

**COMPARATIVE ANALYSIS OF THE EFFECTIVENESS OF BIOCHAR AND  
ACTIVATED CARBON FILTER MEDIA IN GREYWATER TREATMENT**

**BY**

**OMIUNU, OMOLE OHIREIMEN**

**ENG1905213**

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## **PLAGIARISM**

This work **COMPARATIVE ANALYSIS OF THE EFFECTIVENESS OF BIOCHAR AND ACTIVATED CARBON FILTER MEDIA IN GREYWATER TREATMENT** by OMIUNU, Omole Ohireimen with Matriculation Number ENG1905213 of the Department of Civil Engineering, Faculty of Engineering, University of Benin city, Edo state, Nigeria, has passed the PLAGIARISM TEST.

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**Engr. Oria-Usifo E. E.**

Date

Project Coordinator

## CERTIFICATION

This is to certify that this project work **COMPARATIVE ANALYSIS OF THE EFFECTIVENESS OF BIOCHAR AND ACTIVATED CARBON FILTER MEDIA IN GREYWATER TREATMENT** was carried out by OMIUNU OMOLE OHIREIMEN with Mat No. ENG1905213 in the Department of Civil Engineering, Faculty of Engineering in University of Benin, Benin city, Edo state.

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Engr. (Mrs.) Ambrose-Agabi, Esther  
Project supervisor

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Date

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Engr. Prof. (Mrs.) N. I. Ihimekpen  
Head of Department

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Date

## **DEDICATION**

I dedicate this work first to God Almighty. Then to my Parents, guardians and mentors who have been the source of my Encouragement.

## ACKNOWLEDGEMENT

I would like to express my deepest gratitude to all those who supported me throughout this project. First and foremost, I am sincerely thankful to Engr. (Mrs.) Ambrose-Agabi Esther, my project supervisor, for her continuous guidance, encouragement, and invaluable feedback, which greatly contributed to the successful completion of this work.

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## ABSTRACT

This study was aimed at conducting a comparative analysis of the performance of biochar and activated carbon as filter media for greywater remediation and also evaluating key parameters including adsorption capacity, removal efficiency for specific contaminants, and environmental impacts through laboratory experiments, the study also assessed the effectiveness of both materials in removing common greywater contaminants such as organic compounds, nutrients and heavy metals.

Biochar was prepared from plantain peels that was pyrolyzed at 600°C and activated with zinc chloride, while Activated carbon was produced through the pyrolysis of wood and activated through the use of zinc chloride as the activation reagent. The properties of the produced was characterized through the use of FTIR and SEMEDS characterization methods. The greywater sample was passed through both filter media and the adsorption efficiency of both filter media was measured by evaluating the reduction in contaminants such as organic matter, nutrients, and suspended solids before and after treatment.

Biochar reduced pH by 26.7%, while activated carbon lowered it by 21%. Activated carbon was more effective, reducing turbidity by 56.5%, suspended solids by 45.5%, and heavy metals (iron 82.7%, lead 81.5%, cadmium 90.7%). Both reduced conductivity and total dissolved solids by 57–60%. Biochar increased alkalinity and hardness, while activated carbon lowered them by 57%. Biochar removed more chloride and performed similarly well for magnesium. In conclusion, activated carbon emerged as the more effective filtration medium for treating greywater.

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## **ACRONYMS**

BOD – Biochemical Oxygen Demand

COD – Chemical Oxygen Demand

FTIR – Fourier Transform Infrared Spectroscopy

PPRC – Pollution Prevention Resource Center

SEMEDS – Scanning Electron Microscopy with Energy-Dispersive X-ray Spectroscopy

SOCs – Synthetic Organic Compounds

TSS – Total Suspended Solids

VOCs – Volatile Organic Compounds

# CHAPTER ONE

## INTRODUCTION

### 1.1 Background of Study

The escalating challenges of water Scarcity and Pollution and the growing demand for sustainable water management solutions draws attention to the need for more innovative and sustainable water treatment solutions, particularly in greywater remediation.

"Greywater" refers to wastewater generated from domestic activities such as Cooking, cleaning and bathing, it constitutes 65-100% of discharged by households (Morel and diener, 2006) and also typically contains a variety of contaminants such as detergents, food particles, oils and microorganisms. Without proper treatment, discharging greywater into the environment can lead to water pollution, Soil degradation and health risks. Reusing treated greywater for irrigation, flushing toilets or even for potable purposes can significantly conserve fresh water and promote sustainable water management practices. Greywater is noticeably different from blackwater which is gotten from bathrooms and toilets and is contaminated by Sewage. Water and waste management systems in low- and middle-Income countries often fail to incorporate grey water management (Katukiza et al, 2015"; Narayan et al., 2021) in waste water removal, allowing residents in unsewered areas dispose greywater into open drains, nearby watercourses or directly onto the ground creating unsightly conditions. Because of pathogens, salts, suspended solids, fats, oil and chemicals in greywater, it adversely affects public and environmental health by affecting disease vectors and reducing soil and water quality (WHO 2006, Carden et al, 2007a).

Activated Carbon is a form of carbon commonly used to filter contaminants from water and air among other uses. It is processed(activated) to have small, Low-volume pores that greatly increase the surface area available for adsorption. Activated Carbon is widely used in water treatment due to its high surface area, porosity and strong adsorption capacity for a range of contaminants, including organic compounds and heavy metals. it is Produced through the activation Carbon-rich materials at high temperatures.

Biochar, another form of Carbon-rich charcoal produced through Pyrolysis of biomass (Pyrolysis being the thermochemical decomposition of organic materials at high 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) has gained attention as a sustainable and cost-effective alternative to activated Carbon, its production process is less energy intensive and it can be derived from organic waste materials, contributing to waste management. Biochar has shown potential in adsorbing contaminants from water, including heavy metals and organic pollutants.

## **1.2 Statement of the Problem**

The rapid growth of the human population, along with expanding industrial and agricultural practices, is a major contributor to pollution in low- and middle-income countries (Owa, 2014). Greywater which makes up about 50–80% of total household wastewater is often discharged untreated into nearby water bodies (Li et al., 2009). Poor sanitation and inadequate wastewater disposal can lead to severe environmental and public health issues, contributing to 1.8 million deaths annually (Corcoran et al., 2010; WHO Report, 2009). Household greywater from everyday activities such as bathing, washing dishes, and doing laundry carries detergents, oils, and other particles that harm water quality and damage ecosystems. Most places have used activated carbon to clean greywater as it is very effective at capturing and removing harmful pollutants. However, producing activated carbon is both expensive and uses a lot of energy. This makes it less suitable for communities that do not have abundant financial or energy resources. An alternative solution is biochar. Biochar is made by heating biomass waste in a low-oxygen environment. This process produces a carbon-rich material that is not only cheaper to produce but also more sustainable, since it uses waste materials and requires less energy. This study hopes to offer a more practical solution for improving water quality and protecting both public health and the environment.

### **1.3 Aim and Objectives**

The aim of this study is to conduct a comparative analysis of the effectiveness of biochar and activated carbon as filter media for greywater remediation.

The objectives are to:

- (i) prepare and characterize biochar and activated carbon.
- (ii) evaluate and compare the efficiency of the filter media.
- (iii) analyze the environmental impact and suitability of using biochar and activated carbon as filter media.

### **1.4 Scope of Study**

The scope of study includes;

- (i) Sourcing of Biochar and Activated carbon and characterizing the physical and chemical properties of both.
- (ii) Measuring the removal efficiency of both biochar and activated carbon and comparing both.
- (iii) Evaluating the environmental impact, performance and energy requirement.

### **1.5 Justification of study**

The performance of biochar and activated Carbon in greywater remediation is justified due to its potential impact on the environment and public health. Greywater, which constitutes a significant portion of house hold wastewater, poses risks if untreated, leading to pollution and hazards such as diseases. By exploring filtration methods, this study aims to enhance greywater treatment facilities and promote reuse of water. both known for their adsorptive properties but this study will highlight their differences, in choosing the best material for large scale implementation. This research addresses a societal issue by potentially lowering water treatment costs and reducing pollution.

## CHAPTER TWO

### LITERATURE REVIEW

#### 2.1 GENERAL

Water is an essential resource for the functioning of the ecosystem that benefits human beings. As population grows, places are urbanized and industry expands quickly. Both water demand and the amount of wastewater rise significantly. Wastewater is of concern when discharged untreated in water bodies or soil, as it is associated with pollution, damage to soil properties, and mosquito breeding. The quantity of wastewater produced by a household depends on the practices of the household in question which is 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 immediate area. However, there are sustainable opportunities for water remediation from wastewater that could help minimize freshwater needs and preserve water bodies and soil. As a type of wastewater, greywater is all wastewater from a household which includes outflows from washbasins, bathrooms, kitchen sinks, and laundry machines, with the exception of toilet water, which is called blackwater and contains more organic matter and harmful pathogens as it includes water from toilets. (Qrenawi and Mahmoud, 2019). Not only does greywater account for 80% of the household wastewater, but studies in various countries report that 14-225 L/Person/day of greywater is produced (Siegrist et al., 1976). Therefore, greywater is safer to manipulate and simpler to treat as it can be reused in areas that do not require potable water such as crop irrigation, garden watering, toilet flushing, and discharge into water bodies (Thompson et al., 2020). . The reuse of greywater reduces the pressure on

freshwater resources and thereby preserves the environment and decreases the cost of water. Greywater in this scenario is a resource of water rather than wastewater.

The concentration and quality of the contaminants in the greywater depend on its source and unfortunately, by its origin, greywater contains several chemicals, bacteria, viruses, nutrients, heavy metals, and organic micropollutants. Greywater can be recycled and reused for various purposes, primarily irrigation and landscape watering. However, the reuse of such greywater without pretreatment can have negative impacts on the soil, can pollute the groundwater, the surface water, and/or contribute to the transmission of diseases. It also adversely affects public and environmental health by attracting disease vectors and reducing soil and water quality (Alexander and Godrej, 2015).

Greywater is often found in greater volumes in low-income countries than in higher-income countries due to lower water consumption and the high cost and the insufficiency of centralized wastewater treatment plants in low-income countries. Justify the choice of the onsite filtration system with local and inexpensive filter materials.

### **2.1.1 Greywater Sources**

Greywater refers to the relatively clean wastewater generated from various domestic activities, excluding water that comes from toilets, which is classified as blackwater due to the higher level of contamination. Greywater is often considered a valuable resource and can be treated and reused for non-potable purposes, thereby reducing demand for fresh water.

Greywater can be gotten from the following sources;

**Showers and Bathtubs:**

Greywater from showers and bathtubs constitutes one of the largest volumes in a household. This water generally contains residues from soap, shampoo, and conditioners, along with trace amounts of body oils, dirt, and hair. Despite these impurities, bathwater is relatively clean compared to other wastewater streams and is ideal for reuse in non-potable applications such as garden irrigation, landscape watering, and toilet flushing. Although it is one of the least contaminated forms of greywater, periodic microbial contamination can occur, necessitating basic treatment to ensure its safety for reuse.

