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BIOSORPTION PROPERTY OF NONWOVEN DUCK *(Anas platyrhynchos domestica)* FEATHER FABRIC AS A FILTRATION MEDIUM FOR LEAD CONTAMINANTS IN WATER

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ABSTRACT

Heavy metal contamination in water is a global issue that poses significant health risks, necessitating sustainable, low-cost filtration alternatives. This study investigated the use of nonwoven duck feather fabrics as an alternative waste-filtration medium for the adsorption of lead from synthetic wastewater. An experimental quantitative research design was employed to evaluate the biosorption capacity of nonwoven duck feather fabric (Anas platyrhynchos domestica). Specifically, the nonwoven duck feathers were first pretreated with NaOH to enhance their adsorption capacity. With polypropylene binder fiber, the pretreated duck feathers were bound to 7x7 cm-sized fabrics with varying feather-to-binder ratios (70:30, 75:25, 80:20) using a convection oven. To simulate contaminated wastewater, 10 synthetic wastewater samples were prepared using distilled water and lead nitrate and sealed in plastic containers. Using Inductively Coupled Plasma-Optical Emission Spectrometry (ICP-OES), the initial lead concentration in the samples was analyzed. After the initial concentration of the samples was measured, the nonwoven duck feather fabrics were placed in plastic containers for 1 hour to adsorb lead from the synthetic wastewater. The samples are then reanalyzed by ICP-OES to quantify the final lead concentrations in the synthetic wastewater. The data is then treated with Kruskal-Wallis to obtain the results. The results showed that nonwoven duck feather fabrics in ratios of 70:30, 75:25, and 80:20 feather-to-binder ratios are capable of adsorbing lead from wastewater. However, there was no significant difference in adsorption capacity or percentage removal among the three ratios.

KEYWORDS: *Heavy Metal Contamination, Anas Platyrhynchos Domestica, Lead (Pb) Removal, Keratin Biosorbent, Biosorption, Duck Feather Fabric*

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INTRODUCTION

Heavy metal contamination of water resources is a widespread and pressing environmental issue, affecting both ecosystems and human health on a global scale (Hikmat et al., 2023; Jumoke & Ajayi, 2025; Lubal, 2024). These metals are not only toxic but also bioaccumulative, posing long term risks as they move through good chains and persist in the environment (P. Zhang et al., 2023). Additionally, conventional filtration materials for heavy metal removal, such as activated carbon remain expensive despite their widespread use in water treatment industries (Pet et al., 2024).

Globally, areas with significant industrial activity encounter severe issues associated with heavy metal contamination. The Yangtze River Basin in China has undergone significant water quality deterioration due to industrial effluents (Di et al., 2019) whereas the Niger Delta in Nigeria persists in facing oil-induced pollution, leading to increased concentrations of mercury and lead in aquatic environments (Chinedu & Chukwuemeka, 2018). Numerous physiochemical techniques employed for the removal of heavy metals, including ion exchange, reverse osmosis, and membrane filtering are expensive and often generate secondary pollutants (Geremew, 2017; Rahman et al., 2025; Tripathi & Ranjan, 2015; P. Zhang et al., 2023).

In the Philippines, heavy metal pollution is also a serious concern. Rivers such as the Meycauayan in Bulacan and the Alinsaog in Zambales have been found to contain high concentrations of heavy metals (Pleto et al., 2020). Mining regions in Benguet and Palawan contribute to the release of toxic metals, adding to the country's growing problem of water equality management (Diwa et al., 2023). In Leyte and Metro Manila, heavy metal contamination in water bodies remains a serious concern, yet filtration technologies like membrane systems and chemical precipitation are often too costly for widespread use (Siddique et al., 2025).

