Development of Biofilter Using a Biochar from Pericarp of Durian, Mangosteen, and Banana in Reducing Nickel Concentration in Wastewater

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Abstract: *Disposing of agricultural waste like durian husk, mangosteen shell, and banana peel is a global issue, overwhelming landfills and harming the environment. In the Philippines, where these tropical fruits are abundant, mismanagement exacerbates waste problems. However, the physical and chemical properties of these wastes make them ideal for adsorbing heavy metals. This study aimed to convert durian husk, mangosteen shell, and banana peel into biochar and use them as biofilters to reduce nickel concentrations in wastewater. Four filtration treatments were tested: one without biochar and three with different biochar. Results showed that durian husk biochar, mangosteen shell biochar, and banana peel biochar achieved average reduction efficiencies of 93.89%, 88.33%, and 86.11%, respectively. These findings indicate that biochar derived from these agricultural wastes can effectively reduce heavy metal concentrations, offering a sustainable solution to waste management and environmental pollution.*

Keywords: Durian Husk, Mangosteen Shell, Banana Peel, Biochar, Nickel

1. INTRODUCTION

Water quality is one of the biggest issues today, threatening public health, agriculture, and economic development [1]. Poor water quality impacts social, economic, and environmental aspects of life. Massive amounts of untreated wastewater are dumped into rivers, lakes, and coastal areas, contaminating our limited freshwater resources. New contaminants like pesticides, industrial chemicals, pharmaceuticals, personal care products, and climate change are also emerging threats to water quality.

The escalating global concern over heavy metal contamination and environmental pollution has significantly propelled the scientific community to investigate this critical issue [2] [3]. The rapid pace of industrialization and economic development has led to the accelerated release of various heavy metals from multiple sources [4]. These metals are often reported as persistent and highly toxic to living organisms, particularly when their concentrations surpass permissible thresholds. Contaminated water poses severe health risks and contributes to waterborne diseases; however, these issues can be mitigated through preventative measures implemented at the household level.

Soil and water quality are pivotal for agricultural output, food security, and ecosystem health. They play a crucial role in supporting the growth and development of organisms within an ecosystem. Given their importance for human, animal, and industrial uses such as irrigation, safeguarding and managing these resources is essential. Biosorption emerges as a promising method for mitigating heavy metal contamination due to its cost-effectiveness and environmental benefits. This technique utilizes biomasses like agricultural waste, forest wood, and sewage sludge. For example, durian husk, a major agricultural waste, can become an environmental hazard if improperly disposed of, with an average of 255,353 MT of durian fruit produced annually [5]. Employing durian husk as an adsorbent could enhance water quality. Similarly, banana peels, accounting for approximately 35% of the banana's weight, create 3.5 million tons of waste per year, contributing to greenhouse gas emissions and prolonged degradation. Mangosteen peels, generating about 30.8 million tons globally each year, present a disposal problem due to their slow fermentation and unpleasant odor [6] [7].

Durian husk, mangosteen shells, and banana peels have demonstrated considerable potential for pollutant removal from water. According to [8], durian husks are effective in removing heavy metal ions due to their high carbon content and porous structure. Mangosteen shells have been found to efficiently remove phenol from wastewater, as reported by [9]. Additionally, banana peels exhibit significant adsorption capacity for organic dyes in wastewater, attributable to their content of cellulose, hemicellulose, and lignin [10]. Furthermore, banana peel biochar has shown efficacy in removing heavy metals from contaminated water, owing to its high carbon content and surface area [11]. These natural materials offer promising, cost-effective, and environmentally friendly solutions for addressing water and waste pollution.

This study aims to provide valuable insights into the effectiveness of adsorbents derived from durian husk, banana peel, and mangosteen shell and to support the development of sustainable and eco-friendly technologies tailored to the needs of nickel (Ni) mining communities.

2. MATERIALS AND METHODS

Figure 1 details the process of producing biochar from durian husk, mangosteen shell, and banana peel. This process is pivotal in defining the biochar’s properties, which influence its efficiency in nickel removal from wastewater. The figure also includes the filtration design, medium preparation, sample collection, initial and final concentrations, and the filtration procedure.

