process is irreversible. Pyrolysis produces gas, liquids and a solid product rich in carbon.

1.2 Statement of the research Problem

Greywater, which accounts for approximately 50-80% of total household wastewater mostly ends up in receiving water bodies (Li *et al.,* 2009). The provision of inadequate sanitation and wastewater disposal facilities leads to environmental and public health problems which is responsible for 1.8 million deaths annually (Corcoran *et al*., 2010; WHO Report, 2009). Although centralized wastewater systems are common in industrialized countries, they are complex and expensive to construct and operate. This however is not a viable option for most communities in developing countries. There is therefore the need to source for simple and affordable environment friendly techniques to treat greywater.

1.3 Justification of the Study

Previous studies and designs utilize activated carbon as adsorbents in water treatment systems. Recent studies however showed that biochar especially those with high lignin

content when pyrolyzed at temperatures above 450^{o}C show similar molecular structure like that of activated carbon and can therefore be a possible replacement to Activated Carbon (McLaughlin *et al.*, 2009; Kearns, 2012). This study aims to experimentally determine the effectiveness of biochar in greywater remediation. Biochar is cheaper, available and more environmentally friendly when compared to activated carbon, ion exchange resins, membrane filtration, reverse osmosis and nano filtration (Kearns, 2012). Biochar production techniques are also cheap and easy for local communities and so, this might be a better treatment option for community wastewater remediation especially in developing countries.

1.4 Aim and Objectives

This research aims to determine the effectiveness and efficiency of biochar derived from different lignin containing trees; *Vitellariaparadoxa* (Shea Tree), *Khayasenegalenses* (Mahogany), *Ficussycomous*(Fig) in remediating greywater.

The research has these following specific objectives.

1. To produce biochar and activated carbon from different parent material
2. To use the biochar and activated carbon to make filters with physical properties like those of sand filters.
3. To determine the efficiency of the prepared filters in remediating chemical and physical parameters; pH, Electronic Conductivity (EC), Ammonium Nitrogen (NH_4-N), Total Nitrogen (Tot-N), Phosphate Phosphorus (PO_4 -P), Nitrate Nitrogen (NO_3-N), Biological Oxygen Demand and Chemical Oxygen Demand (COD) from greywater.

4. To compare the performance of the biochar with activated carbon made from same parent materials in greywater remediation.

5. To determine the effect of particle size, time and parent material in adsorbing the stated parameters.

1.5 Scope and Limitation of the study

This studywas to determine the effectiveness of biochar from three specifically identified tropical lignin containing trees (*Vitellariaparadoxa*, *Khayasenegalenses*, *Ficussycomous)* in remediating greywater fromSuleiman Hostel of Ahmadu Bello University Zaria (A.B.U). Physical and chemical parameters tested were: pH, Electrical Conductivity (EC), Amonium Nitrogen (NH_4-N), Total Nitrogen (Tot-N), Phosphate-Phosphorus(PO_4-P), Total Nitrogen, Nitrate Nitrogen (NO_3-N), Chemical Oxygen Demand (COD) and(BOD)Biological Oxygen Demand. The constant mass of Carbon used throughout the experiment and the variation in daily concentration of pollutants in the greywater source however served as limitations in this study. It was addresses by adding an extra column which served as control to monitor changes in the greywater. This research was limited to Greywater and not industrial or other domestic wasterwater.

CHAPTER TWO

LITERATURE REVIEW

2.1 Greywater

Morel and Diener, (2006) defined greywater as household wastewater that does not come from a toilet, meaning it is wastewater that does not contain urine or feces. Ludwig,(2012) and Mungai, (2008) reported that greywater makes up 50% to 80% of a household's wastewater. They further stressed that the quantity of greywater produced by a household depends above all on practices of the household in question which are directly influenced by the amount of freshwater available, the cost and supply route of that freshwater, the number of people living in the household, their ages and gender and the living conditions in the nearby area.

Winblad and Simpson, (2004) observed that the quality of greywater, e.g. level of contamination, varies depending on the household‘s water habits and the chemicals used. Murphy, (2006) noted that freshwater shortages and conservation will not only reduce the quantity of greywater produced, but also its quality, resulting in greywater that is more concentrated due to less dilution . Just as greywater quality and quantity varies from household to household, it likewise varies within a household depending on the source of the specific greywater. Morel and Diener, (2006) classifiedgreywater into three different types: kitchen, bathroom and laundry.

Oron,*et al.*,(2014) reported that domestic water use industrialized countries approximates amounts to 100-150 l/c/d (litre/*capita*/day), of which 60-70% is transformed into greywater, while most of the rest is consumed for toilet flushing and released as blackwater. Oron,*et al.*,(2014) iterated thatgreywater reuse for toilet flushing can reduce the in-house net water consumption by 40-60 l/c/d, leading to 10-20% reduction of the urban water consumption, which is significant especially under water

scarcity situation.Oron, *et al.,* (2014) further advised that additional reduction can be achieved by reusing greywater for garden irrigation which is a considerable water consumer in some semi arid regions (Australia, California, Israel, etc.).Friedler and Galil,(2003) showed that by the year 2023, with moderate penetration ratio of greywater reuse systems of 20-30% (percentage of houses having greywater reuse units installed), reuse of greywater in the urban sector in Israel could save 30-55 millioncubic meters per year, 25-45 and 5-10 Million Cubic Meters per year in toilet flushing and garden irrigation respectively. With a projected population ten million people, this amounts to about 5% of the total future urban water demand in the country, which they observed equals the capacity of a medium size seawater desalination plant.

2.1.1 Greywater from Bathroom

Bathroom greywater is regarded as the least contaminated greywater source within ahousehold. It contains soaps, shampoos, toothpaste, and other body care products.Bathroom greywater also contains shaving waste, skin, hair, body-fats, lint, and traces ofurine and faeces. Greywater originating from shower and bath may thus be contaminatedwith pathogenic microorganisms(Morel and Diener, 2006).

2.1.2 Greywater from Laundry

Laundry greywater contains high concentrations of chemicals from soap powders (suchas sodium, phosphorous, surfactants, Nitrogen) as well as bleaches, suspended solids and possibly oils, paints, solvents and non-biodegradable fibres from clothing. Laundry greywater can contain high amounts of pathogens when nappies are washed(Morel and Diener, 2006).

2.1.3 Greywater from Kitchen

Kitchen greywater contains food residues, high amounts of oil and fat, including dishwashingdetergents. In addition, it occasionally contains drain cleaners and bleach. Kitchen greywateris high in nutrients and suspended solids. Greywater from dishwashers may be very alkaline (dueto builders), it also shows high suspendedsolids and salt concentrations (Morel and Diener,2006).

2.1.4 Greywater Remediation

Morel and Diener, (2006) suggested that greywater should be regarded as a valuable resource and not a waste as it has great potential to reduce water stress currently faced in regions around the world. They further iterated that greywater reuse may lead to considerable economic benefit.

The United State Department of Statistics (US-DOS), (2001) also reported that in Amman, Jordan an extensive survey of urban farmers revealed that percent use greywater to irrigate gardens. Faruquiand Al-Jayyousi,(2002) similarly iterated that household treating and re-use of greywater locally may bring an annual benefit of USD 376 accounted for by increasing product yield as well as reduced water and fertilizer cost.

With a typical production of 90-120l/p/d (litres per person per day), Morel and Diener, (2006) suggested the need to remediate greywater.Igboro*et al.,* (2015) outlined the benefits of reusing greywater which include domestic and gardening purposes.

Allen *et al.,* (2010) suggested different methods of greywater remediation amongst which are: disinfection using chlorine, ozone or ultraviolet light, use of anaerobic

biological treatment, use of membrane bio-reactor, use of sand filtration and the use of activated carbon filters.

Igboro*et al.,* (2016) stated that some basic pollutants of greywater: BOD, Turbidity, Total Solids and E. coli can be improved using locust bean seed, leaves and bark.

2.2 Biochar

Pollution Prevention Resource Centre (PPRC),(2014)defined biochar as ‘a name for charcoal when it is used for a particular purpose such as soil amendment, water treatment, carbon sequestration, bio-bags and energy production’.Harris, (1999) quoted that the biochar production process mirrors that of charcoal which can be considered as one of the oldest invented industrial technologies of Homo sapiens. However, it can be differentiated from charcoal and other similar materials by considering the fact that biochar is synthesized completely with the intention of being applied to the soil for improving the soil fertility, carbon sequestration and other uses (Harris, 1999).

Pollution Prevention Resource Centre (PPRC), (2014) established that biochar’s incredible porosity and surface area gives it a high capacity to adsorb a wide variety of contaminants from water. They further suggested that biochar can be thought as a cheaper version of activated Carbon which can be used in many of the same applications. They presented a research by PPRC in the Pacific North West showed that biochar can effectively reduce contaminants including heavy metals, Volatile Organic Compounds (VOCs), Synthetic Organic Compounds (SOCs), Oxygen Demand, Phosphorus, Phosphates, Ammonim, Nitrates, Nitrogen, Total Suspended Solids (TSS) and polyaromatic hydrocarbons.

2.2.1 Biochar Production

The process of producing biochar is known as pyrolysis. This refers to the thermal decomposition of biomass under low or restricted oxygen conditions. The pyrolyticprocess parameters such as temperature, heating rate, pressure, energy values of bio-oils and physico-chemical properties all have effect on the production of biochar (Clay and Malo, 2012).

Biochar yield as well as, its chemical and physical characteristics of biochar depends on thenature of the feedstocks used (woody against herbaceous) and operating conditions and environmentof the pyrolysis unit (low against high temperature, residence time; slow vs. fast pyrolysis, heatingrate and feedstock preparation, etc.). Baldock and Smernik, (2002) reported that the wide range of process parameters leads to theformation of biochar products that vary considerably in their elemental and ash composition,density, pore size, surface chemical properties, water and ion adsorption and release, surfacearea, pH and uniformity of biochars' physical structure. Similar studies were also reported in literature such as Antal andGronli, (2003);Downie*et al.*, (2009);Amonette and Joseph,(2009);Krull*et al.*,(2009); Chan and Xu, (2009).

The biochar yield from the pyrolysis of biomass is influenced by the pyrolysistemperature, its lignin, cellulose, and hemicellulose content and to a lesser extent the extractiveconcentrations of the feedstock according to McKay and Roberts, (1982), Antal and Gronli, (2003). Demirbas, (2004) reported that woodybiomass with high lignin contents typically produce greater char yields than those derived fromherbaceous feedstocks. A common feature among the various pyrolysisprocesses is that C content shows a consistent increase with increasing temperature (Antal andGronli, 2003; Schnitzer*et al.*, 2007; Zabaniotou*et al.*, 2008; Lehman and Joseph, 2009). Biochars with largeamounts of poly-condensed aromatic structures are obtained by pyrolyzingfeedstocks attemperatures between 400 and 600^{o}C (Antal and Gronli,

2003; Amonette and Joseph, 2009).Temperatures above 500^{o}C commonly produce chars with Carbon contents greater than 80%, attemperatures between 400 and 500^{o}C biochars have C contents that range from 60 to 80%, wherebiochars produced at low temperatures (< 350^{o}C) have C content that vary from 15 to 60%(Lehman and Joseph, 2009). For a detailed description of the thermal degradation process (dehydration,pyrolysis, graphene formation and carbonization) that transforms biomass.

2.2.2 Biochar for Water Treatment

Liang *et al.*, (2006) reported that biochar has the potential to increase Cation Exchange Capacity (CEC) in soils and he attributed this characteristics to the structural nature of biochar. Steinbiss*et al.*,(2009) reported that biochar may enhance microbial growth by providing pores as refuge to micro-organisms or by providing larger surface area for take-up.

Khan*et al.*, (2010) published that organic materials generally possess some adsorption capacity and their high carbon content provides resistance to decomposition. They also stated that charring these organic material usually increases their adsorption capacity by providing larger surface area for adsorption.Agoyi, (2015) studied the adsorption performance of cow bone char in a fix bed system and reported that cow bone adsorbent was useful in treating Lead and Chromium from contaminated wastewater.

Taghizadeh-Toosi*et al.*,(2012) published that biochar had been found to adsorb gaseous ammonia and make it readily available to plants.

Berger, (2012) pointed out that biochar which is an organic material pyrolysed/charred often by means of low cost techniques might be an interesting alternative to replace the industrial activated Carbon for greywater cleaning. She further evaluated and compared biochar with activated Carbon in cleaning synthesized greywater and published that

biochar performed more effectively in removing Total Phosphorus and Phosphates whereas both media had average performance in cleaning organic matter primarily Chemical Oxygen Demand (COD) and Methylene Blue Active Substances(MBAS) from the synthesized greywater. Similarly, Dalahmeh, (2013) also studied the performance of pine made biochar, activated Carbon and sand filters in removing nutrients from synthetic greywater. She published that the performance of the filters were more influenced by the Hydraulic and Organic loading rates of the previous runs in the experiment.