The Davao Region exhibits localized effects of heavy metal exposure. Research in the Davao Gulf and its surroundings has indicated that cadmium (Cd) and lead concentrations in surface waters exceed permissible limits, while downstream sediments contain cadmium (Cd), copper (Cu), iron (Fe), magnesium (Mn), and zinc (Zn), with some levels exceeding ecological safety criteria (Badong & Bersabal, 2018). Investigations of mangrove clam *(Pegophysema philippiana)* populations indicated detectable concentrations of cadmium and lead in Sta. Cruz, Davao del Sur, is ascribed to regional agricultural and industrial endeavors (Balingit et al., 2024). Evaluations of tap water at Davao Oriental State University (DOrSU) indicated lead concentrations of 0.01 mg/L, compliant with the regulatory standards of PNSDW, WHO, and USEPA; nevertheless, identified as over suggested carcinogenic risk thresholds (Balingit et al., 2024).

These localized findings highlight an urgent need to address the research gap by advancing sustainable, low-cost filtration approaches, such as those utilizing abundant poultry byproducts like duck *(Anas platyrhynchos domestica)* feathers, whose keratin-rich structure has shown potential for heavy metal adsorption while also reducing solid waste disposal impacts (Alvarez et al., 2023; Basak et al., 2021).

This study aims to assess the biosorption capacity and percentage removal of nonwoven duck feather fabric in removing lead from synthetic wastewater. This research seeks to provide mechanisticand experimental evidence supporting the potential of nonwoven duck feather fabrics as a filtration medium for lead contaminants in water.

Research Questions

1. Is there a significant difference in the biosorption capacity of nonwoven duck *(Anas platyrhynchos domestica)* feather fabrics in removing lead from synthetic wastewater under controlled experimental conditions?
2. Is there a significant difference in the removal efficiency of lead for nonwoven duck *(Anas platyrhynchos domestica)* feather fabrics prepared with varying fabric-to-binder ratios?
3. Is there a significant difference in the percentage removal of lead in varying fabric-to-binder ratios of nonwoven duck feather fabric while keeping pH, temperature, and contact time constant?

METHODS

Study Design

This study employed an experimental quantitative research design to evaluate the biosorption capability of nonwoven duck feather *(Anas platyrhynchos domestica)* fabric as a filtration medium for the removal of lead from synthetic wastewater. The experiment investigated the effect of varying feather-to-polypropylene binder ratios (70:30, 75:25, and 80:20) on lead removal efficiency and adsorption capacity. A control setup consisting of synthetic wastewater without fabric contact was included to establish baseline lead behavior independent of biosorption. All experimental conditions, including fabric mass, solution volume, contact time, pH, and temperature, were kept constant to isolate the effect of fabric composition.

Data analysis involved descriptive statistics and inferential testing to assess differences in adsorption performance among treatment groups. Normality and homogeneity of variance were evaluated for ANOVA but does not meet the requirements. Alternatively, the Kruskal–Wallis test was used as a non-parametric test due to sample size considerations.

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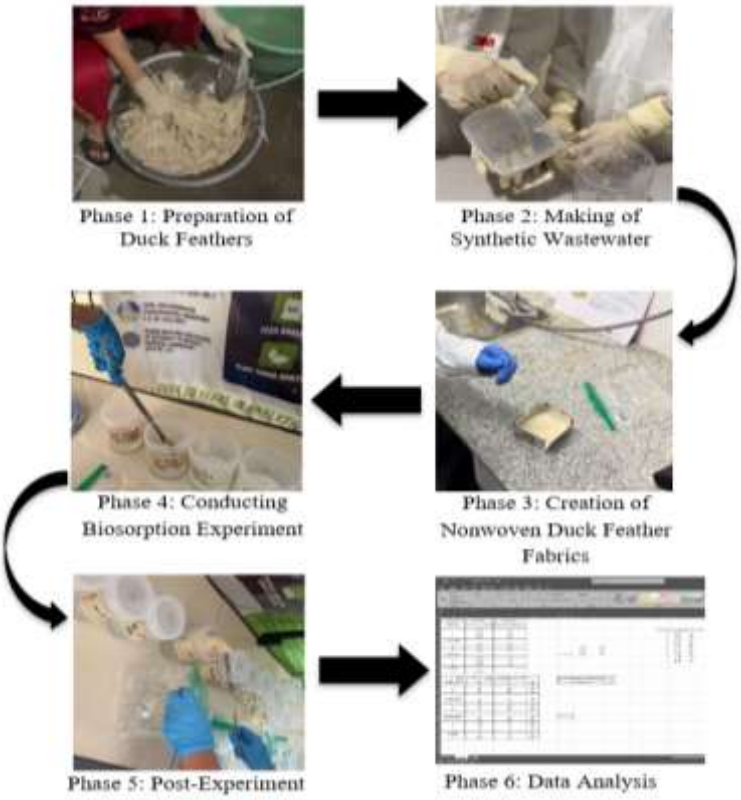