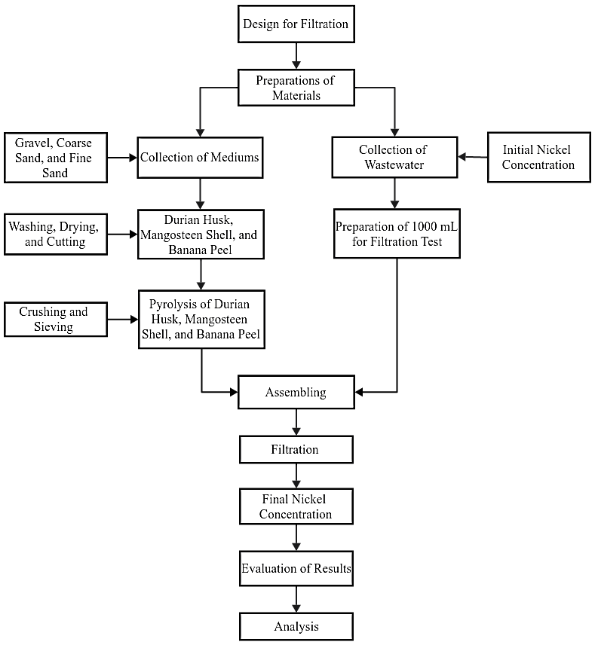

Fig. 1. General framework of the study.

2.1 Research design

This study utilized a completely randomized design (CRD) to assess the Ni removal effectiveness of durian husk biochar (DHB), mangosteen shell biochar (MSB), and banana peel biochar (BSB) on wastewater samples collected from Agatha Mining Ventures, Inc. CRD ensured unbiased treatment assignment, where each wastewater sample had an equal chance of receiving any of the biochar (treatments) or being included in the control group (untreated). The control group serves as a baseline for nickel concentration, allowing us to isolate the impact of the biochar treatments on nickel removal when compared to the treated samples.

The experiment was conducted at a laboratory temperature of 25°C. Four treatments included DHB, MSB, BPB, and a control group with no biochar amendment. Each treatment was replicated three times for a total of twelve (n=12) experimental units. Microsoft Excel was used to generate random numbers for each experimental unit. These random numbers were then ranked, and the corresponding rank was assigned. Table 4 showed the experimental layout where (A) was the control group, (B) was the DSB, (C) was the MSB, and (D) was the BPB. The number after the letter denotation represented the replication of the treatment.

Table 1. Randomized treatment assignment for biochar filtration.

Run	Treatment	Run	Treatment
1	C2	7	A3
2	A1	8	D3
3	C1	9	B2
4	B1	10	D1
5	C3	11	A2
6	D2	12	B3

The concentration level of Ni reduction efficiency was measured in percentage (%) by taking the difference between the result before the treatment and the result after the treatment and dividing the result before the treatment multiplied by hundred as shown in the equation below.

$$\%\ Reduction\ Efficiency = \frac{C_i - C_f}{C_i} \times 100 \qquad \text{[Eq. 1]}$$

Where C_i and C_f are the initial and final concentration of Ni in mg/L, respectively.

2.2 Preparation and collection of waste materials

Durian husk, mangosteen shells, and banana peels were collected at Langihan Road Supermarket, Butuan City, Agusan del Norte. The collected durian husk was fully ripe, the mangosteen shell had deep purple, and the banana peel was ripe. The collected waste materials were rinsed with tap water several times until the water was clear. This step was performed to remove any dirt, debris, odor, or impurities that may be present on the surface of the durian husk, mangosteen shell, and banana peel. After cleaning, the durian shell, mangosteen shell, and banana peel were sun-dried and air-dried for 63 hours. The purpose of drying is to evaporate any remaining water on the surface or within the pores of the durian husk, mangosteen shell, and banana peel.

