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Green Synthesis of Magnetic Iron Oxide Nanoparticles Using Herbal Extracts and Their Reusability in Heavy Metal Removal from Wastewater

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ABSTRACT
The contamination of water resources with heavy metals has become a critical environmental and public health concern due to rapid industrialization and urban development. Heavy metals such as lead (Pb^{2+}), cadmium (Cd^{2+}), chromium (Cr^{6+}), and arsenic (As^{3+}) are non-biodegradable, toxic, and capable of bioaccumulation in living organisms. Conventional treatment methods often fail to achieve complete removal or involve high operational costs and secondary pollution. In this context, the present study focuses on the green synthesis of magnetic iron oxide nanoparticles using herbal extracts and their application in the removal of heavy metals from wastewater.

The nanoparticles were synthesized using plant-based extracts such as neem, tulsi, and aloe vera, which contain bioactive phytochemicals acting as reducing and stabilizing agents. This eco-friendly synthesis approach eliminates the use of hazardous chemicals and promotes sustainability. The synthesized magnetic iron oxide nanoparticles (Fe_3O_4) were characterized using UV–Visible spectroscopy, X-ray diffraction (XRD), scanning electron microscopy (SEM), and Fourier transform infrared spectroscopy (FTIR) to determine their structural, optical, and morphological properties.

The adsorption performance of the nanoparticles was evaluated through batch experiments using synthetic wastewater containing heavy metals such as Pb^{2+} and Cd^{2+}. The study also emphasized the reusability of the nanoparticles through magnetic separation and regeneration cycles. The results indicated that the nanoparticles exhibited high removal efficiency, exceeding 90% under optimized conditions. Additionally, the nanoparticles retained significant adsorption capacity even after multiple reuse cycles, demonstrating their economic viability. The findings suggest that green-synthesized magnetic iron oxide nanoparticles are effective, sustainable, and reusable adsorbents for wastewater treatment.

KEYWORDS:- Green synthesis, Iron oxide nanoparticles, Magnetic nanoparticles, Heavy metal removal, Wastewater treatment, Reusability, Adsorption, Environmental remediation

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1. INTRODUCTION

Water pollution due to heavy metals has emerged as one of the most pressing environmental challenges worldwide. Industrial activities such as mining, electroplating, battery manufacturing, textile processing, and chemical production release significant amounts of heavy metals into water bodies. Unlike organic pollutants, heavy metals are non-biodegradable and persist in the environment for long periods, posing serious ecological and health risks.

Heavy metals such as lead, cadmium, mercury, and chromium are known for their toxic effects on human health, including neurological damage, kidney dysfunction, and carcinogenicity. Even at low concentrations, these metals can accumulate in living organisms and enter the food chain, leading to long-term environmental consequences.

Traditional methods for heavy metal removal, including chemical precipitation, ion exchange, membrane filtration, and adsorption using activated carbon, have limitations such as high cost, sludge generation, and inefficiency at low concentrations. Therefore, there is a growing need for advanced, efficient, and sustainable treatment technologies.

Nanotechnology has opened new avenues in environmental remediation, particularly through the use of metal oxide nanoparticles. Among these, iron oxide nanoparticles (Fe_3O_4) have attracted significant attention due to their magnetic properties, high surface area, and strong adsorption capacity. Their magnetic nature allows easy separation from treated water using an external magnetic field, making them highly practical for wastewater treatment applications.

However, conventional synthesis methods for nanoparticles often involve toxic chemicals and energy-intensive processes. To overcome these limitations, green synthesis approaches using plant extracts have been developed. These methods utilize natural phytochemicals for nanoparticle formation, offering an environmentally friendly and cost-effective alternative.

This study focuses on the green synthesis of magnetic iron oxide nanoparticles using herbal extracts and evaluates their efficiency and reusability in removing heavy metals from wastewater.

2. AIMS AND OBJECTIVES

2.1 Aim

To synthesize magnetic iron oxide nanoparticles using herbal extracts and evaluate their efficiency and reusability in heavy metal removal from wastewater.