**Bathroom Sinks:**

Water from bathroom sinks, used primarily for handwashing, brushing teeth, and other daily grooming activities, also contributes a significant portion of greywater. This water typically contains minimal organic residues and suspended solids, which makes it relatively straightforward to treat. Its low level of contaminants allows for simpler treatment processes, enabling its reuse in applications like flushing toilets and watering gardens, thereby reducing the need for fresh water in these everyday tasks.

**Laundry:**

Laundry greywater presents a challenge due to the variety of substances it carries. Washing machines discharge water that contains detergents, fabric softeners, bleaches, and other additives that introduce chemicals such as sodium, phosphorus, nitrogen, and various surfactants. Additionally, laundry water often contains suspended solids like lint and fibers, and may occasionally pick up oils, solvents, or even trace amounts of paints. The inclusion of items like nappies in laundry loads can further increase the risk of pathogen presence.

Therefore, laundry greywater typically requires a more rigorous treatment process to remove both chemical and biological contaminants before it can be safely reused.

### **Kitchens:**

Kitchen greywater is one of the most challenging streams to treat due to its high load of organic matter and fats. Water used in kitchens, whether for dishwashing, cleaning countertops, or rinsing food preparation surfaces, is often filled with food residues, significant amounts of oil and fat, and high concentrations of detergents. This stream may also contain occasional traces of stronger chemicals, such as drain cleaners or bleach, resulting in elevated levels of suspended solids and dissolved nutrients. Specialized treatment systems such as those incorporating grease traps, sedimentation tanks, and advanced filtration techniques are essential for effectively processing kitchen greywater for safe reuse.

### **Utility Sinks and Basements:**

Additional greywater can be collected from utility sinks found in laundry rooms, basements, or garages. These sinks are commonly used for tasks such as mopping floors, rinsing cleaning equipment, or washing tools. Although the water from these sources may include minor residues from cleaning agents and dirt, it is generally less contaminated than kitchen greywater. As such, utility sink water is a valuable supplement to the overall greywater supply and can be efficiently treated for use in outdoor irrigation, cleaning, and other non-potable applications.

### **Dishwashers:**

Modern dishwashers in many households are designed with separate drainage systems that capture rinse water as greywater, isolating it from the more heavily soiled kitchen sink water.

Dishwasher greywater usually contains lower levels of organic solids and suspended particulates, although it still carries traces of detergents and food particles. This relatively consistent quality makes it an attractive candidate for targeted treatment systems, allowing for its reuse in applications like toilet flushing or garden watering, where the lower contaminant load facilitates simpler and more effective processing.

### **Outdoor Cleaning Activities:**

Beyond indoor sources, greywater can also be harvested from various outdoor cleaning activities. Water used for washing vehicles, cleaning patios, or hosing down driveways is typically captured and directed into greywater systems. Although this water may pick up some dirt, grease, or organic debris during these activities, it generally has a lower concentration of chemical contaminants compared to kitchen or laundry water. Consequently, outdoor cleaning greywater is particularly well-suited for direct applications such as landscape irrigation and other non-potable uses, contributing valuable additional volume to household water recycling efforts.

### **2.1.2 Greywater Components**

Greywater is the relatively clean water from household activities that contains a mix of substances affecting its quality and the treatment needed for reuse. Here's a simple breakdown of its common components:

**Water:** The main part of greywater. Even small amounts of contaminants can change its quality, affecting how it is treated.

**Soaps and Detergents:** These contain surfactants that help remove dirt and oils but can also cause foaming and add extra chemicals like phosphates, dyes, or fragrances.

Dirt and Grease: Dirt comes from soil and other particles washed off surfaces. Grease, usually from kitchens, is an oily substance that doesn't mix well with water and can block filters and pipes.

Hair and Fibers: Hair from showers and fibers from clothes may seem small but can accumulate and clog pipes and filters.

Food Particles: Food bits from kitchen sinks add organic matter. As they break down, they can use up oxygen and promote bacterial growth, sometimes causing odors or blockages.

Skin Cells: Shed skin cells contribute organic material that can feed bacteria and affect water turbidity.

Lotions and Personal Care Products: Lotions, creams, and similar products add chemicals that can change the water's pH and form complex compounds, requiring extra treatment.

Cleaning Agents: Other cleaning chemicals, such as bleach and disinfectants, may also be present. These can be corrosive or toxic, so they must be neutralized during treatment.

Kitchen-generated greywater tends to have /organic loads due to food preparation and washing activities (Al-Gheethi et al., 2016). In contrast, greywater from laundry activities tends to have higher volumes of physical or chemical pollutants, attributed to the use of soaps or laundry detergents and the washing of soiled clothes. Greywater from personal hygiene activities, such as showering or handwashing may also contain faeces and other associated pathogens (Bakare et al., 2017).

### **2.1.3 Greywater Characteristics**

Greywater quality is determined by a combination of physical, chemical, and biological factors:

#### **Physical Properties:**

- Color: Indicates the presence of dissolved or suspended substances.
- Odor: Can reveal contamination or the presence of specific compounds.
- Temperature: Influences both chemical reactions and biological activity.

#### **Chemical Properties:**

- pH Level: Affects solubility and reactivity of chemicals.
- Organic Matter (BOD/COD): Measures the amount of biodegradable and oxidizable material.
- Nutrients: Essential for plant growth but can lead to eutrophication if in excess.
- Salinity: Impacts the suitability for irrigation or other uses.
- Surfactants: Common in household cleaners, affecting water treatment processes.

#### **Biological Properties:**

- Pathogens: Potential disease-causing organisms that may pose health risks.
- Coliform Bacteria: Indicators of microbial contamination and water quality.
- Microbial Activity: Overall biological activity that can affect water degradation and treatment efficiency.

### **2.1.4 Considerations for Greywater Reuse**

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 great economic benefit. Based on its characteristics, greywater treatment might involve simple filtration to remove particulates, while more advanced biological treatment to reduce BOD and COD levels and disinfection to eliminate pathogens. Some of the physical and chemical characteristics of greywater have a negative impact on the environment and must be measured before and after filtration.

### **2.1.5 Public Health Implications of Greywater Reuse**

Although greywater is generally cleaner than blackwater, its improper treatment and management can lead to serious health risks. Domestic greywater—sourced from showers, sinks, laundry, kitchens, and other everyday activities—may harbor harmful microorganisms such as bacteria, viruses, and protozoa, which can cause gastrointestinal distress, respiratory infections, and skin issues when people come into contact with or accidentally ingest contaminated water. In addition, chemical residues from detergents, cleaning agents, and personal care products can persist in greywater, potentially disrupting hormonal balance or provoking allergic reactions, especially when used in irrigation that comes into contact with food crops. Inadequate storage or stagnant conditions can further encourage the proliferation of these pathogens, transforming otherwise benign greywater into a significant public health hazard. To counter these risks, it is essential to implement advanced treatment methods such as robust filtration systems, ultraviolet disinfection, and biological processing to ensure that greywater is safe for non-potable applications like irrigation and toilet flushing. Moreover, raising public awareness and strictly adhering to regulatory standards are critical steps in mitigating exposure risks, particularly in densely populated communities. Without these

comprehensive measures, the environmental and water-saving benefits of greywater reuse could be overshadowed by the potential for increased infections, chemical exposure, and broader ecological damage.

### **2.1.6 Environmental Impact of Greywater Reuse**

Reusing greywater offers considerable environmental advantages while also posing potential ecological risks if not properly managed. On the positive side, greywater reuse can significantly reduce the demand for fresh water by providing an alternative source for non-potable applications such as irrigation and toilet flushing, which in turn alleviates pressure on municipal water supplies and helps conserve valuable freshwater resources. This practice also decreases the volume of wastewater entering treatment plants, potentially lowering energy consumption and the associated carbon footprint of water processing facilities. Moreover, using greywater can contribute to sustainable land management practices by supplying nutrients to soils when treated appropriately, thereby enhancing plant growth and reducing the need for chemical fertilizers. However, the environmental benefits may be compromised if greywater is inadequately treated. Residual chemicals, detergents, and high nutrient loads particularly nitrogen and phosphorus can lead to soil contamination and the eutrophication of nearby water bodies, triggering harmful algal blooms that disrupt aquatic ecosystems. Additionally, persistent organic pollutants and heavy metals, if present in greywater, can accumulate in the soil and enter the food chain, potentially impacting biodiversity and ecosystem health. The alteration of soil pH and structure due to untreated greywater can further diminish land productivity and long-term soil fertility. Thus, while greywater reuse has the potential to contribute to more resilient and sustainable water and agricultural systems, it demands stringent treatment protocols, regular monitoring, and

adherence to environmental standards to mitigate its adverse effects and ensure that the practice remains both ecologically sound and beneficial.

## **2.2 Biochar and Activated Carbon**

The carbonization of local, low-cost feedstocks (oil palm and coconut shells, sugar cane bagasse, coffee husk, firewood) has attracted much attention as an alternative method for producing carbonaceous materials, e.g., biochar, that is suitable for the treatment of greywater and contaminated drinking water in low- and middle-income countries (Dalahmeh et al., 2016). Biochar is a stable carbon material obtained by heating biomass at elevated temperatures (500–800°C) with little or no oxygen (Ahmed et al., 2016). Monitoring several key parameters can have a significant effect on the ability of biochar to adsorb organic compounds, which involves pH, organic matter residuals, surface area and pore volume, and the degree of carbonization (Oh and Seo, 2016). It has been reported that biochar can efficiently adsorb both organic and inorganic pollutants (Ramola et al., 2014), but may show limited ability to selectively adsorb contaminants which are present at high concentrations due to low porosity (Ahmed et al., 2016).

Biochar is a form of charcoal that is produced through the pyrolysis of organic material such as agricultural wastes and municipal wastes in a low-oxygen environment and has drawn interest due to its expanding use in many environmental applications. 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). It has emerged as a promising material in greywater remediation due to its enhanced properties such as rich carbon content, enhanced surface area, high cation exchange capacity, and stable structure (Rizwan 2016). Its use in the water sector has become increasingly popular due to biochar enhanced physiochemical properties for wastewater decontamination (Tareq et al;2019).

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 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, Ammonium, Nitrates, Nitrogen, Total Suspended Solids (TSS) and polyaromatic hydrocarbons.

Surface area, high porosity, mineral composition are the main biochar properties that affect its capability to adsorb organic, inorganic and even pathogenic contaminants in water (Enaime et al;2020). Several factors influence biochar properties, including temperature, heating rate, pressure, and residence time. High temperature pyrolysis generally results in biochar with a larger surface area and pore volume, making it ideal for the adsorption of organic contaminants, while inorganic pollutants can be removed more effectively by biochar produced at low temperature pyrolysis. The characteristics of biochar should be altered to enable higher removal rate of certain resistant compounds that are present in low quantities in wastewater. Despite the fact that biochar's potential drawbacks should be considered, its potential in wastewater remediation should not be overlooked. It can be

produced using various techniques, and it may reduce heavy metals and other contaminants that could be released during its use.

