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Green Synthesis of Cadmium Sulphide Nanoparticles from Curry Leaves (Murraya Koenigii) and Its Applications in Domestic Wastewater Treatment

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Abstract

The study presented in this paper focuses on the green synthesis of cadmium sulfide (CdS) nanoparticles using curry leaves, exploring their potential applications in domestic wastewater treatment. The synthesis process is environmentally friendly, leveraging the natural properties of curry leaves to produce nanoparticles without the use of harmful chemicals. The synthesized CdS nanoparticles were characterized using techniques such as Scanning Electron Microscopy (SEM) and Energy-Dispersive X-ray Spectroscopy (EDX), which confirmed their elemental composition and purity. The EDX analysis revealed atomic percentages of 48.8% cadmium and 13.6% sulfur, indicating a purity of approximately 50%, suggesting the need for further purification for specific applications.

The effectiveness of CdS nanoparticles in reducing total organic carbon (TOC) and inorganic carbon (IC) levels in domestic wastewater was evaluated. Results demonstrated a significant decrease in both TOC and IC levels across multiple samples after the addition of CdS nanoparticles, highlighting their potential as an effective treatment option for wastewater management. The study emphasizes the importance of sustainable practices in nanotechnology and environmental engineering, showcasing how natural resources can be utilized to address pressing environmental challenges. The findings contribute to the growing body of research on the application of nanomaterials in wastewater treatment, offering insights into their effectiveness and potential for further development. Overall, this research underscores the promising role of green synthesized nanoparticles in enhancing water quality and promoting sustainable environmental practices.

Keywords
Cadmium Sulphide Nanoparticles, Green Synthesis, Wastewater Treatment, Murraya Koenigii, Environmental Sustainability

1. Introduction
The increasing global demand for clean water, coupled with the challenges posed by rapid industrialization and urbanization, has made effective wastewater treatment a critical environmental concern. Traditional wastewater treatment methods often rely on chemical processes that can be harmful to both the environment and human health. These methods frequently fail to adequately reduce biochemical oxygen demand (BOD) and total organic carbon (TOC) levels, leading to the need for innovative and sustainable solutions. The problem is further exacerbated by the rising levels of pollutants in domestic wastewater, necessitating the exploration of alternative treatment methods that are both effective and environmentally friendly(Singh et al. 2023).

Recent literature highlights the potential of nanotechnology in enhancing wastewater treatment processes. Among various nanoparticles, cadmium sulphide (CdS) nanoparticles have garnered attention due to their unique semiconductor properties, which make them suitable for applications in photocatalysis and pollutant degradation(Qutub et al. 2016) .Studies have demonstrated that CdS nanoparticles can significantly reduce BOD and TOC levels in wastewater, thereby improving water quality(Kovo et al. 2023). However, conventional synthesis methods for these nanoparticles often involve hazardous chemicals and high energy consumption, raising concerns about their environmental sustainability(Osman et al. 2024). In contrast, green synthesis methods utilizing natural materials, such as plant extracts, have emerged as a promising alternative. These methods not only minimize environmental impact but also offer a cost-effective approach to nanoparticle production(Fahim et al. 2024).

This research aims to investigate the green synthesis of CdS nanoparticles using Murraya koenigii (curry leaves) as a sustainable reducing and stabilizing agent. The study employs a sol-gel method to produce environmentally friendly nanoparticles, which are then characterized for their size, morphology, and composition(Chowdhury et al. 2024). The effectiveness of the synthesized CdS nanoparticles in reducing BOD and TOC levels in domestic wastewater samples will be evaluated. The primary objectives of this work are to synthesize and characterize CdS nanoparticles, assess their performance in wastewater treatment, and evaluate their environmental impact and biocompatibility(Soni et al. 2024). By focusing on the use of natural materials for nanoparticle production, this research contributes to the understanding of sustainable practices in wastewater management and promotes the adoption of eco-friendly solutions in the field of environmental engineering(Wahab et al. 2024)(Ruíz-Baltazar 2024).

1.1 Objectives
The primary objectives of this research are:

- To synthesize cadmium sulphide nanoparticles using Murraya koenigii through a green synthesis method.
- To characterize the synthesized nanoparticles using techniques such as SEM, EDX, and XRD.

- To evaluate the effectiveness of CdS nanoparticles in reducing BOD and TOC levels in wastewater samples.
- To assess the environmental impact and biocompatibility of the synthesized nanoparticles. These objectives will be articulated in the conclusion, emphasizing the unique contributions of this research to the field of environmental engineering.

2. Literature Review

Nanoparticles have garnered significant attention in recent years due to their unique properties and potential applications across various fields, including medicine, electronics, and environmental science. Among the various types of nanoparticles, cadmium sulphide (CdS) nanoparticles have emerged as a promising material due to their semiconductor properties, which make them suitable for applications in photocatalysis, sensors, and wastewater treatment.

