Addressing Climate Change with Green Technologies: Biomass-Based Remediation of Heavy Metals in Hattar Industrial Estate Wastewater

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Abstract

Heavy metals in industrial wastewater, such as lead, mercury, and cadmium, pose significant environmental and health risks. This study examines the use of biomass from seasonal fruit and vegetable peels (banana, onion, watermelon, and melon) to reduce heavy metal concentrations in wastewater from Hattar Industrial Estate, specifically from FAG Pharma and Fauji Banaspati. Four samples were prepared with varying biomass quantities and treatment durations: Sample 1 (1g biomass, 6-hour treatment with 3 hours of mixing and 3 hours of resting), Sample 2 (2g biomass, 6-hour treatment with 3 hours of mixing and 3 hours of resting), Sample 3 (1g biomass, 24-hour treatment with 12 hours of mixing and 12 hours of resting), and Sample 4 (2g biomass, 24-hour treatment with 12 hours of mixing and 12 hours of resting). Water quality was assessed using BOD, COD, TDS, TSS, EC, pH, and Atomic Adsorption Spectroscopy (AAS) for metal detection. The best results were observed in Sample 4, with 2g of biomass and a 24-hour treatment, showing the greatest reduction in heavy metal concentrations. This approach provides a cost-effective method for treating industrial wastewater.

Keywords: Heavy Metals; Biomass; Industrial Waste: Climate Change; Green Technologies

1. Introduction

The presence of heavy metals in industrial wastewater poses significant threats to both human health and the environment. Heavy metals such as lead, mercury, and cadmium are highly toxic and tend to accumulate in ecosystems, where they can adversely affect plants, animals, and humans. This issue is particularly critical in industrial estates, where concentrations of these metals are often elevated. Effluents from various industries in the Hattar Industrial Estate have been found to contain high levels of heavy metals, including chromium, cadmium, copper, lead, nickel, and zinc. Numerous studies conducted globally have focused on identifying and implementing solutions to mitigate this problem. Various studies are being conducted globally to develop sustainable solutions through the reuse of wastewater.

Reference [1] presents an overview of wastewater reclamation and reuse in the Mediterranean region, focusing on existing guidelines and regulations. Reference [2] explores the effectiveness of microalgae and biomass in the treatment of food processing wastewater. Their study achieved over 90% nutrient removal, suggesting that biomass-based systems could be effective in addressing both nutrient and heavy metal pollution in industrial effluents. [3] presents a method for treating food processing wastewater using reverse osmosis and microalgae cultivation to recover nitrogen, phosphorus, and biomass. The process achieves over 90% nutrient removal and produces valuable resources. [4] explored various water/wastewater treatment methodologies, emphasizing the use of

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agricultural waste materials, such as fruit peels, which contain rich functional groups capable of heavy metal adsorption. The study explores how wastewater management supports 11 out of 17 UN Sustainable Development Goals (SDGs), enhancing water availability, health, income, renewable energy, and environmental sustainability. It also discusses the challenges of effective implementation [5]. [6] investigates wastewater treatment using a high-performance biological system with high biomass concentration, which improves pollutant removal efficiency and sustainability. [7] Presents a systematic literature review on wastewater treatment and reuse, focusing on their role in sustainable water resources management. [8] highlights the synergistic interaction between algae and bacteria, improving pollutant removal and treatment efficiency while promoting sustainable wastewater management. This paper discusses the effects of water pollution, identifying major toxic pollutants, their sources, and impacts [9]. [10] evaluates the sustainability of wastewater treatment technologies using economic, environmental, and societal indicators. It highlights differences in sustainability across systems like mechanical, lagoon, and land treatments, depending on local contexts.

