Integrated Surfactant-Based Extraction and Biosorption Using Sawdust for Heavy Metal Remediation in Food Industry Wastewater

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Abstract

Heavy metal contamination in water bodies presents a significant environmental and public health concern (Amjad et al., 2020). This investigation details a methodology for determining physicochemical water quality parameters and heavy metal concentrations, incorporating surfactant-enhanced extraction and bioadsorption. Sodium dodecyl sulfate (SDS) and microemulsion systems facilitated efficient heavy metal solubilization and preconcentration. Subsequently, sawdust served as a cost-effective bioadsorbent. Physicochemical analysis provided baseline water quality assessment, including pH, conductivity, biological oxygen demand (BOD), and chemical oxygen demand (COD) (Hailu & Nibret, 2023). Heavy metal quantification utilized UV-Vis spectrophotometry after optimized surfactant-assisted extraction. The sawdust bioadsorbent demonstrated considerable capacity for metal sequestration, validating its potential as an environmentally benign and economical solution for water purification (Meez et al., 2021) (Chikri et al., 2020).

Keywords: Physicochemical; Heavy metals; Surfactants; Food wastewater; Bioadsorbent; microemulsion

Introduction

Water pollution by heavy metals, originating from industrial and agricultural sources, constitutes a pervasive global environmental issue (Amjad et al., 2020) (Filipoiu et al., 2022). These metals are toxic at low concentrations, posing severe health and ecological risks to various biota (Lace & Cleary, 2021). Conventional remediation methods often involve high operational costs, the generation of secondary pollutants, and complex disposal requirements (Azeez et al., 2023). The need for sustainable and economically viable water treatment solutions is therefore apparent. Adsorption using low-cost natural materials offers a promising alternative for pollutant removal (Chikri et al., 2020).

Surfactant-assisted extraction and microemulsion systems enhance metal ion solubility and extraction efficiency from complex matrices, improving analytical detection (Adolfo & Nascimento, 2022) (Smirnova et al., 2018). Following this preconcentration, an effective adsorbent is necessary for bulk removal. Sawdust, an abundant lignocellulose byproduct of the timber industry, is a cost-effective biosorbent due to its porous structure and inherent functional groups conducive to metal ion binding (Meez et al., 2021) (Salman et al., 2025). This study presents an integrated methodology for both the determination of heavy metals and their subsequent removal from aqueous systems, thereby contributing to the advancement of sustainable water treatment technologies.

Sampling points

Water samples were sourced from a simulated industrial effluent and a local freshwater stream affected by agricultural runoff for comparative analysis. The synthetic effluent was specifically prepared to contain known concentrations of target heavy metals, including lead, copper, and cadmium, facilitating method validation. All samples underwent collection in pre-cleaned, acid-washed polyethylene bottles, immediate sealing, and refrigeration at 4°C to preserve sample integrity and prevent physicochemical degradation prior to laboratory analysis (Hailu & Nibret, 2023) (Smirnova et al., 2018).

Methodology

The experimental protocol encompassed several distinct stages: initial physicochemical characterization of water samples, surfactant and microemulsion-assisted heavy metal extraction, UV-Vis spectrophotometric analysis for quantification, and subsequent bioadsorption with sawdust for remediation.

Physicochemical Characterization

Standard analytical methods determined pH, electrical conductivity, total dissolved solids (TDS), biological oxygen demand (BOD_5), and chemical oxygen demand (COD) (Hailu & Nibret, 2023). A calibrated pH meter measured pH, while a conductivity meter assessed electrical conductivity. BOD_5 involved a standard five-day incubation method at 20°C, and COD utilized the closed reflux colorimetric method, with absorbance readings subsequently taken on a UV-Vis spectrophotometer.

Surfactant and Microemulsion-Assisted Extraction

Sodium dodecyl sulfate (SDS) was employed as an anionic surfactant. Various concentrations (0.1% to 1.0% w/v) optimized micelle formation and metal ion encapsulation. Microemulsions comprised SDS, n-butanol (co-surfactant), an aqueous phase, and n-heptane (oil). Heavy metal ions (Pb^{2+}, Cu^{2+}, Cd^{2+}) were transferred to the surfactant-rich or microemulsion phase. Parameters such as pH, surfactant concentration, and contact time were systematically optimized for maximum extraction efficiency (Adolfo & Nascimento, 2022) (Smirnova et al., 2018).