Activated carbon is a specially treated form of carbon that has many tiny pores, greatly increasing its surface area. This structure makes it very effective at trapping and removing contaminants from water, air, and other substances. It is typically made from carbon-rich materials such as coconut shells, nutshells, wood, or coal.

There are two main methods to produce activated carbon:

Physical Activation:

Carbonization: The raw material is heated in a low-oxygen environment, turning it into a basic form of carbon.

Pore Formation: The carbon is then heated again, often with steam, which creates a network of small pores in the material. These pores dramatically increase the surface area, allowing the carbon to capture more contaminants.

Chemical Activation:

The raw material is mixed with chemicals like phosphoric acid or potassium hydroxide before heating. These chemicals help break down the material more efficiently and promote the formation of uniform, tiny pores during the heating process.

The key process that makes activated carbon so effective is called adsorption. In adsorption, contaminants stick to the surface of the carbon particles rather than being absorbed into them. Thanks to the vast network of pores, there are many places for unwanted molecules to attach, which means activated carbon can remove a wide range of harmful substances.

One of the most common uses of activated carbon is in water treatment. It helps remove impurities such as organic chemicals and disinfection byproducts, which can affect the taste

and safety of drinking water. As water treatment needs have grown more complex, activated carbon is also used to capture modern pollutants like traces of pharmaceuticals and chemicals from personal care products that enter the water supply.

Activated carbon is not only important for water purification; it also plays a role in air filtration, industrial processes, and even medicine. In air filters, it captures volatile organic compounds (VOCs) and other pollutants. In emergency medicine, activated carbon is sometimes used to treat poisoning by binding to toxins in the stomach, which prevents them from being absorbed into the bloodstream.

In summary, activated carbon is a versatile material with a highly porous structure that makes it excellent at trapping a wide range of contaminants. Whether used in water and air filters, industrial applications, or medical treatments, its ability to adsorb harmful substances is key to protecting public health and the environment.

### **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 pyrolytic process parameters such as temperature, heating rate, pressure, energy values of bio-oils and physio-chemical properties all have effect on the production of biochar (Clay and Malo, 2012). It involves heating organic materials (300-700°C) in a low-oxygen environment. This process thermally decomposes the organic matter, yielding biochar along with bio-oil and syngas as by-products.

### 2.2.2 Surface area

Biochar's surface area is important because it tells us how many active sites are available for ion exchange. In simple terms, a higher surface area means more places where ions can attach and be exchanged. Research shows that the type of biomass used to make biochar plays a bigger role in determining its surface area than the temperature at which it is produced.

For instance, a meta-analysis by Li et al. found that the relationship between the biochar surface area and different biomass groups had an  $R^2$  value between 0.721 and 0.766. This strong correlation means that the characteristics of the biomass (like its inorganic elements and ash content) are very influential. In contrast, the correlation between surface area and pyrolysis temperature was much weaker ( $R^2 = 0.238$ ). This tells us that while temperature does have an effect, it is not as important as the type of biomass used.

Biochar made from lignocellulosic biomass (plant-based materials such as wood, straw, or crop residues) can have a very wide range of surface areas—from as low as 0.25 m<sup>2</sup>/g to as high as 780 m<sup>2</sup>/g. On the other hand, biochar made from manure or sewage sludge usually has a surface area below 100 m<sup>2</sup>/g. The lower surface area in manure-based biochar is often due to high levels of alkali and alkaline earth metals, which block the tiny pores (micropores) that would normally increase the surface area.

When it comes to pyrolysis temperature, the surface area of biochar generally increases as the temperature rises. This is because higher temperatures help create more micropores in the cell walls of the biomass. Around 500 °C, there is a rapid increase in surface area because the cellulose and hemicellulose components in the biomass completely break down (a process known as devolatilization), releasing gases that form new pores. However, when

the temperature goes above 600 °C, these micropores can start to expand and collapse, which may reduce the overall surface area. Ma et al. explain this process in more detail. At temperatures between 250 °C and 350 °C, the increase in surface area is mainly due to the initial devolatilization, which creates new pore structures—mostly mesopores (pores of intermediate size). When the temperature rises to between 450 °C and 550 °C, the further breakdown of holocellulose (another component of biomass) and the formation of two-dimensional fused rings result in more micropores and mesopores, further increasing the surface area. Then, at even higher temperatures (650 °C to 750 °C), the biochar develops more mesopores and macropores, and the structure of the fused rings changes into graphite-like formations, which helps maintain a high surface area. Chen et al. argue that the surface area of biochar can continue to increase up to around 900 °C. Beyond 900 °C, the surface area may either decrease or level off. The changes in the pore structure occur because of two main effects. First, as the biomass polymers break down (devolatilization), they release volatile compounds that form new pores. Second, the formation of fused rings and graphite structures creates cracks that also act as new pores. Moreover, higher temperatures reduce the condensation of tar, which would otherwise block these pores. In summary, the final surface area of biochar is largely determined by the type of biomass used especially its inorganic elements and ash content with pyrolysis temperature also playing a role by influencing how the pores form and evolve.

Activated carbon is widely used for purification because of its highly porous structure, which provides an extensive surface area for trapping contaminants. The effectiveness of activated carbon is largely determined by its network of pores, which play a crucial role in adsorption. These pores are categorized into three types: micropores, mesopores, and

macropores. Micropores, being the smallest, provide the majority of the surface area and are especially important for capturing tiny molecules, making them the most critical for adsorption. Mesopores and macropores, which are larger in size, help transport contaminants deeper into the structure, allowing for more efficient pollutant capture by the micropores. The natural characteristics of the raw material used to produce activated carbon, such as its internal structure, inorganic content, and ash content, significantly influence the formation of these pores. Studies suggest that the raw material plays a more decisive role in determining the pore structure than other production factors like temperature. However, temperature still has a major effect, as it helps shape the final pore network. In general, higher temperatures lead to increased pore formation, thereby expanding the overall surface area. At moderate temperatures, micropores develop rapidly, enhancing the adsorption capacity of activated carbon. However, at excessively high temperatures, micropores may begin to widen into mesopores or even collapse, reducing the total surface area and making the material less effective. Because of this, maintaining an optimal balance in temperature is crucial to ensuring that activated carbon has the right mix of pore sizes to maximize its filtration efficiency. The ability of activated carbon to remove pollutants is a direct result of this complex pore system, which provides countless active sites where impurities can adhere. This unique structure makes activated carbon an essential material for filtering water, purifying air, and even serving as an antidote in medical treatments. Whether it is used in large-scale industrial processes or everyday household applications, its efficiency depends entirely on the presence of an intricate and well-developed pore system, which enables it to adsorb and retain a vast range of contaminants.

### **2.2.3 Applications of biochar:**

Biochar is a natural material that plays a key role in cleaning up pollution and improving our environment. It is made from organic matter that is heated in a low-oxygen setting, which creates a porous structure perfect for trapping harmful substances. In community-level treatment plants, biochar helps remove contaminants from large amounts of wastewater, ensuring that the water released back into nature is much cleaner. In homes, biochar is used in greywater treatment systems to purify water from sinks and showers, so that it can be safely reused for tasks like watering gardens. In agriculture, adding biochar to soil not only improves its quality and water retention but also reduces the need for chemical fertilizers, making farming practices more sustainable. By capturing dangerous chemicals and enhancing water and soil quality, biochar offers a simple yet effective solution to many environmental challenges and helps protect our natural resources for the future.

### **2.2.4 Role of Biochar in Greywater Treatment:**

Biochar plays a crucial and versatile role in greywater treatment by addressing a wide range of challenges and significantly enhancing water quality through several mechanisms. Its highly porous structure makes it exceptionally effective at adsorbing contaminants, including pathogens, bacteria, and heavy metals, thereby not only improving the water's clarity and safety but also preventing these harmful substances from reaching natural water bodies. Moreover, biochar is particularly adept at capturing excess nutrients like nitrogen and phosphorus that are frequently present in greywater; by reducing these nutrient levels, it lowers the risk of eutrophication and the associated negative impacts on natural water ecosystems. In addition to these functions, the porous structure of biochar provides an ideal

habitat for beneficial microorganisms. These microbes colonize the biochar and actively contribute to the breakdown of organic pollutants, thereby enhancing the overall efficiency of the treatment process and promoting a healthier ecosystem within the treatment system. Another significant advantage of biochar is its ability to stabilize the pH of greywater, a factor that is essential for both maintaining plant health in agricultural reuse and ensuring the optimal performance of chemical and biological treatment processes. A balanced pH also helps control nutrient levels and prevents the formation of harmful compounds in overly acidic or alkaline environments. Furthermore, biochar excels at trapping suspended solids and particulate matter, which not only improves water clarity but also complements other filtration methods such as sand filters, resulting in a more comprehensive treatment system. Overall, the functions of biochar including contaminant and nutrient removal, pathogen trapping, pH stabilization, support for beneficial microbial growth, and particulate capture underscore its importance as a sustainable and effective component in modern greywater treatment strategies, ensuring environmental health and enabling the safe reuse of water for various applications.

### **2.2.5 Challenges of Using Biochar and Activated Carbon in Greywater Remediation**

#### **(1) Biochar:**

Several critical challenges associated with using biochar in greywater treatment systems are; one, the variability of its performance; the adsorption capacity of biochar can differ widely depending on the type of biomass used and the specific processing methods, which leads to unpredictable pollutant removal. Moreover, regenerating biochar to restore its filtering capacity after it has adsorbed contaminants is a complex process that is both energy-intensive and prone to generating secondary waste, thereby complicating the reuse of the

material. Disposal of spent biochar also poses environmental concerns, as improper management may result in the release of harmful substances during degradation, potentially undermining its ecological benefits. Furthermore, integrating biochar into existing greywater treatment often requires significant modifications, which can introduce additional environmental risks if not carefully managed.

## **(2) Activated Carbon:**

Activated carbon is highly regarded for its strong adsorption capabilities in water treatment, yet its application in greywater remediation presents several significant challenges. First, the production of activated carbon is both energy-intensive and expensive, relying on non-renewable raw materials and complex activation processes that drive up manufacturing costs. Over time, its performance can decline as the material becomes fouled by the accumulated pollutants, leading to reduced adsorption efficiency. The regeneration of spent activated carbon is equally problematic as the process is often energy-demanding and can degrade the material's structure, further diminishing its effectiveness over multiple uses. Disposal of used activated carbon also poses environmental risks, as improper handling may result in the release of harmful contaminants back into the environment.