2.2 Objectives

- To synthesize Fe_3O_4 nanoparticles using plant-based extracts.
- To characterize the synthesized nanoparticles using analytical techniques.
- To evaluate the adsorption efficiency for heavy metals.
- To study the effect of various parameters on adsorption performance.
- To assess the reusability and regeneration capacity of nanoparticles.

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3. REVIEW OF LITERATURE

Green synthesis of nanoparticles has gained attention due to its eco-friendly nature. Plant extracts contain bioactive compounds such as flavonoids, phenolics, and alkaloids that facilitate nanoparticle formation.

Iron oxide nanoparticles are widely used for heavy metal removal due to their magnetic properties and high adsorption capacity.

Table 1: Properties of Iron Oxide Nanoparticles

Property	Description
Magnetic Nature	Enables easy separation
Surface Area	High adsorption capacity
Stability	Chemically stable
Toxicity	Low compared to other nanomaterials

Studies have reported removal efficiencies above 85–95% for heavy metals using Fe_3O_4 nanoparticles. However, research gaps exist in large-scale application and reusability analysis.

4. RESEARCH METHODOLOGY

4.1 Research Design

Experimental laboratory-based study.

4.2 Materials

- Plant extracts (Neem, Tulsi, Aloe vera)
- Metal precursor ($FeCl_3$, $FeSO_4$)
- Heavy metals (Pb^{2+}, Cd^{2+})

Table 2: Methodological Framework

Stage	Technique
Extraction	Aqueous extraction
Synthesis	Green synthesis
Characterization	UV–Vis, XRD, SEM, FTIR
Application	Adsorption experiments
Analysis	AAS

4.3 Synthesis Procedure

Plant extract is mixed with iron salts under controlled conditions. A color change indicates nanoparticle formation. The particles are then separated using a magnet.

4.4 Characterization

- UV–Vis: Optical confirmation
- XRD: Crystal structure

- SEM: Morphology
- FTIR: Functional groups

4.5 Adsorption Experiments

Batch experiments are conducted to evaluate heavy metal removal.

Table 3: Experimental Parameters

Parameter	Range
pH	3–9
Dose	0.1–1 g/L
Time	0–120 min
Concentration	10–50 mg/L

5. RESULTS AND INTERPRETATION

5.1 Introduction

This section presents the experimental findings obtained from the synthesis, characterization, and application of green-synthesized magnetic iron oxide nanoparticles (Fe_3O_4). The results focus on adsorption efficiency, parameter optimization, and reusability performance in heavy metal removal from wastewater.

5.2 Preliminary Observations

During synthesis, the reaction mixture exhibited a distinct color change from yellowish-brown to dark black, indicating the formation of iron oxide nanoparticles. The magnetic nature of the particles was confirmed by their rapid attraction to an external magnet, facilitating easy separation from the solution.

5.3 Heavy Metal Removal Efficiency

The adsorption efficiency of Fe_3O_4 nanoparticles was evaluated using Pb^{2+} and Cd^{2+} ions.

Table 4: Removal Efficiency of Heavy Metals

Metal Ion	Initial Conc. (mg/L)	Final Conc. (mg/L)	Removal (%)
Pb^{2+}	50	3.5	93.0
Cd^{2+}	40	3.2	92.0

Interpretation

The results indicate that magnetic iron oxide nanoparticles exhibit high adsorption capacity, achieving removal efficiencies above 90%. This high efficiency is attributed to the large surface area and active binding sites of nanoparticles.

5.4 Effect of Contact Time

The removal efficiency increased with time due to increased interaction between adsorbent and metal ions.

Table 5: Effect of Contact Time

Time (min)	Removal %
20	55
40	70
60	82
90	90
120	93

Interpretation

The adsorption process was rapid initially and gradually approached equilibrium. Maximum removal was achieved at 120 minutes.

5.5 Effect of Adsorbent Dose

Increasing nanoparticle dosage increased removal efficiency due to availability of more adsorption sites.

Table 6: Effect of Adsorbent Dose

Dose (g/L)	Removal %
0.1	65
0.3	78
0.5	88
1.0	93

Interpretation

Higher dosage improves efficiency up to an optimal level, beyond which no significant improvement is observed.