2.3 Pyrolysis of DHB, MSB, and BPB

The dried durian husk, mangosteen shell, and banana peel were subjected to pyrolysis, a thermochemical process where organic materials are decomposed by heat in the absence of oxygen. This process transforms the starting materials into biochar, the final product of interest in this study.

In this experiment, a traditional pyrolysis method was employed. The dried materials were placed in a closed drum with a limited number of small holes. This restricted air/oxygen flow within the drum, promoting the desired oxygen-depleted environment for pyrolysis. The drum was then positioned in the soil and externally heated using a fire for two (2) hours.

After pyrolysis, the resulting biochar (pyrolyzed durian husk, banana peel, and mangosteen peel) was left inside the drum to cool down. This cooling step allows safe handling of the biochar before further processing. The cooled biochar was then crushed and sieved through a 0.50 mm mesh to obtain a uniform particle size fraction. Selecting a smaller particle size aligns with findings by Liao and Thomas [12], who reported that biochar with a particle size range of 0.15-0.50 mm exhibited higher removal rates of heavy metals. For each treatment sample, 177 g of pyrolyzed biochar was used to achieve the depth required for the study.

2.4 Collection and processing of wastewater sample

Wastewater samples were collected in AMVI at exactly 11 am on a sunny day. The researcher used three 6-liter polyethylene (PET) bottles. The PET bottle was sterilized thoroughly and safe for contamination. The tip of the bottle was placed 2 inches below the surface water. The collected wastewater samples from the settling pond were stored in cold storage and were sent to Davao Analytical Laboratories, Inc. (DALC). for water analysis to determine the initial Ni concentration.

2.5 Preparation of biofilter

The incorporation of multiple layers, including gravel, coarse sand, biochar, and fine sand, in filtration systems has been widely studied due to its effectiveness in water treatment and pollutant removal. Gravel, as the initial layer in the filtration sequence, plays a crucial role in providing structural support and facilitating uniform distribution of water flow. Studies have demonstrated that gravel enhances hydraulic conductivity and prevents clogging by allowing water to pass through freely, thus reducing the risk of channeling and ensuring efficient filtration [13].

Coarse sand, the subsequent layer in the filtration system, further enhances filtration efficiency by trapping larger particles and promoting the removal of sediment and debris. Research has shown that coarse sand effectively removes suspended solids and enhances water quality by reducing turbidity and sediment load [14]. Its larger particle size allows for greater porosity and permeability, enabling the effective filtration of water while minimizing hydraulic resistance and pressure drop across the filtration media [15].

Biochar, derived from the pyrolysis of organic materials such as agricultural waste, serves as a highly efficient adsorbent in filtration systems due to its high surface area, porous structure, and abundant functional groups. Studies have demonstrated that biochar effectively removes contaminants such as heavy metals, organic compounds, and nutrients from water through mechanisms such as adsorption, ion exchange, and complexation [16]. Its use in filtration systems offers sustainable and cost-effective solutions for water treatment, with potential applications in stormwater management, agricultural runoff control, and industrial wastewater treatment [17].

Fine sand, as the final layer in the filtration sequence, provides the last line of defense in removing finer particles and further improving water quality. Studies have shown that fine sand effectively traps fine sediments, pathogens, and colloidal particles, resulting in cleaner and clearer water [18]. Its smaller particle size allows for finer filtration, ensuring the removal of residual contaminants and achieving the desired water quality standards.

The use of gravel, coarse sand, biochar, and fine sand in filtration systems offers a comprehensive approach to water treatment, combining physical filtration, adsorption, and biological processes to achieve effective pollutant removal and water purification. These materials provide distinct advantages in terms of structural support, particle trapping, contaminant adsorption, and fine filtration, making them essential components in the design and operation of filtration systems for various applications [19].