[11] reviewed wastewater treatment and reuse, specifically in industrial areas, highlighting challenges in treating effluents from heavy industries. His research underscores the potential of low-cost biomass-based solutions to address these challenges in developing regions. [12] investigated the biosorption process using high-performance biological systems, focusing on the role of biomass concentration and its ability to enhance pollutant removal. They found that increasing biomass concentration generally improved metal ion adsorption. One approach being explored is the use of biomass as a potential remediation method. The effectiveness of biomass depends on factors such as surface area, porosity, chemical composition, and functional groups capable of metal binding.

Biomass, such as agricultural waste or plant materials, has shown promise in reducing heavy metal levels by acting as a sorbent or adsorbent. Numerous treatment methods have been developed to reduce heavy metal concentrations in industrial wastewater. However, these conventional methods have limitations such as high costs and potential waste problems. As a result, exploring alternative, cost-effective, and environmentally friendly approaches to reduce heavy metal concentrations in industrial wastewater is essential. One emerging approach is the use of biomass for heavy metal removal. Biomass, which refers to organic materials derived from living organisms, has shown promise as a biosorbent for heavy metals. Biosorption is the process by which biomass materials bind and remove heavy metal ions from wastewater.

Including membrane filtration, ion-exchange, adsorption, chemical precipitation, nanotechnology treatments, electrochemical and advanced oxidation processes.

2. Methodology

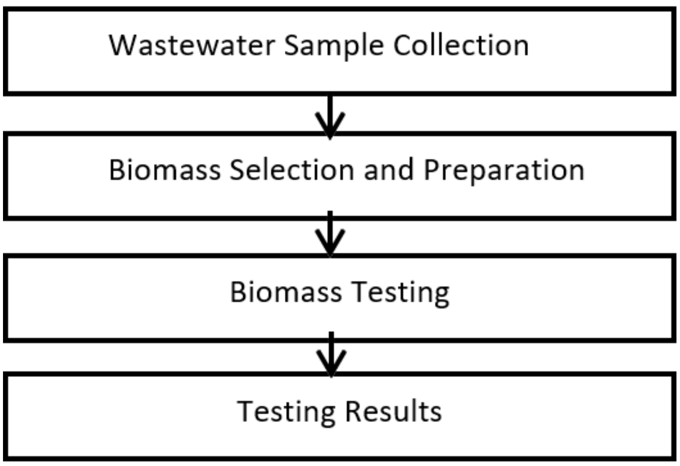

Figure 1. Research Methodology

2.1. Site Selection and visit:

Fauji Banaspati and FG Pharmaceutics located in Hattar Industrial Estate Haripur, were selected for sample collection. Wastewater Sample was collected from the from the drains of two selected Industries.

2.2. Biomass Selection and Preparation:

Seasonal fruits and vegetables peels i.e. cantaloupe, banana, watermelon, and Onions were selected for their availability and potential biosorption properties. The peels were thoroughly cleaned with distilled water to remove any impurities or contaminants. After cleaning, the peels were sun-dried completely to ensure removal of moisture and to preserve their integrity. Once dried, the peels were crushed into a fine powder form to increase their surface area, which enhances their ability to adsorb heavy metals.

