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# Adsorption Techniques for Heavy Metal Removal from Industrial Wastewater in Damonjodi, Odisha.

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The contamination of water resources by heavy metals, particularly in industrial zones, is a growing environmental concern. This research investigates the efficacy of adsorption techniques for the removal of heavy metals from industrial wastewater in Damonjodi, Odisha. As a region with considerable mining and industrial activities, Damonjodi's wastewater streams contain toxic metals such as lead (Pb), cadmium (Cd), and chromium (Cr), which pose significant risks to human health and the ecosystem. This study evaluates various adsorbents, including activated carbon, agricultural waste products, and synthetic adsorbents, assessing their performance in terms of removal efficiency, cost-effectiveness, and environmental sustainability. The findings provide insights into the practical applications of adsorption methods for treating industrial wastewater in the region, offering potential solutions for environmental remediation.

**Keywords:** Adsorption, Heavy Metals, Industrial Wastewater, Environmental Remediation, Activated Carbon, Agricultural Waste Products, Damonjodi, Odisha.

## 1. Introduction

Heavy metal contamination in industrial wastewater is a pervasive issue worldwide, with severe consequences for both the environment and human health. The region of Damonjodi, Odisha, is home to several mining and industrial operations that release pollutants, including toxic metals such as lead (Pb), cadmium (Cd), chromium (Cr), and arsenic (As), into the local water bodies. These metals, even in low concentrations, can cause serious health problems, including cancer, kidney damage, and developmental disorders.

The removal of heavy metals from industrial wastewater is critical, and various treatment technologies have been explored. Among them, adsorption is one of the most widely used and cost-effective methods due to its simplicity, efficiency, and adaptability to different pollutants. This paper focuses on exploring the potential of adsorption techniques for the removal of heavy metals from industrial effluents in Damonjodi.

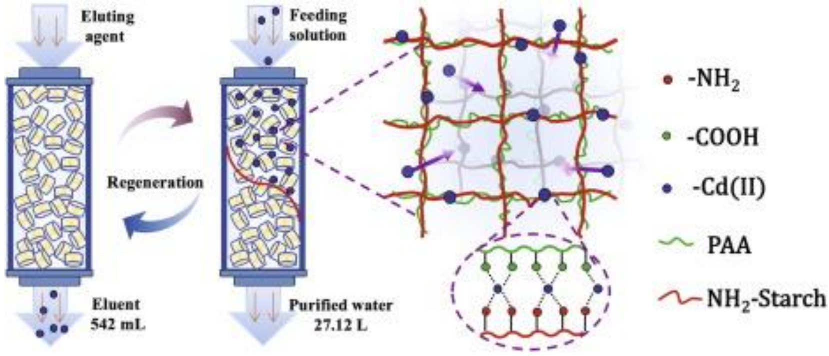


Fig -1

**2. Literature review**

Adsorption works by transferring pollutants from the liquid phase to the surface of a solid adsorbent, typically driven by physical or chemical interactions. Various materials, including activated carbon, natural clays, agricultural waste, and synthesized adsorbents, have been investigated for their effectiveness in heavy metal removal.

Activated carbon is one of the most commonly used adsorbents due to its high surface area and porosity. It has been widely applied for the removal of heavy metals from industrial effluents, including those in the mining sector (Kumar et al., 2014). However, the cost of activated carbon remains a limitation, especially for large-scale operations. To address this, researchers have focused on low-cost alternative adsorbents, such as agricultural waste products, which are abundant in many regions of India, including Odisha. Materials like neem bark (Azadirachta indica), rice husk, and coconut shells have shown considerable potential for heavy metal uptake (Babel & Kurniawan, 2003).

Several studies have reported high removal efficiencies of heavy metals using adsorption methods. For example, the use of neem leaf powder has been shown to efficiently remove lead and copper from aqueous solutions (Kumar et al., 2017). The surface properties of neem leaves, including functional groups like carboxyl, hydroxyl, and amino, facilitate the binding of metal ions. Similarly, rice husk ash, a readily available by-product, has demonstrated the ability to adsorb cadmium and lead with significant efficiency (Bhowmick et al., 2020).