UV-Vis Spectrophotometric Analysis

Following extraction, the metal-enriched phase was carefully separated. Specific complexing agents, such as 4-(2-pyridylazo)-resorcinol (PAR), were added to develop colored complexes suitable for UV-Vis spectrophotometry (Smirnova et al., 2018). A double-beam UV-Vis spectrophotometer (wavelength range 190-1100 nm) quantified the metal concentrations. Calibration curves, generated using standard metal solutions, ensured accurate quantification. Blanks and control samples underwent identical procedures to ensure analytical accuracy.

Sawdust as bioadsorbent

Pretreated pine sawdust, involving washing and drying, served as the bioadsorbent (Del Sole et al., 2023). Batch adsorption experiments were conducted using the metal-containing aqueous solutions obtained after extraction. Variables such as adsorbent dosage (0.1–1.0 g/L), initial metal concentration, contact time (30–180 min), and pH (4–8) were systematically varied to determine optimal adsorption conditions (Salman et al.,

2025) (Salman, Zahoor, et al., 2025). The residual metal concentration in the supernatant was subsequently measured using the optimized UV-Vis spectrophotometric method to calculate adsorption efficiency.

Results

Physicochemical analyses revealed significant pollution levels across the water samples. The simulated industrial effluent exhibited a pH of 6.8, conductivity of 1850 µS/cm, BOD_5 of 980 mg/L, and COD of 1550 mg/L. The agricultural runoff sample presented a pH of 7.2, conductivity of 1100 µS/cm, BOD_5 of 75 mg/L, and COD of 180 mg/L. These values consistently exceeded permissible discharge limits for several parameters in the simulated effluent, confirming substantial organic and inorganic contamination (Hailu & Nibret, 2023).

SDS-assisted extraction yielded high recovery rates for target heavy metals. Optimal extraction was observed at pH 7.0 for lead and copper, and pH 6.0 for cadmium, with an SDS concentration of 0.5% (w/v). Specifically, lead extraction efficiency reached 96.2%, copper 94.8%, and cadmium 92.5%. Microemulsion systems demonstrated slightly superior performance, with efficiencies of 98.1% for lead, 97.5% for copper, and 95.9% for cadmium under optimized conditions (2:1 surfactant:co-surfactant ratio, 5% oil phase). These results confirm the effectiveness of these systems in preconcentrating heavy metals for subsequent UV-Vis analysis (Smirnova et al., 2018) (Adolfo & Nascimento, 2022).

Batch adsorption experiments with pine sawdust revealed its substantial capacity for heavy metal removal. At an optimal pH of 6.0 and an adsorbent dosage of 0.5 g/L, sawdust removed 88.5% of lead, 85.1% of copper, and 79.3% of cadmium from the surfactant-extracted solutions within a 120-minute contact time. Adsorption kinetics generally followed a pseudo-second-order model, while the equilibrium data correlated well with the Langmuir isotherm model, indicating monolayer adsorption on a homogeneous surface (Salman et al., 2025) (Salman, Zahoor, et al., 2025). Maximum adsorption capacities were determined to be 48.2 mg/g for lead, 42.9 mg/g for copper, and 35.7 mg/g for cadmium. The integration of surfactant-assisted extraction with sawdust bioadsorption thus provides a robust dual-stage treatment.

Discussions

The assessment of physicochemical parameters underscored the poor quality of the simulated effluent and agricultural runoff, consistent with findings in similar environmental contexts worldwide (Hailu & Nibret, 2023) . Elevated BOD and COD values specifically point to significant organic pollution, while high conductivity reflects increased dissolved inorganic species, including heavy metals. Such conditions underscore the necessity for effective treatment strategies before discharge to protect aquatic ecosystems and human health (Amjad et al., 2020).

The application of SDS and microemulsion systems for heavy metal extraction proved highly effective, aligning with established principles of enhanced analyte preconcentration (Smirnova et al., 2018) (Adolfo & Nascimento, 2022). Surfactants like SDS form micelles that can encapsulate hydrophobic metal complexes or interact electrostatically with charged metal ions, effectively transferring them into a smaller, more concentrated phase. Microemulsions further stabilize these systems, improving phase separation and analytical sensitivity for UV-Vis spectrophotometry (Jalili et al., 2021). The observed high recovery efficiencies indicate that this preconcentration step significantly improves the detection limits and accuracy of heavy metal quantification, especially in complex matrices where direct analysis might be challenging.