Figure 1. Flowchart of the Data Collection Process

Instrumentation

Duck feathers were collected from Agdao Livestock Market in Davao City, Philippines. The raw materials were thoroughly rinsed with tap water to eliminate extraneous debris and subsequently submerged in a detergent solution for 30 minutes to facilitate degreasing and further purification(A). After the detergent bath, the feathers were rinsed and air-dried for 24 hours. After it was dried, NaOH pretreatment was utilized using a 0.1 M (4g/L) solution for 24 hours (B), and washed with distilled water until pH levels are achieved (Baroroh Lili Utami et al., 2020). Measuring the pH level would be done using pH testing strips from the rinse water. Wang et al. (2016) used the air-drying technique for drying the feathers, but did not include the specific length of time. The same technique was used in a clean environment for a length of 48 hours to have sufficient time for removing moisture (C).



Figure 2. Preparing the Duck Feathers

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Synthetic wastewater was prepared using distilled water and lead nitrate ($Pb(NO_3)_2$). A total of 10 samples were prepared: three per feather-to-binder ratio and one control (no treatment). To prevent contamination and exposure, the researchers used protective equipment such as a hazmat suit, gloves, goggles, and a mask. Due to the 0.2 M $Pb(NO_3)_2$ stock solution being highly concentrated, it was first diluted to 0.01 M by adding 5 mL of the 0.2 M stock to distilled water up to a final volume of 100 mL, then mixing thoroughly (A). For the final synthetic wastewater, 15 mL of the 0.01 M solution was mixed with 300 mL of distilled water (315 mL total) and stirred well to ensure uniform lead ion distribution (A & B).



Figure 3. Making of Synthetic Wastewater

The clean, dried, and pretreated duck feathers were prepared for nonwoven production by cutting and separating the barbs and barbules (A), since the rachis and calamus require additional processing. The barbs and barbules were then layered with a polypropylene binder to promote random distribution and better feather to binder contact before bonding (B). Each sample had a total mass of 2.5 g, with feather-to-binder ratios of 70:30, 75:25, and 80:20. The mixture was placed on a 7 × 7 cm aluminum mold and pre-pressed to flatten layers and reduce gaps for more uniform bonding.

The fabric was thermally bonded in a convection oven at 180°C for 6 minutes (D), following evidence that this method effectively forms functional feather-based nonwovens (Paşayev et al., 2019). This condition is also below the reported stability limit of duck feather composites (~250°C), minimizing the risk of keratin degradation (Basak et al., 2021). After bonding, the fabrics were cooled at room temperature and stored in Ziploc bags until adsorption testing.

