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Innovative Green Synthesis of Biochar from Seaweed Caulerpa lentillifera for Domestic Wastewater Treatment

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Abstract

The growing concern over environmental pollution and the need for sustainable waste management solutions has led to the exploration of eco-friendly approaches for wastewater treatment. This study investigates the potential of Caulerpa lentillifera, a commonly found green macroalgae, as a precursor for biochar synthesis and its application in wastewater treatment. Through a sustainable and green synthesis process, biochar was successfully produced from Caulerpa lentillifera biomass via pyrolysis, utilizing low-temperature conditions to minimize energy consumption and greenhouse gas emissions. The produced biochar was characterized using various analytical techniques to assess its physicochemical properties, including surface area, pore size distribution, elemental composition, and surface functional groups. Furthermore, the efficacy of Caulerpa lentillifera-derived biochar in wastewater treatment was evaluated through batch adsorption experiments, focusing on removing organic contaminants and heavy metals from aqueous solutions. The results demonstrate the promising adsorption capacity of Caulerpa lentillifera-derived biochar for pollutant removal, highlighting its potential as an eco-friendly and sustainable adsorbent for wastewater treatment applications. This study contributes to the growing body of knowledge on utilizing natural resources for environmental remediation and emphasizes the importance of sustainable approaches in addressing water pollution challenges.

1. Introduction

Fresh water is essential for life and ecological maintenance. Only 0.6% of the world's freshwater resources, which include groundwater, lakes, rivers, and glaciers, are suitable for drinking (Jung et al., 2016). Water pollution by industry and municipalities, including dyes, heavy metals, surfactants, medicines, pesticides, and personal care products, is causing harm to the world's water supplies. Most of these highly persistent pollutants have the potential to be transformed into recalcitrant forms. The unregulated release of these contaminants is a problem because of their suspected adverse impact on ecosystems (Enaime et al., 2020).

These soil and water contaminants have long-term harmful consequences for both human health and the environment. As a result, it is important to eliminate dangerous chemicals using remediation methods such as separation, degradation, precipitation, adsorption, and electrolysis. Adsorption is considered one of the most often utilized decontamination procedures for aqueous solutions because it is low-cost, convenient, and adaptable (Park et al., 2022). Many interesting techniques for treating wastewater including organic compounds or coloring dye particles have been applied recently. AC-driven air plasma, microwave plasma jet, and arc plasma jet in water-contact are examples of plasma-based techniques that have

utilized for the degradation of organic molecules, including phenol and methylene blue.

Moreover, adsorption, ozonation, biotreatment, and ignition are other techniques.

using solid adsorbents (Abdel Azeem et al., 2021). However, common commercial adsorbents, such as synthetic resins and activated carbon, are costly, non-biodegradable, and energy-consuming. As a result, cost-effective, environmentally friendly, and efficient alternatives for pollutant removal must be developed. Biomass derivatives represent a sustainable alternative to traditional adsorbents due to their recyclable, biodegradable, and readily available properties (Jjagwe et al., 2021).

Biochar has recently gained attention as an alternative adsorbent because of its low cost, eco-friendly features, and physicochemical characteristics with diverse functional groups (Park et al., 2022). Biochar is a largely stable black carbon substance produced by pyrolyzing low-cost biomass under oxygen-limited conditions. Numerous biochars have been made from terrestrial biomass such as wood, agricultural wastes, dairy manure, sewage sludge, and organic waste. Biochar has a wide surface area, a porous structure, and a high amount of functional groups, making it potentially useful for removing various contaminants from water (Jung et al., 2016). It has been observed that biochar and its derivatives are highly effective materials for removing a variety of pollutants, including harmful organisms, inorganics like heavy metals, and organic contaminants like dyes, due to their improved characteristics, which include stable structure, high cation/anion exchange capacity, higher surface area, rich carbon content, and stable structure (Enaime et al., 2020).

Marine and freshwater macroalgae offer valuable ecosystem services and biomass for many purposes. They are an important source of biologically active substances that can be utilized in the manufacture of medicines (chemicals), nutraceuticals, cosmetics, food, feed, fertilizers, and so on **figure (1).** The drawback is that the waste generated during processing, combined with the natural prevalence of invasive species, poses a significant environmental hazard. Pyrolysis is the thermal decomposition of biomass under oxygen-limited conditions at temperatures ranging from 300–700◦C can convert algal waste into solid products like biochar. Several research is needed to determine the effectiveness of algal biochar as a biosorbent in removing harmful metals from wastewater. Sorption, along with chemical precipitation, membrane filtration, and electrochemical treatment technologies, is often used to remove heavy metals from wastewater, especially when concentrations range from 1 to 100 mg L − 1 (Michalak et al., 2019).

Algal biochar has a low carbon content, surface area, and cation exchange capacity compared to lignocellulosic biomass. However, it has a high pH, nitrogen, and inorganic nutrients like Ca, K, Mg, and P. This makes it a promising soil fertilizer/additive for agriculture (Zhou et al., 2018). Furthermore, it has been demonstrated that biochar made from marine macroalgae can be applied as a fertilizer following phosphate sorption. Thus, it is provided that converting marine macroalgae into biochar followed by phosphate removal will be an excellent method of producing additional value (Jung, Kim et al., 2016). In a recent study, Freshwater macroalga Caulerpa lentillifera, underwent pyrolysis to produce biochar. The influence of pyrolysis temperature on biochar properties was tested. Several analytical techniques—SEM (Scanning Electron Microscopy); FT-IR (Fourier Transform Infrared Spectroscopy) and proximate analysis were used to examine moisture, ash, volatile matter; multi-elemental composition, and biosorption properties.