Bernd *et al.*, (2013) also reported that biochar has the possibility of replacing coal based activated Carbon as adsorbent for contaminants and pathogens in water purification systems. They further hypothesized that biochar could be used for pathogen removal from wastewater while at the same time being loaded with nutrient and contaminants.

Ghezzehei*et al.,* (2014) published that biochar can adsorb up to 20 – 43% of ammonium and 19 – 65% of phosphates in flushed dairy manure in 2 hours. They also suggested the potential of biochar in recovering nutrient from dairy waste water and improving soil fertility if the enriched biochar is returned to the soil.Foereid, (2015) noted that biochar has so far been mainly promoted for soil amendment and also a good adsorbent. They suggested that biochar may also hold promise in low cost wastewater treatment than activated Carbon which has been used for a long while. They further suggested that biochar could potentially be used to adsorb nutrient from wastewater and then the loaded biochar or mixture of sludge and biochar could be added to soil.

Huggins *et al.,* (2016) performed comparative batch sorption and column studies between Granular Activated Carbon (GAC) and biochar for wastewater treatment. They reported that biochar had greater adsorption capacity at high initial concentration of

Total COD, Phosphates and Ammonia. They also reported similar performance of biochar for bed column studies. They attributed the performance of biochar to its macro porous structure as compared to the microporous structure of Granular Activated Carbon.

2.3 Introduction to Parent Material Used for the Biochar production

2.3.1 Khaya*senegalensis*

Khaya*senegalensis* is a species of tree in the Meliaceae family that is native to Africa. Common names include African mahogany, dry zone mahogany, Gambia mahogany, khaya wood, Senegal mahogany, cailcedrat, acajou, djalla, and popularly known as Mahogany in Northern Nigeria.

African mahogany is a medium-sized tree which can grow up to 15–30 m in height and 1 m in diameter. The bark is dark grey to grey-brown while the heartwood is brown with a pink-red pigment made up of coarse interlocking grains. The tree is characterized by leaves arranged in a spiral formation clustered at the end of branches.

2.3.2 Vitellaria*paradoxa*

Vitellaria*paradoxa*commonly known as shea tree, shi tree or simply vitellaria, is a tree of the Sapotaceae family. It is the only species in genus Vitellaria, and is indigenous to Africa. Vitellaria*paradoxa* is a small to medium-sized tree (min. 7) 10-15 (max. 25) m high; much branched, dense, spreading, round to hemispherical crown. In mature trees, the bole is short, usually 3-4 m but exceptionally 8m, with a diameter ranging from 0.3 to 1 m, but most frequently 0.6 m. Bark conspicuously thick, corky, horizontally and longitudinally deeply fissured; protects older trees against bush fires. Slash pale pink, secreting white latex, as do broken twigs or petioles. Leaves in dense clusters, spirally

arranged at the end of stout twigs. They are covered by thick bark showing numerous leaf scars. Petioles 5-15 cm long, leaves oblong. Juvenile leaves rust-red and pubescent, later coriaceous, glabrous and dark green, shining, 12-25 cm long and 4-7 cm wide, leaf margin wavy and bent (Orwa*et al.*, 2009).

2.3.3 Ficus*sycomorus*

Ficussycomorus locally known as Fig or Cedia (Hausa) is a fig species that has been cultivated since ancient times. Ficussycomorus grows to 20 m tall and has a considerable spread with a dense round crown of spreading branches. The leaves are heart-shaped with a round apex, 14 cm long by 10 cm wide, and arranged spirally around the twig. They are dark green above and lighter with prominent yellow veins below, and both surfaces are rough to the touch. The petiole is 0.5–3 cm long and pubescent. The fruit is a large edible fig, 2–3 cm in diameter, ripening from buff-green to yellow or red. They are borne in thick clusters on long branchlets or the leaf axil. Flowering and fruiting occurs year-round, peaking from July to December. The bark is green-yellow to orange and exfoliates in papery strips to reveal the yellow inner bark. Like all other figs, it contains a latex (Zohary and Maria, 2000).

2.4 Lignin

Lignin is a heterogeneous and highly cross-linked macromolecule that represents the second most abundant natural polymeric material on earth (Guerra *et al.*, 2006). Lignin is that which makes plants "woody" as the name comes from the neuter Latin noun "lignum" meaning "wood" (Harkin, 1969). Kearns, (2012) suggested that the adsorption of cellulose material is a primary function of its lignin content. Lignin is a complex macromolecule, and hence, it has been stated many times that there is no single method for the accurate determination of the quality or quantity of lignin (Davin

et al., 2008;Brinkmann*et al.*, 2002).Aygun*et al.*, (2003) noted that the mechanical strength is a characteristic used for defining the quality of biochar and activated carbon as it relates to its ability to endure wear and tear during use. For this reason however, agricultural wastes, such as nut shells and fruit stones are of interest as activated carbons because of their high mechanical strength and hardness. These properties can be explained by high lignin and low ash contents.

2.5 Adsorption

The word adsorption was first coined by a German Physicist Heinrich Kayser in 1881. It is the adhesion of atoms, ions or molecules from a gas, liuid or dissolved solid to a surfact. The process creates a film of the adsorbate on the surface of the adsorbent. Dabrauski, (2003) referred to adsorption as the change in concentration of a given substance at the interface as compared with the neighboring phases. Depending on the type of phases in contact, adsorption can be classified as:

- Liquid – gas
- Liquid – liquid
- Solid – Liquid
- Solid – Gas.

2.5.1 The Science of Adsorption

Taking the gas solid phase as an example, the basic concept in adsorption occurring at every interface is the real adsorption system which is defined as an equilibrium one including the adsorbent being in contact with the bulk phase and the interfacial layer. This layer consist of two region, the part of gas residing in the force field of the solid and the surface layer of the solid. The terms adsorption deals with the process in which molecules accumulate in the interfacial layer but desorption denotes the converse

process. The material in the adsorbed state is referred to as the ‘adsorbate’, but that in the bulk gas or vapour phase prior to being adsorbed is called the ‘adsorptive’. The penetration by the adsorbate molecules into the bulk solid phase is determined as ‘absorption’. The term ‘sorption’ is also used to denote both adsorption and absorption, when both occur simultaneously or cannot be distinguished (Dabrowski, 2003).Adsorption is recognized as the most efficient, promising and widely used fundamental approach in wastewater treatment process (Foo and Hameed, 2010)

2.5.2 Adsorption Isotherm

This is a fundamental concept in the science of adsorption. It is the equilibrium relation between the quantity of the adsorbed material and the pressure or concentration in the bulk fluid phase at constant temperature. Apart from the result in the calorimetric measurements, the adsorption isotherm is the primary source of information in the adsorption process.

2.5.3 Adsorption Isotherm Models

In general, an adsorption isotherm is an invaluable curve describing the phenomenon governing the retention (or release) or mobility of a substance from the aqueous porous media or aquatic environments to a solid-phase at a constant temperature and pH (Limousin*et al*., 2007). Adsorption equilibrium (the ratio between the adsorbed amount with the remaining in the solution) is established when an adsorbate containing phase has been contacted with the adsorbent for sufficient time, with its adsorbate concentration in the bulk solution is in a dynamic balance with the interface concentration (Dabrowski, 2003). Its physicochemical parameters together with the underlying thermodynamic assumptions provide an insight into the adsorption mechanism, surface properties as well as the degree of affinity of the adsorbents (Malek

and Farooq, 1996). Over the years, a wide variety of equilibrium isotherm models (Langmuir, Freundlich, Brunauer–Emmett–Teller, Redlich– Peterson, Dubinin–Radushkevich, Temkin, Toth, Koble–Corrigan, Sips, Khan, Hill, Flory–Huggins and Radke–Prausnitz isotherm), have been formulated in terms of three fundamental approaches (Bulut et al., 2008). Kinetic consideration is the first approach to be referred. Hereby, adsorption equilibrium is defined being a state of dynamic equilibrium, with both adsorption and desorption rates are equal (Langmuir, 1916).

2.5.4 Two Major Isotherms

Langmuir isotherm model

Langmuir adsorption isotherm, originally developed to describe gas–solid-phase adsorption onto activated carbon, has traditionallybeen used to quantify and contrast the performance of different bio-sorbents (Langmuir, 1916). In its formulation, this empirical model assumes monolayer adsorption (the adsorbed layer is one molecule in thickness), with adsorption can only occur at a finite (fixed) number of definite localized sites, that are identical and equivalent, with no lateral interaction and steric hindrance between the adsorbed molecules, even on adjacent sites (Padmesh et al., 2006). In its derivation, Langmuir isotherm refers to homogeneous adsorption, which each molecule possess constant enthalpies and sorption activation energy (all sites possess equal affinity for the adsorbate), with no transmigration of the adsorbatein the plane of the surface (Kundu and Gupta, 2006).

Freundlich isotherm model

Freundlich isotherm is the earliest known relationship describing the non-ideal and reversible adsorption, not restricted to the formation of monolayer. This empirical model can be applied to multilayer adsorption, with non-uniform distribution of

adsorption heat and affinities over the heterogeneous surface. Historically, it is developed for the adsorption of animal charcoal, demonstrating that the ratio of the adsorbate onto a given mass of adsorbent to the solute was not a constant at different solution concentrations (Ahmaruzzaman, 2008). In this perspective, the amount adsorbed is the summation of adsorption on all sites (each having bond energy), with the stronger binding sites are occupied first, until adsorption energy are exponentially decreased upon the completion of adsorption process.

At present, Freundlich isotherm is widely applied in heterogeneous systems especially for organic compounds or highly interactive species on activated carbon and molecular sieves. The slope ranges between 0 and 1 is a measure of adsorption intensity or surface heterogeneity, becoming more heterogeneous as its value gets closer to zero. Whereas, a value below unity implies chemisorptions process where 1/n above one is an indicative of cooperative adsorption. Recently, Freundlich isotherm is criticized for its limitation of lacking a fundamental thermodynamic basis, not approaching the Henry's law at vanishing concentrations.

CHAPTER THREE

MATERIALS AND METHODS

The materials, instruments and experimental procedures for this research are presented in this chapter.

3.1 List of materials and equipment

Table 3.1. Laboratory equipment used for this research.

S/N	MATERIALS/EQUIPMENT	MODEL	AVAILABILITY
1.	Glass Beaker	BEX 230	WREE Lab
2.	Digital pH meter	pHS-2S	WREE Lab
3.	Digital Electrical Conductivity meter	Hanna HI 207	WREE Lab
4.	Oven	Griffin 20X	WREE Lab
5.	20ml sample bottles	PET 1	WREE Lab
6.	Immersion Thermometer	NA	WREE Lab
7.	Weighing Balance	FA2004B	WREE Lab
8.	Incubator	Griffin TS	WREE Lab
9.	Reflux Machine	NA	WREE Lab
10.	Glass rod	Technico 200C	WREE Lab
11.	Lovibond Apparatus	S500C	WREE Lab
12.	Kjelahl Apparatus	NA	Soil Science Lab
23.	Masking Tape	NA	Samaru Market
24.	Foil Paper	NA	Samaru Market
25.	Marker (Parmanent Type)	Huaying 3200	Samaru Market
26.	Rubber Clips	NA	Samaru Market
27.	Furnance	Gemco 20kW	IDC Lab

Table 3.2. Workshop Materials used during research

S/N	MATERIALS/EQUIPMENT	MODEL	AVAILABILITY
1.	12.7 ball gauge	P112FGP-WH	Samaru Local market
2.	12.7 mm pipe	P112FGP-WH	Samaru Local market
3.	101.6 mm plug	NA	Samaru Local market
4.	101.6 mm pipe	P112FGP-WH	Samaru Local market
5.	PVC gum	AbroOATEY 31008	Samaru Local market
6.	Silk Sieve	NA	Samaru Local market
7.	Saw and Screw	NA	Samaru Local market
8.	12.7mm rubber bolt and washers	NA	Samaru Local market
9.	101.6 mm metal clip	NA	Samaru Local market
10.	Pipe Threading Machine	NA	ABU Works Dept.
11.	Grinder	NA	
12.	Weighing Scale	SM-600	
23.	2mm and 4.7mm sieve	ASTM 4.7/2	

Table 3.3 Materials used for this study

S/N	MATERIALS/EQUIPMENT	MODEL	AVAILABILITY
1.	Sand (0.5mm to 0.7mm)	Rapid Sand	Samaru
2.	Wood derived biochar	NA	Samaru

3.	Greywater sample	NA	ABU, Suleiman Hostel

3.2 Experiment plan

1. A known mas of 10kg of the trees (*Vitellariaparadoa, Khayasenegalenses, FicusSycomous)* was obtained, sundried for 10 days then oven dried at 105^{o}C for three hours. The dried wood were then chipped into average sizes of 200mm each.
2. The dried wood were then pyroluzed at 650^{o}C using a Gemcofurnance.
3. The resulting biochar was ground into different particle sizes and classified into (2mm <x<4.7mm and x<2mm)
4. The classified biochar groups were then halved after which one set was activated using H_2SO4 and then washed with distilled water.
5. The resulting biochar and activated carbon were then used as filters in PVC constructed filter columns.
6. Greywater from Ahmadu Bello University Suleiman Hostel was then passed through the filters at a hydraulic loading rate of 0.033m^3/m^2/day for 21 days.
7. Their performance in remediating the greywater was analyzed using ANOVA.
8. The effects of particle size, time, parent material and activation status between the sets were also considered during the remediation process.