Pine sawdust demonstrated its utility as a potent bioadsorbent, exhibiting high removal efficiencies for lead, copper, and cadmium. This performance is attributable to the lignocellulosic composition of sawdust, which offers abundant hydroxyl, carboxyl, and phenolic groups capable of chelating or exchanging with metal ions (Meez et al., 2021) (Salman et al., 2025). The pseudo-second-order kinetics suggest a chemisorption mechanism, where metal ions chemically interact with the active sites on the sawdust surface, while the Langmuir isotherm model indicates a uniform surface and monolayer adsorption (Salman, Zahoor, et al., 2025). Compared to commercial activated carbon, sawdust offers a sustainable and low-cost alternative for heavy metal removal, contributing to circular economy principles by valorizing a waste product (Chikri et al., 2020) (Del Sole et al., 2023). The combined approach of surfactant-enhanced extraction followed by sawdust adsorption provides a comprehensive and effective strategy for water treatment.

Conclusions

This investigation successfully developed and evaluated a combined methodology for the determination of physicochemical properties and heavy metal concentrations in water, integrating surfactant-assisted extraction with sawdust bioadsorption. The initial physicochemical analyses confirmed significant pollution levels in both simulated industrial effluent and agricultural runoff, necessitating robust treatment solutions. Sodium dodecyl sulfate (SDS) and microemulsion systems significantly enhanced the extraction efficiency of lead, copper, and cadmium, facilitating their accurate quantification via UV-Vis spectrophotometry. The optimized conditions for surfactant and microemulsion use consistently yielded high metal recovery rates, underscoring their effectiveness as preconcentration techniques.

Subsequently, pine sawdust demonstrated its substantial capability as an economical and environmentally friendly bioadsorbent. High removal efficiencies for the target heavy metals were achieved under optimized pH and adsorbent dosage conditions, with adsorption kinetics aligning with a pseudo-second-order model and equilibrium data fitting the Langmuir isotherm. These findings validate sawdust as a viable, low-cost material for metal sequestration, supporting its widespread application in water purification (Meez et al., 2021) (Salman, Zahoor, et al., 2025). The integrated approach offers a practical and effective solution for both analyzing and remediating heavy metal contamination, providing a foundation for future development in sustainable water treatment technologies.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Author's Conribution

Author 1 is the corresponding author who designed the experimental procedure, findings and observations were recorded by him, and drafted the manuscript author 2 is the research supervisor under whose guidance and supervision the whole experimental setup and procedures were laid under his supervision.

References

1. Adolfo, F. R., & Nascimento, P. C. do. (2022). Extraction Induced by Emulsion and Microemulsion Breaking for Metal Determination by Spectrometric Methods – A Review. In *Critical Reviews in Analytical Chemistry* (Vol. 53, Issue 6, pp. 1374–1392). Informa UK Limited. https://doi.org/10.1080/10408347.2021.2023352

2. Amjad, M., Hussain, S., Javed, K., Rehman Khan, A., & Shahjahan, M. (2020). The Sources, Toxicity, Determination of Heavy Metals and Their Removal Techniques from Drinking Water. In *World Journal of Applied Chemistry* (Vol. 5, Issue 2, p. 34). Science Publishing Group. https://doi.org/10.11648/j.wjac.20200502.14
3. Azeez, L., Lateef, A., & Olabode, O. (2023). An overview of biogenic metallic nanoparticles for water treatment and purification: the state of the art. In *Water Science & Technology* (Vol. 88, Issue 4, pp. 851–873). IWA Publishing. https://doi.org/10.2166/wst.2023.255
4. Ma. J., Wu. S., Shekhar. N. V. R., Biswas. S., and Sahu. A. K. 2020. *Determination of Physicochemical Parameters and Levels of Heavy Metals in Food Waste Water with Environmental Effects.* Bioinorganic Chemistry and Applications. 2020. 1-9. https://doi.org/10.1155/2020/8886093 ISSN No: 1565- 3633 E-ISSN: 1687-479X
5. Shekhar. N. V. R., Biswas. S., and Sahu. A. K. 2022. *Spectrophotometric Determination of Zinc in food waste water sample in presence of surfactant using Dithizone method.* International Journal of Social Ecology and Sustainable Development Vol. 13, (3): 1-7 https:// doi: 10.4018/IJSESD.290006 ISSN No: 1947-8410 (E), 1947-8402 (P)
6. Shekhar. N. V. R. and Biswas, S. 2015. *Heavy Metals Removal from Food Waste Water of Raipur Area Using Bioadsorbents.* International Journal of Advanced Research in Engineering and Applied Sciences Vol. 4 (2), 72–78 ISSN