Additionally, bio-sorption, the use of living organisms or their by-products, is gaining attention due to its eco-friendly nature. Algae, fungi, and bacteria can be used to remove heavy metals from wastewater, as they possess metal-binding sites on their cell walls (Gadd, 2009). Studies suggest that microbial bio-sorbents from locally available species in Odisha can be developed for cost-effective heavy metal removal in mining regions like Damonjodi.

While adsorption is an effective technique, there are several challenges that need to be addressed. One major issue is the regeneration of adsorbents. Many adsorbents, especially those derived from natural sources, have limited reusability, which can increase the cost of treatment in the long run. Moreover, the effectiveness of the adsorbents can vary depending on the specific characteristics of the wastewater, such as pH, temperature, and the presence of competing ions (Kumar & Kumar, 2015).

Another concern is the scalability of adsorption systems. While laboratory-scale studies demonstrate promising results, the performance of these systems on a larger scale, particularly in industrial settings, may be influenced by factors such as flow rate and the concentration of contaminants. As such, pilot-scale studies and optimization of operational parameters are essential before full-scale implementation.

## 2. Materials and Methods

### 2.1. Study Area

The study was conducted in Damonjodi, a region located in the Koraput district of Odisha, India, which serves as an important industrial hub. This region is home to various mining operations, including bauxite extraction and alumina refining. The industrial activities in this area generate significant amounts of effluent, which contain various hazardous metals such as aluminum, iron, and other toxic substances. These metals are released into local water bodies, including rivers and lakes, which serve as crucial water sources for surrounding communities. Consequently, the contamination of these water bodies poses a severe risk to both aquatic life and public health (Sahoo et al., 2018).

To address the impact of these contaminants, the present study focused on analyzing and treating wastewater samples obtained from various industrial discharge points in Damonjodi. The main goal of the study was to evaluate the effectiveness of different adsorbents in removing hazardous metals from wastewater, which could help mitigate the environmental damage caused by these industrial activities. By testing different adsorbents, the study aimed to identify a cost-effective and sustainable solution for wastewater treatment in the region.

### 2.2. Adsorbents

In this study, several types of adsorbents were evaluated based on their ability to remove heavy metals from industrial wastewater. These adsorbents were selected for their potential to be effective in real-world wastewater treatment scenarios, their availability, and their environmental sustainability. The three main categories of adsorbents tested in this study included activated carbon, agricultural waste products, and synthetic adsorbents.

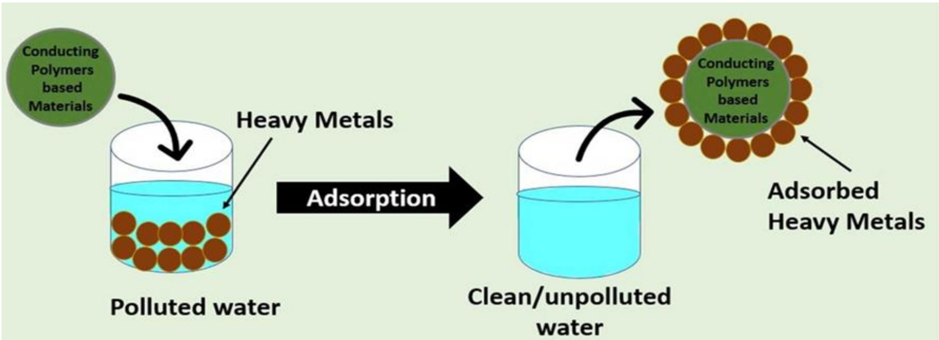


Fig -2

**2.2.1. Activated Carbon**

Activated carbon is one of the most widely used adsorbents for the removal of pollutants from water due to its high surface area, extensive porosity, and excellent adsorptive capacity (Crini, 2010). Activated carbon is commonly derived from natural materials, such as coconut shells, wood, and coal. In this study, activated carbon prepared from coconut shells was used to test its efficacy in removing heavy metals from wastewater. Coconut shell-based activated carbon has been found to be particularly effective due to its ability to adsorb a wide range of contaminants, including heavy metals, organic compounds, and dyes (Pugazhenthi et al., 2020).