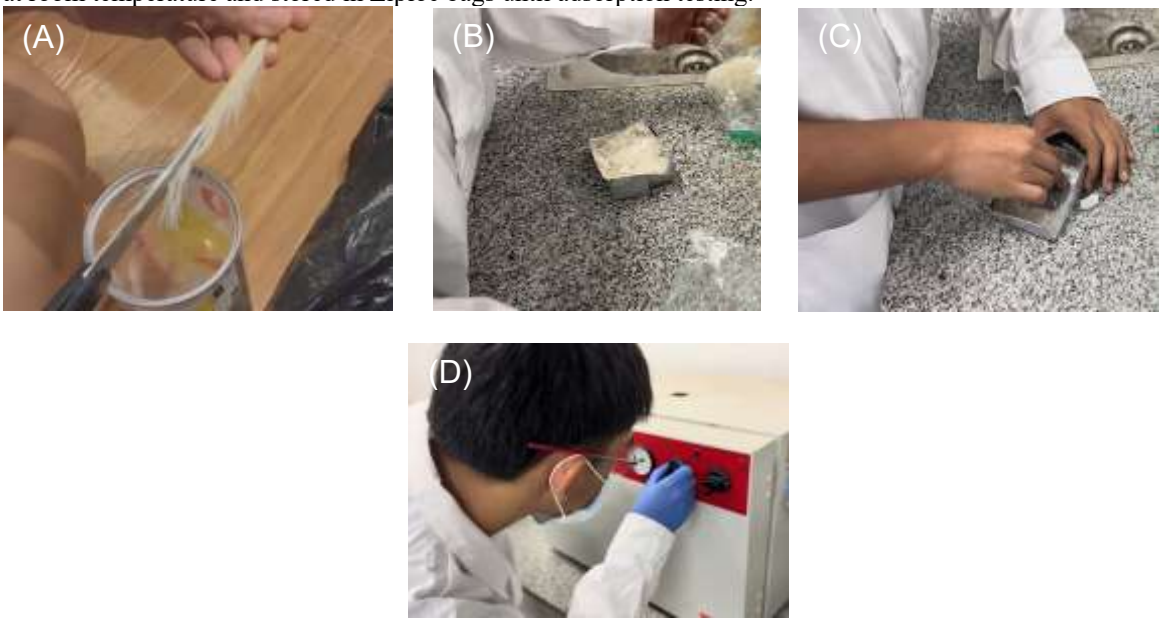


Figure 4. Creation of Duck Feather Fabrics

Initial lead concentrations of the synthetic wastewater were measured before adding the fabrics. Analysis was conducted at Davao Analytical Laboratory Inc. (DALinc) in Davao City, Philippines, using Inductively Coupled Plasma–Optical Emission Spectrometry (ICP-OES) with expert assistance. The test needed 100mL of the wastewater sample which makes the final volume of the water to be 215mL during adsorption test and final concentration test.After the initial analysis, nonwoven duck feather fabric pieces were placed in sealed containers with the synthetic wastewater and left for 1 hour under controlled conditions and a fixed contact time (A). Separate samples were prepared for each feather-to-binder ratio to evaluate their effect on adsorption efficiency. After 1 hour, the fabrics were removed using clean equipment to avoid contamination (B), and the containers were sealed for testing. Final lead concentrations were then measured using ICP-OES at DALinc.

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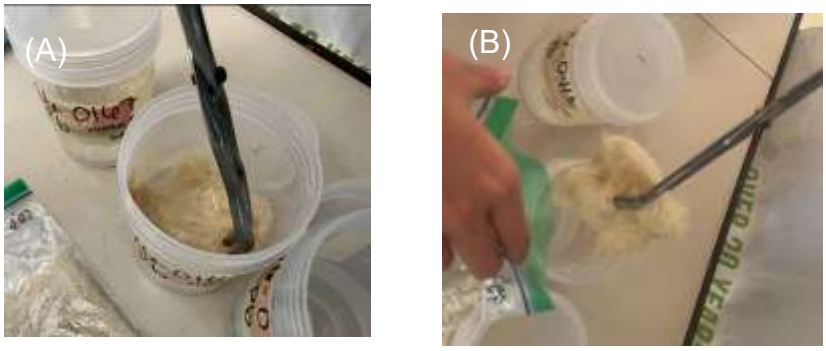


Figure 5. Biosorption Experiment

Data Analysis

The following statistical tools were applied to analyze the collected data and address the study's research questions:
Percentage removal was calculated using the formula: ((Ci-Cf) / Ci) * 100, where Ci represents the initial concentration of lead and Cf represents the final concentration of lead in milligrams per liter (mg/L). Adsorption capacity was calculated using the formula: q = ((Ci - Cf)V) / m, where V represents the volume of the synthetic wastewater in litres and m represents the mass of the fabric in grams.