3.3 Preparation of filter material.

3.3.1 Preparation of Biochar

The trees used for this study: from *Vitellariaparadoa* (Shea tree), *Khayasenegalenses* (Mahogany)and *FicusSycomous*(Fig) were identified in Samaru area of Zaria in Nigeria and its stems were cut down. The stems were then chopped down into smaller pieces using an axe and 10 kg of each of the tree were obtained.

The 50kg obtained from each tree was sun dried for 48 hours to reduce the moisture content. They were further dried at a temperature of 105^{o}C using a furnace for three hours.

The dried chipped wood was then pyrolyzed at a temperature of 650^{o}C using a 20kWGemco furnace and the resulting biochar were collected, grinded and sieved using a 4.7mm standard sieve and a 2mm standard sieve. This resulted to obtaining two sets of biochar for each tree (one with a range from 2mm to 4.7mm and the other set of less than 2mm). Each set was then halved resulting to a total of 12 sets. (four for each parent material). The first half of the set (a total of 6 samples, 2 for parent material) were then activated with concentrated H_2SO_4.

During the pyrolysis of the woods, same quantity of 50 kg each were subjected to the furnace for pyrolysis but their yield were different. Their yield obtained after the pyrolysis was proportional to their lignin content. The shea-tree had the most yield of 36% after the pyrolysis with mahoganyand the fig yielding 30% and 25% respectively.

3.3.2 Activation of Biochar

A total of 6 samples (fine and coarse) from each tree were then soaked in a solution ofSulphuric acid diluted to 10% with distilled water for 24 hours after which it was dried and charred. The resulting activated biochar was then washed using distilled water and sun dried for 10 hours.

3.4 Construction of Filter Columns

The filter columns were constructed using 101.6mm diameter Polyvinyl Chloride (PVC) pipes, 12.7mm diameter PVC pipes, stoppers, control valves, PVC gum and sets of bolts and washers. 400 mm of the 101.6mm diameter PVC pipe was measured and cut. A stopper was then fitted at the bottom of the 101.6mm diameter pipe using a pvc gum. A hole of half 12.7mm diameter was drilled at the center of the stopper using a hand drill and a pipe of length 50mm and 12.7mm diameter with a threaded edge was then inserted in the hole and held firm by12.7mmbolts and washers. The edge of the 12.7mmdiameter pipe was then fitted with a control valve.

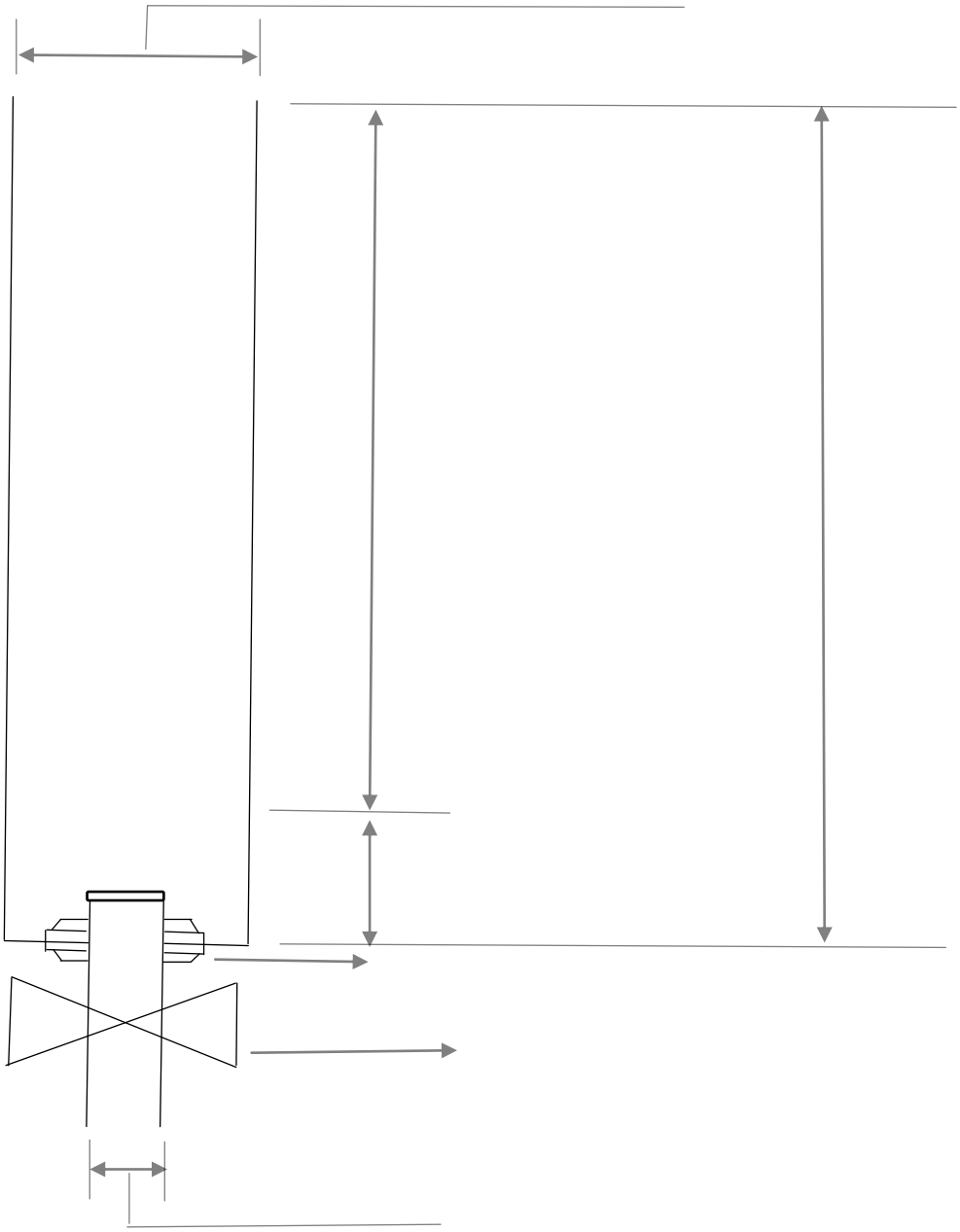


Figure 3.1. Schematic Diagram of filter column

3.5 Preparation and Loading of Filter Columns

The top of the12.7mm diameter pipe inside the filter was sealed with a 212µm mesh. A filter membrane made from cotton which measures about 20mm thick was then added to the 212µm mesh surface. Rapid sand of sizes between 0.5 and 0.7mm was washed and poured in to a level of 5cm from inside the column. Seven hundred grams (700g) of each of the biochar and activated Carbon were then measured and added to their specific column which was then labelled appropriately. The set biochar column gave a total of Twelve (12) columns each with different biochar content with a thirteenth column with no biochar and sand in it which served as the control column.

15 litres of greywater from Suleiman Hostel was obtained at 8 AM in the morning and another 15 litres at 4 PM in the evening was obtained and mixed to obtain a composite sample. 2 litres of the composite sample was then loaded in each of the 13 columns.200ml of the filtrate was collected and replaced daily with composite sample of that day.

3.6 Determination of Lignin Content of the filter media

A fraction (0.3)g of dried extracted raw biomass was weighed in glass test tubes and 3 mL of 72% H_2SO_4 was added. The sample was kept at room temperature for 2 hours with carefully shaking at 30 min intervals to allow for complete hydrolysis. After the initial hydrolysis, 84 ml of distilled water was added. The second step of hydrolysis was made to occur in an autoclave for 1 h at 121°C. The slurry was then cooled at room temperature. Hydrolyzates were filtered through vaccum using a filtering crucible. The acid insoluble lignin was determined by drying the residues at 105^{o}C and accounting for ash by incinerating the hydrolyzed samples at 575 ^{o}C in a muffle furnace. The acid soluble lignin fraction was determined by measuring the absorbance of the acid

hydrolyzed samples at 320 nm. The lignin content was calculated as the summation of acid insoluble lignin and acid soluble lignin. This method was suggested by United State Department of Energy, Sluiter*et al* (2008).

3.7 Determination of Physical Parameters

The physical properties of the filters which include bulk density, particle density, porosity, air dry water content were determined using Standard Soil Physics procedures as reported by Hillel (1982). Particle size range was determined by using 4.7mm and 2mm standard sieves while pyrolysis yield was determined percentage wise.

3.8 Laboratory Analysis of Samples

Daily samples obtained from the 200ml bottles were tested in the laboratory immediately. Physico-Chemical parameters of pH, EC, Tot-N, Tot-P, PO_4-P, NO_3-N, NH_3-N, BOD and COD were tested and recorded for a period of 21 days.pH and Electrical Conductivity (EC) were determined using a portable standardized Hanna instrument.

Electrical conductivity were tested using a standardized calibrated instrument while the other parameters were analyzed using laboratory methods. The table below gives the summary of all the laboratory analysis methods, standards, equipment and reagents used during the analysis. Total Nitrogen was determined by standard Kjaldahl method after dilution with Bromocresol given as indicator. Nitrate Nitrogen was also determined with the Kjaldahl method using Magnesium Oxide and Boric Acid with Devarda's alloy. Ammonium Nitrogen was analyzed using the Lovibond Apparatus with Nessler reagent and Rochelle Salt. The Chemical Oxygen Demand (COD) was determined using the Potassium Dichromate method. On the other hand, BOD was determined after incubating for five (5) days using alkali iodized-azadide reagent,

Manganese Sulphate and Sulphuric acid using starch as an indicator on the titration with Sodiumthiosulphate. The yellow method was used to determine available Phosphorus method with a spectrophotometer using Ascorbic Acid, Potassium, Ammonium vanadate, Ammonium molybdate, nitric acid and Potassium antimonyl tartrate. Similarly, Total Phosphorus was determined with the spectrophotometer using Ammonium molybdate, Hydrochloric Acid and Tin Chloride. Table I shows a summary of procedures and instruments used.

Treatment Efficiencies were calculated using the formular

$$E = \frac{Cin - Cout}{Cin} \qquad (3.1)$$

Where E is efficiency in %

Cin is initial concentration of pollutants

Cout is Final concentration of pollutants

Table 3.4 Laboratory Procedures and reagents used

PARAMETER	REGENTS	MEASUREMENT RANGE	UNIT	METHOD	APPARATUS
COD	H_2SO_4, $K_2CR_2O_7$, Ferrous indicator, Ferrous AmoniumSulphate	Not Applicable	mgl^{-1}	Quantitative	-
BOD	MaganeseSulphate, Alkali iodized-azadide reagent, H_2SO_4, $Na_2S_2O_3$, starch	Not Applicable	mgl^{-1}	Winkler	-
NH_4-N	Nesslers reagent, Rochelle salt	COLOUR INTENSITY	mgl^{-1}	Colorimetric	lovibond
NO_3-N	Boric acid, Magnesium Oxide, Devarda's alloy	Not Applicable	mgl^{-1}	Kjeldahl	Kjeldahl Apparatus
TOT-N	H_2SO_4, NaOH, Boric SoiumSulphate, CupperSulphate, Bromocresol Green Inicator	Not Applicable	mgl^{-1}	Kjeldahl	Kjeldahl Apparatus
PO_4-P	Ascorbic acid, potassium antimonyl tartrate, amonium vanadate, ammonium molybate, nitric acid	420nm	mgl^{-1}	Yellow Method	Spectrophotometer
TOT-P	Ammonium molybdate, , Hydrochloric Acid, Tin Chloride	500 – 700 nm	mgl^{-1}		Spectrophotometer
pH	NONE	0 – 14	NONE	Direct	Hanna Instrument
EC	NONE	0 – 20,000	µS/cm	Direct	Hanna Instrument
Lignin	H_2SO4	320nm	%w/w	Indirect	Spectrophotometer

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Results

The 200ml sample collected daily from all the thirteen filters were tested in the laboratory and values were recorded throughout the 21 days of the experiment. The experiment was replicated three times and the results were analyzed using Microsoft Excel 2013 and Instat Statistic Package Version 3 (Graph-pad). Results for each analyzed parameter is presented in a pair of tables.