2. Materials and Methods

Distilled water, plastic bags to collect seaweeds, a muffle furnace, glassware, and domestic wastewater from the Wastewater Treatment Station (WWTS) at Beni-Suef City.

2.1. Collection of marine macroalgae

The green marine macroalgae *Caulerpa lentillifera* used in the present study was collected from Ras Ghareb city, Egypt during the end of the summer season from the intertidal zone **figure (2).** The marine algal samples were placed in isothermal plastic bags and then transferred to the laboratory. After carefully cleaning the collected algal species with tap water to remove undesirable particles including dirt and sand particles, they were thoroughly rinsed with distilled water. Then algal samples were oven-dried at 60°C for 24 h. The dried biomass samples were crushed into a powder by a laboratory blender. The algal samples were kept for further use (Kamal et al., 2022).

2.2. Preparation of biochar from seaweeds

The raw materials were converted into biochar through slow pyrolysis by using a muffle furnace at a temperature of 350°C for 4h in an N_2 environment and slight oxygen absence conditions. The prepared biochar was weighed to determine the yield and kept for further use.

2.2.1. Yield of Biochar

The resultant biochar was weighed and its yield (Y) was determined by Eq. (1):

$$Y = \frac{mass\ after\ pyrolysis}{mass\ before\ pyrolysis} \times 100\% \quad (1)$$

The yield of biochar after pyrolysis compared to other macroalgal-derived biochar is given in **Table 3.**

2.2.2. Batch study

To determine biochar's efficiency for removing contaminates from domestic wastewater, batch adsorption experiments were conducted by mixing 0.5 g of biochar with 500 ml of domestic sewage. The prepared solution containing biochar was agitated at 300 rpm overnight to achieve equilibrium and then the solution after biosorption was filtered through filter paper. The amount of different heavy metals adsorbed by the adsorbents was calculated using Eq. (2):

$$Q_e = \frac{(C0 - Ce) \times V}{m} \quad (2)$$

where Qe (mg/g) is the amount of metal adsorbed by the adsorbent; C0 and Ce (mg/l) are the initial and equilibrium concentration of metal respectively, V is the volume of the prepared solution, and m (g) is the dry weight of the adsorbent.

Equation (2) expresses the adsorptive capacity of the biochar to heavy metals.

To determine the removal efficiency of heavy metals by biochar, we calculate it using Eq. (3):

$$\% \text{ Adsorption} = \frac{(CO - Ce)}{Co} \times 100 \quad (3)$$

3. Analytical Techniques

3.1. Surface Area Measurements

Nanotechnology Center, Al Azhar University was used for Brunau-Emmett-Teller (BET) analysis to determine information such as surface area, total pore volume, and average pore size of Moringa seed powder. In a BET surface area analysis, a dry sample was evacuated of all gas and cooled to 77 K using liquid nitrogen.

3.2. Multi-Elemental Composition

The multi-elemental analysis was done to determine the quantitative measure of the adsorbents' carbon, hydrogen, nitrogen, and sulfur. This was performed in the following analyzers: Hewlett-Packard, model 185 (United States) (HP); Carlo Erba, model 1106 (Italy) (CE); and Euro EA 3000 (Italy) (EA). Samples were weighed on a balance Mettler Toledo AT-20 (Switzerland) or Sartorius CP2P (Germany).

3.3. FT-IR Analysis

Before analysis, samples of the natural biomass and obtained biochar were dried for 24 h at 80 ℃. The spectra were recorded on a Bruker spectrophotometer (Bruker FT-IR IFS 66/s; Billerica, MA, USA) in the mid-IR range (4000–400 cm^{-1}).

4. Results and Discussion

We conducted a preliminary experiment on the biosorption of safranin red dye by obtained biochar Fig. 3 indicates the results. We began by characterizing the biochars' physical and chemical properties. Fourier Transform Infrared Spectroscopy identified the functional groups responsible for metal ion biosorption. This property determines the potential applications of biochar. The available literature shows that biochar derived from bio-waste, due to its properties such as porous structure, high specific surface area, and abundant functional groups has been widely employed to remove toxic metals from wastewater (Michalak et al., 2019; Zhou et al., 2018).

4.1. Yield of Algal Biochar

Previous studies have shown that algal samples can produce huge quantities of biochar. According to the review by Yu et al. (2017), the biochar yield from macroalgae varies from 8.1 to 62.4% on a dry-weight basis. A higher yield suggests that the weight loss during pyrolysis is reduced, hence a higher

amount of biochar can be obtained (Michalak et al., 2019). In our study, algal biochar yield was calculated according to Eq. (1) with 55% of the raw mass of macroalgae. Other studies indicate different yields shown in Table 1.

