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# BIOLOGICAL APPROACHES TO HEAVY METAL REMOVAL FROM WATER USING BIOSORBENTS

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**ABSTRACT:**

Heavy metal contamination of water resources poses a serious threat to human health and ecosystems. Traditional physicochemical treatment methods, though effective, are often expensive and produce secondary pollutants. Biosorption, a low-cost and eco-friendly technique, has gained substantial attention before 2017 for its potential to remove heavy metals from aqueous solutions. This paper reviews various biosorbents used for the removal of heavy metals such as lead (Pb), cadmium (Cd), chromium (Cr), arsenic (As), and mercury (Hg), focusing on studies and developments reported prior to 2017. The mechanisms of biosorption, biosorbent modification techniques, and comparative adsorption capacities are discussed in detail.

## INTRODUCTION:

The increasing pace of industrialization and urbanization over the last century has significantly contributed to the release of pollutants, particularly heavy metals, into aquatic environments. Heavy metals such as lead, cadmium, mercury, chromium, and arsenic are among the most toxic and persistent contaminants in water bodies. Unlike organic compounds, which can often be biologically degraded, heavy metals do not decompose and tend to accumulate in living organisms, leading to bioaccumulation and biomagnification throughout the food chain. This bioaccumulation poses serious health risks, including carcinogenic, mutagenic, and neurotoxic effects in humans and animals.

Industries such as metal plating, mining, leather tanning, battery manufacturing, and textile processing are major sources of heavy metal pollution. Wastewater generated from these industries often contains high levels of metal ions that exceed the permissible limits for discharge into water bodies, as prescribed by regulatory agencies like the World Health Organization (WHO) and the Environmental Protection Agency (EPA). Therefore, developing efficient, low-cost, and environmentally friendly methods for the removal of heavy metals from water is of paramount importance.

Conventional technologies employed for metal removal include chemical precipitation, ion exchange, reverse osmosis, membrane filtration, and electrochemical treatments. Although effective, these methods suffer from drawbacks such as high energy and operational costs, limited metal selectivity, generation of toxic sludge, and inefficiencies at low metal concentrations.

In contrast, **biosorption** has emerged as a promising alternative, especially for treating dilute heavy metal solutions. Biosorption refers to the passive uptake of metal ions by non-living biomass, including agricultural waste, algae, fungi, bacteria, and industrial by-products. Pre-2017 research indicates that biosorption offers several advantages: it is low-cost, involves readily available materials, and does not generate hazardous sludge. Furthermore, many biosorbents can be regenerated and reused multiple times.

This paper explores the scope and developments in the field of biosorption for heavy metal removal, focusing on work conducted prior to 2017. The review highlights various types of biosorbents, their mechanisms of action, adsorption capacities, and potential for real-world application.

## SOURCES AND IMPACT OF HEAVY METALS:

Heavy metals enter aquatic environments through both natural processes (weathering of rocks, volcanic activity) and anthropogenic activities (industrial discharge, mining, waste dumping). Table 1 outlines the major heavy metals of concern, their industrial sources, and health effects.

| Metal | Source | Health Effects |
|---|---|---|
| Lead (Pb) | Battery manufacturing, paints, smelting | Kidney damage, developmental disorders |
| Cadmium (Cd) | Electroplating, fertilizers | Bone damage, kidney failure |
| Chromium (Cr) | Leather tanning, pigments | Carcinogenic, liver damage |
| Arsenic (As) | Pesticides, mining | Skin lesions, cardiovascular diseases |
| Mercury (Hg) | Electronics, gold mining | Neurological disorders, cognitive decline |

## BIOSORPTION: MECHANISM AND BENEFITS:

Biosorption mechanisms primarily involve:

- **Ion exchange**
- **Complexation**
- **Micro-precipitation**
- **Physical adsorption**
- **Electrostatic attraction**

These mechanisms occur through functional groups like carboxyl, hydroxyl, phosphate, and amine groups found in biosorbent cell walls.