2.1 Synthesis of Nanoparticles

The synthesis of nanoparticles can be achieved through various methods, including physical, chemical, and biological approaches. Traditional physical and chemical methods often involve the use of hazardous chemicals and high energy consumption, raising concerns about environmental sustainability and safety. In contrast, green synthesis methods have gained popularity as they utilize natural materials and environmentally friendly processes(Nyabadza et al. 2023). Green synthesis involves the use of biological entities such as plants, bacteria, and fungi to produce nanoparticles. This method not only reduces the environmental impact associated with conventional synthesis but also offers a cost-effective and sustainable alternative. For instance, Goud (2016) demonstrated the successful green synthesis of CdS nanoparticles using plant extracts, highlighting the potential of natural materials in nanoparticle production. The use of plant extracts not only provides a source of reducing agents but also stabilizes the nanoparticles, preventing agglomeration.

2.2 Advantages of Using Natural Materials

Murraya koenigii, commonly known as curry leaves, has been identified as a suitable candidate for the green synthesis of nanoparticles. The leaves contain various phytochemicals, including flavonoids, alkaloids, and phenolic compounds, which possess reducing and stabilizing properties(Bee et al. 2022). These compounds facilitate the reduction of metal ions to form nanoparticles while simultaneously stabilizing them in solution.

The advantages of using Murraya koenigii for nanoparticle synthesis include its abundance, low cost, and biocompatibility. Additionally, the use of plant-based materials minimizes the risk of toxic byproducts associated with chemical synthesis methods. Studies have shown that nanoparticles synthesized using plant extracts exhibit enhanced biocompatibility and lower toxicity, making them suitable for various applications, including biomedical and environmental fields (Haider et al. 2024).

2.3 Applications of CdS Nanoparticles in Wastewater Treatment

CdS nanoparticles have shown great promise in the field of wastewater treatment, particularly in the degradation of organic pollutants. Their semiconductor properties enable them to act as effective photocatalysts under UV or visible light irradiation. Several studies have reported the effectiveness of CdS nanoparticles in degrading dyes, heavy metals, and other organic contaminants in wastewater(Lee et al. 2023).

For example, research conducted by Ghasempour (2010) demonstrated that CdS nanoparticles could significantly reduce the concentration of organic pollutants in wastewater through photocatalytic degradation. The study highlighted the role of CdS nanoparticles in breaking down complex organic molecules into less harmful substances, thereby improving water quality. Furthermore, the incorporation of CdS nanoparticles into wastewater treatment systems has been shown to enhance the overall efficiency of the treatment process, leading to lower BOD and TOC levels (T2).

In addition to their photocatalytic properties, CdS nanoparticles also exhibit antimicrobial activity, which can further contribute to the treatment of wastewater. Chikwem (2018) evaluated the antimicrobial properties of various plant extracts, including Murraya koenigii, and found that the synthesized nanoparticles exhibited significant antimicrobial activity against a range of pathogens. This dual functionality of CdS nanoparticles—degradation of organic pollutants and antimicrobial action—positions them as a valuable tool in the quest for effective wastewater treatment solutions.

the literature indicates that the green synthesis of CdS nanoparticles using natural materials such as Murraya koenigii presents a sustainable and effective approach to nanoparticle production. The advantages of using plant extracts not only enhance the synthesis process but also contribute to the biocompatibility and environmental friendliness of the resulting nanoparticles. Furthermore, the applications of CdS nanoparticles in wastewater treatment demonstrate their potential in addressing critical environmental challenges, particularly in the degradation of organic pollutants and the improvement of water quality. This literature review underscores the importance of continuing research in this area to further explore the capabilities and applications of green-synthesized nanoparticles in environmental remediation.

3. Methods

The synthesis of cadmium sulphide (CdS) nanoparticles was conducted using a green synthesis method involving Murraya koenigii (curry leaves). The process involved several key steps, which are illustrated in the process flow chart below (Figure 1). The methodology is divided into several key stages: preparation of plant material, synthesis of CdS nanoparticles, characterization of nanoparticles, and evaluation of their effectiveness in wastewater treatment.