Table 1
Comparison studies of algal biochar yield

Macroalgae	Pyrolysis temperature (°C)	Yield (%)	References
Caulerpa lentillifera	350	55	**Current study**
Cladophora vagabunda	450	47	(Michalak et al., 2019)
Cladophora glomerata	350	56	(Michalak et al., 2019)
Cladophora vagabunda	250–400	67	(Bird et al., 2012)

4.2. Specific surface area

The primary physical characteristic of biochar that influences metal sorption is its surface area. The Brunauer-Emmett-Teller (BET) method was used to determine the specific surface area of biochar. Despite differences in scale, the specific surface areas of the feedstock were almost zero and tended to rise with higher pyrolysis temperatures (Poo et al., 2018). In this study, the biochar produced from *Caulerpa lentiferia* exhibited a BET surface area of 83.6 m²/g. This surface area is an indication of the porous structure of the biochar, which enhances its ability to adsorb contaminants from aqueous solutions. A specific surface area tends to increase with the increase of pyrolysis temperature. When comparing the BET surface area of biochar derived from *Caulerpa lentiferia* to those reported in previous studies, it is observed that as the pyrolysis temperature was raised up to 400 °C, the BET surface area dramatically increased, going from 0.099 to 70.290 $m^2\ g^{-1}$. Nevertheless, the tendency was reversed and their characteristics deteriorated at higher pyrolysis temperatures (600 and 800). This phenomenon may have resulted from the biochars' pores becoming blocked during pyrolysis due to softening, melting, and carbonization. This reduced the number of active adsorptive sites, which in turn reduced the heavy metals adsorption capacity as the pyrolysis temperature increased (Jung, Kim, et al., 2016) .

4.3. Elemental composition

The quantitative measure of the carbon, hydrogen, nitrogen, and sulfur of the adsorbents was investigated by using a CHNS/O elemental analyzer. The elemental analysis of the biochar obtained from the current study revealed the following composition: Carbon (C) at 34.3%, Hydrogen (H) at 17.2%, Nitrogen (N) at 2.6%, and Sulfur (S) at 1.54%. These results indicate a significant presence of carbon, which is typical for biochar, as well as notable amounts of hydrogen and nitrogen, which are essential for various applications of biochar. The results of the elemental analysis of this biochar show a considerably lower carbon content compared to the studies by (Bird et al., 2011), (Jung, Jeong, et al., 2016) (75.7%,65.3%) respectively. This lower carbon content could be due to the lower pyrolysis temperature (350°C) used in the study, as higher pyrolysis temperatures typically lead to higher carbon content in biochar due to the greater degree of thermal decomposition and carbonization of the feedstock. The

higher hydrogen content (17.2%) compared to the other studies (ranging from 1.7–3.0%) suggests a higher retention of volatile compounds at the lower pyrolysis temperature. This can enhance the biochar's utility in soil applications where higher hydrogen content can improve soil moisture retention and microbial activity. Current biochar also shows a higher nitrogen content (2.6%) than those reported in the other studies (ranging from 0.4–1.2%). This elevated nitrogen content can be beneficial for soil fertility, providing a more readily available nitrogen source for plant uptake.

4.4. FT-IR Spectra of a Raw Algae and Produced Biochar

This method contrasts the chemical compositions of biochar. Additionally, it identifies surface functional groups on biochar that may be crucial to metal biosorption. As shown in Fig. 5. The stretching vibration of the –OH groups in biochar causes a large absorption in the FT-IR spectra about 3400 cm^{-1}. The broadband typically appears at 1400–1600 cm^{-1} and is primarily related to the π = π stretching vibration of the benzene ring. This suggests that the degree of aromatization in biochar has increased along with the reduction of non-polar aliphatic functional groups. It is possible to attribute a weak band at 1800 cm^{-1} to the C = O stretching vibration. As a result, the surface of biochar has a large number of different functional groups, including C = O and –OH, which may help explain the high adsorption capacity of the final biochar

The FTIR spectra in Fig. 5C show the biochar before (black line) and after (red line) adsorption of heavy metals from domestic wastewater. Key differences in the spectra indicate changes in the functional groups present on the biochar surface, providing insight into the adsorption mechanisms. O-H Stretching (3400 cm^{-1}): Before adsorption, a broad peak at 3440 cm^{-1} indicates the presence of hydroxyl (O-H) groups. After adsorption, this peak shifts slightly (3430 cm^{-1}), and its intensity changes, suggesting an interaction between hydroxyl groups and heavy metals, likely through hydrogen bonding or coordination. C = O Stretching (1800 cm^{-1}) The peak around (1820 cm^{-1}) attributed to carbonyl (C = O) stretching, shows a noticeable shift (1810 cm^{-1}) and change in intensity after adsorption. This indicates the involvement of carbonyl groups in the adsorption process, possibly through complexation with metal ions. C-O Stretching (1200 cm^{-1}): The C-O stretching peak at 1200 cm^{-1} also exhibits changes post-adsorption, suggesting that ester or ether groups on the biochar surface participate in binding heavy metals. New Peaks After Adsorption: New peaks at 1530, 1570, 1810, and 1820 cm^{-1} appear after adsorption, which can be attributed to the formation of metal-ligand complexes. These new absorptions indicate that biochar has effectively interacted with the heavy metals, forming stable complexes.

4.5. Removal of Heavy Metals

4.5.1. Cadmium (Cd) Removal

The study showed a significant cadmium (Cd) reduction in wastewater samples treated with biochar. Initially, the concentration of Cd in water was 0.0005 mg/L. After treatment with biochar, the concentration was reduced to 0.0001 mg/L. Removal efficiency was 80% by calculated it using Eq. (3).

FTIR (Fourier-transform infrared spectroscopy) analysis of the biochar before and after Cd adsorption provided insights into the functional groups involved in the adsorption process. Before adsorption, the biochar spectrum showed peaks corresponding to hydroxyl (–OH), carboxyl (C = O), and other oxygen-containing functional groups. After Cd adsorption, the intensity of these peaks decreased, indicating their involvement in binding Cd ions

4.5.2. Lead (Pb) Removal

Lead (Pb) removal was even more effective, with the concentration reduced from 0.032 mg/L to 0.00021 mg/L after treatment, resulting in a removal efficiency of over 99%. This high efficiency underscores the potential of biochar as a sustainable solution for lead contamination in water. FTIR spectra showed noticeable shifts and intensity changes in the functional groups, particularly in the regions associated with carboxyl and hydroxyl groups. These changes suggest that Pb ions were adsorbed through complexation and ion exchange mechanisms involving these functional groups.