Mean for both percentage removal and adsorption capacity was also calculated for each treatment group. An outlier value was included in the calculation. To determine if there is a significant difference among groups, the Kruskal-Wallis test was used.

RESULTS

The Experimental Setup

The experiment tested how different material compositions affect the removal of a contaminant from a prepared solution under controlled conditions. Initial levels were measured, the material was exposed to the solution for a fixed time, then final levels were measured to determine removal efficiency and uptake capacity. Results were compared across treatment groups using appropriate statistical analysis.

Table 1. Control Sample

Control	Ci (mg/L)	Cf (mg/L)	ΔC (mg/L)	% removal
1	90.2	79.7	10.5	11.64%

Ci = Initial Concentration Cf = Final Concentration ΔC = Change in Concentration

Table 1 shows that the control sample (without the duck feather fabric) still exhibited a measurable decrease in lead concentration, with Ci = 90.2 mg/L and Cf = 79.7 mg/L, resulting in a ΔC of 10.5 mg/L and 11.64% removal. This indicates that a portion of the observed lead reduction can occur even in the absence of the adsorbent, possibly due to baseline effects such as settling, container interactions, or minor procedural losses during handling. Therefore, this control value serves as the baseline reduction that should be considered when interpreting the adsorption performance of the fabric-treated ratios, to ensure that improvements in removal are attributed to the nonwoven duck feather material rather than background changes alone.

Table 2. 70:30 Fabric Ratio Percentage Removal and Adsorption Capacity

70:30	Ci (mg/L)	Cf (mg/L)	ΔC (mg/L)	% removal	q (mg/g)
1	105	91	14	13.3%	1.20
2	124	99.8	24.2	24.4%	2.08
3	135	84.4	50.4	37.33%	4.33
Mean			**29.53**	**23.39%**	**2.54**

Ci = Initial Concentration Cf = Final Concentration ΔC = Change in Concentration q = Adsorption Capacity

Table 2 shows that the 70:30 feather-to-binder fabric showed consistent lead reduction in all three replicates, with percentage removal ranging from 13.33% to 37.33% (mean = 23.39%). As the initial concentration (Ci) increased (105 → 124 → 135 mg/L), the drop in concentration (ΔC) also increased (14.0 → 24.2 → 50.4 mg/L), and this was reflected in higher % removal (13.33% → 24.4% → 37.33%) and higher adsorption capacity (q) (1.20 → 2.08 → 4.33 mg/g). Overall, the ratio achieved a mean ΔC of 29.53 mg/L and a mean q of 2.54 mg/g, indicating measurable lead uptake per gram of fabric, but the wide spread in q values suggests that adsorption performance was variable across replicates and likely influenced by differing starting concentrations and replicate conditions.

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Table 3. 75:25 Fabric Ratio Percentage Removal and Adsorption Capacity

75:35	Ci (mg/L)	Cf (mg/L)	ΔC (mg/L)	% removal	q (mg/g)
1	108	113	-5	-4.63%	-0.43
2	119	90.8	28.2	23.70%	2.42
3	77.7	62.9	14.8	19.05%	1.27
Mean			**12.67**	**12.71%**	**1.09**

Ci = Initial Concentration Cf = Final Concentration ΔC = Change in Concentration q = Adsorption Capacity

Table 3 shows that the 75:25 fabric ratio had the widest spread in performance, with percentage removal ranging from −4.63% to 23.70% (mean = 12.71%). Two replicates showed positive removal, but one replicate had negative removal (Ci = 108 mg/L, Cf = 113 mg/L; ΔC = −5 mg/L), indicating an apparent increase in final lead concentration and raising within-group variability compared with other ratios. This same replicate also produced a negative adsorption capacity (q = −0.43 mg/g), which reduced the overall mean q to 1.09 mg/g. Despite this anomalous trial, the other replicates still showed measurable uptake (q = 1.27–2.42 mg/g) alongside positive concentration drops (ΔC = 14.8–28.2 mg/L), suggesting that lead binding was possible under the 75:25 composition, but the results were less consistent and may be more sensitive to small experimental variations.