Based on the study by Koivusalo, et. al. [20], a biochar-sand filtration system with biochar and sand layers each at a depth of 3 inches was evaluated for its effectiveness in treating stormwater runoff. The research demonstrated significant reductions in pollutants such as heavy metals, suspended solids, and nutrients, highlighting the potential of biochar-sand filters for mitigating urban stormwater pollution

A study by Siwila [21] and Kepa [22] emphasized the role of inlet dimensions in ensuring uniform flow distribution and minimizing hydraulic inefficiencies within filtration media. They also include that the space for a water inlet in a filtration system depends on various factors such as the flow rate, the size and type of filtration media, and the intended purpose of the system.

In this study, the filtration column was made using the clear polyvinyl chloride (PVC) pipe with a length of 325 mm, an outer diameter of 90 mm, and 84 mm of inner diameter. The filter was composed of porous materials: gravel, coarse sand, generated biochar, and fine sand as shown in Figure 2. Utilizing a range of filtration materials like gravel prevents blockages by maintaining open spaces, coarse sand stops and trapping larger particles, biochar as a biofilter to reduce the target heavy metal, and fine sand that can capture smaller particles. This helps in improving the effectiveness and sustainability of filtration procedures.

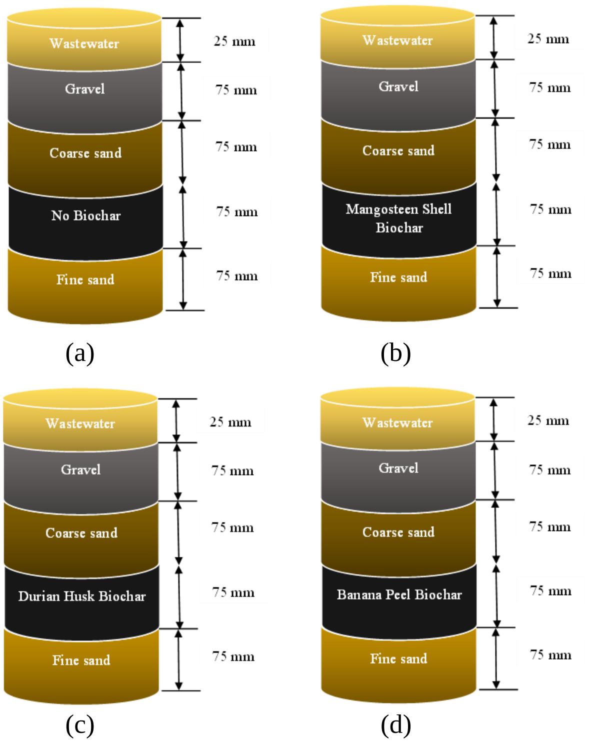

Fig. 2. Schematic of the biofilter using different biochar: (a) no biochar, (b) MSB, (c) DHB, and (d) BPB.

2.6 Statistical analysis

Following biofiltration treatment with DHB, MSB, and BSB, the Ni concentration remaining in the treated wastewater samples was analyzed using a one-way analysis of variance (ANOVA). ANOVA is a statistical test used to compare the means of three or more groups (treatments in this case – DHB, MSB, BSB) and assess if there are statistically significant differences in Ni removal efficiency among the biochar. If the ANOVA indicates a statistically significant overall difference ($p < 0.05$) in nickel removal efficiency among the biochars, post-hoc tests will be employed to identify which specific biochar treatments differ from each other. One appropriate post-hoc test for multiple comparisons following a one-way ANOVA is Tukey's Honestly Significant Difference (HSD) test. This test allowed for the determination of which biochar treatment(s) were statistically more effective in removing nickel from the wastewater compared to the others.

3. RESULTS AND DISCUSSIONS

The traditional pyrolysis method was employed to generate biochar from durian husk, mangosteen husk, and banana peel, providing a sustainable solution for managing agricultural waste. Through this process, organic material was heated in the absence of oxygen, resulting in the decomposition of biomass and the production of a carbon-rich substance known as biochar. Despite its simplicity, traditional pyrolysis offers practical advantages for converting these agricultural residues into valuable biochar, which can be utilized for various applications including soil amendment, and pollutant removal. However, it's important to note that the properties of biochar produced via traditional pyrolysis may vary depending on factors such as temperature, residence time, and feedstock composition, potentially influencing its effectiveness in specific applications like heavy metal adsorption in wastewater treatment. This study did not conduct post-treatments after the biochar was produced due to limitation in time and resources.