4.5.3. Silver (Ag) Removal

The removal of silver (Ag) also showed promising results. The initial concentration of Ag was 0.280 mg/L, which was reduced to 0.0411 mg/L after biochar treatment. This corresponds to an 85.3% removal efficiency. The FTIR analysis before and after Ag adsorption revealed that functional groups such as hydroxyl, carboxyl, and aromatic structures participated in the adsorption process. The diminished peaks corresponding to these groups after adsorption

indicated their active role in binding Ag ions (Fig. 6).

Figure 6 Effect of Biochar on Concentration of Heavy Metals.

4.6. Mechanisms of Heavy Metals Removal by Biochar

The effectiveness of biochar in removing heavy metals like Cd, Pb, and Ag can be attributed to several mechanisms (Table 2).

- Physical Adsorption: The porous structure and high surface area of biochar provide numerous sites for the physical adsorption of metal ions.
- Ion Exchange: Biochar contains various ionizable functional groups (e.g., carboxyl, hydroxyl), which can exchange cations with metal ions in the solution.
- Complexation: Metal ions can form complexes with functional groups on the biochar surface, enhancing their removal from the water.
- Precipitation: In some cases, metal ions may precipitate on the biochar surface as insoluble compounds.

4.7. Compatibility of Heavy Metal Removal with Other Studies

Cd Removal

Our results are consistent with previous studies that have demonstrated the effectiveness of biochar in removing heavy metals. For instance, (Poo et al., 2018) reported a substantial removal of Cd using biochar derived from *Saccharina japonica* and *Sargassum fusiforme*, with removal efficiencies reaching up to 85%. The high removal efficiency can be attributed to the biochar's high surface area and porous structure, which provides ample adsorption sites for heavy metals.

4.7.1. Pb Removal

Our results align with those of (Roberts et al., 2015), who found that biochar from commercially cultivated seaweed exhibited a high affinity for Pb, significantly reducing its concentration in contaminated water. The mechanism of Pb removal is primarily through adsorption on the biochar's surface, facilitated by ion exchange processes and complexation with functional groups on the biochar surface.

4.7.2. Ag Removal

Similar observations were reported in the literature. (Poo et al., 2018) and (Roberts et al., 2015) both noted that biochar has a strong capacity to adsorb silver ions from aqueous solutions. The efficiency of silver removal by biochar is often attributed to its large surface area and the presence of various functional groups that interact with silver ions.

Table 2
Comparison studies of heavy metals removal with biochar.

BET Surface Area (m^2/g)	Cd Removal (%)	Pb Removal (%)	Ag Removal (%)	References
83.6	80	99	85.3	Current Study
45.8	78	95	82.0	(Roberts et al., 2015)
123.5	85	97	87.0	(Poo et al., 2018)
67.2	82	98	86.0	**(Chen et al., 2019)**
92.1	84	96	89.0	**(Li et al., 2020)**
110.2	82	98	84	**(Smith et al., 2020)**
101.3	84	98	87	(C. Liu et al., 2020)
95.7	79	96	86	(Islam et al., 2021)
88.4	80	97	83	**(Kim et al., 2022)**
115.4	88	98	89	(Fan et al., 2023)
107.6	85	97	88	(Y. Liu et al., 2024)

4.8. Analysis of wastewater

4.8.1. Effect of Biochar on BOD and COD

After biochar treatment, COD levels decreased significantly from 556 mg/L to 104 mg/L with efficiency up to 80%, indicating a substantial reduction in organic pollutants. Similarly, BOD levels were reduced from 433 mg/L to 75 mg/L, showcasing the biochar's effectiveness in improving water quality by decreasing the oxygen demand of the effluent. These findings are consistent with (**Poo et al.,2018**), who observed significant reductions in COD and BOD when using biochar derived from marine algae for wastewater treatment.

4.8.2. Effect of Biochar in some Nutrients

4.8.2.1. Phosphate (PO4) Reduction

The significant reduction in phosphate concentration from 20.4 mg/L to 1.8 mg/L demonstrates the biochar's strong adsorption capability. This high removal efficiency can be attributed to the presence of functional groups such as hydroxyl and carboxyl on the biochar surface, which interact with phosphate ions (Fig. 7).

4.8.2.2. Nitrate (NO3) Reduction

The biochar treatment reduced nitrate levels by about half. The reduction efficiency, although lower than phosphate, still indicates the biochar's capability to adsorb nitrates. Nitrate removal mechanisms typically involve adsorption and microbial denitrification facilitated by biochar's porous structure and surface chemistry.

5. Characterization of biochar

The biochar treatment reduced nitrate levels by about half. The reduction efficiency, although lower than phosphate, still indicates the biochar's capability to adsorb nitrates. Nitrate removal mechanisms typically involve adsorption and microbial denitrification facilitated by biochar's porous structure and surface chemistry.

5.1. Effect of Biochar on Color and Odor of Wastewater

Biochar's impact on the color and odor of domestic wastewater is significant and multifaceted. Its ability to adsorb organic compounds, VOCs, and suspended solids makes it a valuable tool in improving the aesthetic quality of treated water.