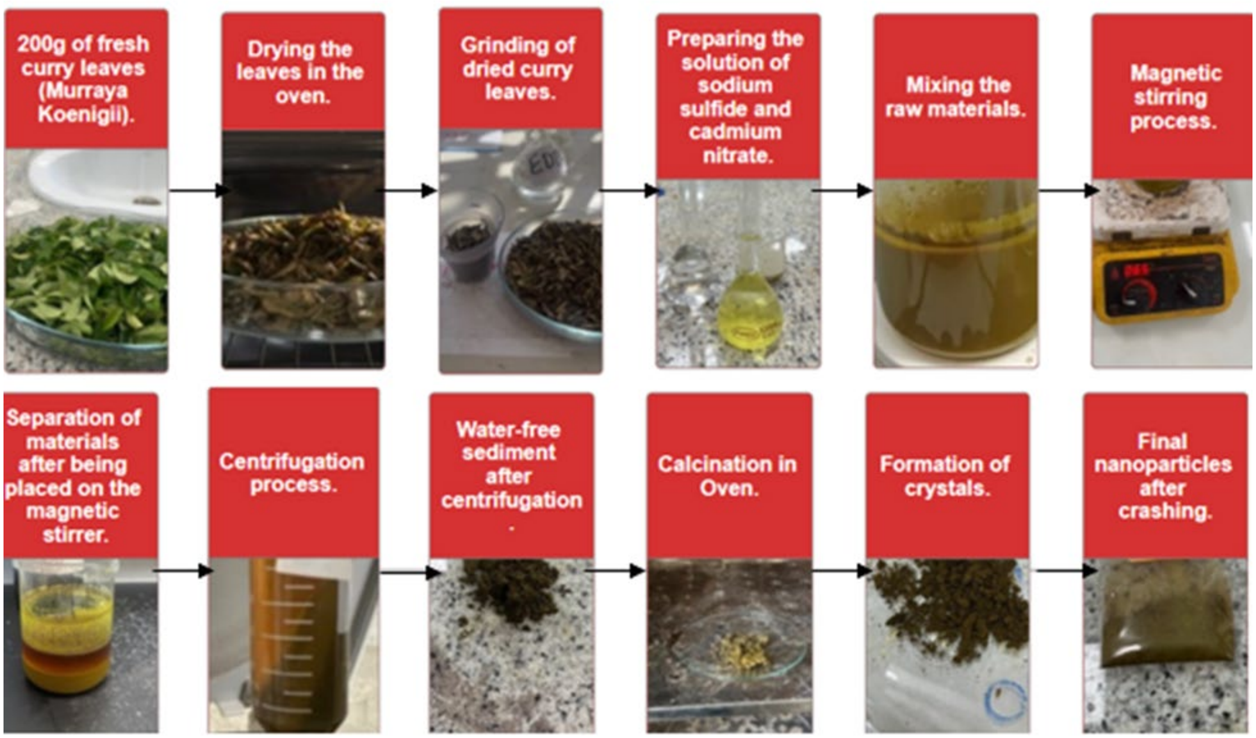

Figure 1. Process Flow Chart for the Synthesis of Cadmium Sulphide Nanoparticles

3.1 Preparation of Plant Material

Fresh Murraya koenigii leaves were collected from local sources and thoroughly washed with distilled water to remove any dirt and impurities. The cleaned leaves were then dried in an oven at 120 °C for 2.5 hours to eliminate moisture content. Once dried, the leaves were ground into a fine powder using a grinding machine, and the powder was sieved to obtain uniform particles measuring approximately 300 µm in size. This powdered form of curry leaves served as the reducing and stabilizing agent in the synthesis of CdS nanoparticles.

3.2 Synthesis of Cadmium Sulphide Nanoparticles

The synthesis of CdS nanoparticles was carried out using a sol-gel method, which is a widely recognized approach for producing nanoparticles. The following steps were undertaken:

1. **Preparation of Precursor Solutions**: A solution of cadmium nitrate ($Cd(NO3)2$) was prepared by dissolving 10 grams of cadmium nitrate in 400 ml of deionized water. Simultaneously, a sodium sulfide ($Na2S$) solution was prepared by dissolving 10 grams of sodium sulfide in 400 ml of deionized water.
2. **Mixing of Solutions**: Ten grams of the prepared Murraya koenigii leaf powder was added to the cadmium nitrate solution. The mixture was stirred continuously on a magnetic stirrer at a temperature of 65 °C and a

speed of 500 rpm for 6 hours. This step facilitated the reduction of cadmium ions by the phytochemicals present in the curry leaf extract, leading to the formation of CdS nanoparticles.

3. **Precipitation and Separation**: After the stirring process, the resulting mixture was allowed to settle, and the precipitate containing the CdS nanoparticles was separated from the liquid phase. The precipitate was then subjected to centrifugation at 6000 rpm for 10 minutes to remove any unreacted materials and impurities.
4. **Drying and Calcination**: The collected precipitate was dried in an oven at 107 °C for 2 hours to obtain dry CdS nanoparticles. The dried nanoparticles were then calcined to enhance crystallinity and stability.

3.3 Characterization of Cadmium Sulphide Nanoparticles

The synthesized CdS nanoparticles were characterized using several analytical techniques to determine their structural, morphological, and compositional properties:

1. **Scanning Electron Microscopy (SEM)**: The surface morphology of the CdS nanoparticles was examined using SEM. This technique provided insights into the shape and size distribution of the nanoparticles.
2. **Energy-Dispersive X-ray Spectroscopy (EDX)**: EDX analysis was performed in conjunction with SEM to determine the elemental composition of the synthesized nanoparticles. The purity of the CdS nanoparticles was assessed based on the atomic percentages of cadmium and sulfur.
3. **X-ray Diffraction (XRD)**: The crystallinity of the CdS nanoparticles was evaluated using XRD. The diffraction patterns were analyzed to identify the crystalline phases and calculate the average particle size using the Scherrer formula.