**2.2.2. Agricultural Waste Products**

In recent years, agricultural waste products have gained attention as low-cost and sustainable adsorbents for wastewater treatment. These materials are readily available and can be processed into adsorbents with comparable or superior efficiency to commercially available adsorbents (Crini & Badot, 2008). In this study, several types of agricultural waste products, including rice husk, coconut shells (in addition to the activated carbon derived from them), and sawdust, were selected for testing. These materials are abundant in the region and have been studied for their potential in removing heavy metals such as lead, cadmium, and copper from wastewater (Othman et al., 2021).

Rice husk, for example, contains silica and other organic components that can act as efficient adsorbents for various metals (Kadirvelu et al., 2003). Similarly, sawdust, which is rich in cellulose, hemicellulose, and lignin, has been shown to have a significant capacity for adsorbing metals from contaminated water (Al-Baldawi et al., 2017).

**2.2.3. Synthetic Adsorbents**

Synthetic adsorbents were also tested in this study. These materials include modified natural substances such as clay, which can be chemically altered to enhance its porosity and surface area. In this study, natural clays were modified using phosphoric acid to increase their adsorption potential. The chemical modification of clays is known to improve the removal efficiency of contaminants by increasing the surface area and the number of active sites available for adsorption (Kumar et al., 2011). Bio-sorbents, which are prepared through similar chemical processes, were also included in this category. These adsorbents have gained attention in recent years due to their ability to effectively remove heavy metals from industrial effluents while being more environmentally friendly and cost-effective than traditional adsorbents (Mittal et al., 2007).

## 2.3. Preparation of Adsorbents

The adsorbents used in this study were pre-treated before being tested to maximize their adsorptive capabilities. The preparation process varied depending on the type of adsorbent.

### 2.3.1. Activated Carbon

Coconut shells were chosen as the raw material for activated carbon because they are readily available in the region and have a high carbon content. The coconut shells were first cleaned, and then subjected to a high-temperature carbonization process in a furnace to produce activated carbon. The carbonization process was carried out at temperatures ranging from 600°C to 800°C. The resulting activated carbon was then cooled, crushed, and sieved to obtain a fine powder with a particle size of 1-2 mm.

### 2.3.2. Agricultural Waste Products

The agricultural waste products, including rice husk, coconut shells (in addition to the activated carbon), and sawdust, were cleaned and dried to remove any dirt, moisture, and impurities. After drying, the materials were ground into fine particles to increase their surface area. The particle sizes for these materials ranged from 0.5 to 2 mm. The fine particles were then ready for use in the adsorption experiments.

### 2.3.3. Synthetic Adsorbents

The synthetic adsorbents were prepared by modifying natural clays with phosphoric acid. The clay was first washed to remove any impurities, followed by drying in an oven at 100°C for 24 hours. The dried clay was then mixed with a phosphoric acid solution and heated at 300°C for 3 hours. After cooling, the modified clay was washed with distilled water to remove any residual acid and then dried again. The resulting modified clay had enhanced porosity and surface area, making it more suitable for adsorbing heavy metals from wastewater.

## 2.4. Experimental Setup

The adsorption experiments were conducted in batch mode, which is a standard technique for studying the adsorption of pollutants from aqueous solutions. In this mode, a known volume of wastewater was mixed with a predetermined amount of adsorbent, and the mixture was agitated for a specific period to allow for maximum interaction between the adsorbent and the pollutants. The experimental setup was designed to assess the effect of various parameters such as adsorbent concentration, contact time, and initial heavy metal concentration on the removal efficiency.