3.1 Ni concentration of untreated and treated wastewater samples

The study aimed to treat Agata Mining Venture Inc. wastewater samples using DHB, MSB, and BPB. The untreated and treated wastewater samples were sent to DALC for Ni concentration analysis. The laboratory utilized SMEWW 320B in determining the initial and final nickel concentration of the wastewater sample. Table 2 and 3 showed the initial and final Ni concentration result from the laboratory, respectively.

Table 2. Ni concentration of untreated wastewater sample

Method	Element	Concentration (mg/L)
SMEWW 320B	Ni	0.18

Table 3. Average Ni concentration of treated wastewater sample for each treatment

Treatment	Concentration (mg/L)
A	0.039
B	0.021
C	0.011
D	0.025

The findings clearly show that the biochar derived from durian husks, mangosteen peels, and banana peels has reduced the amount of nickel in the wastewater sample from AMVI. When comparing the treated samples to the untreated wastewater, the average concentration of nickel dropped considerably.

The average concentration of untreated wastewater sample was 0.18 mg/L. The experiment revealed that the concentrations of nickel varied among the different treatments. Treatment C containing the (DHB) showed the lowest concentration at an average of 0.011 mg/L, indicating it's good at reducing the nickel. Treatment B with (MBSB) followed closely with a concentration of 0.021 mg/L, which is still relatively low. Treatment D with (BPB) had a concentration of 0.025 mg/L, indicating a decent reduction compared to treatment A with no biochar, which had the highest concentration at an average of 0.039 mg/L. This shows that there are differences in how well each treatment reduces the nickel, with treatment C being particularly effective.

3.2 Reduction efficiency of biochar

The reduction efficiency serves as a quantitative measure to assess the effectiveness of each filtration column in reducing the concentration of nickel. It typically compares the initial concentration with the final concentration after treatment or filtration. The mean reduction efficiency for treatments A, B, C, and D is shown in Figure 3.

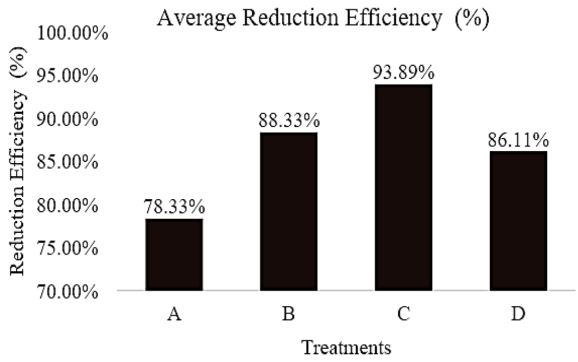

Fig. 3. Average reduction efficiency of different biochar treatments

Based on the data, indicates varying levels of efficiency across the different treatments. Treatment C exhibited the highest efficiency with an average of 93.89%, showing its effectiveness in reducing the nickel concentration. Following closely is treatment B with an efficiency of 88.33%, indicating a considerable but slightly lower performance compared to treatment C. Treatment D shows an efficiency of 86.11%, showing it's also effective but slightly less than treatment B and C. Treatment A recorded the lowest efficiency with an average of 78.33%, indicating that it was less effective in reducing the nickel compared to the other treatments. These findings highlight differences in the performance of the treatments and the importance of selecting the most efficient treatments.

3.3 Statistical analysis of results using One-way ANOVA

In this study, one-way ANOVA was used to determine if there was a statistical difference among the groups. The researchers were interested to see if there was a difference among the treatments with different types of derived biochar with the controlled treatment without biochar in treating the wastewater samples from AMVI. One-way ANOVA is a statistical method used to compare the means of three or more independent groups to determine if there are statistically significant differences between them. The test for equality of variances was done using JASP software. The results showed that the p-value of 0.149 indicates there was an equality of variances and it indicates that the data are normally distributed as shown in Table 4.