The weekly summary of the adsorbed concentration of the pollutants is presented as Mean+ SEM (Standard error of mean). Results presented across the columns shows comparisons between the three parent materials and also comparison between Biochar and Activated Carbon while results presented down the rows showcomparisons between the different particle sizes and different time (in weeks). Differences between the columns are calculated using Fisher Statistics values and Critical Fisher Values (F_C) at minimum of 95% confidence limit.

The comparisons between particle sizes and activation status is shown in terms of P values. P values greater than 0.05 were considered Not Significant and labelled (NS) while P values less than 0.05 and less than 0.01 were considered significant and Highly significant and are represented with asterix signs (**) and (*) respectively. The P-value comparisons were calculated analyzed Bonferroni Multiple Comparison Test .

Table 4.1 shows all the thirteen columns and their labels with their corresponding parent material, activation status and particle sizes.

Table 4.2 shows the calculated physical properties of the filters, their calculated lignin content and their percentage yield after pyrolysis.

TABLE 4.1 DESCRIPTION OF COLUMNS

COLUMNS	**FILTER MATERIAL**	**PARTICLE SIZE (mm)**	**FILTER TYPE**
COLUMN 1	FIG	2 – 4.7	BIOCHAR
COLUMN 2	FIG	< 2	BIOCHAR
COLUMN 3	MAHOGANY	2 – 4.7	BIOCHAR
COLUMN 4	MAHOGANY	< 2	BIOCHAR
COLUMN 5	SHEA TREE	2 – 4.7	BIOCHAR
COLUMN 6	SHEA TREE	< 2	BIOCHAR
COLUMN 7	FIG	2 – 4.7	ACTIVATED CARBON
COLUMN 8	FIG	< 2	ACTIVATED CARBON
COLUMN 9	MAHOGANY	2 – 4.7	ACTIVATED CARBON
COLUMN 10	MAHOGANY	< 2	ACTIVATED CARBON
COLUMN 11	SHEA TREE	2 – 4.7	ACTIVATED CARBON
COLUMN 12	SHEA TREE	< 2	ACTIVATED CARBON
COLUMN CONTROL	-	-	-

Table 4.2 Physical properties of the parent material used.

Parameter	Fig tree		Mahogany		Shea tree	
Particle size (mm)	2 – 4.7	<2	2 – 4.7	<2	2 – 4.7	<2
Air dry water content (%)	61	61	65	65	63	63
Bulk Density (kg/m^3)	307	296	283	270	296	261
Particle Density (kg/m^3)	1694	1694	1810	1810	1940	1940
Lignin Content (%w/w)	21.4	21.4	28.9	28.9	34.9	34.9
Yield after Pyrolysis (%)	25	25	30	30	36	36
Porosity (%)	83	71	74	61	79	65

Table 4.3 shows adsorbed Total Phosphorus from each filters presented as Mean±Standard Error of Mean. Compared Adsorbed concentration of Total Phosphorus for each parent material is presented across the columns while the comparison factors of Time and Particle size is presented down the rows. The results shows averagely same performance for each of the filters. Although minor differences can be observed, the differences does not qualify as statistically significant.

The table also shows that Total Phosphorus adsorption occurred higher in the first week with slight reduction in the second and third week.

Table 4.3 Adsorbed Concentration of Total Phosphorus From Filters

Time (Weeks)	PS (mm)	Biochar (mgl^{-1})			Activated Carbon (mgl^{-1})			Fisher values	
		Fig	Mahogany	Shea	Fig	Mahogany	Shea	F_V	F_C ∝=5%
1	2 – 4	48.414±6.462	47.277±6.514	47.494±6.516	43.677±6.663	40.620±5.623	41.169±6.571	0.146	1.906
	< 2	47.663±6.646	47.611±6.508	47.361±6.676	37.386±6.512	37.390±6.251	40.641±6.737		
2	2 – 4	37.191±0.633	36.697±0.565	36.497±0.536	30.677±0.639	30.670±0.604	29.861±0.489	50.579	1.906
	< 2	36.756±0.687	36.247±0.647	36.043±0.589	27.913±0.484	27.369±0.505	27.406±0.520		
3	2 – 4	26.929±0.998	26.286±1.022	25.747±1.065	21.434±0.885	21.060±0.985	21.181±0.768	10.923	1.906
	< 2	26.163±1.052	24.111±1.163	23.813±1.142	17.896±0.985	17.970±0.840	20.144±0.666		

Table 4.4 shows comparisons between Biochar Filter Columns and Activated Carbon Filter Columns. It also shows comparisons between filters with less than 2mm particle size and filters with a range of 2mm to 4.7mm particle size. Using P values as a standard for the comparisons, the compared results showed no significant difference between all columns compared

Table 4.4 Level of Significant differencesand Comparisons for Total Phosphorus

Time (weeks)	Filter Media	Particle Size Comparison.	P Value	Activation status Comparison	P Value
1	Fig	$B_{2-4.7}$ VS $B_{<2}$	NS	$B_{2-4.7}$ VS $AC_{2-4.7}$	NS
		$AC_{2-4.7}$VS $AC_{<2}$	NS	$B_{<2}$ VS $AC_{<2}$	NS
	Mahogany	$B_{2-4.7}$ VS $B_{<2}$	NS	$B_{2-4.7}$ VS $AC_{<4.7}$	NS
		$AC_{2-4.7}$VS $AC_{<2}$	NS	$B_{<2}$ VS $AC_{<2}$	NS
	Shea	$B_{2-4.7}$ VS $B_{<2}$	NS	$B_{2-4.7}$ VS $AC_{<4.7}$	NS
		$AC_{2-4.7}$VS $AC_{<2}$	NS	$B_{<2}$ VS $AC_{<2}$	NS
2	Fig	$B_{2-4.7}$ VS $B_{<2}$	NS	$B_{2-4.7}$ VS $AC_{2-4.7}$	NS
		$AC_{2-4.7}$VS $AC_{<2}$	NS	$B_{<2}$ VS $AC_{<2}$	NS
	Mahogany	$B_{2-4.7}$ VS $B_{<2}$	NS	$B_{2-4.7}$ VS $AC_{<4.7}$	NS
		$AC_{2-4.7}$VS $AC_{<2}$	NS	$B_{<2}$ VS $AC_{<2}$	NS
	Shea	$B_{2-4.7}$ VS $B_{<2}$	NS	$B_{2-4.7}$ VS $AC_{<4.7}$	NS
		$AC_{2-4.7}$VS $AC_{<2}$	NS	$B_{<2}$ VS $AC_{<2}$	NS
3	Fig	$B_{2-4.7}$ VS $B_{<2}$	NS	$B_{2-4.7}$ VS $AC_{2-4.7}$	NS
		$AC_{2-4.7}$VS $AC_{<2}$	NS	$B_{<2}$ VS $AC_{<2}$	NS
	Mahogany	$B_{2-4.7}$ VS $B_{<2}$	NS	$B_{2-4.7}$ VS $AC_{<4.7}$	NS
		$AC_{2-4.7}$VS $AC_{<2}$	NS	$B_{<2}$ VS $AC_{<2}$	NS
	Shea	$B_{2-4.7}$ VS $B_{<2}$	NS	$B_{2-4.7}$ VS $AC_{<4.7}$	NS
		$AC_{2-4.7}$VS $AC_{<2}$	NS	$B_{<2}$ VS $AC_{<2}$	NS

Table 4.5 shows results for adsorbed COD presented as Mean±Standard Error of Mean. It presents adsorbed results from different parent materials and activation status across the columns while results for different time (in weeks) and different particle sizes are presented down the rows. Differences between the columns are shown using Fisher values and Critical Fisher values are 95% confidence limit.

The table shows that there were no observed significant differences between all the compared parent materials in terms of COD adsorption. It however shows that more adsorption was observed in the second week with less in the first and third week respectively.

Table 4.5 Adsorbed Concentration of COD From Filters

TIME (Weeks)	PS (mm)	Biochar (mgl^{-1})			Activated Carbon (mgl^{-1})			Fisher values	
		Fig	Mahogany	Shea	Fig	Mahogany	Shea	F_V	F_C ∝=5%
1	2 – 4	257.14±24.247	248.57±34.235	364.29±28.356	214.29±30.147	281.43±27.276	335.71±35.245	3.435	1.906
	< 2	245.71±25.435	262.86±33.645	364.29±26.624	211.43±28.320	298.57±26.675	348.57±35.752		
2	2 – 4	312.86±42.410	298.57±44.477	351.43±43.008	218.57±39.123	294.29±39.088	305.71±38.350	0.946	1.906
	< 2	302.86±46.080	289.57±46.723	345.71±44.873	214.29±39.088	292.86±42.802	314.29±44.178		
3	2 – 4	181.43±7.997	171.43±7.997	218.57±10.335	125.71±8.411	188.57±6.335	187.14±8.650	9.554	1.906
	< 2	160.60±10.690	157.14±11,488	205.57±12.509	118.57±9.368	172.86±7.781	177.14±9.440		

Table 4.6 shows comparisons between Biochar and Activated Carbon and also between <2mm particle sized filters and 2 – 4 mm particle sized filters. Using P value as the factor for the comparisons, there were no observed significant differences between all made comparisons except for a single case of the Fig derived filters in week one were comparisons between Biochar and Activated Carbon showed a P value of <0.001 (**) and <0.05(*) respectively.

Table4.6 Level of Significant difference and Comparisons for COD

Time (weeks)	Filter Media	Particle Size comparison.	P Value	Activation status comparison	P Value
1	Fig	$B_{2-4.7}$ VS $B_{<2}$	NS	$B_{2-4.7}$ VS $AC_{2-4.7}$	**
		$AC_{2-4.7}$VS $AC_{<2}$	NS	$B_{<2}$ VS $AC_{<2}$	*
	Mahogany	$B_{2-4.7}$ VS $B_{<2}$	NS	$B_{2-4.7}$ VS $AC_{<4.7}$	NS
		$AC_{2-4.7}$VS $AC_{<2}$	NS	$B_{<2}$ VS $AC_{<2}$	NS
	Shea	$B_{2-4.7}$ VS $B_{<2}$	NS	$B_{2-4.7}$ VS $AC_{<4.7}$	NS
		$AC_{2-4.7}$VS $AC_{<2}$	NS	$B_{<2}$ VS $AC_{<2}$	NS
2	Fig	$B_{2-4.7}$ VS $B_{<2}$	NS	$B_{2-4.7}$ VS $AC_{2-4.7}$	NS
		$AC_{2-4.7}$VS $AC_{<2}$	NS	$B_{<2}$ VS $AC_{<2}$	NS
	Mahogany	$B_{2-4.7}$ VS $B_{<2}$	NS	$B_{2-4.7}$ VS $AC_{<4.7}$	NS
		$AC_{2-4.7}$VS $AC_{<2}$	NS	$B_{<2}$ VS $AC_{<2}$	NS
	Shea	$B_{2-4.7}$ VS $B_{<2}$	NS	$B_{2-4.7}$ VS $AC_{<4.7}$	NS
		$AC_{2-4.7}$VS $AC_{<2}$	NS	$B_{<2}$ VS $AC_{<2}$	NS
3	Fig	$B_{2-4.7}$ VS $B_{<2}$	NS	$B_{2-4.7}$ VS $AC_{2-4.7}$	NS
		$AC_{2-4.7}$VS $AC_{<2}$	NS	$B_{<2}$ VS $AC_{<2}$	NS
	Mahogany	$B_{2-4.7}$ VS $B_{<2}$	NS	$B_{2-4.7}$ VS $AC_{<4.7}$	NS
		$AC_{2-4.7}$VS $AC_{<2}$	NS	$B_{<2}$ VS $AC_{<2}$	NS
	Shea	$B_{2-4.7}$ VS $B_{<2}$	NS	$B_{2-4.7}$ VS $AC_{<4.7}$	NS
		$AC_{2-4.7}$VS $AC_{<2}$	NS	$B_{<2}$ VS $AC_{<2}$	NS

Table 4.7 shows adsorbed Nitrate Nitrogen (NO_3-N) presented as Mean±Standard Error of mean. It shows comparisons between different parent materials across the columns while comparisons for different particle sizes and different time (in weeks) are presented down the rows.

The table indicates that there were no observed significant differences between the different particle sizes, different parent materials and differences in activation status. There was however observed differences between concentrations adsorbed in the first, second and third week with the rate of adsorption more in the second week.