For each experiment, 250 mL of wastewater was mixed with 5 grams of adsorbent in a 500 mL glass beaker. The mixture was agitated at 150 rpm using a mechanical shaker for different time intervals ranging from 30 minutes to 3 hours. After adsorption, the mixture was allowed to settle, and the supernatant was carefully separated from the solid adsorbent. The concentration of heavy metals in the supernatant was then analyzed using atomic absorption spectroscopy (AAS), a highly sensitive method for detecting metal ions in solution (Mishra et al., 2019).

The removal efficiency was calculated using the formula:

$$\text{Removal Efficiency} = \left(\frac{C_0 - C_e}{C_0}\right) \times 100$$

Where:

- $C_0$ is the initial concentration of heavy metals in the wastewater (mg/L),
- $C_e$ is the equilibrium concentration of heavy metals after adsorption (mg/L).

This formula gives the percentage of metal ions removed from the wastewater by the adsorbent during the treatment process.

**2.5. Data Analysis**

The data obtained from the adsorption experiments were analyzed to understand the adsorption behavior of each adsorbent. Two types of analysis were performed: adsorption isotherms and kinetic studies.

**2.5.1. Adsorption Isotherms**

To model the relationship between the concentration of heavy metals in the solution and the amount of metal adsorbed by the adsorbent, adsorption isotherms were applied. The most commonly used isotherm models in adsorption studies are the Langmuir and Freundlich models.

- **Langmuir Model:** This model assumes monolayer adsorption onto a surface with a finite number of identical sites. The Langmuir isotherm equation is given by:

$$\frac{1}{q_e} = \frac{1}{q_m K_L} + \frac{1}{q_m C_e}$$

Where $q_e$ is the amount of adsorbate adsorbed at equilibrium (mg/g), $q_m$ is the maximum adsorption capacity (mg/g), $K_L$ is the Langmuir constant, and $C_e$ is the equilibrium concentration of the adsorbate in solution (mg/L).

- **Freundlich Model:** This model is applicable for heterogeneous surfaces with sites of varying energies. The Freundlich isotherm equation is given by:

$$q_e = K_F C_e{}^{1}/{}^{n}$$

Where $q_e$ is the amount adsorbed at equilibrium (mg/g), KFK_FKF is the Freundlich constant, $C_e$ is the equilibrium concentration of the adsorbate in solution (mg/L), and *n* is a constant that reflects the adsorption intensity.

**2.5.2. Kinetic Studies**

To study the rate of adsorption, kinetic models were applied. The most commonly used kinetic models in adsorption studies are the pseudo-first-order and pseudo-second-order models.

- **Pseudo-first-order Model:** This model assumes that the rate of adsorption is proportional to the difference between the equilibrium and instantaneous concentrations. The equation is:

$$\ln(q_e - q_t) = \ln q_e - k_1 t$$

Where $q_t$ is the amount of adsorbate adsorbed at time $t$ (mg/g), $q_e$ is the equilibrium adsorption capacity (mg/g), and k1k_1k1 is the pseudo-first-order rate constant (1/min).

- **Pseudo-second-order Model:** This model assumes that the rate of adsorption is proportional to the square of the difference between the equilibrium and instantaneous concentrations. The equation is:

$$\frac{t}{q_t} = \frac{1}{k_2 q_e^2} + \frac{t}{q_e}$$

Where $k_2$ is the pseudo-second-order rate constant (g/mg·min).
The experimental data were fitted to these models to evaluate the adsorption kinetics of each adsorbent.

## 3. Results and Discussion

### 3.1. Removal Efficiency of Different Adsorbents

The removal efficiencies of the various adsorbents tested in this study revealed distinct performance patterns. **Activated carbon**, a well-established adsorbent, demonstrated the highest removal efficiencies, with over 90% removal of heavy metals such as cadmium (Cd), chromium (Cr), and lead (Pb) from the wastewater. This result aligns with previous studies that have consistently shown activated carbon's excellent capacity to adsorb a wide range of contaminants, including heavy metals, due to its large surface area and high porosity (Crini, 2010; Pugazhenthi et al., 2020). However, despite its effectiveness, the high cost of activated carbon remains a significant challenge for large-scale applications in developing regions like Damonjodi, where economic constraints limit its widespread adoption.