2.3. Biomass, Bio sorption Testing:

Equal masses of all four types of biomasses were mixed together to create a homogeneous mixed biomass for testing. 100ml of sample solution was taken and 1g of the mixed biomass was added. This was repeated with another set of samples using different amounts of biomasses, that samples are then tested for their specific tests. The samples were then placed on a magnetic stirrer for 3 hours to ensure thorough mixing and interaction between the biomass and the solution. After stirring, they were allowed to rest for 3 hours to facilitate adsorption. A similar procedure was followed for 24 hours, with 12 hours of mixing and 12 hours of resting, to observe the effect of extended contact time on bio sorption efficiency. After the testing process, each sample was filtered to separate the biomass from the solution. The filtered solutions were then analyzed using atomic absorption spectroscopy to quantify the concentration of heavy metals remaining after the biosorption process. In addition to heavy metal analysis, further tests were conducted on 50 mL samples to evaluate water quality parameters, including Total Dissolved Solids (TDS), Total Suspended Solids (TSS), Electrical Conductivity (EC), pH, temperature, Chemical Oxygen Demand (COD), and Biological Oxygen Demand (BOD). The reduction in heavy metal concentrations was compared across varying biomass quantities (1 g and 2 g) and contact times (6 hours and 24 hours). The analysis aimed to determine the optimal conditions for biosorption based on removal efficiency, cost-effectiveness, and practical applicability. For the 6-hour treatment, a 3-hour mixing followed by a 3-hour resting period was employed, while the 24-hour treatment used a 12-hour mixing and 12-hour resting cycle. These durations were selected to ensure sufficient interaction between the biomass and wastewater, while maintaining practical feasibility. The mixing phase facilitates contact between the biomass and contaminants, whereas the resting phase allows adsorption to occur effectively. Alternative time ratios may influence outcomes and warrant investigation in future studies to further enhance the biosorption process. The study also includes a review of various bioremediation techniques, drawing on both domestic and international literature. The focus is on bio sorption, a method where biomass acts as a bio sorbent to remove heavy metal ions from wastewater.

3. Results

3.1. Testing of Initial Samples:

Different types of tests are conducted initially for the Industrial waste water quality testing; Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Suspended Solids (TSS), Total Dissolved Solids (TDS), Electrical Conductivity (EC), Temperature, pH and Atomic Adsorption Spectroscopy (AAS). Table 2 shows the comparison of some water parameters (as a result of initial testing) with NEQS standards.

Table 1 : Initial Waste Water Testing

Parameters	Units	FAG pharma	Fuji Banaspati	NEQS
BOD	mg/l	190	160	80
COD	mg/l	260	210	150
TDS	ppm	448	9592	3500
TSS	ppm	19	317	200
EC	us/cm	139.8	330	30-1500
PH	-	5.3	5.6	6-9
T	C	28.5	26.2	40

3.2. Atomic Adsorption Spectroscopy (AAS):

The number of heavy metals in wastewater is measured using atomic absorption spectroscopy. Table 2 indicated the initial AAS testing on waste water sample collected form two different industries. The decision to use equal proportions of the selected peels (banana, onion, watermelon, and melon)

Table 2 Atomic Adsorption Spectroscopy (AAS)

Heavy Metals	Units	FAG pharma	Fuji Banaspati
Cd	mg/l	0.043	0.055
Cr	mg/l	0	0
Cu	mg/l	0	0
Pb	mg/l	0.288	0.229

Adsorption is essentially a mass transfer process that moves a material from the liquid phase onto the solid surface where it is bound by chemical or physical interactions. Table 4, 5, 6 and 7 indicated the results of different amount of waste water having different quantities of Biomasses amount added.

3.3. Biomass Addition:

Table 3: 1 gm (duration 6-hr)

Heavy Metals	Units	FAG pharma	Fuji Banaspati
Cd	mg/l	0.041	0.030
Pb	mg/l	0	0

3.4. Biomass Addition:

Table 4: 2 gm (duration 6-hr)

Heavy Metals	Units	FAG pharma	Fuji Banaspati
Cd	mg/l	0	0
Pb	mg/l	0.087	0.120

3.5. Biomass Addition:

Table 5: 1 gm (duration -24hr)

Heavy Metals	Units	FAG pharma	Fuji Banaspati
Cd	mg/l	0.016	0.042
Pb	mg/l	0	0

3.6. Biomass Addition:

Table 6: 2 gm (duration 24-hr)