Table4.7 Adsorbed Concentration of NO_3-N from filters

Time (Weeks)	Ps (mm)	Biochar (mgl^{-1})			Activated Carbon (mgl^{-1})			Fisher Values	
		Fig	Mahogany	Shea	Fig	Mahogany	Shea	F_V	F_C ∝=5%
1	2 – 4	77.214±9.598	81.286±7.724	82.214±9.461	73.286±5.410	78.429±8.879	74.286±5.524	0.329	1.906
	< 2	85.714±8.937	83.857±8.374	84.286±8.420	71.286±8.959	77.357±6.955	81.357±7.601		
2	2 – 4	31.286±4.276	33.071±5.085	32.500±5.032	33.000±4.795	29.143±3.892	33.080±5.098	0.064	1.906
	< 2	33.08±5.369	33.500±5.032	32.000±4.923	33.000±4.795	32.500±4.689	37.500±5.032		
3	2 – 4	14.000±1.328	16.000±1.291	15.500±1.041	12.500±1.848	11.500±2.380	13.429±1.605	0.974	1.906
	< 2	15.500±1.041	16.000±1.291	15.000±1.826	12.500±1.500	13.070±1.826	12.000±2.141		

Table 4.8 shows comparisons of adsorbed NO_3-N between Biochar and Activated Carbon and also between <2mm particle sized filters and 2 – 4 mm particle sized filters. Using P value as the factor for the comparisons, there were not observed significant differences between all comparisons.

Table 4.8 Level of significant differences and comparisons for NO_3-N.

Time (weeks)	Filter Media	Particle Size Comparison.	P Value	Activation Status Comparison	P Value
1	Fig	$B_{2-4.7}$ VS $B_{<2}$	NS	$B_{2-4.7}$ VS $AC_{2-4.7}$	NS
		$AC_{2-4.7}$VS $AC_{<2}$	NS	$B_{<2}$ VS $AC_{<2}$	NS
	Mahogany	$B_{2-4.7}$ VS $B_{<2}$	NS	$B_{2-4.7}$ VS $AC_{<4.7}$	NS
		$AC_{2-4.7}$VS $AC_{<2}$	NS	$B_{<2}$ VS $AC_{<2}$	NS
	Shea	$B_{2-4.7}$ VS $B_{<2}$	NS	$B_{2-4.7}$ VS $AC_{<4.7}$	NS
		$AC_{2-4.7}$VS $AC_{<2}$	NS	$B_{<2}$ VS $AC_{<2}$	NS
2	Fig	$B_{2-4.7}$ VS $B_{<2}$	NS	$B_{2-4.7}$ VS $AC_{2-4.7}$	NS
		$AC_{2-4.7}$VS $AC_{<2}$	NS	$B_{<2}$ VS $AC_{<2}$	NS
	Mahogany	$B_{2-4.7}$ VS $B_{<2}$	NS	$B_{2-4.7}$ VS $AC_{<4.7}$	NS
		$AC_{2-4.7}$VS $AC_{<2}$	NS	$B_{<2}$ VS $AC_{<2}$	NS
	Shea	$B_{2-4.7}$ VS $B_{<2}$	NS	$B_{2-4.7}$ VS $AC_{<4.7}$	NS
		$AC_{2-4.7}$VS $AC_{<2}$	NS	$B_{<2}$ VS $AC_{<2}$	NS
3	Fig	$B_{2-4.7}$ VS $B_{<2}$	NS	$B_{2-4.7}$ VS $AC_{2-4.7}$	NS
		$AC_{2-4.7}$VS $AC_{<2}$	NS	$B_{<2}$ VS $AC_{<2}$	NS
	Mahogany	$B_{2-4.7}$ VS $B_{<2}$	NS	$B_{2-4.7}$ VS $AC_{<4.7}$	NS
		$AC_{2-4.7}$VS $AC_{<2}$	NS	$B_{<2}$ VS $AC_{<2}$	NS
	Shea	$B_{2-4.7}$ VS $B_{<2}$	NS	$B_{2-4.7}$ VS $AC_{<4.7}$	NS
		$AC_{2-4.7}$VS $AC_{<2}$	NS	$B_{<2}$ VS $AC_{<2}$	NS

Table 4.9 shows results for adsorbed Phosphate Phosphorus (PO_4-P) presented as Mean±Standard Error of Mean. It presents adsorbed results from different parent materials and activation status across the columns while results for different time (in weeks) and different particle sizes are presented down the rows. Differences between the columns are shown using Fisher values and Critical Fisher values are 95% confidence limit.

The table also showed that there were no observed significant differences between all the compared parent materials in terms of PO_4-P adsorption. It however shows that more adsorption was observed in the first week with less in the second and third week respectively.

Table 4.9 Adsorbed Concentration of PO_4-PFrom Filters

Time (Weeks)	PS (mm)	Biochar (mgl^{-1})			Activated Carbon (mgl^{-1})			Fisher Values	
		Fig	Mahogany	Shea	Fig	Mahogany	Shea	F_V	F_C ∝=5%
1	2 – 4	148.33±19.817	144.69±19.975	145.23±19.981	133.81±20.431	124.84±17.213	126.16±20.145	0.414	1.906
	< 2	146.33±19.823	145.87±20.141	145.17±20.459	115.92±19.966	114.56±19.166	124.52±20.663		
2	2 – 4	113.99±1.941	112.47±1.733	111.86±1.644	94.027±1.959	94.317±2.128	91.524±1.499	51.095	1.906
	< 2	112.47±2.095	111.18±1.986	110.47±1.806	84.409±1.451	83.893±1.542	83.321±1.329		
3	2 – 4	82.539±3.061	80.553±3.132	78.917±3.264	65.710±2.720	64.553±3.019	64.926±2.356	10.848	1.906
	< 2	80.191±3.224	73.903±3.566	72984±3.496	54.844±2.954	55.077±2.576	62.030±2.114		

Table 4.10 shows comparisons of adsorbed PO_4-P between Biochar and Activated Carbon and also between <2mm particle sized filters and 2 – 4 mm particle sized filters. Using P value as the factor for the comparisons, there were not observed significant differences between columns of different particle sizes. Significant differences were observed between biochar and activated Carbon in the second and third week

Table 4.10 Level of Significant Difference and Comparison ForPO_4-P

Time (weeks)	Filter Media	Particle Size Comparison.	P Value	Activation status Comparison	P Value
1	Fig	$B_{2-4.7}$ VS $B_{<2}$	NS	$B_{2-4.7}$ VS $AC_{2-4.7}$	NS
		$AC_{2-4.7}$VS $AC_{<2}$	NS	$B_{<2}$ VS $AC_{<2}$	NS
	Mahogany	$B_{2-4.7}$ VS $B_{<2}$	NS	$B_{2-4.7}$ VS $AC_{<4.7}$	NS
		$AC_{2-4.7}$VS $AC_{<2}$	NS	$B_{<2}$ VS $AC_{<2}$	NS
	Shea	$B_{2-4.7}$ VS $B_{<2}$	NS	$B_{2-4.7}$ VS $AC_{<4.7}$	NS
		$AC_{2-4.7}$VS $AC_{<2}$	NS	$B_{<2}$ VS $AC_{<2}$	NS
2	Fig	$B_{2-4.7}$ VS $B_{<2}$	NS	$B_{2-4.7}$ VS $AC_{2-4.7}$	**
		$AC_{2-4.7}$VS $AC_{<2}$	NS	$B_{<2}$ VS $AC_{<2}$	**
	Mahogany	$B_{2-4.7}$ VS $B_{<2}$	NS	$B_{2-4.7}$ VS $AC_{<4.7}$	**
		$AC_{2-4.7}$VS $AC_{<2}$	NS	$B_{<2}$ VS $AC_{<2}$	**
	Shea	$B_{2-4.7}$ VS $B_{<2}$	NS	$B_{2-4.7}$ VS $AC_{<4.7}$	**
		$AC_{2-4.7}$VS $AC_{<2}$	NS	$B_{<2}$ VS $AC_{<2}$	**
3	Fig	$B_{2-4.7}$ VS $B_{<2}$	NS	$B_{2-4.7}$ VS $AC_{2-4.7}$	**
		$AC_{2-4.7}$VS $AC_{<2}$	NS	$B_{<2}$ VS $AC_{<2}$	**
	Mahogany	$B_{2-4.7}$ VS $B_{<2}$	NS	$B_{2-4.7}$ VS $AC_{<4.7}$	**
		$AC_{2-4.7}$VS $AC_{<2}$	NS	$B_{<2}$ VS $AC_{<2}$	**
	Shea	$B_{2-4.7}$ VS $B_{<2}$	NS	$B_{2-4.7}$ VS $AC_{<4.7}$	*
		$AC_{2-4.7}$VS $AC_{<2}$	NS	$B_{<2}$ VS $AC_{<2}$	NS

Table 4.11 shows results for adsorbed Total Nitrogen (TOT-N) presented as Mean±Standard Error of Mean. It presents adsorbed results from different parent materials and activation status across the columns while results for different time (in weeks) and different particle sizes are presented down the rows. Differences between the columns are shown using Fisher values and Critical Fisher values are 95% confidence limit.

The table shows that there were no observed significant differences between all the compared parent materials in terms of Total Nitrogen adsorption. It however shows that more adsorption was observed in the first week with less in the second and third week respectively.

Table4.11 Adsorbed Concentration of Total NitrogenFrom Filters

Time (weeks)	PS (mm)	Biochar (mgl^{-1})			Activated carbon (mgl^{-1})			Fisher Values	
		Fig	Mahogany	Shea	Fig	Mahogany	Shea	F_V	F_C ∝=10%
1	2 – 4	22.000±1.826	23.000±2.000	23.000±2.000	20.00±1.826	23.00±2.000	23.000±2.000	0.225	
	< 2	23.000±2.000	23.000±2.000	21.00±2.160	22.000±1.826	23.000±2.000	23.000±2.000		
2	2 – 4	12.071±3.299	11.071±2.985	11.071±2.985	12.071±3.299	13.071±3.855	13.071±3.855	0.046	
	< 2	13.071±3.855	12.071±3.299	12.071±3.299	12.071±3.299	13.071±3.855	13.071±3.855		
3	2 – 4	6.214±0.706	6.214±0.706	6.214±0.706	7.214±1.327	6.714±0.938	6.714±1.401	0.172	
	< 2	6.714±0.937	6.214±0.706	5.714±0.786	7.214±1.327	6.714±1.401	6.714±1.401		

Table 4.12 shows comparisons of adsorbed Total Nitrogen between Biochar and Activated Carbon and also between <2mm particle sized filters and 2 – 4 mm particle sized filters. Using P value as the factor for the comparisons, there were not observed significant differences between all comparisons.

Table 4.12 Level of Significant Difference and Comparisons for Total Nitrogen

Time (weeks)	Filter Media	Particle Size Comparison.	P Value	Activation status Comparison	P Value
1	Fig	$B_{2-4.7}$ VS $B_{<2}$	NS	$B_{2-4.7}$ VS $AC_{2-4.7}$	NS
		$AC_{2-4.7}$VS $AC_{<2}$	NS	$B_{<2}$ VS $AC_{<2}$	NS
	Mahogany	$B_{2-4.7}$ VS $B_{<2}$	NS	$B_{2-4.7}$ VS $AC_{<4.7}$	NS
		$AC_{2-4.7}$VS $AC_{<2}$	NS	$B_{<2}$ VS $AC_{<2}$	NS
	Shea	$B_{2-4.7}$ VS $B_{<2}$	NS	$B_{2-4.7}$ VS $AC_{<4.7}$	NS
		$AC_{2-4.7}$VS $AC_{<2}$	NS	$B_{<2}$ VS $AC_{<2}$	NS
2	Fig	$B_{2-4.7}$ VS $B_{<2}$	NS	$B_{2-4.7}$ VS $AC_{2-4.7}$	NS
		$AC_{2-4.7}$VS $AC_{<2}$	NS	$B_{<2}$ VS $AC_{<2}$	NS
	Mahogany	$B_{2-4.7}$ VS $B_{<2}$	NS	$B_{2-4.7}$ VS $AC_{<4.7}$	NS
		$AC_{2-4.7}$VS $AC_{<2}$	NS	$B_{<2}$ VS $AC_{<2}$	NS
	Shea	$B_{2-4.7}$ VS $B_{<2}$	NS	$B_{2-4.7}$ VS $AC_{<4.7}$	NS
		$AC_{2-4.7}$VS $AC_{<2}$	NS	$B_{<2}$ VS $AC_{<2}$	NS
3	Fig	$B_{2-4.7}$ VS $B_{<2}$	NS	$B_{2-4.7}$ VS $AC_{2-4.7}$	NS
		$AC_{2-4.7}$VS $AC_{<2}$	NS	$B_{<2}$ VS $AC_{<2}$	NS
	Mahogany	$B_{2-4.7}$ VS $B_{<2}$	NS	$B_{2-4.7}$ VS $AC_{<4.7}$	NS
		$AC_{2-4.7}$VS $AC_{<2}$	NS	$B_{<2}$ VS $AC_{<2}$	NS
	Shea	$B_{2-4.7}$ VS $B_{<2}$	NS	$B_{2-4.7}$ VS $AC_{<4.7}$	NS
		$AC_{2-4.7}$VS $AC_{<2}$	NS	$B_{<2}$ VS $AC_{<2}$	NS

Table 4.13 shows results for adsorbed BOD presented as Mean±Standard Error of Mean. It presents adsorbed results from different parent materials and activation status across the columns while results for different time (in weeks) and different particle sizes are presented down the rows. Differences between the columns are shown using Fisher values and Critical Fisher values at 95% confidence limit.