### **2.2.6 Activated carbon production**

One of the most broadly used methods for removing water contaminants is adsorption on carbon adsorbents such as activated carbons (Leite et al., 2018). ACs have various structural and morphological properties that enhance adsorption potential, such as large specific surface area, high porosity, and reactive surface chemistry (Tan et al., 2017). For this reason, ACs are effective for removing pharmaceuticals (Mestre et al., 2019), natural organic matter

(Kozyatnyk et al., 2014), heavy metals (Cao et al., 2019), and nutrients from different types of wastewaters (Riley et al., 2018). However, the high production cost and energy consumption of these materials (León et al., 2020), along with a non-renewable source of raw materials (Zhao et al., 2023), limit the extent to which commercial ACs are used in developing countries for water treatment. The adsorption performance of activated carbons is influenced by their porosity, surface area, and functional groups, but they can struggle with low molecular weight compounds, quickly saturate with high pollutant loads, and often need energy-intensive regeneration or replacement (Kozyatnyk et al., 2020).

Activated carbon is also produced through pyrolysis but is differentiated from the production of biochar in several ways. The production of activated carbon involves several key processes, primarily focused on carbonization and activation. Below is a detailed overview of the steps involved in its production:

**Chemical Activation:** Chemical activation involves adding a chemical agent, usually a catalyst, to the carbon material prior to the actual activation process. The chosen chemical agent reacts with the carbon material under specific temperature and time conditions, creating pores and developing a porous structure.

**Physical activation:** For this, carbonaceous materials such as coal, wood or other carbon rich materials are first carbonized which involves heating them in the absence of oxygen. the process removes volatile compounds and has a carbon rich residue called char. The char is then activated by exposing it to high temperatures in the presence of an inert gas. This heat treatment causes the char to undergo physical changes, creating a network of pores and increasing the surface area.

Physical and Chemical Activation: Both physical and chemical activation methods can be combined or modified depending on the desired properties and specific applications of the activated carbon. The choice of raw materials, activation method, and process parameters can influence the pore size distribution, surface chemistry, and adsorption characteristics of the final product.

### **2.2.7 Types of Activated Carbon**

Activated carbon comes in a variety of forms, each designed to suit specific water treatment needs and operational scales. Granular Activated Carbon is perhaps the most widely recognized type, favored in large-scale water treatment facilities because its larger particle size supports high flow rates and allows for easier regeneration, which is essential for continuous operation. In contrast, Powdered Activated Carbon is ideal for smaller applications or for the precise removal of contaminants; its fine particles provide a greater surface area for adsorption, ensuring that even trace amounts of pollutants can be effectively targeted and removed. Beyond these two common types, there are also extruded activated carbon forms, which combine the benefits of granular structures with enhanced mechanical strength, making them particularly useful in fixed-bed systems where durability and structural integrity are critical. Another notable variation is impregnated activated carbon, which is treated with specific chemicals—such as silver or sulfur—to improve its ability to capture certain contaminants like chlorine, mercury, or even harmful microorganisms, thereby extending its functionality in specialized treatment scenarios. Additionally, activated carbon fibers offer an alternative form with an exceptionally high surface area and rapid adsorption rates; these are often employed in both industrial processes and air purification

systems due to their unique fibrous structure. The source of the activated carbon also plays an important role in its effectiveness: for example, coconut shell-based activated carbon is prized for its high micropore volume, making it particularly effective for adsorbing small organic molecules and other trace pollutants, whereas bituminous coal-based activated carbon generally features a more mesoporous structure that is better suited for larger molecules. This wide range of activated carbon types allows water treatment professionals to choose the most appropriate material based on the specific contaminants present, the desired treatment capacity, and the regeneration needs of the system. Each type brings its own advantages and challenges, and when integrated thoughtfully into treatment processes, they collectively contribute to the efficient removal of pollutants, ensuring that the water remains clean and safe for both industrial use and human consumption.

### **2.2.8 Role of Activated Carbon in Greywater Remediation**

Activated carbon plays a vital role in greywater remediation by effectively removing a wide range of pollutants from water. Its extensive network of pores and large surface area allow it to adsorb organic chemicals, including volatile organic compounds such as benzene, toluene, and xylene, which are often present in industrial effluents. Additionally, it is highly efficient at eliminating inorganic contaminants like chlorine and chloramine, commonly used as disinfectants, thereby significantly improving water quality. Activated carbon also targets a variety of other pollutants—adsorbing pesticides, dyes, nitrates, and even certain heavy metals from greywater. However, while it can capture many heavy metals, its ability to remove them comprehensively may be limited, and supplementary treatment methods such as ion exchange or membrane filtration might be required for complete remediation. The

overall performance of activated carbon is influenced by factors such as its source material, activation process, and the specific composition of the greywater being treated. As a result, it is often integrated into multi-stage treatment systems, working in concert with other technologies to ensure that the water meets stringent quality standards for safe reuse in residential, industrial, or agricultural applications.

### **2.2.9 Regeneration and Disposal**

#### **Activated Carbon**

Regeneration:

Activated carbon can be regenerated using thermal methods to restore its ability to adsorb contaminants. However, repeated thermal reactivation tends to gradually lower its effectiveness, meaning that after several cycles, the carbon must eventually be replaced with fresh material. Chemical regeneration is also an option, but it faces similar challenges, often requiring substantial energy and resources, which can increase overall operational costs.

Disposal:

When regeneration is no longer practical, the spent activated carbon must be disposed of properly. Since it may have adsorbed hazardous substances such as heavy metals, pesticides, or persistent organic chemicals, it is typically classified as hazardous waste. This classification mandates that disposal be handled in strict compliance with environmental regulations to avoid any potential contamination of soil, water, or air.

#### **Biochar**

Regeneration:

Biochar can also be reactivated through thermal or chemical treatments to restore its pollutant-absorbing properties. However, these regeneration methods may alter its delicate

porous structure, which is crucial for effective adsorption. As a result, after several cycles of use and regeneration, biochar may lose some of its efficacy, thereby limiting its usefulness in intensive greywater treatment applications.

Disposal:

If regeneration of biochar is not feasible, careful disposal becomes necessary, especially if it has accumulated significant levels of toxins or hazardous pollutants. Improper disposal could lead to the release of these contaminants back into the environment, posing risks to ecosystems and human health. Therefore, it is essential to follow strict disposal guidelines and environmental protocols to ensure that the biochar does not contribute to further pollution.

#### **2.2.10 Differences between biochar and activated carbon:**

##### **Biochar**

Production:

Biochar is manufactured by pyrolyzing organic materials such as agricultural residues, municipal waste, and forestry by-products. This thermal decomposition in a low-oxygen environment transforms these wastes into a carbon-rich material.

Physical and Chemical Properties:

Compared to activated carbon, biochar has a lower surface area and a less intricate porous structure. However, it typically contains a higher proportion of fixed carbon, which can be advantageous in certain applications despite its simpler texture.

Cost and Availability:

Generally, biochar is more affordable to produce. Its production process requires lower

temperatures and simpler techniques, making it more accessible and widely available, especially when derived from abundant organic wastes.

Challenges:

Despite its benefits, biochar faces several hurdles. These include questions around its economic viability, issues with quality control due to variability in production conditions, uncertainties regarding its long-term effects, and challenges related to its regeneration and disposal once it has adsorbed pollutants.

### **Activated Carbon**

Production:

Activated carbon is produced from carbonaceous materials such as coal, coconut shells, nut shells, and wood through either physical or chemical activation processes. These methods develop a highly porous structure that is essential for its adsorptive capabilities.

Physical and Chemical Properties:

It is characterized by a high surface area and a well-developed network of micropores, which makes it extremely effective at adsorbing contaminants. Activated carbon is primarily composed of carbon, with only trace amounts of other minerals present.

Cost and Availability:

Due to the intricate activation processes required, activated carbon is generally more expensive to produce. Nonetheless, it is widely available and remains a popular choice in both industrial and environmental water treatment applications.

Challenges:

The performance of activated carbon can be highly dependent on the specific production conditions used, and it too faces issues related to long-term effectiveness. Additionally,

challenges associated with its regeneration where repeated thermal or chemical treatments may diminish its adsorptive capacity and proper disposal, especially when it has absorbed hazardous contaminants, are important considerations in its lifecycle management.

### **2.3 Introduction to Parent Material Used for the Biochar production**

Plantain peels, typically discarded as waste, serve as a feedstock for producing biochar used in water purification. The process starts with the peels being oven-dried for 24 hours, then broken down and placed into a cubicle. Next, they are ashed at 600°C and ground into a fine powder. This biochar effectively purifies water by absorbing pollutants, balancing pH levels, and supporting beneficial microbes. When applied to soil, it enhances fertility and water retention while capturing carbon, helping to reduce greenhouse gas emissions. Similarly, charcoal is used as the base for making activated carbon. Charcoal is purchased, ground, and sieved using a 75-micron sieve to prepare it for activation with zinc chloride. After the activation process, the material is washed and sieved again. The resulting activated carbon has a highly porous structure with a large surface area, making it excellent for capturing harmful chemicals, heavy metals, and other pollutants in water treatment systems. These eco-friendly techniques convert waste materials into valuable products that improve environmental quality and support water purification efforts.

## 2.4 Previous Work Done

Liang et al., (2006) reported that biochar has the potential to increase Cation Exchange Capacity (CEC) in soils and he attributed the characteristics to the structural nature of biochar.

Steinbisset 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.

Khanet al., (2010) published that those organic materials generally possess some adsorption capacity and their high carbon content provides resistance to decomposition. They also stated that charring this 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-Toosiet 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.

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 was 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. Foerid, (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 12 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.

## **2.5 Research Gap**

Although many researchers (Liang et al., 2006; Steinbisset et al., 2009; Khan et al., 2010; Berger, 2012; Huggins et al., 2016) have shown that biochar and activated carbon can help remove pollutants from wastewater, most of these studies were done using synthetic greywater. This makes it hard to know how these materials will perform with real greywater that people produce in homes, which often contains different contaminants. Also, while some studies have explored biochar made from various plant materials, very little research has focused on biochar made from plantain peels, which are a common agricultural waste product. At the same time, activated carbon made from local charcoal, which is also cheap and widely available, has not been widely tested for greywater treatment in real-life conditions. In addition, most previous studies did not compare both materials under the same setup, making it difficult to know which one works better. Despite the potential of these natural materials, there is still a lack of studies that directly compare the performance of plantain peel biochar and charcoal-based activated carbon for treating real greywater collected from households. This study aims to fill that gap by testing both materials under the same conditions using actual greywater. It will also look at how easy and affordable it is to produce these materials locally. The goal is to find out which material works better and can be recommended for use in simple and low-cost greywater treatment systems, especially in places where people do not have access to advanced water treatment facilities.

## **CHAPTER THREE**

### **METHODOLOGY**

#### **3.1 LOCATION**

The Greywater was sourced from a residential home in Benin city at No. 23, Owoseni street, Benin city, Edo state. The biochar was produced from plantain peels sourced from Ekosodin, Benin city, Edo state. while the activated carbon was produced from charcoal purchased at Igun street, Benin city, Edo state. Subsequent laboratory experiments were carried out at the Benin-owena research laboratory of the University of Benin, Benin city, Edo State.