Table 4. Result for the equality of variance test (Levene's Test)

F	df1	df2	p
2.438	3.000	8.000	0.149

In this case, one-way ANOVA was performed as a parametric statistical technique to test if there is a significant difference among the data as shown in Table 5.

Table 5. One-way ANOVA analysis for different biochar treatments

Cases	Sum of Squares	df	Mean Square	F	p
Group	363.8	3	121.267	0.524	0.678
Residuals	1850.0	8	231.336		

One-way ANOVA did not reveal statistically significant differences ($p > 0.05$) in nickel concentration between the untreated and biochar-treated wastewater samples. While these results suggest that the biochar treatments may not have a substantial impact on nickel removal at the tested concentrations, further research with a larger sample size and a wider range of initial nickel concentrations is warranted. Additionally, investigating the specific properties of each biochar type (e.g., surface area, pore size distribution) could provide valuable insights into potential adsorption mechanisms and explain the observed trends in nickel removal efficiency.

This study employed a traditional pyrolysis method for biochar preparation. While this approach offers a practical advantage, it may not have yielded biochar with the most suitable properties for nickel removal. Traditional methods often lack precise control over pyrolysis parameters like temperature and residence time, which can significantly impact biochar properties like surface area and porosity, both of which are crucial factors influencing metal adsorption capacity. This limitation might partially explain the absence of statistically significant differences in nickel removal efficiency between the biochar treatments. Future research could explore the optimization of pyrolysis parameters to create biochar with tailored properties for enhanced nickel removal from wastewater.

4. CONCLUSION

This study investigated the application of durian husk biochar (DHB), mangosteen shell biochar (MSB), and banana peel biochar (BPB) for nickel removal from wastewater collected from Agata Mining Venture Inc. (AMVI). All biochar treatments resulted in a decrease in nickel concentration, with durian shell biochar exhibiting the highest reduction efficiency (93.89%). These findings suggest that this biochar holds promise for nickel removal. However, the calculated p-value (0.678) did not indicate a statistically significant difference between the treated and control groups. This inconsistency might be attributed to the use of a traditional pyrolysis method and a limited sample size, but further research is necessary to optimize their performance.

5. RECOMMENDATIONS

Future investigations could focus on optimizing pyrolysis parameters to create biochar with enhanced surface area and porosity, potentially leading to a more pronounced nickel adsorption capacity.

Additionally, studying the specific mechanisms by which each biochar type interacts with nickel ions could provide valuable insights for targeted improvements. Comparing the effectiveness of these biochar with established nickel removal methods would also be beneficial for evaluating their practical applicability.

Biochar-based nickel removal offers a potentially sustainable and eco-friendly approach to wastewater treatment in the mining industry. Further research and development efforts are warranted to fully unlock the potential of these biochar for this application.

Researchers must broaden their focus to encompass a wider range of heavy metals beyond nickel, acknowledging the variability in contaminant concentrations within mining areas. This expanded scope will provide a more comprehensive understanding of the potential environmental impacts and mitigation strategies required.

A thorough evaluation of the feasibility of employing agricultural waste materials such as mangosteen, durian, and bananas in practical applications should be conducted. This evaluation should include considerations such as acquisition cost, preparation methods, and disposal procedures, facilitating informed decision-making regarding their utilization.

Researchers must thoroughly assess the yield obtained from the pyrolysis of agricultural waste, ensuring accurate and reliable data for subsequent analyses and conclusions.

Design considerations should be carefully evaluated during the development of devices or technologies, ensuring their effectiveness and suitability for intended applications. Robust and well-designed systems will enhance the practical applicability and scalability of research findings.

To provide a comprehensive assessment, future studies should integrate samples from multiple sites or sources, capturing the diverse range of mining practices and wastewater characteristics. This approach will facilitate a more thorough exploration of the potential efficacy of agricultural waste materials in wastewater treatment applications and inform evidence-based decision-making processes.

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