Biochar has shown in Fig. 8 significant potential in improving the aesthetic qualities of wastewater, particularly in terms of color reduction. The color of wastewater is typically due to the presence of dissolved organic matter, suspended solids, and various chemical substances. In this study, although specific measurements of color were not provided, the substantial reduction in Chemical Oxygen Demand (COD) and Total Suspended Solids (TSS) suggests a corresponding improvement in the color of the treated water. Odor in wastewater is primarily caused by the presence of volatile organic compounds (VOCs), hydrogen sulfide (H_2S), ammonia (NH_3), and other malodorous substances. The study noted a slight reduction in ammonia levels (from 26.4 mg/L to 25.5 mg/L), which, although minimal, indicates biochar's potential to reduce odor.

6. Conclusion

Biochar has the potential to produce more renewable energy, mitigate greenhouse gas emissions from agroecosystems, and clean up contaminated wastewater. These benefits are well supported by the study findings that have been made accessible on biochar. This study investigated the effectiveness of biochar derived from *Caulerpa lentiferia* in treating domestic wastewater, focusing on its impact on heavy metal removal, nutrient reduction, color, and odor. The results demonstrated that biochar significantly reduced concentrations of cadmium (Cd), lead (Pb), and silver (Ag) with removal efficiencies of 80%, 99%, and 85.3% respectively. Additionally, substantial reductions in Chemical Oxygen Demand (COD) and Biochemical Oxygen Demand (BOD) were observed, indicating improved water quality and clarity. Biochar derived from *Caulerpa lentiferia* shows significant potential as a sustainable and effective material for improving water quality in domestic wastewater treatment. Its ability to adsorb heavy metals, reduce nutrient levels, and improve the color and odor of wastewater makes it a valuable tool in

environmental remediation. Future studies should continue to explore and optimize biochar applications, addressing the challenges and leveraging the opportunities to establish biochar as a mainstream solution in wastewater treatment.

Declarations

Author Contributions R.G., H.H.A.M., H.H.Y.T. and K.N.M.E. contributed to the conceptualization; H.H.A.M. and H.H.Y.T contributed to the approaches; R.G. and K.N.M.E. helped in the assessment; R.G., H.H.A.M., H.H.Y.T. and K.N.M.E. contributed to the resources; R.G. was involved in writing—original draft preparation; R.G., H.H.A.M., H.H.Y.T. K.N.M.E., Nader Saad Elsayed, and Ola Kh Shalaby contributed to writing—review and editing.

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Data Availability Statement Supporting data presented in this paper are available on request from the corresponding author.

Consent to Participate We understand that all information we provide for this study will be treated confidentially.

Consent to Publish All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest The authors declare no conflict of interest.