#### **3.2 Material Selection and Characterization**

To promote sustainable water treatment, Locally available and affordable raw materials was used. Plantain peels were chosen for making biochar due to their abundance and environmental benefits, while commercial charcoal was used to produce activated carbon. Both materials were prepared through drying, grinding, and treatment with zinc chloride before being thermally activated. Their effectiveness as filtration media was tested using the jar test machine. Fourier Transform Infrared Spectroscopy (FTIR) identified key functional groups important for adsorbing pollutants, and Scanning Electron Microscopy with Energy Dispersive X-ray Spectroscopy (SEM-EDS) revealed detailed surface structures and elemental compositions, confirming the formation of a porous structure ideal for treating greywater.

### **3.2.1 Preparation of Zinc Chloride-Impregnated Biochar from Plantain Peels**

The raw material, consisting of plantain peels was collected and then oven dried for 24 hours and then broken and placed in a crucible and subjected to a controlled pyrolysis process in a furnace, where they were pyrolyzed at a temperature of 600°C. After carbonization, 70 grams of the produced biochar was accurately weighed. While, 13.6 grams of zinc chloride was measured and dissolved in 1 liter of distilled water to prepare the activating solution. The biochar was then immersed in this zinc chloride solution and allowed to soak at room temperature for 24 hours to ensure complete impregnation of the activating agent. Following the soaking period, the biochar was filtered out then oven dried at 105°C until a constant weight was achieved and subsequently placed in a desiccator to cool down to room temperature. It was then placed in an airtight container to prepare for experiment.

### **3.2.2 Preparation of Activated Carbon from Charcoal**

The raw material charcoal was first purchased, then ground using a mortar and pestle, then sieved through a 75-micron sieve to achieve a uniform particle size. Seventy grams of the sieved charcoal was accurately weighed. Meanwhile, 13.6 grams of zinc chloride was dissolved in 1 liter of distilled water to form a consistent activating solution. The charcoal was then immersed in this solution and allowed to soak at room temperature for 24 hours for complete impregnation. After soaking, the sample was filtered out then dried in an oven at 105°C until its weight remained constant, ensuring all moisture was removed. Finally, the dried activated carbon was placed in a desiccator to prevent moisture intake and to cool

down to room temperature. It was then transferred into an airtight container in preparation for the experiment.

### **3.2.3 Activation of Biochar and Activated carbon**

#### **3.2.3(a) Biochar:**

Seventy grams of biochar was weighed accurately using an analytical balance. While, 13.6 grams of zinc chloride was measured and set aside. A one-liter zinc chloride solution was prepared by dissolving the zinc chloride in distilled water, with thorough mixing to ensure complete dissolution. The weighed biochar was then immersed in the prepared solution and allowed to soak for 24 hours to ensure full impregnation. After soaking, the biochar was transferred to an oven and dried at 105°C until a constant weight was achieved, ensuring that all moisture was removed. Following the drying process, the biochar was cooled in a desiccator to room temperature.

#### **3.2.3(b) Activated Carbon:**

Seventy grams of activated carbon were weighed accurately using an analytical balance. Then, 13.6 grams of zinc chloride was measured and set aside. A one-liter zinc chloride solution was prepared by dissolving the zinc chloride in deionized water and mixing thoroughly until completely dissolved. The activated carbon was immersed in the prepared solution and left to soak for 12–24 hours to ensure full impregnation. After soaking, the activated carbon was transferred to an oven and dried at 105°C until a constant weight was achieved, ensuring complete moisture removal. It was then cooled in a desiccator to room temperature.

### **3.2.4 Characterization of Biochar and Activated carbon**

Both samples were analyzed using the Fourier transform infrared spectroscopy (FTIR) and Scanning electron microscopy with energy dispersive Xray spectroscopy (SEM-EDS) methods of characterization. FTIR helped identify the functional groups on the sample surfaces and revealed any chemical changes from the processing. SEM-EDS was used to study the surface structure and determine the elemental composition. Together, these techniques confirmed that the activation process was successful and provided important details about the samples' structure and chemistry.

### **3.5 Sample Collection**

Greywater was collected directly from a residential property at No. 23 Owoseni Street, New Benin, Benin city, Edo state. ensuring that the sample remained in its natural, unaltered state as it flowed from routine kitchen activities. A standard 1.5-liter bottle was used to capture the water, preserving its original composition. Prior to collection, the bottle was thoroughly cleaned by washing it with distilled water and allowing it to dry completely. After drying, the bottle was rinsed three times with the greywater sample to remove any residual contaminants and ensure the sample's authenticity. Following these rinses, the bottle was filled to the brim to expel any trapped air and then securely corked and sealed to maintain its integrity. Immediately after sealing, the sample was transported to the laboratory for analysis.

### **3.4 Greywater analysis before and after filtration**

The following water quality parameters were determined according to standard methods before treatment:

#### **3.4.1 Procedure for measuring pH**

The pH of the water sample was measured in the laboratory using a pH meter. Initially, the instrument was calibrated with a pH 7.0 buffer solution, and the electrode was rinsed multiple times with distilled water to remove any residues. Next, 20 ml of the water sample was measured into a clean beaker, which had been rinsed with distilled water and a small amount of the sample to ensure it was free from contaminants. Finally, the pH meter was used to obtain the pH reading of the sample.

#### **3.4.2 Procedure for Measuring Turbidity Using a Turbidity Meter**

To measure the turbidity of the greywater sample, a clean container was used to collect water, ensuring no sediment from the bottom was included. The turbidity tube was rinsed with the same water sample to prevent contamination. The sample was stirred and until homogeneous, minimizing air bubbles.

During measurement, the researcher positioned their head 10 cm above the tube to observe the viewing disk as the sample was poured in. Care was taken to avoid bubbles, pausing if necessary to let them rise and the water settle. Water was added slowly until the pattern on the viewing disk became difficult to see, stopping when the pattern was no longer visible.

### **3.4.3 Procedure for Measuring Suspended Solids in Greywater**

To measure suspended solids in greywater, a part of the sample was collected in a clean container, ensuring it was well-mixed and free from sediment. 100ml of the sample was filtered through a pre-weighed, dried filter membrane (typically 0.45  $\mu\text{m}$  pore size), and the volume filtered was recorded. The filter membrane with the retained solids was placed in an oven and dried at a constant temperature (usually 103-105°C) until a constant weight was achieved, which took several hours. The filter was allowed to cool in a desiccator to room temperature to prevent moisture absorption, and then it was weighed with the dried solids. The concentration of suspended solids was calculated using the formula: Suspended Solids (mg/L) =  $(W2 - W1) \times 1000 / \text{Volume of sample (ml)}$ , where W1 was the weight of the filter before filtration and W2 was the weight of the filter after drying. Finally, the concentration of suspended solids in the greywater sample was recorded.

### **3.4.4 Procedure for Measuring Alkalinity in Greywater**

To measure alkalinity in greywater, a representative sample was collected in a clean container, ensuring it was well-mixed. A 30 ml volume of the sample was titrated with a standard acid solution (typically 0.02N sulfuric acid) using a phenolphthalein indicator. The titration was continued until the pink color disappeared, indicating the phenolphthalein alkalinity endpoint. The volume of acid used was recorded. The sample was then further titrated with the same acid solution using a methyl orange indicator until a faint pink color appeared, indicating the total alkalinity endpoint. The volume of acid used was again recorded. The alkalinity was calculated using the formula: Alkalinity (mg/L as  $\text{CaCO}_3$ ) =

$(V \times N \times 50,000) / 30$ , where V is the volume of acid used and N is the normality of the acid. Finally, the alkalinity of the greywater sample was recorded.

#### **3.4.5 Procedure for Measuring Chloride in Greywater**

To measure chloride in greywater, a representative sample was collected in a clean container, ensuring it was well-mixed. A 30 ml volume of the sample was titrated with a standard silver nitrate solution using a potassium chromate indicator. The titration was continued until a persistent reddish-brown color appeared, indicating the chloride endpoint. The volume of silver nitrate used was recorded. The chloride concentration was calculated using the formula: Chloride (mg/L) =  $(V \times N \times 35,453) / 30$ , where V is the volume of silver nitrate used and N is the normality of the silver nitrate solution. Finally, the chloride concentration in the greywater sample was recorded.

#### **3.4.6 Procedure for Measuring Calcium in Greywater**

To measure calcium in greywater, a representative sample was collected in a clean container, ensuring it was well-mixed. A 30 ml volume of the sample was titrated with a standard EDTA solution using an Eriochrome Black T indicator. The titration was continued until the color changed from wine red to blue, indicating the calcium endpoint. The volume of EDTA used was recorded. The calcium concentration was calculated using the formula: Calcium (mg/L) =  $(V \times N \times 40,080) / 30$ , where V is the volume of EDTA used and N is the normality of the EDTA solution. Finally, the calcium concentration in the greywater sample was recorded.

### **3.4.7 Procedure for Measuring Magnesium in Greywater**

To measure magnesium in greywater, a representative sample was collected in a clean container, ensuring it was well-mixed. A 30 ml volume of the sample was titrated with a standard EDTA solution using an Eriochrome Black T indicator, similar to the calcium measurement. The titration was continued until the color changed from wine red to blue, indicating the magnesium endpoint. The volume of EDTA used was recorded. The magnesium concentration was calculated using the formula:  $\text{Magnesium (mg/L)} = (V \times N \times 24,305) / 30$ , where V is the volume of EDTA used and N is the normality of the EDTA solution. Finally, the magnesium concentration in the greywater sample was recorded.

### **3.4.8 Heavy Metal Determination**

Water Analyses of heavy metals (Lead, Iron, and Cadmium) in greywater were done by transferring 500ml of the water into a long beaker, adding 15ml of Conc. HNO<sub>3</sub>, evaporating on a steam bath to approximately 25ml and bringing the volume to 50ml with distilled water. The various heavy metals were analyzed using the atomic absorption spectrophotometer.

### **3.4.9 Procedure for Measuring Conductivity and Total Dissolved Solids**

Before measurement, the greywater sample was thoroughly mixed. A conductivity meter was used to determine the conductivity and total dissolved solids (TDS) of the sample. The meter was first calibrated using a 0.01M potassium chloride (KCl) solution. Then, 100 mL of the greywater sample was measured into a clean beaker. The meter probe was placed into

the sample and held for a few minutes until the digital display reading stabilized, ensuring accurate measurement of conductivity and TDS.

#### **3.4.10 Procedure for Measuring Water Hardness**

Total hardness was determined by measuring 50 ml of the sample into a 250 ml conical flask. 2 ml of the buffer solution with 2 drops of indicator (Erichrome Black T) was added and the mixture swirled. The sample was then titrated against 0.1M EDTA to a blue color endpoint.