Table 4. 80:20 Fabric Ratio Percentage Removal and Adsorption Capacity

80:20	Ci (mg/L)	Cf (mg/L)	ΔC (mg/L)	% removal	q (mg/g)
1	83.4	69.2	14.2	17.03%	1.22
2	76.6	62.0	14.6	19.06%	1.26
3	72.3	52.0	20.3	28.05%	1.75
Mean			**16.37**	**21.40%**	**1.41**

Ci = Initial Concentration Cf = Final Concentration ΔC = Change in Concentration q = Adsorption Capacity

Table 4 shows that the 80:20 ratio produced consistent Pb(II) reduction across all replicates, with positive % removal ranging from 17.03% to 28.05% (mean = 21.40%). The concentration drop (ΔC) was also consistently positive (14.2–20.3 mg/L; mean = 16.37 mg/L), confirming actual reduction in lead concentration in every trial. In the same way, adsorption capacity values were all positive and relatively close (q = 1.22–1.75 mg/g; mean = 1.41 mg/g), indicating stable lead uptake per gram of fabric with lower within-group variability compared to ratios that showed negative or highly scattered results. Overall, the narrower spread in both % removal and q suggests that the higher feather content contributed to more uniform adsorption performance under the 80:20 composition.

Table 5. Kruskal-Wallis Test Statistics of Percentage Removal

Statistic	Value
H-value	1.15*
p-value	0.5611*

*Significant at 0.05**

Table 5 shows the Kruskal–Wallis test for percentage removal resulting into H = 1.15 and p = 0.5611. Since p > 0.05, there is no statistically significant difference in percentage removal among the 70:30, 75:25, and 80:20 ratios. Any differences in mean % removal are likely due to within-group variability rather than a consistent effect of ratio.

Table 6. Kruskal-Wallis Test Statistics of Adsorption Capacity

Statistic	Value
H-value	0.622
p-value	0.7326*

*Significant at 0.05**

Table 6 shows the results of adsorption capacity being H = 0.622 and p = 0.7326. With p > 0.05, there is also no statistically significant difference in adsorption capacity (q) among the three fabric ratios, meaning the observed differences in q are not strong enough to conclude that one ratio performs better than the others based on this sample.

DISCUSSION

Effect of 70:30 Ratio on the Adsorption Capacity and Percentage Removal of the Nonvoven Duck Feather Fabric

The 70:30 feather-to-binder ratio fabrics demonstrated measurable lead reduction across all replicates, with positive percentage removal ranging from 13.33% to 37.33% (mean = 23.39%). The concentration decrease was consistently positive (ΔC = 14.0–50.4 mg/L, mean = 29.53 mg/L), indicating functional adsorption even at a lower feather fraction. The replicate with the highest initial lead level also produced the largest concentration drop and highest removal, suggesting that higher starting concentrations may enhance the apparent removal under the same contact time. This pattern is consistent with keratin-based adsorption, wherein

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functional groups such as amino (–NH_2) and carboxyl (–COOH) can facilitate ion exchange, electrostatic attraction, and complexation-type interactions with metal ions (Abdulwasiu Olawale et al., 2018; Havryliak et al., 2020). In addition, adsorption capacities were uniformly positive (q = 1.20–4.33 mg/g, mean = 2.54 mg/g), confirming that uptake was measurable per unit mass of fabric and supporting the capability of the 70:30 composition to bind lead ions (Abdulwasiu Olawale et al., 2018; Baroroh Lili Utami et al., 2020).

Effect of 75:25 Ratio on the Adsorption Capacity and Percentage Removal of the Nonwoven Duck Feather Fabric

Among the three ratios, the 75:25 feather-to-binder ratio exhibited the greatest inconsistency, including one replicate with negative removal (Cf > Ci) and a corresponding negative adsorption capacity, indicating an apparent increase in measured final lead concentration in that trial. The remaining replicates still showed positive removal and positive adsorption capacity, confirming that lead binding occurred but was less stable across trials. This variability aligns with the sensitivity of adsorption outcomes to experimental and solution conditions such as contact time, pH, dosage, and initial concentration; under a fixed 1-hour contact time and small sample runs, replicate-to-replicate variation may be amplified and can produce unstable or anomalous outcomes (Solgi & Zamaninan, 2020)s. Overall, the 75:25 composition suggests that adsorption is possible, but performance may be more sensitive to minor experimental variations compared with the other ratios.