The table shows that there were no observed significant differences between all the compared parent materials in terms of BOD adsorption. It also shows that the rate of BOD reduction in the filters increase with time unlike other parameters.

Table 4.13 Adsorbed Concentration Of BOD From Filters

Time (weeks)	PS (mm)	Biochar (mgl^{-1})			Activated carbon (mgl^{-1})			Fisher values	
		Fig	Mahogany	Shea	Fig	Mahogany	Shea	F_v	F_c ∝=5%
1	2 – 4	258.00±25.962	156.00±18.601	212.00±26.533	242.00±25.573	226.00±22.716	214.00±21.119	1.421	1.998
	< 2	250.00±26.077	180.00±36.742	238.00±23.324	244.00±23.791	226.00±22.716	210.00±20.736		
2	2 – 4	274.00±10.296	220.00±10.000	238.00±13.928	256.00±10.296	250.00±11.402	228.00±11.576	2.428	1.998
	< 2	268.00±8.602	223.00±9.695	240.00±12.247	250.00±8.944	244.00±11.225	276.80±11.576		
3	2 – 4	310.00±16.733	278.00±16.248	270.00±16.125	296.800±16.852	296.00±11.662	276.80±11.662	1.267	1.998
	< 2	302.04±16.533	272.00±16.533	268.00±8.00	272.00±9.165	292.000±11.576	260.00±13.416		

Table 4.14 shows comparisons of adsorbed BOD between Biochar and Activated Carbon and also between <2mm particle sized filters and 2 – 4 mm particle sized filters. Using P value as the factor for the comparisons, there were no observed significant differences between all comparisons

Table 4.14 Level of significant Difference and comparisons for BOD Results

Time (weeks)	Filter Media	Particle Size comparison.	P Value	Activation status comparison	P Value
1	Fig	$B_{2-4.7}$ VS $B_{<2}$	NS	$B_{2-4.7}$ VS $AC_{2-4.7}$	NS
		$AC_{2-4.7}$VS $AC_{<2}$	NS	$B_{<2}$ VS $AC_{<2}$	NS
	Mahogany	$B_{2-4.7}$ VS $B_{<2}$	NS	$B_{2-4.7}$ VS $AC_{<4.7}$	NS
		$AC_{2-4.7}$VS $AC_{<2}$	NS	$B_{<2}$ VS $AC_{<2}$	NS
	Shea	$B_{2-4.7}$ VS $B_{<2}$	NS	$B_{2-4.7}$ VS $AC_{<4.7}$	NS
		$AC_{2-4.7}$VS $AC_{<2}$	NS	$B_{<2}$ VS $AC_{<2}$	NS
2	Fig	$B_{2-4.7}$ VS $B_{<2}$	NS	$B_{2-4.7}$ VS $AC_{2-4.7}$	NS
		$AC_{2-4.7}$VS $AC_{<2}$	NS	$B_{<2}$ VS $AC_{<2}$	NS
	Mahogany	$B_{2-4.7}$ VS $B_{<2}$	NS	$B_{2-4.7}$ VS $AC_{<4.7}$	NS
		$AC_{2-4.7}$VS $AC_{<2}$	NS	$B_{<2}$ VS $AC_{<2}$	NS
	Shea	$B_{2-4.7}$ VS $B_{<2}$	NS	$B_{2-4.7}$ VS $AC_{<4.7}$	NS
		$AC_{2-4.7}$VS $AC_{<2}$	NS	$B_{<2}$ VS $AC_{<2}$	NS
3	Fig	$B_{2-4.7}$ VS $B_{<2}$	NS	$B_{2-4.7}$ VS $AC_{2-4.7}$	NS
		$AC_{2-4.7}$VS $AC_{<2}$	NS	$B_{<2}$ VS $AC_{<2}$	NS
	Mahogany	$B_{2-4.7}$ VS $B_{<2}$	NS	$B_{2-4.7}$ VS $AC_{<4.7}$	NS
		$AC_{2-4.7}$VS $AC_{<2}$	NS	$B_{<2}$ VS $AC_{<2}$	NS
	Shea	$B_{2-4.7}$ VS $B_{<2}$	NS	$B_{2-4.7}$ VS $AC_{<4.7}$	NS
		$AC_{2-4.7}$VS $AC_{<2}$	NS	$B_{<2}$ VS $AC_{<2}$	NS

Table 4.15 shows results for adsorbed EC presented as Mean±Standard Error of Mean. It presents adsorbed results from different parent materials and activation status across the columns while results for different time (in weeks) and different particle sizes are presented down the rows. Differences between the columns are shown using Fisher values and Critical Fisher values at 95% confidence limit.

The table shows that there were no observed significant differences between all the compared parent materials in terms of EC adsorption. It also shows that the rate of EC reduction in the filters reduces with time,

Table 4.15 Adsorbed Concentration of ECFrom Filters

Time (Weeks)	PS (mm)	Biochar (µS/CM)			Activated Carbon (µS/cm)			Fisher Values	
		Fig	Mahogany	Shea	Fig	Mahogany	Shea	F_V	F_C ∞=5%
1	2 – 4	3279.6±210.38	2044.1±257.00	2951.9±478.15	4280.6±138.36	4660.1±177.33	4495.1±174.59	18.322	1.906
	< 2	2786.6±358.68	1609.7±326.11	2484.0±167.66	3966.3±141.91	4534.0±175.13	4422.37±137.84		
2	2 – 4	2638.6±119.67	2284.0±13.968	2844.0±90.563	3696.3±130.15	3905.1±148.14	3827.0±154.70	55.379	1.906
	< 2	1222.9±119.99	1330.6±71.742	2320.9±112.49	3523.6±162.25	3858.1±149.28	3805.6157.30		
3	2 – 4	2588.6±158.58	2239.1±61.283	2393.4±39.308	2991.9±100.50	3098.1±10.343	3021.1±103.91	59.090	1.906
	< 2	1080.3±43.269	1224.4±81.236	2002.1±38.629	2846.9±138.36	3079.7±104.86	2966.9±105.17		

Table 4.16 shows comparisons of adsorbed EC between Biochar and Activated Carbon and also between <2mm particle sized filters and 2 – 4 mm particle sized filters. Using P value as the factor for the comparisons, it was observed that there were no significant differences between the compared particle sizes. All comparisons between Biochar and Activated Carbon however showed significant differences.

Table 4.16 Level of Significant Differences and Comparisons for EC

Time (weeks)	Filter Media	Particle Size comparison.	P Value	Activation status comparison	P Value
1	Fig	$B_{2-4.7}$ VS $B_{<2}$	NS	$B_{2-4.7}$ VS $AC_{2-4.7}$	**
		$AC_{2-4.7}$VS $AC_{<2}$	NS	$B_{<2}$ VS $AC_{<2}$	**
	Mahogany	$B_{2-4.7}$ VS $B_{<2}$	NS	$B_{2-4.7}$ VS $AC_{<4.7}$	**
		$AC_{2-4.7}$VS $AC_{<2}$	NS	$B_{<2}$ VS $AC_{<2}$	**
	Shea	$B_{2-4.7}$ VS $B_{<2}$	NS	$B_{2-4.7}$ VS $AC_{<4.7}$	**
		$AC_{2-4.7}$VS $AC_{<2}$	NS	$B_{<2}$ VS $AC_{<2}$	**
2	Fig	$B_{2-4.7}$ VS $B_{<2}$	NS	$B_{2-4.7}$ VS $AC_{2-4.7}$	**
		$AC_{2-4.7}$VS $AC_{<2}$	NS	$B_{<2}$ VS $AC_{<2}$	**
	Mahogany	$B_{2-4.7}$ VS $B_{<2}$	NS	$B_{2-4.7}$ VS $AC_{<4.7}$	**
		$AC_{2-4.7}$VS $AC_{<2}$	NS	$B_{<2}$ VS $AC_{<2}$	**
	Shea	$B_{2-4.7}$ VS $B_{<2}$	NS	$B_{2-4.7}$ VS $AC_{<4.7}$	**
		$AC_{2-4.7}$VS $AC_{<2}$	NS	$B_{<2}$ VS $AC_{<2}$	**
3	Fig	$B_{2-4.7}$ VS $B_{<2}$	NS	$B_{2-4.7}$ VS $AC_{2-4.7}$	**
		$AC_{2-4.7}$VS $AC_{<2}$	NS	$B_{<2}$ VS $AC_{<2}$	**
	Mahogany	$B_{2-4.7}$ VS $B_{<2}$	NS	$B_{2-4.7}$ VS $AC_{<4.7}$	**
		$AC_{2-4.7}$VS $AC_{<2}$	NS	$B_{<2}$ VS $AC_{<2}$	**
	Shea	$B_{2-4.7}$ VS $B_{<2}$	NS	$B_{2-4.7}$ VS $AC_{<4.7}$	**
		$AC_{2-4.7}$VS $AC_{<2}$	NS	$B_{<2}$ VS $AC_{<2}$	**

Table 4.17 shows results for adsorbed NH_4-N presented as Mean±Standard Error of Mean. It presents adsorbed results from different parent materials and activation status across the columns while results for different time (in weeks) and different particle sizes are presented down the rows. Differences between the columns are shown using Fisher values and Critical Fisher values at 95% confidence limit.

The table shows that there were no observed significant differences between all the compared parent materials in terms of NH_4-N adsorption. It also shows that the rate of NH_4-N reduction in the filters reduces with time.

Table 4.17 Adsorbed Concentration of NH_4-NFrom Filters

Time (weeks)	PS (mm)	Biochar (mgl^{-1})			Activated carbon (mgl^{-1})			Fisher values	
		Fig	Mahogany	Shea	Fig	Mahogany	Shea	F_v	F_c ∝=5%
1	2 – 4	1.294±0.062	1.283±0.047	1.289±0.043	1.226±0.082	1.266±0.046	1.420±0.056	4.681	1.906
	< 2	1.117±0.058	1.329±0.057	1.220±0.036	1.346±0.075	1.540±0.074	1.923±0.045		
2	2 – 4	0.302±0.214	0.537±0.170	0.263±0.139	0.754±0.103	0.800±0.099	0.897±0.094	3.192	1.906
	< 2	0.317±0.166	0.417±0.176	0.789±0.895	0.777±0.094	0.931±0.688	0.729±0.082		
3	2 – 4	-0.062±0.145	0.074±0.131	0.143±0.151	0.617±0.143	0.651±0.128	0.754±0.153	5.366	1.906
	< 2	-0.058±0.140	0.143±0.134	0.880±0.147	0.817±0.143	0.766±0.140	0.423±0.317		

Table 4.18 shows comparisons of adsorbed NH_4-N between Biochar and Activated Carbon and also between <2mm particle sized filters and 2 – 4 mm particle sized filters. Using P value as the factor for the comparisons, three comparisons showed significant differences in the particle size comparisons. Similarly, three comparisons showed significant differences in the Activation Status comparison as shown in the table.