3.4 Evaluation of Effectiveness in Wastewater Treatment

The effectiveness of the synthesized CdS nanoparticles in wastewater treatment was assessed through a series of experiments:

1. **Sample Collection**: Wastewater samples were collected from the municipality, and their initial characteristics, including total organic carbon (TOC) and biochemical oxygen demand (BOD), were measured.
2. **Treatment Process**: Different dosages of CdS nanoparticles (0.5 g, 1 g, and 1.5 g) were added to separate aliquots of the wastewater samples. The mixtures were stirred for a specified duration to ensure proper interaction between the nanoparticles and the contaminants.
3. **Analysis of Treated Samples**: After treatment, the TOC and BOD levels of the treated wastewater samples were measured to evaluate the reduction in organic pollutants. The results were compared to the initial values to determine the effectiveness of the CdS nanoparticles in improving water quality.

4. Results and Discussion

This section presents the findings from the synthesis of cadmium sulphide (CdS) nanoparticles using Murraya koenigii leaves and their application in treating domestic wastewater. The results are discussed in the context of their implications for environmental sustainability and the effectiveness of green synthesis methods. The characterization of the synthesized nanoparticles was performed using Scanning Electron Microscopy (SEM), Energy Dispersive X-ray Spectroscopy (EDX), and X-ray Diffraction (XRD).

4.1 Morphology and Size

The morphology and size of the cadmium sulphide (CdS) nanoparticles were analyzed using Scanning Electron Microscopy (SEM) as shown in Figure 2. SEM images revealed that the CdS nanoparticles exhibited a spherical morphology with an average size of approximately 100 nm, consistent with findings from previous studies . The images indicated some degree of agglomeration, which is common in nanoparticle synthesis due to intermolecular forces and particle interactions. The agglomeration may affect the nanoparticles' reactivity and stability in wastewater treatment applications.

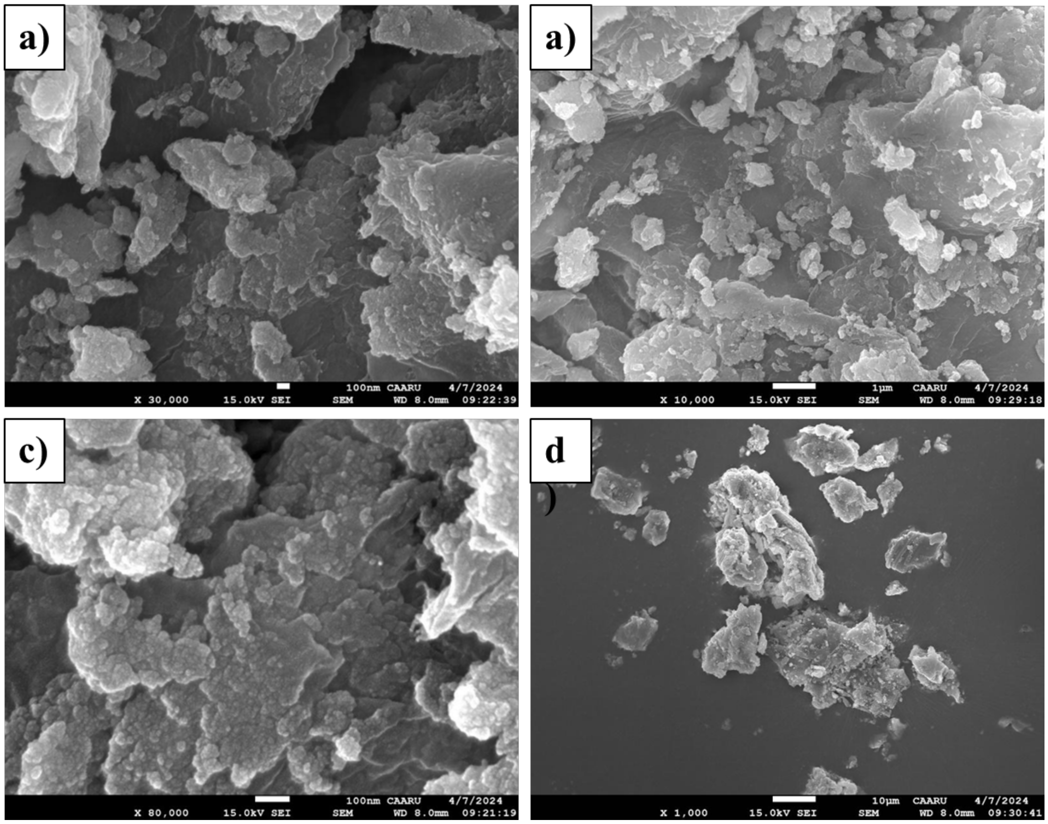

Figure 2. SEM Images of Cadmium Sulphide Nanoparticles

4.2 Elemental Composition

EDX analysis shown in the Figure 3 confirmed the presence of cadmium and sulfur in the synthesized nanoparticles, with atomic percentages of 48.8% Cd and 13.6% S . The purity of the nanoparticles was approximately 50%, indicating that further purification steps may be necessary for specific applications. The EDX spectrum shows strong signals for cadmium and sulfur, confirming the elemental composition of the synthesized nanoparticles.