Where:

Total hardness as  $\text{CaCO}_3$  (mg/L) =  $V \times A \times 1000 / (\text{ml sample})$

- V = volume of titration of sample (ml)

- A = amount of  $\text{CaCO}_3$  (in ml) equivalent to 1 ml EDTA titrant.

#### **3.5 Effect of Dosage on Adsorption Efficiency Using Jar Test Apparatus**

In this study, the influence of adsorbent dosage on the adsorption efficiency of greywater treatment was evaluated using both biochar and activated carbon. Precise amounts of each adsorbent (0.1 g, 0.2 g, 0.3 g, 0.4 g, 0.5 g, and 0.6 g) were measured using a digital balance. Each dose was added to 20 mL of unaltered greywater in a beaker. The beakers were then placed in a Jar Test Machine and stirred at a constant speed for 30 minutes, ensuring thorough mixing and effective contact between the adsorbent and the contaminants. After mixing, the entire mixture was allowed to settle, then filtered using filter paper to remove any residual solids. Finally, each sample was tested for electrical conductivity and total dissolved solids, and the results indicated that 0.5 g of biochar and activated carbon

achieved the highest removal efficiency, significantly lowering EC, TDS, and suspended solids .

### **3.6 Filtration Experiment**

Once the jar test was finished and the water had enough time to settle, the next step was to filter the water using filter paper. Clean funnels were placed on top of dry, clean beakers, and each funnel was fitted with a piece of filter paper. Each funnel and filter paper was used for only one sample to avoid mixing. The water at the top of the jar was gently poured into the funnel without shaking the jar. Pouring slowly helped stop the settled particles from getting into the funnel. As the water flowed through the filter paper, it caught any remaining contaminant still in the water, and the clean water dropped into the beaker underneath.

This process was repeated for all the samples, and a new filter paper was used each time. Every beaker was clearly marked with the type of filter material used and the amount of adsorbent. After filtering, the clean water samples in the beakers were covered to keep them clean. These samples were saved for testing water quality such as turbidity, pH, total dissolved solids, and others. The same steps were followed for all the samples, including those treated with different amounts of biochar and activated carbon, to make sure the process was fair and the results were correct.

### 3.7 Removal Efficiency

The removal efficiency of both filter media was calculated using the equation as shown below in equation 3.1

$$\text{Removal Efficiency} = \frac{C_i - C_f}{C_i} \times 100 \quad (3.1)$$

Where,  $C_i$  is the initial concentration and  $C_f$  is the final concentration.

## RESULTS AND DISCUSSION

### 4.1 Characterization of the Biochar

#### 4.1.1 Fourier Transform Infrared Spectroscopy (FTIR) Analysis

Fourier Transform Infrared Spectroscopy (FTIR) is a widely used analytical technique for identifying the functional groups present in a material, providing insight into its chemical structure and potential reactivity. For this biochar characterization, FTIR analysis helps determine the specific bonds and functional groups responsible for adsorption and interaction with contaminants in greywater. These functional groups influence the material's ability to retain pollutants, making FTIR a necessary tool in assessing biochar's effectiveness as a filtration medium.

By analyzing the absorption peaks at different wavenumbers, FTIR reveals the molecular composition of biochar, including hydroxyl, carbonyl, and aromatic structures. These features contribute to its adsorption efficiency, chemical stability, and overall performance in water treatment applications. The table below summarizes the functional groups identified in the biochar sample, along with their respective wavenumbers and possible bond assignments.

**Table 4.1:** FTIR Table

Wavenumber (cm <sup>-1</sup> )	Functional Group	Possible Bond/Assignment
3611.8	Hydroxyl (-OH)	O-H stretching (free OH in alcohols or phenols)

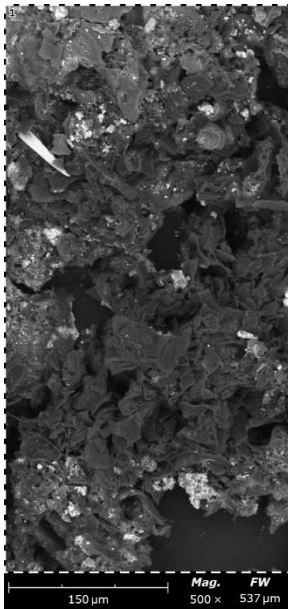
3213.0	Amine (-NH) or Hydroxyl (-OH)	N-H stretching (amines) or H-bonded O-H stretching (alcohols, carboxylic acids)
2105.9	Alkyne (-C≡C) or Nitrile (-C≡N)	C≡C or C≡N stretching
1897.2	Carbonyl (C=O)	C=O stretching (anhydrides, conjugated ketones)
1609.6	Aromatic (C=C)	C=C stretching (benzene ring)
1375.4	Methyl (-CH <sub>3</sub> )	C-H bending (methyl group)
1059.8	C-O Stretch	C-O stretching (alcohols, ethers, esters)
1013.8	C-O Stretch	C-O stretching (secondary alcohols or polysaccharides)

In FTIR (Fourier Transform Infrared) analysis, wavenumber (measured in  $\text{cm}^{-1}$ ) shows the energy level where a substance absorbs infrared light, causing certain chemical bonds to vibrate. Each bond or functional group like O-H, C=O, or C-H absorbs energy at a specific wavenumber, which helps identify what is present in the material. The possible bond or assignment tells us what type of bond is likely responsible for the absorption at that point. This helps match the FTIR results to real chemical groups. These functional groups are very important in understanding how well biochar works in water treatment. Hydroxyl (-OH) and carbonyl (C=O) groups create active sites that attract and hold pollutants, especially heavy metals and organic substances, through hydrogen bonding and electrostatic attraction. Aromatic (C=C) groups add chemical stability, making the biochar last longer during use. Alkyne (-C≡C) and nitrile (-C≡N) groups give extra reactive spots that increase the biochar's ability to capture contaminants. Methyl (-CH<sub>3</sub>) and carbonyl (C=O) groups affect the surface charge and water interactions, helping pollutants stick better. C-O bonds, often found in alcohols and esters, also support adsorption by offering more bonding areas.

#### 4.1.2 Scanning Electron Microscopy with Energy Dispersive Xray Spectroscopy (SEMEDS) Analysis

SEM-EDS analysis helps examine the surface structure and elemental composition of biochar, both of which affect its performance in greywater treatment. SEM imaging provides a detailed view of the material's porosity and surface texture, which influence how well it can trap contaminants. A highly porous structure improves adsorption, making biochar more effective in filtration.

EDS analysis identifies the elements present in biochar, such as carbon, oxygen, nitrogen, and trace minerals, which impact its chemical reactivity and stability. These elements determine how biochar interacts with pollutants and how durable it is during water treatment. Understanding these properties helps evaluate biochar's efficiency and suitability as a sustainable filtration material for greywater remediation.



**FIG 4.1 High Magnification SEM Image**

**Table 4.2 Constituent Elements**

<b>Element</b>	<b>Atomic weight and concentration</b>
Carbon	83.39% Atomic, 73.52% weight
Nitrogen	9.45% Atomic, 9.72% weight
Potassium	2.33% Atomic, 6.67% weight
Sodium	2.29% Atomic, 3.86% weight
Chlorine	0.80% Atomic, 2.08% weight
Calcium	0.47% Atomic, 1.39% weight
Silicon	0.61% Atomic, 1.25% weight
Phosphorus	0.36% Atomic, 0.82% weight
Magnesium	0.17% Atomic, 0.30% weight
Iron	0.04% Atomic, 0.17% weight
Sulphur	0.04% Atomic, 0.09% weight
Aluminum	0.04% Atomic, 0.08% weight
Titanium	0.02% Atomic, 0.05% weight
Manganese	0.00% Atomic, 0.00% weight

The SEM-EDS results help explain how biochar performs in water treatment by showing its adsorption efficiency, chemical stability, and overall effectiveness. The SEM images reveal a highly porous surface, which is important because more pores mean more space to trap pollutants like organic compounds, heavy metals, and suspended solids. This improves biochar's ability to clean greywater. The EDS analysis shows a high carbon content, which makes biochar strong and stable, allowing it to last longer in filtration systems. Nitrogen in

the biochar helps attract and bind contaminants, while minerals like potassium, calcium, and magnesium support ion exchange, further improving pollutant removal. Together, these features make biochar a durable and efficient filtration material for greywater treatment.

## 4.2 Characterization of the Activated carbon

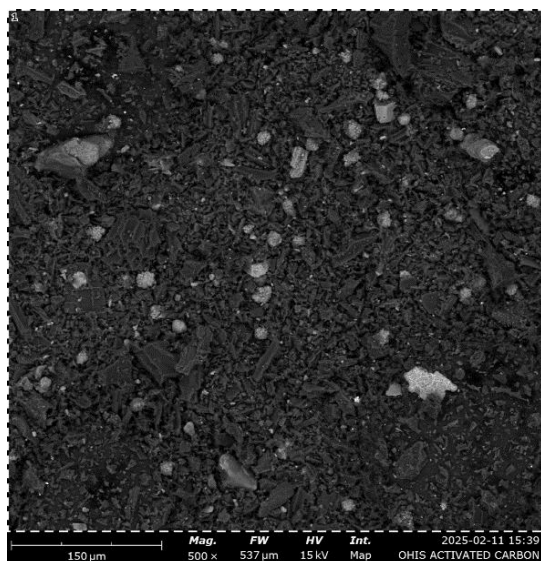
### 4.2.1 Fourier Transform Infrared Spectroscopy (FTIR)

**Table 4.3 FTIR Table**

Wavenumber (cm <sup>-1</sup> )	Functional Group	Possible Bond/Assignment
2853.9	Alkane (-CH)	C-H stretching (sp <sup>3</sup> hybridized)
2340.8	Carbon Dioxide (CO <sub>2</sub> )	CO <sub>2</sub> asymmetric stretching
2091.0	Alkyne (-C≡C) or Nitrile (-C≡N)	C≡C or C≡N stretching
1997.9	Combination Band	Overtone or combination mode
1684.8	Carbonyl (C=O)	C=O stretching (aldehydes, ketones, amides)
1558.0	Aromatic (C=C)	C=C stretching (benzene ring)
1423.8	Methyl (-CH <sub>3</sub> ) or Carboxyl (-COO <sup>-</sup> )	C-H bending or COO <sup>-</sup> symmetric stretching
1002.7	C-O Stretch	C-O stretching (alcohols, ethers, esters)
872.2	Out-of-plane bending	C-H bending (aromatic or alkene)

The FTIR analysis of activated carbon shows the presence of various functional groups, each playing an important role in how well it removes contaminants from greywater. The wavenumber values represent the energy levels where specific chemical bonds absorb infrared light, helping identify the types of bonds present. These include C-H stretching from alkanes, CO<sub>2</sub> asymmetric stretching, C≡C or C≡N triple bond stretching, and different forms of C=O and C=C bond vibrations. Functional groups such as hydroxyl (-OH) and carbonyl (C=O) provide active sites that attract and bind pollutants through hydrogen bonding and electrostatic interactions, making the activated carbon effective at adsorbing

organic substances and heavy metals. Aromatic (C=C) structures contribute to the material's chemical stability, helping it remain strong and efficient across repeated filtration cycles. Alkyne (-C≡C) and nitrile (-C≡N) groups offer additional reactive spots that improve its ability to capture a wider variety of contaminants. Methyl (-CH<sub>3</sub>) and carboxyl (-COO<sup>-</sup>) groups influence the surface charge and how the material interacts with water, improving its ability to attract and hold pollutants.