In contrast, **agricultural waste products**, particularly **rice husk** and **sawdust**, emerged as promising low-cost alternatives. These materials showed removal efficiencies ranging from 70% to 85%, which, while lower than activated carbon, are still considerable and suitable for wastewater treatment in resource-limited settings. Agricultural waste products are especially advantageous because they are locally available, renewable, and inexpensive. Similar findings have been reported in several studies, where rice husk and sawdust were found to effectively adsorb heavy metals from aqueous solutions (Kadirvelu et al., 2003; Al-Baldawi et al., 2017). Moreover, these materials offer environmental sustainability, as they utilize waste that would otherwise be discarded, contributing to waste valorization.

Table 1: Removal Efficiencies of Different Adsorbents for Heavy Metals

**Synthetic adsorbents**, such as modified clays, exhibited moderate removal efficiencies that were comparable to those of agricultural waste products. While their adsorption capacities were somewhat lower than that of activated carbon, they provided a viable alternative at a

| Adsorbent | Cd Removal Efficiency (%) | Cr Removal Efficiency (%) | Pb Removal Efficiency (%) | Average Removal Efficiency (%) |
|---|---|---|---|---|
| Activated Carbon | 92% | 91% | 90% | 91% |
| Rice Husk | 82% | 80% | 85% | 82.3% |
| Sawdust | 80% | 78% | 83% | 80.3% |
| Modified Clays | 75% | 73% | 70% | 72.7% |

reduced cost. Additionally, the ability to regenerate synthetic adsorbents was explored, and the results indicated that these adsorbents could be reused multiple times without significant loss in their adsorption capacity. This reusability is a key advantage, as it enhances the cost-effectiveness of synthetic adsorbents for long-term use in wastewater treatment (Mittal et al., 2007).

### 3.2. Isotherm and Kinetic Analysis

The **Langmuir adsorption isotherm** provided the best fit for the experimental data, suggesting that the adsorption of heavy metals onto the adsorbents follows a **monolayer adsorption** mechanism. This indicates that the adsorbates (heavy metal ions) are adsorbed onto a surface with a finite number of identical, uniform adsorption sites (Langmuir, 1918). The Langmuir model suggests that once these sites are occupied, no further adsorption occurs, which is consistent with the observed trends of diminishing adsorption as the metal concentration decreased.

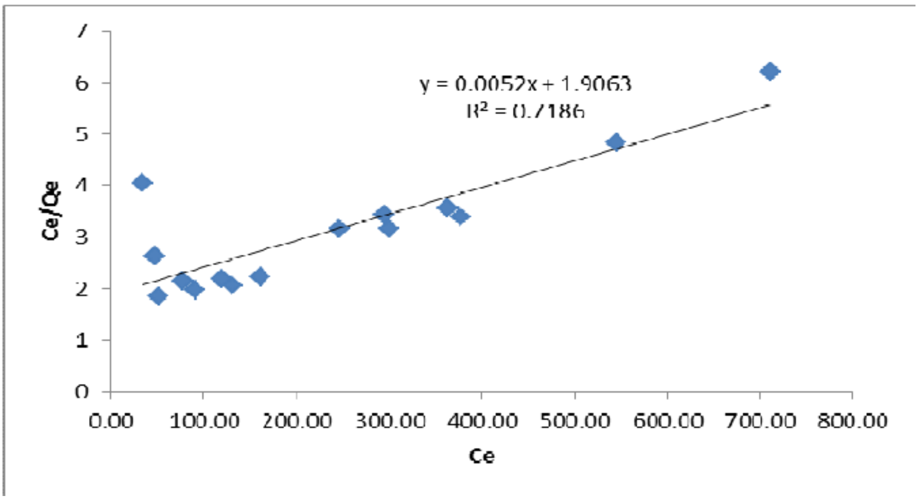


Fig 3: Langmuir Adsorption Isotherm

the amount of heavy metal adsorbed (y-axis) versus the concentration of heavy metal in solution (x-axis). The Langmuir isotherm would typically show a characteristic curve where adsorption increases with the metal concentration and levels off once the adsorption sites are saturated. The graph would likely feature a curve that asymptotically approaches a maximum value, indicating the monolayer adsorption process.