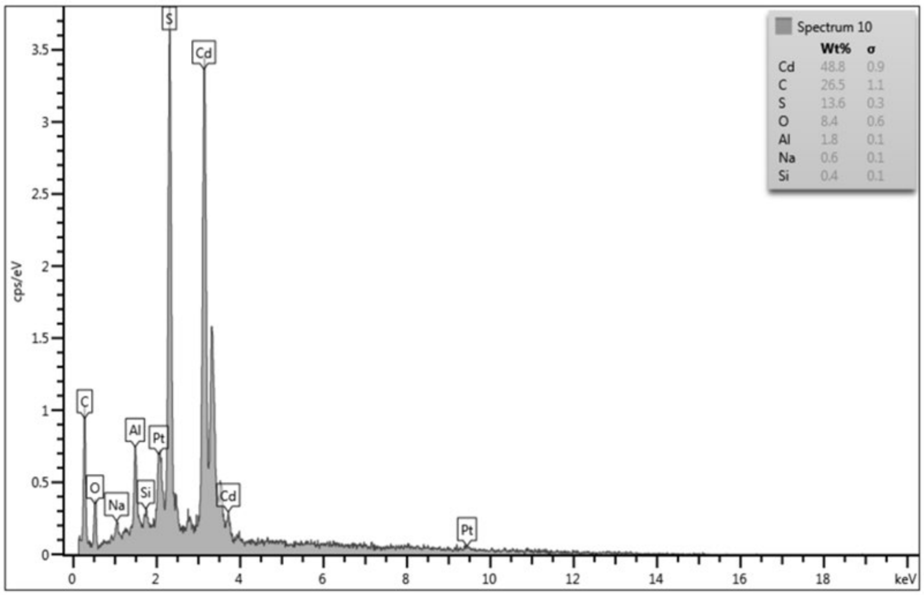

Figure 3. EDX Analysis of Green Synthesis CdS Nanoparticles Using Murraya Koenigii

4.3 Crystallinity

The crystallinity of the cadmium sulphide (CdS) nanoparticles was assessed using X-ray Diffraction (XRD) analysis. The XRD pattern provides information about the crystalline structure and phase purity of the synthesized nanoparticles, as shown in Figure 4. XRD patterns showed characteristic peaks at 2θ values of 26.6°, 43.9°, and 51.8°, confirming the crystalline nature of the CdS nanoparticles. The average particle size calculated using the Scherrer formula was found to be 13.13 nm, indicating that the nanoparticles were within the nanoscale range, which is essential for their application in wastewater treatment. The XRD pattern displays characteristic peaks that confirm the crystalline nature of the CdS nanoparticles, indicating successful synthesis and the presence of the desired phase.

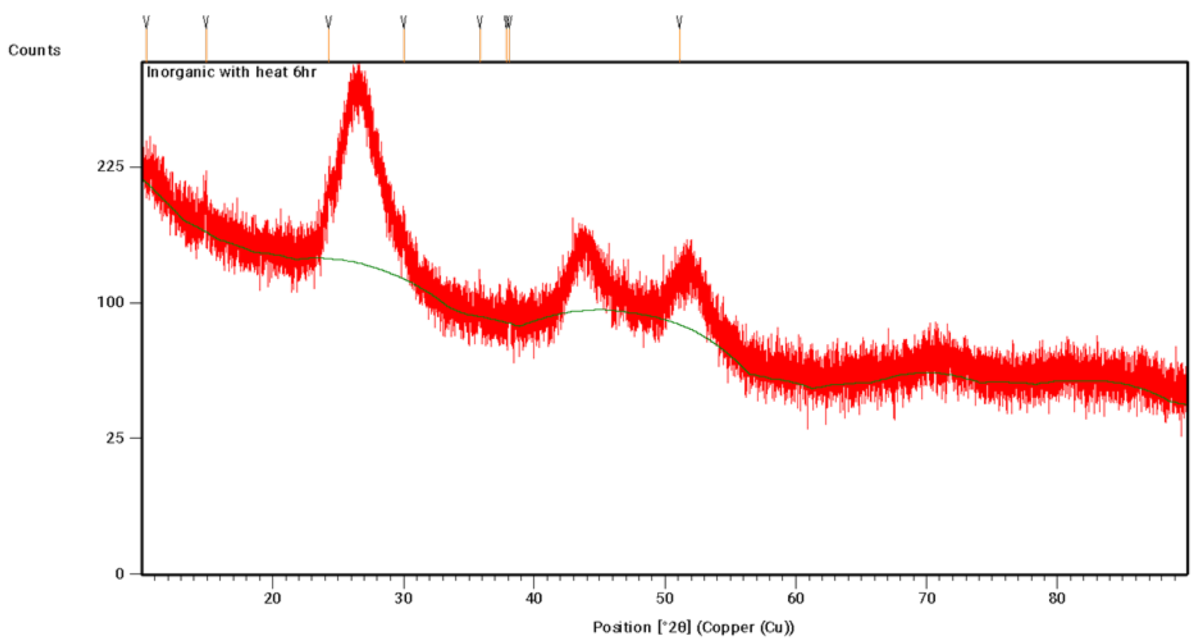

Figure 4. XRD Pattern of Cadmium Sulphide Nanoparticles (CdS NPs)