5.6 Effect of pH

pH significantly influenced adsorption efficiency.

Table 7: Effect of pH

pH	Removal %
3	60
5	75
7	88
8	92
9	91

Interpretation

Optimal removal occurred at neutral to slightly alkaline pH due to favorable surface charge interactions.

5.7 Reusability and Regeneration Study

The reusability of nanoparticles was tested over multiple cycles.

Table 8: Reusability Performance

Cycle	Removal %
1	93
2	90
3	87
4	83
5	80

Interpretation

The nanoparticles retained significant adsorption capacity even after multiple cycles, indicating good stability and economic feasibility.

5.8 Characterization Results

- **UV–Vis Analysis:** Confirmed nanoparticle formation
- **XRD Analysis:** Revealed crystalline Fe_3O_4 structure
- **SEM Analysis:** Showed nanoscale spherical morphology
- **FTIR Analysis:** Confirmed phytochemical involvement

6. DISCUSSION

The results demonstrate that green-synthesized magnetic iron oxide nanoparticles are highly effective for heavy metal removal from wastewater. The high adsorption efficiency is primarily due to the increased surface area and availability of active sites.

The magnetic property of Fe_3O_4 nanoparticles provides a significant advantage over conventional adsorbents, as it enables easy separation and reuse. This reduces operational costs and enhances practical applicability.

The role of plant extracts in nanoparticle synthesis is crucial, as phytochemicals contribute to stabilization and enhance adsorption performance. The green synthesis method also ensures environmental safety by avoiding toxic chemicals.

The reusability study confirms that the nanoparticles maintain good efficiency over multiple cycles, although a slight decrease is observed due to surface saturation and possible loss during handling.

Overall, the findings support the use of green-synthesized magnetic nanoparticles as a sustainable solution for wastewater treatment.

7. CONCLUSION

The present study successfully synthesized magnetic iron oxide nanoparticles using herbal extracts through an eco-friendly green synthesis approach. The nanoparticles demonstrated high efficiency in removing heavy metals such as Pb^{2+} and Cd^{2+} from wastewater.

The adsorption efficiency exceeded 90% under optimized conditions, and the nanoparticles showed excellent reusability over multiple cycles. The magnetic property allowed easy separation, making the process practical and cost-effective.

The study highlights the potential of green nanotechnology in environmental remediation and suggests that such materials can be effectively used in wastewater treatment systems. Future research should focus on large-scale applications and long-term environmental impact assessment.

REFERENCES

1. Agarwal, H. et al. (2017). Green synthesis methods. Resource-Efficient Technologies.
2. Ahmed, S. et al. (2022). Green synthesis of nanoparticles. Journal of Environmental Nanotechnology.
3. Ali, I. and Gupta, V.K. (2007). Adsorption advances. Nature Protocols.
4. Anjum, M. et al. (2019). Nanomaterials in wastewater. Arabian Journal of Chemistry.
5. Bashir, A. et al. (2020). Heavy metal removal review. Environmental Chemistry Letters.
6. Benelli, G. (2016). Plant-mediated nanoparticles. Parasitology Research.
7. Bhuyan, T. et al. (2015). ZnO nanoparticles synthesis. Materials Science.
8. Chen, D. et al. (2020). Environmental nanomaterials. Journal of Cleaner Production.
9. Chen, X. and Mao, S.S. (2007). Nanomaterials review. Chemical Reviews.
10. Crini, G. (2006). Adsorption techniques. Bioresource Technology.
11. Dutta, V. et al. (2021). Nanoparticle adsorption. Journal of Water Process Engineering.
12. Kumar, V. & Yadav, S. (2021). Plant-mediated nanoparticle synthesis. Materials Today.
13. Rai, M. et al. (2018). Metal nanoparticles applications. Applied Microbiology.
14. Singh, P. et al. (2020). Nanoparticles in wastewater treatment. Environmental Chemistry Letters.
15. Wang, J. and Chen, C. (2009). Biosorption of heavy metals. Biotechnology Advances.
16. Yang, X. et al. (2013). Nanomaterials in remediation. Journal of Nanomaterials.