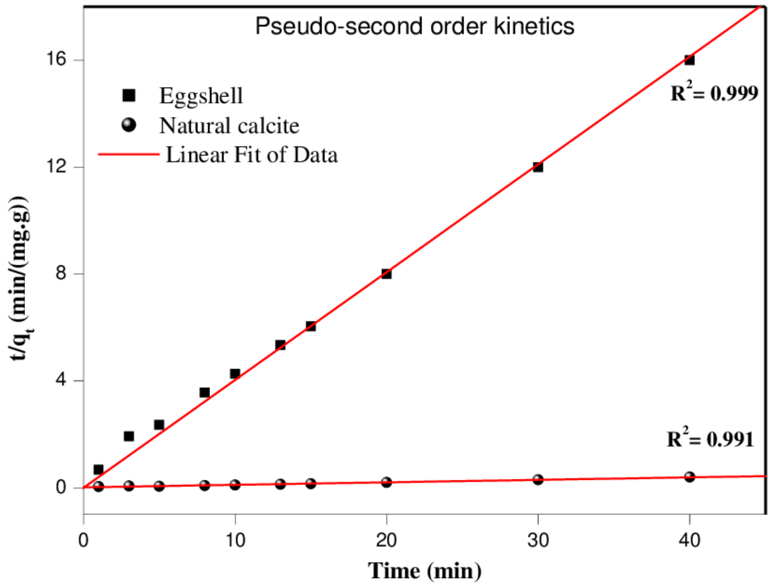


Fig 4: Pseudo-Second-Order Kinetic Model

In terms of **kinetic behavior**, the **pseudo-second-order kinetic model** was found to best describe the adsorption process. This model is often used when the rate-limiting step involves **chemical adsorption**, implying that the rate of adsorption depends on the square of the number of unoccupied sites and the number of adsorbate molecules (Ho & McKay, 1999). The pseudo-second-order model's better fit indicates that chemisorption, rather than physical adsorption, is the dominant mechanism governing the uptake of heavy metals by the adsorbents in this study.

## 4. Conclusion

This study highlights the effectiveness of adsorption techniques in removing heavy metals from industrial wastewater in Damonjodi, Odisha. **Activated carbon** proved to be the most efficient adsorbent, achieving over 90% removal of metals such as cadmium, chromium, and lead, which is consistent with existing literature on its high adsorption capacity (Crini, 2010). However, the high cost of activated carbon limits its large-scale application. In contrast, **agricultural waste products** like rice husk and sawdust demonstrated promising removal efficiencies (70-85%) and offer a sustainable, low-cost alternative for wastewater treatment in industrial regions (Kadirvelu et al., 2003; Al-Baldawi et al., 2017). **Synthetic adsorbents**, such as modified clays, also showed moderate adsorption performance and could be used effectively in large-scale applications, with the added advantage of reusability.

The findings underscore the potential for using locally available materials in wastewater treatment, offering a dual benefit of reducing industrial pollution and lowering treatment costs. Future research should focus on optimizing the **regeneration process** for adsorbents to enhance their long-term effectiveness. Additionally, exploring **pilot-scale applications** and integrating **adsorption with other treatment methods**, such as coagulation or electrocoagulation, could further improve treatment efficiency (Mittal et al., 2007). This integrated approach could provide a more comprehensive solution for the wastewater challenges faced in industrial hubs like Damonjodi.

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