4.4 Initial Characterization of Wastewater Samples

The effectiveness of the synthesized CdS nanoparticles in treating wastewater was assessed by adding different dosages (0.5 g, 1 g, and 1.5 g) to the wastewater samples. The results of the post-treatment analysis are summarized in Table 1.

Table 1. Changes in Water Quality Parameters Before and After the Addition of Cadmium Sulphide Nanoparticles (CdS NPs) in Domestic Wastewater

Parameter	Before Adding CdS NPs	Sample	After Adding CdS NPs (Day 0)	After Adding CdS NPs (Day 5)
Total Organic Carbon (TOC)	229.2 ppm	1. 0.5g CdS NPs	218 ppm	195 ppm
		2. 1g CdS NPs	206 ppm	160 ppm
		3. 1.5g CdS NPs	105 ppm	137 ppm
Total Carbon (TC)	268.8 ppm	1. 0.5g CdS NPs	241.9 ppm	201.6 ppm
		2. 1g CdS NPs	228.5 ppm	174.7 ppm
		3. 1.5g CdS NPs	215 ppm	147.8 ppm
Inorganic Carbon (Ic)	39.60 ppm	1. 0.5g CdS NPs	37.62 ppm	33.66 ppm
		2. 1g CdS NPs	35.64 ppm	31.68 ppm
		3. 1.5g CdS NPs	33.66 ppm	27.72 ppm
Dissolved Oxygen (DO)	16.2 mg/L	1. 0.5g CdS NPs	13.3 mg/L	3.9 mg/L
		2. 1g CdS NPs	10 mg/L	2.7 mg/L
		3. 1.5g CdS NPs	4.8 mg/L	1.6 mg/L

The analysis of domestic wastewater before and after the addition of cadmium sulphide nanoparticles (CdS NPs) revealed significant changes in key parameters, including Total Organic Carbon (TOC), Total Carbon (TC), Inorganic Carbon (Ic), and Dissolved Oxygen (DO).

4.5 Total Organic Carbon (TOC)

Levels were measured at 229.2 ppm before the addition of CdS NPs. After the introduction of different dosages of CdS NPs, TOC levels decreased across all samples. Specifically, for Sample 1 with 0.5g of CdS NPs, TOC reduced to 218 ppm on Day 0 and further decreased to 195 by Day 5. Sample 2 with 1g of CdS NPs showed a decrease from 206 ppm on Day 0 to 160 ppm on Day 5. The most significant reduction was observed in Sample 3 with 1.5g of CdS NPs, where TOC levels dropped from 105 ppm on Day 0 to 137 ppm on Day 5. These results indicate that the addition of CdS NPs effectively contributed to the reduction of organic carbon content in the wastewater (Figure 5).

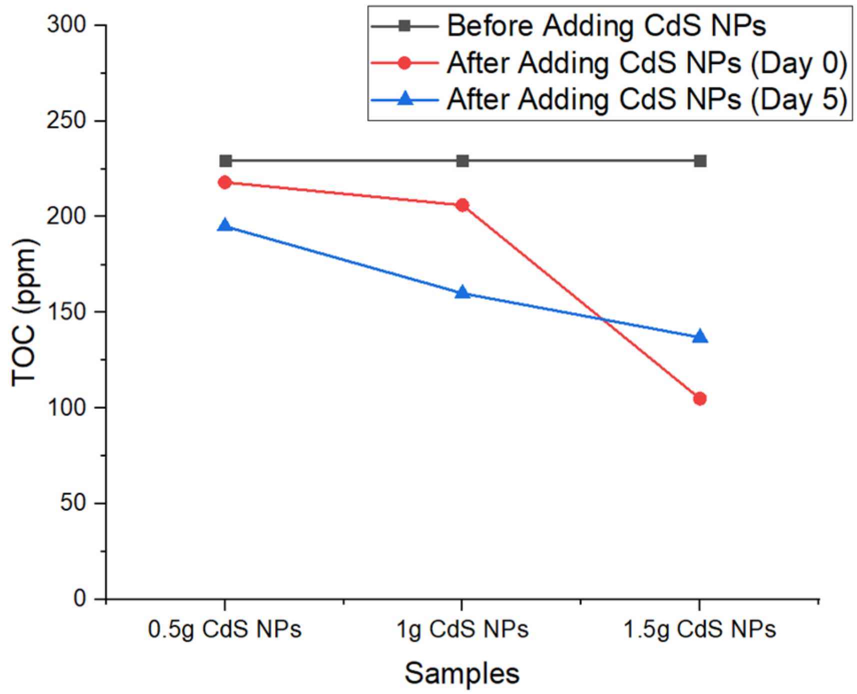

Figure 5. Effect of CdS nanoparticles on Total Organic Carbon (TOC) levels in domestic water.