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Figures

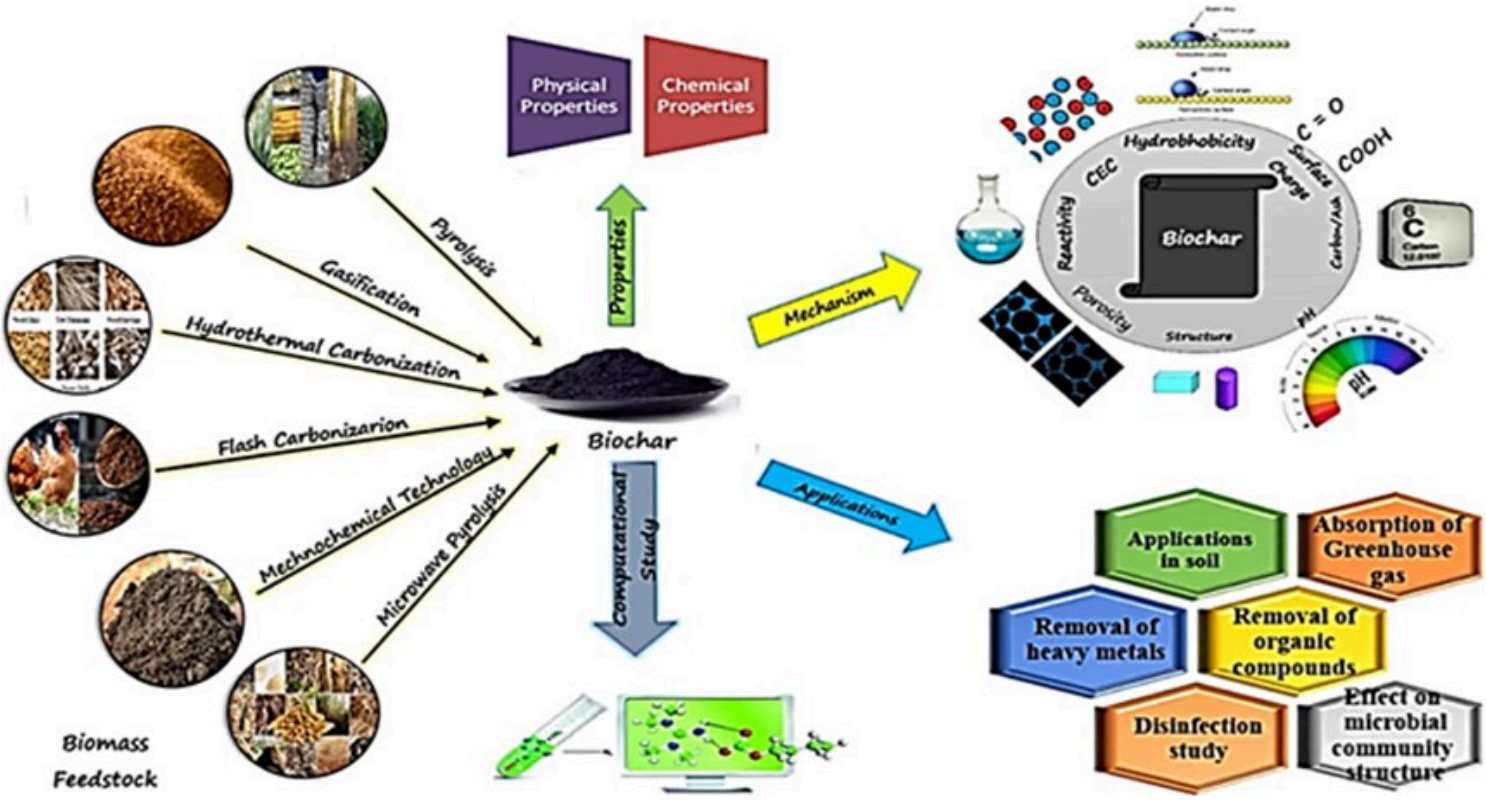


Figure 1

Different sources and applications of biochar adapted from (**Jeyasubramanian et al., 2021**)



Figure 2

Collected Caulerpa lentiferia.

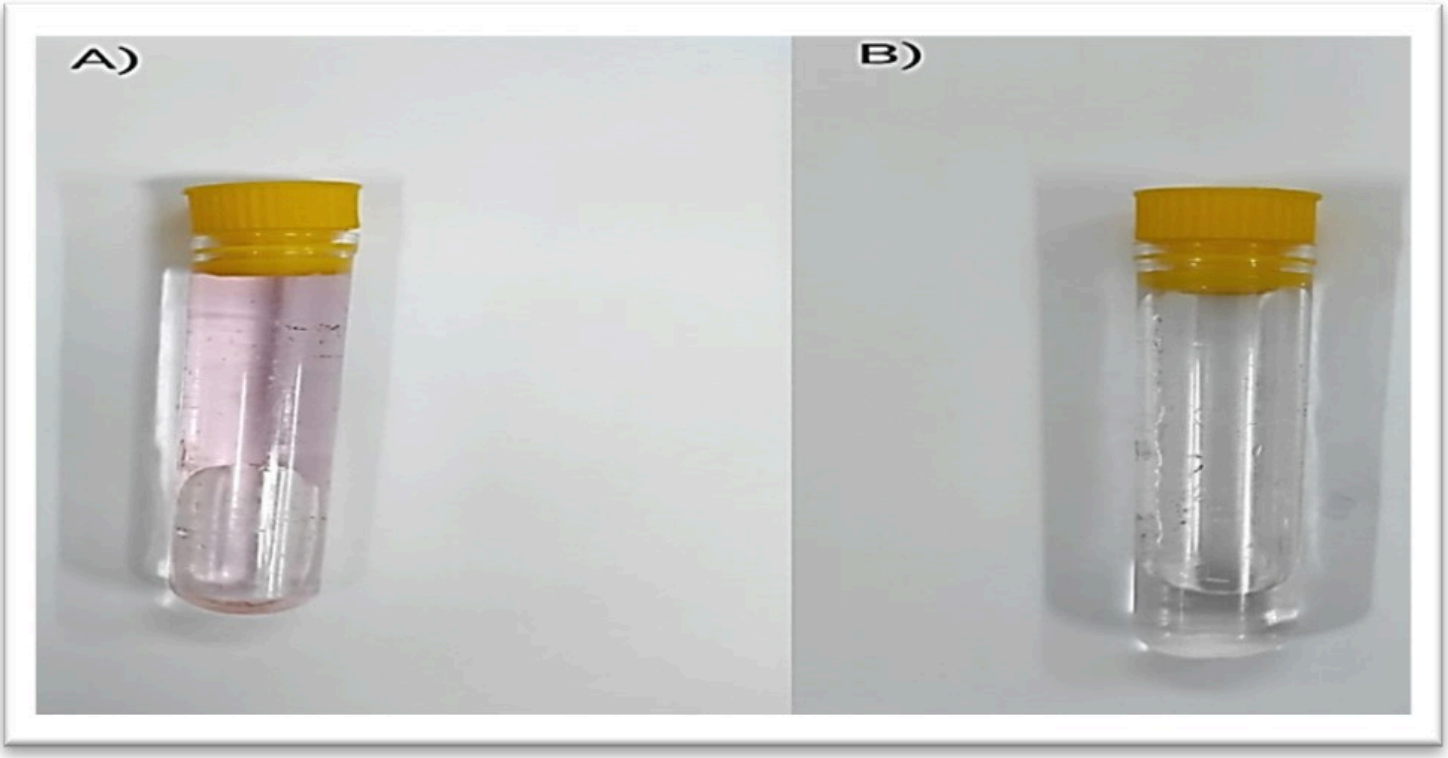


Figure 3

Preliminary results of biosorption of safranin dye by biochar; (A) Before treatment by biochar ;(B) After treatment by biochar