**Fig 4.2 High magnification Sem Image**

**Table 4.4 Constituents elements**

<b>Element</b>	<b>Atomic weight and Weight concentration</b>
Carbon	91.56% Atomic, 86.54% Weight
Nitrogen	5.52% Atomic, 6.09% Weight
Potassium	0.07% Atomic, 0.21% Weight
Sodium	0.27% Atomic, 0.50% Weight
Chlorine	0.08% Atomic, 0.21% Weight
Calcium	0.61% Atomic, 1.93% Weight
Silicon	1.36% Atomic, 3.01% Weight
Phosphorus	0.00% Atomic, 0.00% Weight
Magnesium	0.07% Atomic, 0.30% Weight
Iron	0.12% Atomic, 0.53% Weight
Sulphur	0.00% Atomic, 0.00% Weight
Aluminium	0.18% Atomic, 0.38% Weight
Titanium	0.00% Atomic, 0.00% Weight
Manganese	0.07% Atomic, 0.30% Weight

#### **4.2.2 Scanning Electron Microscopy with Energy Dispersive Xray Spectroscopy (SEMEDS)**

SEM imaging shows a highly porous structure, which plays a vital role in adsorption efficiency. The presence of numerous micropores increases the surface area, allowing activated carbon to effectively capture contaminants such as organic pollutants, heavy metals, and suspended particles, making it highly efficient in water purification.

The EDS results highlight a high carbon content, which strengthens the material's structure and enhances its durability in filtration systems. Oxygen and nitrogen functional groups improve pollutant binding, aiding the adsorption process. Additionally, trace elements like calcium, sodium, and silicon contribute to ion exchange and chemical interactions, further boosting contaminant removal. These combined properties make activated carbon a strong, stable, and efficient filtration material for improving greywater quality.

#### **4.3 GREYWATER ANALYSIS**

Assessing greywater is vital for evaluating the effectiveness of biochar and activated carbon as filtration media in greywater treatment. This study measured key water quality parameters, including pH, turbidity, electrical conductivity (EC), total dissolved solids (TDS), and heavy metal concentrations, both before and after treatment. This measurement allowed for the determination of each adsorbent's removal efficiency. The Jar Test Machine was used to optimize the interaction between greywater contaminants and adsorbents by simulating coagulation, flocculation, and sedimentation processes. By comparing the initial and final pollutant concentrations, the analysis provided insights into how well each filtration medium performed in reducing contaminants and improving water quality.

Precise amounts of each adsorbent (0.1 g, 0.2 g, 0.3 g, 0.4 g, 0.5 g, and 0.6 g) were measured using a digital balance . Each dose was added to 20 mL of unaltered greywater in a beaker. The beakers were then placed in a Jar Test Machine and stirred at a constant speed for 30 minutes, ensuring thorough mixing and effective contact between the adsorbent and the contaminants. The samples were then filtered, after which electrical conductivity and total dissolved solids were tested, and the 0.5 g solution was selected for further testing.

#### **4.3.1 Biochar results for greywater remediation before and after treatment**

The table presents the analysis of greywater before and after treatment using biochar. Key parameters, including pH, electrical conductivity (EC), total dissolved solids (TDS), turbidity, and heavy metal concentrations, were measured to assess biochar's effectiveness as a filtration media.

**Table 4.5 Biochar Greywater Remediation result before and after treatment**

pH dropped from 8.28 to 6.07, making the water more neutral. Suspended solids slightly

Parameters	Before	After
PH	8.28	6.07
Turbidity (NTU)	292	294
Suspended solids(mg/l)	202	195
Electrical conductivity(s/cm)	658	284
Total dissolved solids(mg/l)	329	142
Alkalinity(mg/l)	14	146
Chloride(mg/l)	261.22	49.42
Hardness(mg/l)	42	146
Calcium(mg/l)	8.02	6.41
Magnesium(mg/l)	5.35	2.43
Iron(mg/l)	0.75	0.32
Lead(mg/l)	0.26	0.14
Cadium(mg/l)	0.14	0.052

decreased from 202 mg/L to 195 mg/L, while electrical conductivity and total dissolved solids dropped, showing the removal of dissolved particles. Chloride levels fell from 261.22 mg/L to 49.42 mg/L, proving biochar's ability to absorb ions. However, hardness increased from 42 mg/L to 146 mg/L, likely due to minerals released from the biochar. Heavy metals were greatly reduced, with iron dropping from 0.75 mg/L to 0.32 mg/L, lead from 0.26 mg/L to 0.14 mg/L, and cadmium from 0.14 mg/L to 0.052 mg/L

#### **4.3.2 Activated carbon results for greywater remediation before and after treatment**

The table below shows the greywater quality parameters before and after treatment with activated carbon. Initially, the greywater contained high contaminant levels, requiring detailed analysis. Baseline parameters, including pH, electrical conductivity (EC), total dissolved solids (TDS), turbidity, and heavy metal concentrations, were measured. The untreated greywater exhibited high EC and TDS levels, and significant turbidity due to

suspended particles. Additionally, heavy metals were present at concerning levels. These initial measurements served as a benchmark for evaluating the effectiveness of activated carbon in removing these contaminants during treatment.

**Table 4.6 Activated Carbon Greywater Remediation result**

PH	8.28	6.54
Turbidity (NTU)	292	127
Suspended solids(mg/l)	202	110
Electrical conductivity(s/cm)	658	263
Total dissolved solids(mg/l)	329	131
Alkalinity(mg/l)	14	6
Chloride(mg/l)	261.22	126
Hardness(mg/l)	42	18
Calcium(mg/l)	8.02	3.54
Magnesium(mg/l)	5.35	2.67
Iron(mg/l)	0.75	0.13
Lead(mg/l)	0.26	0.048
Cadium(mg/l)	0.14	0.013

The pH dropped from 8.28 to 6.54, making the water more neutral. Suspended solids decreased from 202 mg/L to 110 mg/L, while electrical conductivity and total dissolved solids dropped from 658  $\mu$ S/cm to 263  $\mu$ S/cm and 329 mg/L to 131 mg/L, respectively, indicating the removal of dissolved particles. Turbidity significantly decreased from 292 NTU to 127 NTU, showing improved water clarity. Chloride levels reduced from 261.22 mg/L to 126 mg/L, demonstrating effective ion adsorption. Hardness dropped from 42 mg/L to 18 mg/L, along with reductions in calcium (8.02 mg/L to 3.54 mg/L) and magnesium (5.35 mg/L to 2.67 mg/L). Heavy metal concentrations were significantly reduced, with iron

decreasing from 0.75 mg/L to 0.13 mg/L, lead from 0.26 mg/L to 0.048 mg/L, and cadmium from 0.14 mg/L to 0.013 mg/L.

#### 4.4 Removal Efficiency

Removal efficiency helps determine how well biochar and activated carbon improve greywater quality by reducing contaminants like suspended solids, organic matter, and heavy metals. The effectiveness of each material depends on its porous structure, surface properties, and ability to trap pollutants. In this study, different dosages were tested to assess their impact on greywater treatment. The findings highlight the potential of biochar and activated carbon as effective and sustainable filtration materials.

**Table 4.7 Removal Efficiency**

Paramter	Biochar Removal Efficiency (%)	Activated Carbon Removal Efficiency (%)
PH	26.7% reduction	21.0% reduction
Turbidity	0.7% (slight increase)	56.5% reduction
Suspended solids	3.5% reduction	45.5% reduction
Electrical conductivity	56.9% reduction	60.0% reduction
Total dissolved solids	56.9% reduction	60.2% reduction
Alkalinity	943% increase	57.1% reduction
Chloride	81.0% reduction	51.7% reduction
Hardness	247.6% increase	57.1% reduction
Calcium	20.1% reduction	55.9% reduction
Magnesium	54.6% reduction	50.1% reduction
Iron	57.3% reduction	82.7% reduction
Lead	46.2% reduction	81.5% reduction
Cadium	62.9% reduction	90.7% reduction

#### **4.4.1 Biochar**

The results show that biochar is good at removing some contaminants but also adds some minerals to the water. It reduced dissolved solids and conductivity by 56.84%, meaning fewer dissolved particles remained. Chloride dropped by 81.08%, and heavy metals like iron, lead, and cadmium decreased by over 50%, showing biochar's ability to trap pollutants. Magnesium and calcium also reduced, but only slightly. However, water hardness increased by 247.62%, and alkalinity rose sharply by 942.86%, meaning biochar released minerals into the water. Turbidity and suspended solids changed only a little. This means biochar works well for cleaning water but may need further treatment to control mineral release.

#### **4.4.2 Activated carbon**

The results show that activated carbon effectively removes various contaminants from water. It significantly reduced heavy metals, with cadmium, iron, and lead decreasing by 90.71%, 82.67%, and 81.54%, respectively. Dissolved solids and electrical conductivity dropped by around 60%, indicating fewer dissolved impurities. Turbidity and suspended solids were also reduced by 56.51% and 45.54%, improving water clarity. Additionally, alkalinity and hardness decreased by 57.14%, while calcium and magnesium dropped by 55.86% and 50.09%, respectively. These findings confirm that activated carbon is highly efficient in improving water quality by removing pollutants and making the water safer for use.

#### 4.5 Comparative analysis of Biochar and Activated Carbon in Greywater Treatment

**Table 4.8 Treatment Results of Both Biochar and Activated Carbon**

Parameter	Before Treatment	After Biochar	Removal Efficiency (Biochar)	After Activated Carbon	Removal Efficiency (Activated Carbon)
pH	8.28	6.07	26.7% reduction	6.54	21.0% reduction
Turbidity (NTU)	292	294	0.7% increase	127	56.5% reduction
Suspended Solids (mg/L)	202	195	3.5% reduction	110	45.5% reduction
Electrical Conductivity ( $\mu\text{S}/\text{cm}$ )	658	284	56.9% reduction	263	60.0% reduction
Total Dissolved Solids (mg/L)	329	142	56.9% reduction	131	60.2% reduction
Alkalinity (mg/L)	14	146	943% increase	6	57.1% reduction
Chloride (mg/L)	261.22	49.42	81.0% reduction	126	51.7% reduction
Hardness (mg/L)	42	146	247.6% increase	18	57.1% reduction
Calcium (mg/L)	8.02	6.41	20.1% reduction	3.54	55.9% reduction

			reduction		
Magnesium (mg/L)	5.35	2.43	54.6% reduction	2.67	50.1% reduction
Iron (mg/L)	0.75	0.32	57.3% reduction	0.13	82.7% reduction
Lead (mg/L)	0.26	0.14	46.2% reduction	0.048	81.5% reduction
Cadmium (mg/L)	0.14	0.052	62.9% reduction	0.013	90.7% reduction

The results from this study give a detailed understanding of how biochar and activated carbon perform when used to treat greywater. These results are linked to the main aim of the study, which was to compare the two materials in terms of how well they can improve greywater quality and to find out if they are suitable for use in simple, low-cost water treatment systems, especially in places with limited access to advanced water systems.