Effect of 80:20 Ratio on the Adsorption Capacity and Percentage Removal of the Nonwoven Duck Feather Fabric

The 80:20 feather-to-binder ratio fabrics showed the most stable performance, with positive percentage removal in all replicates and a narrower spread relative to the other treatments. The consistency of removal indicates more uniform adsorption behavior across trials, which is consistent with the expectation that higher feather content increases keratin-related binding sites and the availability of functional groups capable of interacting with metal ions (Chen et al., 2022; Y. Zhang et al., 2015). Adsorption capacity values were also consistently positive (q = 1.22–1.75 mg/g), supporting measurable lead uptake per gram of fabric and aligning with the more consistent percentage removal observed for this ratio (Abdulwasiu Olawale et al., 2018; Baroroh Lili Utami et al., 2020).

Biosorption Potential of Nonwoven Duck Feather Fabrics for Lead Removal

Across all feather-to-binder ratio fabrics, the generally positive percentage removal values indicate that lead reduction occurred in most trials, supporting the feasibility of duck feather–based nonwovens as biosorbent filtration media. This pattern is consistent with studies describing duck feathers as keratin-rich materials whose surface functional groups can interact with metal ions (Chen et al., 2022; Y. Zhang et al., 2015), and also having the capability to accumulate heavy metals including lead, which further supports the plausibility of lead interaction and uptake during contact (Sani et al., 2020). In addition to percentage removal, the adsorption capacity values were generally positive across treatments, confirming that lead uptake was measurable per unit mass of fabric, which is expected for keratin-based biosorbents (Abdulwasiu Olawale et al., 2018).

However, the results indicated no statistically significant differences among ratios. This suggests that, under the present conditions and limited replicates, within-group variability outweighed between-group differences, and any apparent ranking across ratios may not be stable. Notably, Jin et al. (2013) also reported comparable copper sorption capacities among duck-feather composite nonwovens with 70–80% feather content and noted that binder content in the 20–30% range did not significantly influence copper sorption, indicating that ratio effects within this composition window may be subtle. Despite the lack of statistical difference, all treated samples except for the outlier showed higher concentration change compared to the change in the control variable, indicating that all ratios were able to adsorb lead ions.

In summary, this study successfully evaluated the lead removal efficiency of nonwoven duck feather fabrics across varying feather-to-binder ratios. The consistently positive adsorption capacities and removal percentages across most experimental trials confirm that all three tested ratios (70:30, 75:25, and 80:20) are viable media for lead biosorption. Furthermore, the observed performance fluctuations suggest that maximizing biosorbent efficacy requires a strategic balance between high keratin content and the structural integrity provided by the binder. These findings validate the potential of duck feather-based nonwovens as sustainable, low-cost alternatives for heavy metal remediation, while also showing the importance of further optimization in fabrication and adsorption conditions.

CONCLUSION

In conclusion, the findings of the study suggest that the nonwoven duck *(Anas platyrhynchos domestica)* feather fabric has the capability to adsorb lead from synthetic wastewater. Moreover, based on the results, nonwoven duck *(Anas platyrhynchos domestica)* feather fabric also has the capacity to hold adsorbed lead. Since there is no significant difference in the percentage removal from the data drawn from varying ratios used (80:20, 75:25, 70:30), the researchers failed to reject the null hypothesis, which indicates that there is no significant difference in the percentage removal and adsorption capacity in the tested feather-binder ratios. Regardless of the results showing that there is no significant difference on both percentage removal and adsorption capacity, the study shows that nonwoven duck *(Anas platyrhynchos domestica)* feather fabric, is able to adsorb lead and has potential to be used as a filtration medium.

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