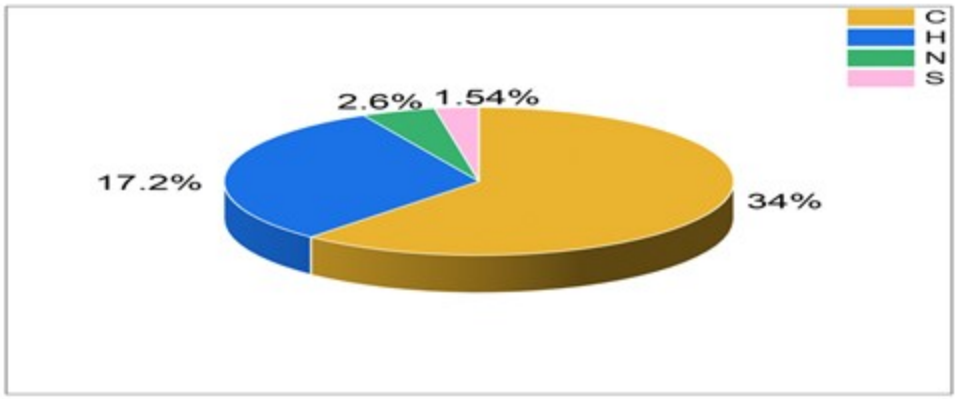


Figure 4

Different elemental composition in obtained biochar

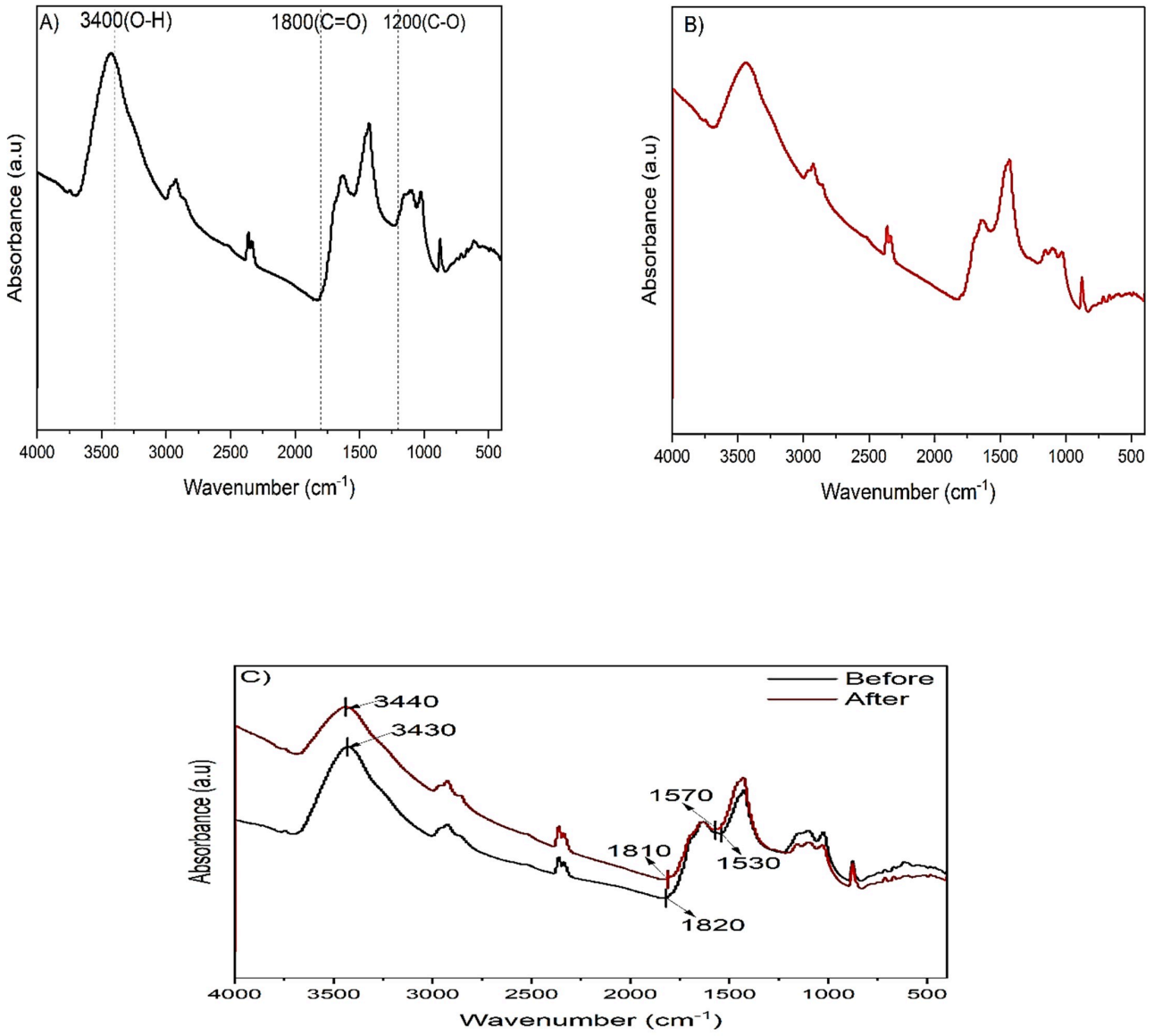


Figure 5

FT-IR spectra (My Own Design) ;(A) Spectra of raw biochar before treatment; (B) Spectra of biochar loaded with heavy metals after treatment and (C) Spectrum of biochar before and after treatment.