4.6 Total Carbon (TC)

Values also exhibited a declining trend. Initially recorded at 268.8 ppm, TC levels decreased in all samples after the addition of CdS NPs. For Sample 1, TC was measured at 241.9 ppm on Day 0 and decreased to 201.6 ppm by Day 5. Sample 2 showed a reduction from 228.5 ppm to 174.7 ppm, while Sample 3 decreased from 215 ppm to 147.8 ppm. The consistent reduction in TC across all samples further supports the effectiveness of CdS NPs in reducing carbon content in wastewater (Figure 6).

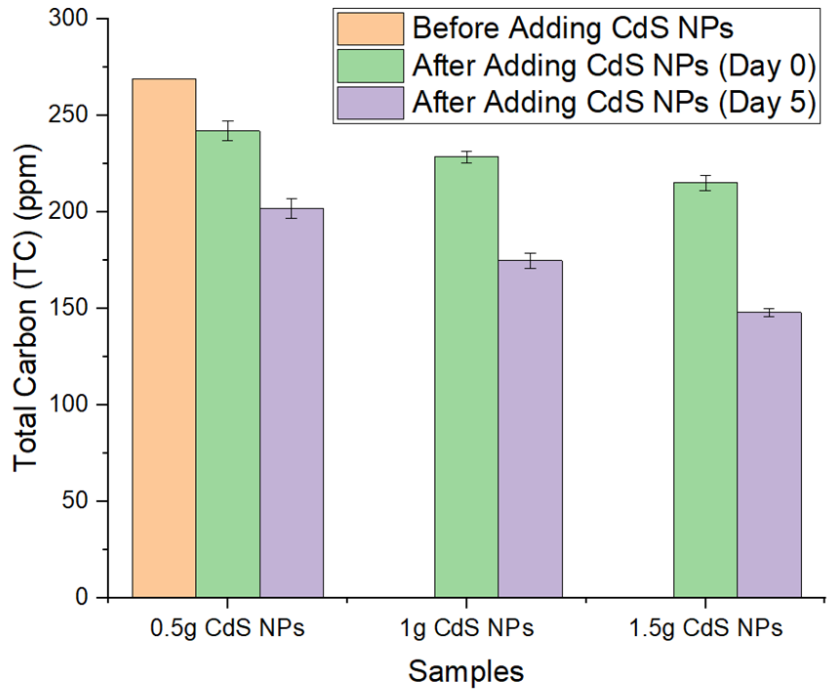

Figure 6. Effect of CdS nanoparticles on Total Carbon (TC) levels in domestic water.

4.7 Inorganic Carbon (IC)

Levels were recorded at 39.60 ppm before the addition of CdS NPs. After treatment, Sample 1 showed Ic levels of 37.62 ppm on Day 0 and 33.66 ppm on Day 5. Sample 2's Ic decreased from 35.64 ppm to 31.68 ppm, and Sample 3's Ic levels dropped from 33.66 ppm to 27.72 ppm. The decrease in Ic indicates that the addition of CdS NPs not only reduced organic carbon but also affected the inorganic carbon content in the wastewater (Figure 7).

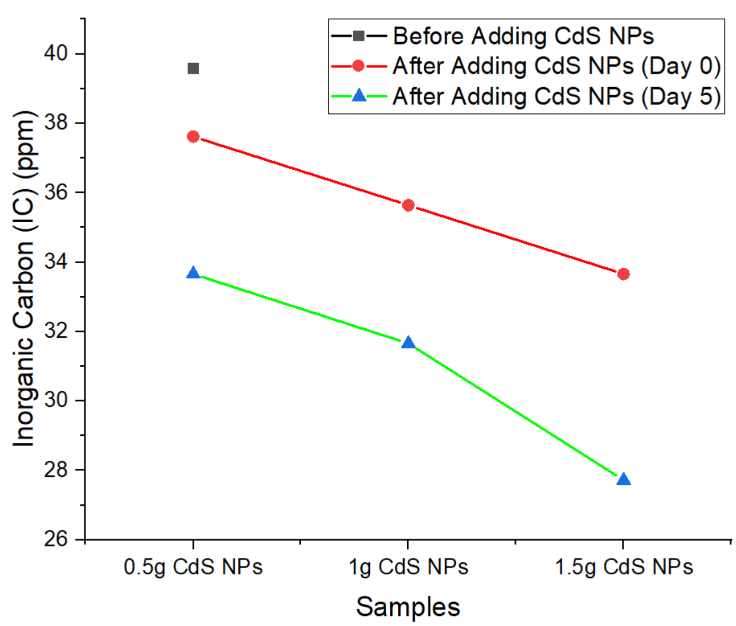

Figure 7. Effect of CdS nanoparticles on Inorganic Carbon(IC) levels in domestic water.