Table 4.18 Level of Significant Difference and Comparisons for NH_4-N

Time (weeks)	Filter Media	Particle Size comparison.	P Value	Activation status comparison	P Value
1	Fig	$B_{2-4.7}$ VS $B_{<2}$	NS	$B_{2-4.7}$ VS $AC_{2-4.7}$	NS
		$AC_{2-4.7}$VS $AC_{<2}$	NS	$B_{<2}$ VS $AC_{<2}$	*
	Mahogany	$B_{2-4.7}$ VS $B_{<2}$	NS	$B_{2-4.7}$ VS $AC_{<4.7}$	NS
		$AC_{2-4.7}$VS $AC_{<2}$	**	$B_{<2}$ VS $AC_{<2}$	NS
	Shea	$B_{2-4.7}$ VS $B_{<2}$	NS	$B_{2-4.7}$ VS $AC_{<4.7}$	NS
		$AC_{2-4.7}$VS $AC_{<2}$	**	$B_{<2}$ VS $AC_{<2}$	NS
2	Fig	$B_{2-4.7}$ VS $B_{<2}$	NS	$B_{2-4.7}$ VS $AC_{2-4.7}$	NS
		$AC_{2-4.7}$VS $AC_{<2}$	NS	$B_{<2}$ VS $AC_{<2}$	NS
	Mahogany	$B_{2-4.7}$ VS $B_{<2}$	NS	$B_{2-4.7}$ VS $AC_{<4.7}$	NS
		$AC_{2-4.7}$VS $AC_{<2}$	NS	$B_{<2}$ VS $AC_{<2}$	NS
	Shea	$B_{2-4.7}$ VS $B_{<2}$	NS	$B_{2-4.7}$ VS $AC_{<4.7}$	NS
		$AC_{2-4.7}$VS $AC_{<2}$	NS	$B_{<2}$ VS $AC_{<2}$	NS
3	Fig	$B_{2-4.7}$ VS $B_{<2}$	NS	$B_{2-4.7}$ VS $AC_{2-4.7}$	NS
		$AC_{2-4.7}$VS $AC_{<2}$	NS	$B_{<2}$ VS $AC_{<2}$	**
	Mahogany	$B_{2-4.7}$ VS $B_{<2}$	NS	$B_{2-4.7}$ VS $AC_{<4.7}$	*
		$AC_{2-4.7}$VS $AC_{<2}$	NS	$B_{<2}$ VS $AC_{<2}$	NS
	Shea	$B_{2-4.7}$ VS $B_{<2}$	*	$B_{2-4.7}$ VS $AC_{<4.7}$	NS
		$AC_{2-4.7}$VS $AC_{<2}$	NS	$B_{<2}$ VS $AC_{<2}$	NS

Table 4.19 showed results for pH for all the filter columns. Results comparisons for different parent materials and activation status are read across columns while comparisons for different particle sizes and different time are shown down the rows.

The table showed that there were no observed significant differences between the different parent materials. It also shows that there were significant differences between the Biochar and Activated Carbon.

Table 4.19 Direct Reading of pHFrom Filters

Time (weeks)	PS (mm)	Biochar			Activated carbon			Fisher values	
		Fig	Mahogany	Shea	Fig	Mahogany	Shea	F_v	F_c ∝=5%
1	2 – 4	7.674±0.171	8.043±0.092	8.780±0.065	6.829±0.052	6.800±0.148	6.90±0.135	45.32	1.641
	< 2	8.064±0.076	8.43±0.250	8.84±0.142	6.757±0.104	6.90±0.122	6.883±0.135		
2	2 – 4	7.211±0.208	7.494±0.159	7.820±0.152	6.909±0.284	6.874±0.202	6.830±0.184	5.38	1.641
	< 2	8.114±0.351	7.830±0.195	8.253±0.261	6.993±0.201	6.773±0.205	7.019±0.156		
3	2 – 4	7.596±0.145	7.449±0.071	7.396±0.086	7.283±0.208	7.177±0.168	7.034±0.194	7.062	1.641
	< 2	7.726±0.086	7.507±0.146	8.234±0.148	7.203±0.201	7.196±0.193	7.236±0.147		

Table 4.20 shows comparisons of pH between Biochar and Activated Carbon and also between <2mm particle sized filters and 2 – 4 mm particle sized filters. Using P value as the factor for the comparisons, there were no observed significant differences between all the compared particle sizes. All the comparisons between Biochar and Activated Carbon showed significant difference in the first week. The columns made from Mahogany and Shea showed significant differences in the second column while only the <2mm Shea columns showed significant difference in the third week.

Table 4.20 Level of Significant Difference and Comparisons for pH

Time (weeks)	Filter Media	Particle Size comparison.	P Value	Activation status comparison	P Value
1	Fig	$B_{2-4.7}$ VS $B_{<2}$	NS	$B_{2-4.7}$ VS $AC_{2-4.7}$	**
		$AC_{2-4.7}$VS $AC_{<2}$	NS	$B_{<2}$ VS $AC_{<2}$	**
	Mahogany	$B_{2-4.7}$ VS $B_{<2}$	NS	$B_{2-4.7}$ VS $AC_{<4.7}$	**
		$AC_{2-4.7}$VS $AC_{<2}$	NS	$B_{<2}$ VS $AC_{<2}$	**
	Shea	$B_{2-4.7}$ VS $B_{<2}$	NS	$B_{2-4.7}$ VS $AC_{<4.7}$	**
		$AC_{2-4.7}$VS $AC_{<2}$	NS	$B_{<2}$ VS $AC_{<2}$	**
2	Fig	$B_{2-4.7}$ VS $B_{<2}$	NS	$B_{2-4.7}$ VS $AC_{2-4.7}$	NS
		$AC_{2-4.7}$VS $AC_{<2}$	NS	$B_{<2}$ VS $AC_{<2}$	NS
	Mahogany	$B_{2-4.7}$ VS $B_{<2}$	NS	$B_{2-4.7}$ VS $AC_{<4.7}$	**
		$AC_{2-4.7}$VS $AC_{<2}$	NS	$B_{<2}$ VS $AC_{<2}$	*
	Shea	$B_{2-4.7}$ VS $B_{<2}$	NS	$B_{2-4.7}$ VS $AC_{<4.7}$	*
		$AC_{2-4.7}$VS $AC_{<2}$	NS	$B_{<2}$ VS $AC_{<2}$	**
3	Fig	$B_{2-4.7}$ VS $B_{<2}$	NS	$B_{2-4.7}$ VS $AC_{2-4.7}$	NS
		$AC_{2-4.7}$VS $AC_{<2}$	NS	$B_{<2}$ VS $AC_{<2}$	NS
	Mahogany	$B_{2-4.7}$ VS $B_{<2}$	NS	$B_{2-4.7}$ VS $AC_{<4.7}$	NS
		$AC_{2-4.7}$VS $AC_{<2}$	NS	$B_{<2}$ VS $AC_{<2}$	NS
	Shea	$B_{2-4.7}$ VS $B_{<2}$	NS	$B_{2-4.7}$ VS $AC_{<4.7}$	NS
		$AC_{2-4.7}$VS $AC_{<2}$	NS	$B_{<2}$ VS $AC_{<2}$	**

Table 4.21 shows the measured level of pollutants at the end of the first week. All results are reported in MGL^{-1} except for pH which has no unit and EC which is reported in µS/cm.

Table 4.21 Summary of Measured Parameters for All Columns in Week 1

Parameter	Initial Reading	Biochar						Activated carbon					
	(Control)	FIG (2-.7MM)	FIG (<2MM)	MAH (2-.7MM)	MAH (<2MM)	SHEA (2-.7MM)	SHEA (<2MM)	FIG (2-.7MM)	FIG (<2MM)	MAH (2-.7MM)	MAH (<2MM)	SHEA (2-.7MM)	SHEA (<2MM)
TOT – P	90	1.21	1.64	2.61	2.64	2.34	2.72	7.31	11.26	8.24	11.87	8.64	10.72
COD	600	40	50	60	60	20	10	150	150	80	60	60	50
NO_3-N	125	14	7	7	7	10.5	7	7	7	17.5	7	7	7
pH	8.5	7.1	7.2	7.2	7.3	7.3	7.41	8.12	8.14	8.0	8.7	8.51	9.13
PO_4-P	275.85	3.71	5.03	8.0	8.09	7.17	8.34	22.41	34.51	25.56	36.38	26.48	32.86
TOT-N	35	7	7	7	7	7	7	7	7	7	7	7	7
BOD	400	50	60	110	190	90	60	60	60	70	70	80	80
EC	7231	3161	4017	4132	4712	274	3192	1689	1804	1301	1370	1414	1368
NH_4-N	1.9	0.44	0.72	0.52	0.52	0.64	0.52	0.64	0.64	0.56	0.52	0.64	0.8

Table 4.21 shows the measured level of pollutants at the end of the first week. All results are reported in MGL^{-1} except for pH which has no unit and EC which is reported in µS/cm.

Table 4.22 Summary of Measured ParametersFor All Columns In Week 2

Parameter	Initial Reading	Biochar						Activated carbon					
	(Control)	FIG (2-.7MM)	FIG (<2MM)	MAH (2-.7MM)	MAH (<2MM)	SHEA (2-.7MM)	SHEA (<2MM)	FIG (2-.7MM)	FIG (<2MM)	MAH (2-.7MM)	MAH (<2MM)	SHEA (2-.7MM)	SHEA (<2MM)
TOT – P	40.22	4.81	5.36	5.26	6.13	5.41	6.07	11.12	13.67	11.31	14.31	11.74	14.04
COD	500	50	80	80.00	90.00	20.00	30.00	130.00	140.00	60.00	70.00	40.00	60.00
NO_3-N	54.5	7	10.5	7	7	7	7	7	7	7	7	7	7
pH	89.49	6.34	6.58	6.37	6.29	6.4	6.7	6.77	7.11	7.31	7.51	7.49	7.51
PO_4-P	123.27	14.74	16.43	16.12	18.79	16.58	18.6	34.08	41.90	34.67	43.80	35.98	43.03
TOT-N	35	7.00	7.00	7.00	7.00	7.00	7.0	7.00	7.00	7.00	7.00	7.00	7.00
BOD	270	50.00	60.00	100.00	110.00	80.00	80.0	70.00	80.00	70.00	70.00	90.00	90.00
EC	6092	1822	3490	2115	3001	1925	2431	1162	1483	1017	1078	1126	1163
NH_4-N	1.8	1.12	0.96	0.88	1.04	0.96	0.16	0.20	0.12	0.20	0.20	0.16	0.52

Table 4.22 shows the measured level of pollutants at the end of the second week. All results are reported in MGL^{-1} except for pH which has no unit and EC which is reported in µS/cm.

Table 4.23 Summary of Measured ParametersFor All Columns In Week 3

Parameter	Initial Reading	Biochar						Activated carbon					
	(Control)	FIG (2-.7MM)	FIG (<2MM)	MAH (2-.7MM)	MAH (<2MM)	SHEA (2-.7MM)	SHEA (<2MM)	FIG (2-.7MM)	FIG (<2MM)	MAH (2-.7MM)	MAH (<2MM)	SHEA (2-.7MM)	SHEA (<2MM)
TOT – P	37.11	2.64	4.77	3.85	6.59	3.64	6.82	8.86	10.59	6.59	9.82	7.15	8.32
COD	240	60	90	70	90	30	60	130	140	60	80	70	80
NO_3-N	28	7	0	0	0	0	7	7	7	10.5	7	0.5	10.5
pH	7.93	7.31	7.46	7.23	7.61	7.41	7.32	7.82	7.91	7.66	7.57	7.63	8.14
PO_4-P	113.74	8.09	14.62	11.86	20.20	11.16	20.90	27.16	32.46	20.21	30.10	21.91	23.50
TOT-N	21	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00
BOD	350	80	80	110	110	110	140	120	120	100	110	120	130
EC	4412	2314	2518	1424	2497	1104	1588	818	1036	712	773	772	836
NH_4-N	1.2	1.12	1.20	1.04	0.88	0.96	0.20	0.44	0.24	0.28	0.20	0.36	0.64

Table 4.23 shows the measured level of pollutants at the end of the third week. All results are reported in MGL^{-1} except for pH which has no unit and EC which is reported in µS/cm.

4.2 Discussion of Results

4.3 Greywater Influent Characteristics

The greywater was found to be highly polluted than reported in similar studies. This was probably due to the non-regulation of products used in laundry and toilets such as phosphorus containing soap and detergents as the value of Total Phosphorus in the greywater source was 90mg/l which was a very high value when compared to other greywater reports (3.6mg/l Berger,(2012); 4 – 14mg/l Eriksson *et al.,* (2002). Organic matter load in the water was also high compared to other literatures. BOD and COD values were 450mg/l and 600mg/l respectively as compared to Friedler,(2004) with 377mg/l and 679mg/l. Friedler, (2004) also reported an electrical conductivity value of 1040µS/cm which was low compared to 7231µS/cm obtained in this study.

4.4 Treatment Efficiency

4.4.1 Organic Matter

There were no observed significant difference between filter media of different particle sizes. Activated carbon significantly reduced organic matter than biochar among columns with observed significant difference. Between the three parent material, the fig column had significant reduction in BOD in all the three weeks. It was observed that BOD reduction was steady in the first week, it increased in thesecond week and then decreased again in the third week .

High efficiencies were observed for both Activated Carbon (85 – 95%) and biochar (76 – 90%). Similar results were observed for BOD removal with efficiency range of 65 – 80%

for Activated Carbon and 68 – 75% for Biochar. Similar results were reported by Berger, (2012)

4.4.2 Electrical Conductivity

There were no significant difference in electrical conductivity of the filters with different particle sizes. Remarkable significant differences was observed between biocharand activated carbon. Biochar showed higher efficiencies (85 – 90%) than Activated Carbon (65 – 81%). As reported by Amonette&Josheph, (2009), lower observed efficiencies of Activated Carbon may be attributed to acid used for the activation which might altered the mineral composition and functional chemical groups of the surface. This in turn might have altered the charge and surface activity of the surface hence its lower efficiency. The results in the activated carbon kept increasing from the first to the second week and then slightly reduced in the third week.