Heavy Metals	Units	FAG pharma	Fuji Banaspati
Cd	mg/l	0.009	0.017
Pb	mg/l	0	0

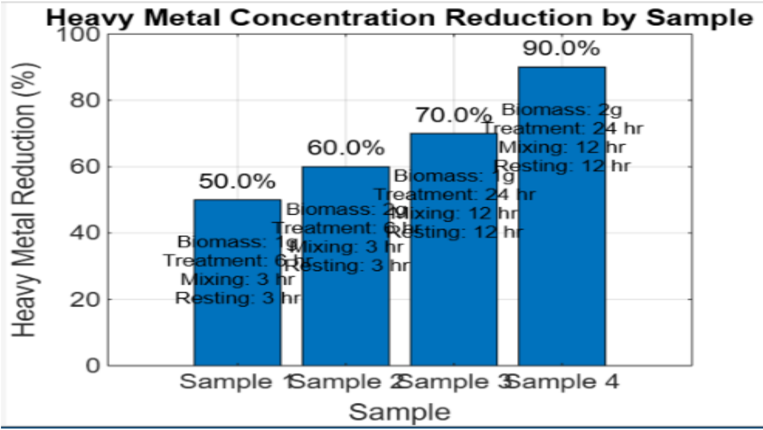

Figure 2: Overview of Metal Reduction in Samples by Biomass

Figure 2 indicates the pictorial view of overall metal reduction in all four samples with the addition of Biomass quantity.

Table 7: Overall Results for Fauji Banaspati

Element	Duration	Biomass (gm)	Initial value (mg/l)	Final value (mg/l)	Sample (ml)	Reduction Factor %
Cd	6	1	0.055	0.03	100	45.45
Pb	6	1	0.229	0	100	100
Cd	6	2	0.055	0	100	100
Pb	6	2	0.229	0.12	100	47.59
Cd	24	1	0.051	0.042	100	17.64
Pb	24	2	0.051	0.017	100	66.66

Table8: Overall Results for FG Pharmaceutical

Element	Duration	Biomass (gm)	Initial value (mg/l)	Final value (mg/l)	Sample (ml)	Reduction Factor %
Cd	6	1	0.043	0.041	100	4.65
Pb	6	1	0.288	0	100	100
Cd	6	2	0.043	0	100	100
Pb	6	2	0.288	0.087	100	69.79
Cd	24	1	0.026	0.016	100	38.64
Pb	24	2	0.026	0.009	100	65.38

4. Conclusions

The objective of this study was to evaluate the efficiency of biomass in biosorbing heavy metals from wastewater. Using atomic absorption spectroscopy (AAS), the study found that biomass, derived from the peels of seasonal fruits and vegetables (banana, onion, watermelon, and melon), significantly reduced the concentrations of heavy metals, specifically cadmium (Cd) and lead (Pb), in wastewater samples from the Hattar Industrial Estate. The biomass was prepared by drying, grinding, and mixing the peels in equal proportions, then adding varying amounts of this biomass to the wastewater to determine the optimal quantity for effective metal removal. Four different sample conditions were tested: 1 g of biomass for 6 hours (3 hours of mixing and 3 hours of resting), 2 g of biomass for 6 hours, and 1 g and 2 g of biomass for 24 hours (12 hours of mixing and 12 hours of resting). The results showed that the 2 g biomass with a 24-hour treatment was the most effective in reducing heavy metal concentrations. This suggests that biomass has strong potential for removing heavy metals through mechanisms such as ion exchange, complexation, and adsorption at functional groups within the bio sorbent structure.

5. Practical Implementations

Biomass-based heavy metal removal offers a cost-effective, scalable, and environmentally sustainable method for treating industrial wastewater. Utilizing agricultural waste such as fruit and vegetable peels allows industries to reduce waste disposal costs while avoiding the use of harmful chemical treatments. This method can be easily integrated into existing wastewater treatment systems and provides a practical, low-maintenance alternative. When stored in cool, dry conditions, the biomass maintains its effectiveness for several months, making it suitable for long-term use. This approach supports compliance with environmental regulations and wastewater discharge standards, while also promoting sustainability by decreasing dependence on toxic chemicals. Further research may enhance the process by evaluating various biomass types and treatment conditions, thereby improving efficiency and broadening its applicability across different industrial sectors.

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