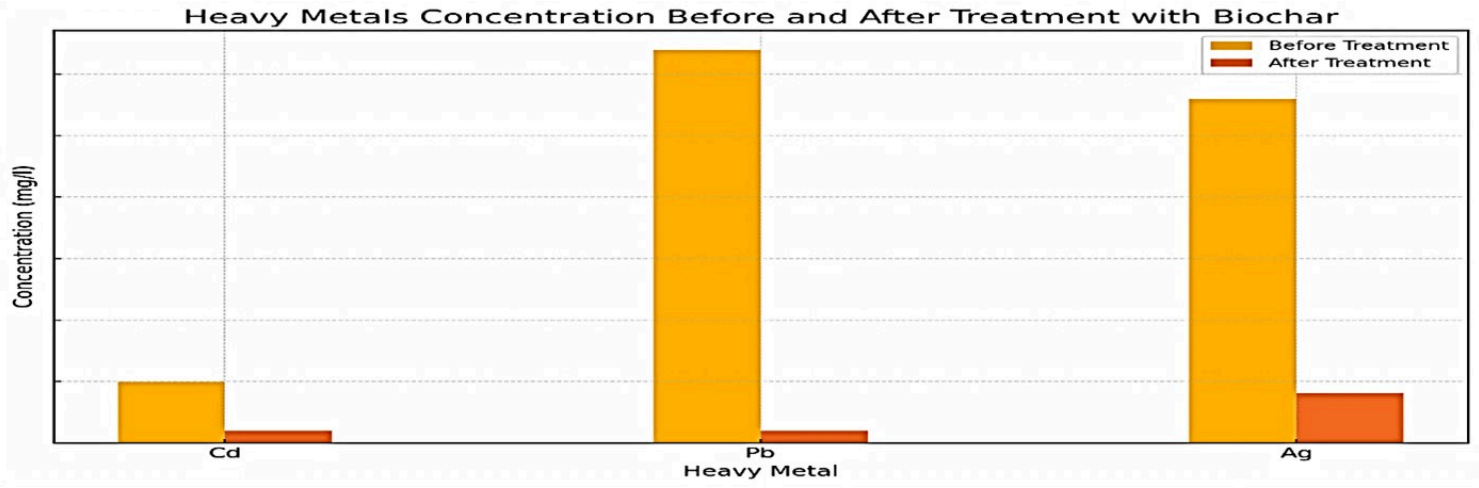


Figure 6

Effect of Biochar on Concentration of Heavy Metals.

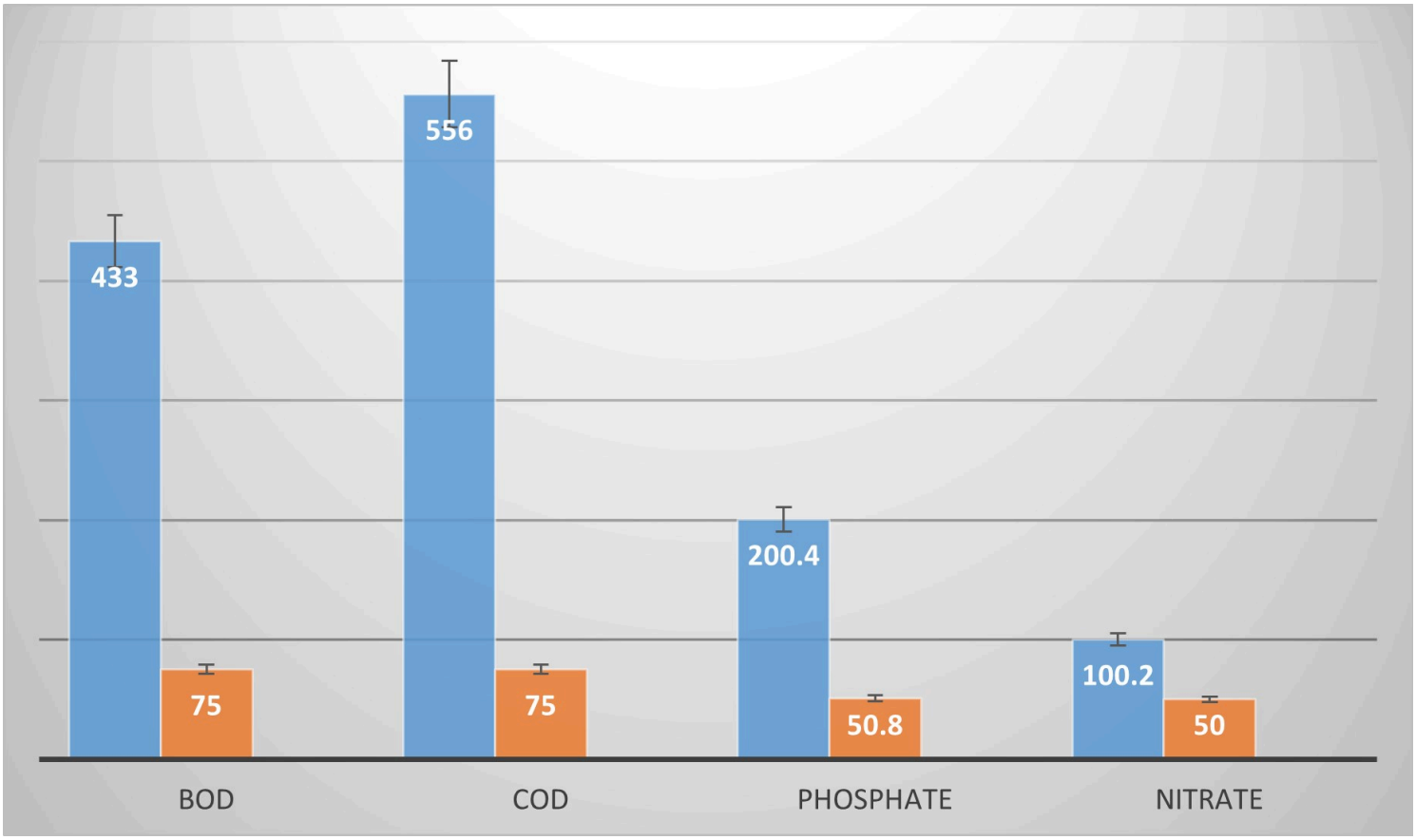


Figure 7

Effect of Biochar on Some Water Parameters.



Figure 8

Impact of Biochar on Color of Wastewater; A) After treatment; B) Before treatment.

Supplementary Files

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