The study showed that activated carbon performed better than biochar in almost all the water quality parameters tested. One of the key measurements was turbidity, which shows how cloudy a sample of water is. High turbidity usually means the water has many suspended particles, which can include dirt, organic matter, or bacteria. After treatment with activated carbon, turbidity was reduced by 56.51%, meaning the water became much clearer. However, with biochar, turbidity actually increased slightly by 3.47%, showing that the water became cloudier instead of clearer. This increase may have been caused by fine particles coming off the biochar itself or by its inability to trap small particles effectively. Another important

parameter was suspended solids, which are tiny pieces of matter floating in the water. Activated carbon removed 45.54% of suspended solids, while biochar only removed 3.47%, showing that it was not very effective in this area. These results reflect the physical structure of the two materials. Activated carbon has a more developed porous surface and a higher surface area, which helps it trap and hold more particles. This confirms what is already known in other studies, which describe activated carbon as a strong adsorbent. The fact that the activated carbon used in this study was made from ordinary charcoal and still performed this well shows that local materials, when properly treated, can be very effective.

In terms of dissolved substances, which include salts, minerals, and soap residues, both materials showed the ability to reduce the concentration of these pollutants, but activated carbon was more efficient. Electrical conductivity (EC), which measures the ability of water to conduct electricity and is related to the amount of dissolved salts, was reduced by 60.03% with activated carbon and by 57.76% with biochar. Similarly, total dissolved solids (TDS), which include all inorganic and organic substances dissolved in water, were reduced by 60.18% with activated carbon and by 57.85% with biochar. These results show that both materials worked reasonably well in removing dissolved contaminants, but activated carbon still had a slightly better performance. The better result for activated carbon is supported by earlier laboratory tests done on the materials. FTIR analysis showed that activated carbon had functional groups like hydroxyl ( $-OH$ ) and carbonyl ( $C=O$ ), which are known to interact well with dissolved ions. SEM images also showed that activated carbon had a more open and porous structure compared to biochar, giving it more space for trapping and adsorbing particles and dissolved substances from the greywater.

One of the most surprising and important results from the study was the effect of the materials on alkalinity and hardness. Activated carbon reduced both alkalinity and hardness by 57.14%, which is a desirable outcome because lower alkalinity and hardness usually mean better water quality. However, biochar had the opposite effect. It increased alkalinity by 943.06% and hardness by 247.61%. These increases suggest that the biochar released substances into the water instead of removing them. High alkalinity can cause problems like scaling in pipes and poor effectiveness of soap, while high hardness can damage plants if the water is reused for irrigation. The high increase in these values shows that the biochar used in this study, even though it was chemically activated with zinc chloride, was not properly stabilized and may need to be improved through additional treatment, such as thorough washing or changing the activation method. These results clearly show that in its current form, the biochar is not suitable for use as a standalone filter for greywater.

Another important part of the experiment was testing how well the materials could remove heavy metals, which are toxic even in small amounts and can come from soaps, detergents, and old pipes. Activated carbon removed 82.67% of iron, 81.54% of lead, and 90.71% of cadmium, showing very strong performance. Biochar also removed these metals, but at lower levels, 57.3% of iron, 46.2% of lead, and 62.9% of cadmium. These values show that while biochar has some ability to remove harmful metals, it is not as effective as activated carbon. This is an important finding because removing heavy metals is critical to making greywater safe for reuse or disposal. The results confirm that activated carbon is better suited for removing dangerous substances from greywater, especially in environments where health risks must be kept low.

Even though biochar did not perform as well as activated carbon overall, there were some parameters where it did better. Biochar removed 81.08% of chloride, compared to 51.74% by activated carbon. For magnesium, biochar removed 54.21%, slightly higher than the 50.09% removed by activated carbon. This shows that biochar can still be useful for removing specific ions, and it may be helpful to use it alongside other materials in a layered filter system. In conclusion, the results of this study clearly show that activated carbon is the more effective and reliable material for treating greywater. It performed better in almost every area, including turbidity, suspended solids, electrical conductivity, total dissolved solids, alkalinity, hardness, and heavy metal removal. While biochar is less effective overall, it still has potential, especially for chloride and magnesium removal. It is cheaper to make, can be produced from waste materials, and may be suitable for use in combination with other filter types. However, before it can be used widely, more work is needed to improve its stability and performance.

#### 4.5.1 Comparison of Biochar and Activated Carbon cost of production in Water Treatment

**Table 4.9 Comparing cost of production**

Cost Component	Biochar (₦)	Activated Carbon (₦)	Remarks
Raw material	None	500	Plantain peel (waste) for biochar; purchased charcoal for AC
Greywater (gotten from home)	None	None	Collected for treatment experiment
Pyrolysis (plantain peels)	6,000	—	Heating process to convert peels to biochar
Charcoal Grinding and sieving	—	None	Grinding was done free of charge
Chemical activation (e.g. ZnCl <sub>2</sub> )	5,000	5,000	ZnCl <sub>2</sub> used separately in preparation of each material

Greywater Characterization	20,000	20,000	Each treatment sample analyzed before and after filtration
Heavy Metal Characterization	2,000	2,000	Each greywater treatment tested for iron, lead, cadmium
Characterization – Instrumentation	45,000	45,000	Each material separately tested for surface structures.
Total Production Cost	₦78,000	₦72,500	Sum of all applicable costs

Even though both biochar and activated carbon were treated the same way with the same chemical (zinc chloride), the same heating temperature, soaking time, and drying method there was still a difference in their production costs. This is mainly because of the type of material used and how each one was prepared. Biochar was made from plantain peels, which are a waste product and cost nothing. Turning the peels into biochar involved heating them (pyrolysis) at 600°C and then activating them with zinc chloride. This process is simple and uses less energy and equipment. According to the cost table, the total cost to produce biochar was ₦78,000. This included ₦6,000 for pyrolysis, ₦5,000 for the activating chemical, ₦20,000 for greywater tests before and after treatment, ₦2,000 for testing heavy metals, and

₦45,000 for FTIR and SEM-EDS laboratory tests. Because the plantain peels were free and didn't need extra preparation, there were no extra costs for raw materials or grinding.

Activated carbon, on the other hand, was made from charcoal. Even though it was activated using the same steps as biochar, charcoal had to be bought, which added to the cost. It also needed to be ground and sieved to make the particles uniform before activation. But in this case, the grinding and sieving were done for free, so no cost was added for that. The total cost to produce activated carbon was ₦72,500, which included ₦500 for charcoal, ₦5,000 for the activating chemical, ₦20,000 for greywater tests, ₦2,000 for heavy metal tests, and ₦45,000 for FTIR and SEM-EDS.

So, although activated carbon ended up being slightly cheaper in this case, the difference was mostly because biochar required a pyrolysis step (₦6,000), while charcoal didn't. If the pyrolysis could be done using a simple local method or free fuel like firewood, the cost of biochar could go down even more.

In conclusion, the cost table shows that activated carbon cost ₦72,500 to produce, while biochar cost ₦78,000. However, biochar still has a big advantage—it uses free, locally available waste and has fewer steps to prepare. This makes biochar a good low-cost option for treating greywater, especially in places where money and resources are limited.

## 4.6 Findings

The study revealed that both biochar and activated carbon significantly improved greywater quality by reducing electrical conductivity, total dissolved solids, and heavy metal concentrations. Activated carbon proved to be more effective in lowering turbidity, suspended solids, and heavy metals like iron, lead, and cadmium, due to its highly porous structure that enhances adsorption. Meanwhile, biochar excelled in reducing pH and effectively removing chloride, though it was less efficient in particulate removal compared to activated carbon. Experiments with different dosages (ranging from 0.1 g to 0.6 g per 20 mL of greywater) helped identify the optimal amount of adsorbent for the best performance. Despite both materials undergoing identical activation conditions with zinc chloride, biochar remained the more cost-effective option, as it is produced from inexpensive and readily available plantain peels using a simpler process. Characterization through Fourier Transform Infrared Spectroscopy (FTIR) and Scanning Electron Microscopy with Energy Dispersive Xray Spectroscopy (SEMEDS) confirmed the presence of functional groups and high carbon content in both media, with variations in surface structure influencing their adsorption performance. In conclusion, while activated carbon showed superior efficiency in removing particulates and heavy metals, biochar emerged as a sustainable and budget-friendly alternative, making the choice between the two depend on treatment objectives and economic factors.

## **CHAPTER FIVE**

### **CONCLUSION AND RECOMMENDATIONS**

#### **5.1 CONCLUSION**

In conclusion, the comparison between biochar and activated carbon for greywater treatment demonstrates that while both materials have distinct advantages, activated carbon is the more effective option. Activated carbon significantly improves water quality by reducing turbidity, suspended solids, and harmful heavy metals such as lead, iron, and cadmium, while also lowering electrical conductivity and total dissolved solids. These reductions contribute to clearer, safer water suitable for various applications, including drinking water and industrial effluent management. In contrast, biochar, although it performs well in removing chloride and magnesium, has limited efficacy in removing other contaminants and can even negatively impact water quality by increasing alkalinity and hardness. Therefore, for achieving optimal water purification, activated carbon is the recommended choice. Future efforts could focus on further enhancing biochar's performance through activation or chemical modification, which may provide a more cost-effective alternative in specific contexts. Ultimately, the choice of material should align with the specific water quality goals, cost constraints, and environmental sustainability considerations.

#### **5.2. RECOMMENDATIONS**

Based on the findings of this study, the following recommendations are made:

The study demonstrates that biochar and activated carbon can effectively treat greywater by significantly reducing turbidity, suspended solids, and heavy metals. However, certain

aspects require further improvement. While a dosage of 0.5 g has proven effective in achieving high pollutant removal, the reductions in nutrient levels and pH were modest, suggesting that these parameters need additional modifications. Future research should investigate whether 0.5 g is the minimum effective dosage or if lower amounts could still maintain performance, which would help reduce operational costs and minimize environmental impacts. Extending research to real-world treatment systems is vital for confirming the long-term effectiveness and practicality of these filter media. In-depth studies will help optimize the technology for sustainable and cost-effective greywater management.

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