The fig column performed better than the shea tree and the Mahoganycolumn for both biochar and activated carbon in the first week but shea-butter column performed better in the second and third week than the other two parent materials.

4.4.3 NH_4-N Adsorption

There were no observed significant differences between the compared particle sizes. Comparing the activation status however, biochar showed higher efficiency (68 – 89%) than Activated Carbon which showed very low efficiency (36 – 89%). The shea tree showed the best remediation performance among the compared parent materials. Ammonium Nitrogen values in the first week was lower compared to the second and third

week. This formation of biofilm at the surface of the adsorbent might be the possible cause of this decrease as suggested by Moore *et al,* (2001).

4.4.4 NO_3-N Adsorption

The highest efficiency recorded in this study was for the removal of Nitrates where Activated Carbon had an efficiency range from 93 – 100% while biochar showed efficiency of 91 – 99%. Filters from the shea tree performed excellently for both Activated Carbon and biochar than the two other parent materials used.

The reduction rate of Nitrate as observed from the control sample indicates the instability of Nitrate which might have aided in the recorded high removal efficiency. Similarly, the performance of the shea tree column shows that adsorption is also another factor behind the reduction of Nitrate.

There was not observed significant differences between the compared particle sizes in the reduction of Nitrate from the greywater.

4.4.5 pH Stabilization.

The initial pH of the greywater was qui*et al*kaline and remained so as shown the result from the control column. Filters from the biochar column slowly stabilized the pH during the three weeks duration while the activated Carbon filters rapidly acidified the greywater in the first week before stabilizing it.Reaction between the greywater and the activated carbon surface might be a possible cause for the rapid reduction in alkalinity of the

greywater in the first week as observed from the activated Carbon filters. This result however differs from that reported by Berger, (2012)

4.4.6 Total Nitrogen Adsorption

Results obtained from adsorption of Total Nitrogen was steady throughout the experiment. Although the pollutants have been brought to an average stable value of 7.5mg/l, there were no observed significant difference between different particle sizes, parent material and even between biochar and activated carbon.

4.4.7 Total Phosphorus Adsorption

Treatment efficiency of Total Phosphorus remained high throughout the experiment with activated Carbon having and efficiency range from 92 – 99% while biochar recorded 88 – 92%. The high efficiency recorded in the first week despite high control value suggest that adsorption might be the primary factor responsible for the reduction of Total Phosphorus in the greywater.

4.4.8 PO_4-P Adsorption

Although the initial phosphate value of the greywater was high, reduction efficiency remained high throughout the experiment. Removal efficiency of phosphate followed a similar pattern with that of Total Phosphorus which is inline with a similar study reported by PPRC, (2014).

4.5 Summary of Discussion of Results

4.5.1 Effect of Particle Size

Apart from the two instances in NH_4N and Total-P, differences between the 2 – 4.7mm and <2mm did not show significant difference for both Biochar and Activated Carbon. Although small differences were recorded, they were not qualified as statistically significant. The larger particle sizes (2 – 4.7mm) however performed better than the smaller particle sizes (<2mm) for both biochar and Activated Carbon. This can be attributed to the particle size distribution of the filter media. The larger sized filter (2-4.7mm) had higher porosity hence more residence time, higher hydraulic conductivity and therefore more adsorption as reported by Dalameh, (2013).

4.5.2 Effect of Parent Material

Among the three parent materials compared (Fig, Mahogany and Shea tree), Biochar and Activated Carbon from the shea tree recorded best performance in remediating COD, EC, NH_4-N, PO_4-P and TOT-P. Neutral performance was recorded in remediation of NO_3-N and TOT-N. Filters from the Mahogany tree recorded best for pH stabilization for both Biochar and Activated Carbon. The Fig tree has the best performance in remediation of BOD.

These differences can be attributed to differences in the lignin content of the trees as suggested by Kearns*et al*., (2014).

4.5.3 Effect of Activation

The activated carbon was observed to have better performance in remediation of COD, NO_3-N, PO_4-P, TOT-P, pH and BOD. Biochar however showed better performance in

remediating EC, NH4-N and Tot-N. Of the observed differences, only differences in COD, EC, PO_4-N and NH_4-N were observed to be statistically significant.

Differences in performance between the Biochar and the Activated Carbon may be attributed to the mineral composition and the functional chemical groups of the surface which determines charge and activity at the surface. This in turn affects the rate and type of pollutants to be adsorbed. The activation of the Activated Carbon with H_2SO_4 acid might have altered the surface composition (Amonette andJosheph, 2009)

4.5.4 Effect of Time

Although better remediation was observed in the third week, the first week had the best remediation performance in terms of efficiency as the pollution load was more in the first week and significantly reduced in the two final weeks except for BOD which kept increasing. The first week recorded better performance in remediating NH_4-N, NO_3-N, PO_4, TOT-N, TOT-P and pH. BOD was best remediated in the second week while Electrical Conductivity was best remediated in the third week.

This pattern agrees with the assumption of Trulear and Characklis,(1982), who suggested that adsorption is a prerequisite for microbial attachment where the medium host the microbes and the adsorbed nutrient provides the feed.

It also agrees with the Langmuir monolayer assumption as to adsorption.

4.6 General Results Performance

Results from the experiment showed that all the filter column had significant performance in remediating the pollutants from the contaminated water. It also showed that there were variations in their treatment efficiency levels as time, parent material and activation status played a significant role in their performance. Phosphate Phosphorus, Ammonium Nitrogen and Total Phosphorus were better absorbed at the first week while most of the other parameters; COD, Electrical Conductivity, Nitrate-Nitrogen, BOD, Total-Nitrogen and pH showed acceptable concentration after the third week. The filter columns had remediated all the polluted water from all the tested parameters to levels that meets the effluent discharge standard in many countries and is even suitable for other purposes like unrestricted irrigation, reclaimed domestic use as seen in table 4.25

TABLE 4.24 Treatment EffeciencyOf Filters

PARAMETER	ACTIVATED CARBON						BIOCHAR					
	FIG (2-4.7)	FIG (<2)	MAHOG ANY (2-4.7)	MAHOG ANY (<2)	SHEA 2-4.7	SHEA <2	FIG (2-4.7)	FIG (<2)	MAHOG ANY (2-4.7)	MAHOG ANY (<2)	SHEA 2-4.7	SHEA <2
EC	81	65	80	65	85	78	88	85	90	89	89	88
TOT-P	97	94	96	92	96	92	90	88	93	89	92	91
NO_3-N	93	100	100	100	100	94	94	94	91	94	99	91
BOD_5	80	80	73	73	73	65	70	70	75	73	70	68
NH_4-N	41	36	45	53	49	89	76	87	85	89	81	66
TOT-N	80	80	80	80	80	80	80	80	80	80	80	80
COD	90	85	88	85	95	90	78	76	90	86	88	86
PO_4-P	97	95	96	93	96	92	90	88	93	89	92	91
pH	-	-	-	-	-	-	-	-	-	-	-	-

TABLE 4.25 INTERNATIONAL WASTEWATER STANDARDS AND REUSE.

PARAMETER	INTERNATIONAL WASTE WATER RE-USE STANDARDS					
	FAO	**EU**	**JORDAN**	**EGYPT**	**ITALY**	**CHINA**
EC (US/CM)	**3000**		**1500**			
NO_3-N (MG/L)	**30**					
PH	**6.5-8.4**		**6 – 9**		**6 – 9.5**	**6 - 9**
NH_4-N (MG/L)	**5**					**5**
BOD (MG/L)	**100**					
TOT-N (MG/L)	**45**	**10 – 15**			**15**	**15**
PO_4-P (MG/L)	**2**	**1 – 2**				
TOT-P (MG/L)	**-**				**2**	**0.5**
COD (MG/L)	**150**	**125**	**100**	**40**	**100**	
RE-USE	Unrestricted Irrigation	Discharge from urban wastewater treatment plants	Reclaimed Domestic reuse	Unrestricted Irrigation	Irrigation, urban Reuse	Impoundments And lakes
SOURCE	Ayers *et al* (1985)	Council directive (1991)	Dalahmeh*et al*.(2011)	Smith &Bani-Melhem (2012)	Chaillou*et al*.(2009)	Ernst *et al*. (2006)

CHAPTER FIVE

SUMMARY, CONCLUSION AND RECOMMENDATION

5.1 Summary

The potential of biochar to remediate greywater was investigated. Greywater from Suleiman Hostel in Ahmadu Bello University was obtained and subjected to biocharfilters made from three different parent trees; *Vitellariaparadoxa* (Shea tree), *Khayasenegalenses* (Mahogany), *Ficussycomous*(Fig)for a period of 21 days. The biochar was prepared by slow pyrolysis of the trees and was used as filters in the experiment. The filters were classified into different sizes (range from 2mm to 4.7mm and another range of less than 2mm) to ascertain the effect of particle size on the efficiency of treatment. Same biochar of the same particle size were also activated using 20%H_2SO_4solution to produce activated carbon which was also utilized as filter media. Columns made from PVC pipes were designed,constructed and used as filter columns during the experiment. 2 liters of greywater (composite sample) was loaded in all the 13 columns (12 with filter media and one as control) at the beginning of the experiment and daily composite samples were also loaded daily to replace the quantity taken for laboratory analysis of basic greywater pollutants (EC, NH_4-N, TOT-N, PO_4-P, pH, NO_3-N, TOT-P, BOD and COD). The composite samples were collected at 8:00 AM and 4:00PM daily.

The results from the laboratory analysis were subjected to statistical analysis using Microsoft Excel 2013 and Graph Pad Instat version 3. Results from both biochar and activated carbon were compared and biochar shows better performance in remediating COD, BOD, Tot-Phosphorus, PO_4-P and even in stabilizing the pH of the greywater. Activated carbon only performed better in remediating NH4-N and Electrical conductivity.

Neutral performance were observed from NO_3-N and TOT-N adsorption. The performance efficiencies of both biochar and activated carbon in remediating greywater in this study was found to be similar with results from similar studies made by Berger, 2012.

5.2 CONCLUSION

1. In this study, a column adsorption of physic-chemical parameters of greywater was experimentally studied using biochar and activated carbon made from three different parent materials and their remediation potential was determined. The effect of particle sizes, activation status, parent materials and time was considered during the remediation process.
2. Treatment efficiencies of both biochar and activated carbon was found to be high when compared to the results from the control column. Biochar however showed better performance in stabilizing pH, adsorption of PO_4-P, TOT-P, BOD and COD. Neutral performance was observed in treating Total Nitrogen and NO_3-N. Activated carbon performed better in reducing electrical conductivity and NH_4-N.
3. Production and handling of biochar was more cheaper and easier compared to the high cost of producing Activated Carbon which requires skilled knowledge handling and with the results obtained from this study, biochar can function as an activated carbon hence its better replacement.
4. It was observed that the rate of adsorption between different particle sizes is heavily dependent on the porosity and distribution among the particle sizes than between the differences in the sizes itself.

5. The filters made from the shea tree had the best performance followed by the Mahogany then the Fig. This suggest that Adsorption is possibly function of the woodiness or lignin content of the trees
6. Adsorption in terms of efficiency was best observed in the first week and deteriorated in the second and third week for most of the filters. This suggest the formation of biofilm and possible compliance to the Langmuir's Isotherm model.

5.3 RECOMMENDATION

1. It is recommended that Biochar should be tried as an alternative to Activated Carbon in most treatment systems.
2. Further studies should be conducted to observe the performance of Biochar under different Hydraulic Loading conditions.
3. It is recommended that other tropical trees with higher lignin content should be investigated, charred and tried as filter media.
4. It is also recommended that the used biochar to be tried for soil amendment potential.

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APPENDICES

APPENDIX A

PICTURE OF CONSTRUCTED FILTER COLUMNS



Pictures of sealed Filter Columns before loading



Crossection of filter columns on stand



Picture of unsealed columns during loading



Crossection of filter columns on stand.

APPENDIX B

United States Department of Energy Method of determining Lignin

0.3 g of dried extracted raw biomass was weighed in glass test tubes and 3 ml of 72% H_2SO_4 was added. The sample was kept at room temperature for 2 hours with carefully shaking at 30 min intervals to allow for complete hydrolysis. After the initial hydrolysis, 84 ml of distilled water was added. The second step of hydrolysis was made to occur in an autoclave for 1 h at 121 °C. The slurry was then cooled at room temperature. Hydrolyzates were filtered through vaccum using a filtering crucible. The acid insoluble lignin was determined by drying the residues at 105 oC and accounting for ash by incinerating the hydrolyzed samples at 575 ^{o}C in a muffle furnace. The acid soluble lignin fraction was determined by measuring the absorbance of the acid hydrolyzed samples at 320 nm. The lignin content was calculated as the summation of acid insoluble lignin and acid soluble lignin.