4.8 Dissolved Oxygen (DO)

Levels were initially measured at 16.2 mg/L. Following the addition of CdS NPs, a notable decline in DO was observed. For Sample 1, DO decreased from 13.3 mg/L on Day 0 to 3.9 mg/L on Day 5. Sample 2's DO levels dropped from 10 mg/L to 2.7 mg/L, while Sample 3 experienced a reduction from 4.8 mg/L to 1.6 mg/L. The significant decrease in DO levels suggests that the microbial activity associated with the decomposition of organic matter was influenced by the presence of CdS NPs, leading to increased oxygen consumption (Figure 8).

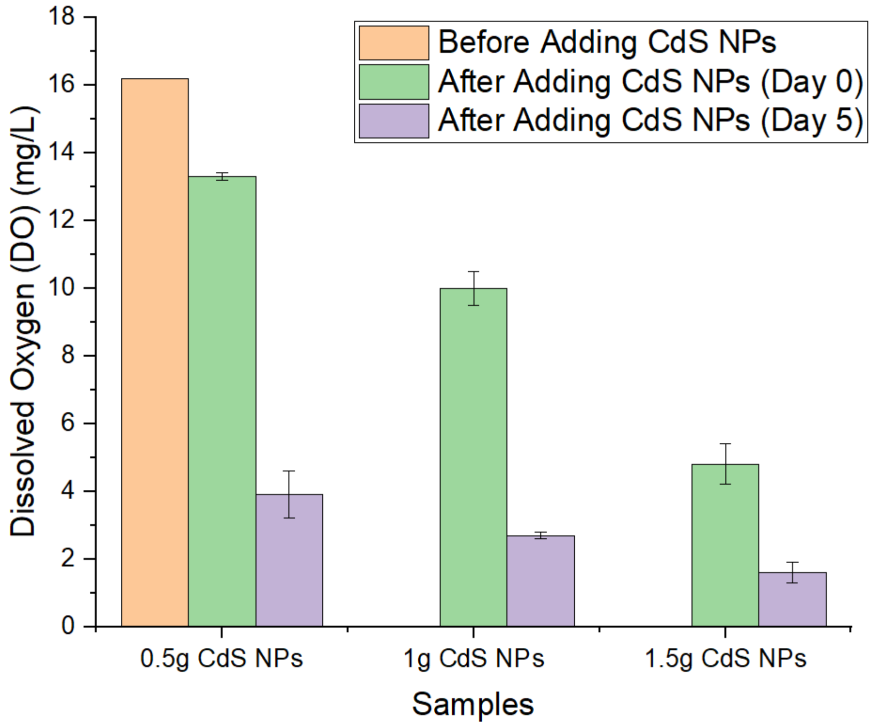

Figure 8. Effect of CdS nanoparticles on Dissolved Oxygen (DO) levels in domestic water.

The results indicate that the addition of CdS NPs effectively reduced TOC, TC, and Ic levels in domestic wastewater, demonstrating their potential as a treatment method for improving water quality. The observed decrease in DO levels highlights the impact of CdS NPs on microbial activity, which is crucial for the biodegradation of organic pollutants. These findings support the use of CdS NPs in wastewater treatment processes, contributing to environmental sustainability and the reduction of organic contaminants in water bodies.

5. Conclusion

This study successfully demonstrated the efficacy of cadmium sulphide nanoparticles (CdS NPs) in enhancing the quality of domestic wastewater through the reduction of key parameters such as Total Organic Carbon (TOC), Total Carbon (TC), Inorganic Carbon (Ic), and Dissolved Oxygen (DO). The results indicated a significant decrease in TOC and TC levels following the addition of varying dosages of CdS NPs, highlighting their effectiveness in removing organic contaminants from wastewater.

The analysis revealed that the highest reduction in TOC and TC occurred with the application of 1.5g of CdS NPs, underscoring the relationship between nanoparticle dosage and pollutant removal efficiency. Additionally, the observed decline in DO levels suggests that microbial activity was significantly influenced by the presence of CdS NPs, leading to increased oxygen consumption as organic matter was decomposed.

Overall, the findings of this study support the potential application of CdS NPs as a sustainable and effective method for wastewater treatment. Their ability to reduce organic and inorganic carbon levels while promoting microbial degradation processes positions them as a viable alternative to conventional treatment methods. However, it is important to note that while the treated water may meet certain safety standards for non-potable uses, the presence of CdS NPs necessitates caution regarding its suitability for human consumption. Future research should focus on optimizing CdS NP dosages and exploring their long-term environmental impacts to ensure safe and effective wastewater treatment solutions.

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