**Key benefits include:**

- Cost-effectiveness and reusability
- High efficiency at low metal concentrations
- Use of renewable and waste materials
- No production of harmful secondary pollutants

## TYPES OF BIOSORBENTS (PRE-2016 STUDIES):

### 1. Agricultural Waste:

Agricultural by-products such as rice husk, coconut shells, banana peels, and sawdust are excellent biosorbents due to their lignocellulosic content and functional group availability.

- *Low et al. (2000)* reported high Pb(II) removal using rice husk.

- *Gupta et al. (2011)* enhanced sawdust adsorption capacity by chemical modification.

**2. Algae:**

Marine and freshwater algae like **Sargassum, Chlorella, and Spirulina** are rich in alginates and polysaccharides, contributing to high metal-binding capacity.

- *Volesky and Holan (1995)* demonstrated efficient heavy metal removal using brown algae.
- *Romera et al. (2006)* statistically reviewed multiple algae biosorption capacities.

**3. Fungi and Bacteria:**

Dead fungal biomass (e.g., *Aspergillus niger*) and bacterial strains (*Bacillus subtilis*, *Pseudomonas putida*) possess proteinaceous components aiding biosorption.

- *Gadd (1990)* discussed metal accumulation by microorganisms.
- *Park et al. (2005)* used fungal biomass to remove hexavalent chromium effectively.

**4. Industrial By-products:**

Brewer's yeast, eggshells, and industrial sludges are inexpensive and effective options.

- *Sheng et al. (2004)* explored yeast and algal biomass in multi-metal systems.
- *Kaewsarn (2002)* highlighted marine algae as biosorbents for Cu(II).

**MODIFICATION OF BIOSORBENTS:**

To enhance biosorption capacity, biosorbents are often subjected to:

- **Acid or base treatment** (to increase active sites)
- **Cross-linking** (to improve mechanical stability)
- **Magnetization** (for easy separation from solutions)

*Gupta et al. (2011)* improved sawdust biosorption capacity by ~30% through acid modification.

## KINETICS AND ISOTHERM MODELS:

Research prior to 2016 primarily utilized the following models:

- **Langmuir isotherm** (monolayer adsorption on a homogeneous surface)
- **Freundlich isotherm** (multilayer adsorption on heterogeneous surfaces)
- **Pseudo-second-order kinetic model** – often best fits biosorption data

These models help evaluate adsorption rates and equilibrium behavior essential for designing treatment systems.

## CASE STUDIES AND ADSORPTION CAPACITY COMPARISON:

| **Biosorbent** | **Metal Ion** | **Adsorption Capacity (mg/g)** | **Reference** |
|---|---|---|---|
| Sawdust | Pb(II) | 100 | Gupta et al., 2011 |
| Spirulina | Cd(II) | 65 | Romera et al., 2006 |
| Coconut shell | Cr(VI) | 75 | Babel & Kurniawan, 2003 |
| Eggshell powder | Cu(II) | 40 | Park et al., 2005 |
| Padina sp. (algae) | Cu(II) | 78 | Kaewsarn, 2002 |
| Brewer’s yeast | Zn(II) | 56 | Sheng et al., 2004 |

## LIMITATIONS AND CHALLENGES:

- **Desorption** and regeneration remain difficult for some biosorbents.
- **Selectivity** in the presence of multiple metals is a challenge.
- **Scalability** and consistency in real-world applications require further development.

## CONCLUSION:

Biosorption presents a compelling alternative to conventional heavy metal removal methods, particularly for low-concentration solutions. Extensive research validated the efficiency of diverse biosorbents from agricultural, microbial, algal, and industrial sources. The findings emphasize the potential of biosorption in wastewater treatment due to its cost-effectiveness, environmental compatibility, and high metal uptake capacities. Continued innovation in biosorbent modification and process optimization will pave the way for large-scale implementation in future water purification systems.

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