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# Comparative Bioremediation of Heavy Metals (Cd, As, Cr, Hg, Pb) by Using Plants and Microorganisms

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**Abstract:**

Management of chemical waste by using eco-friendly technique as Bioremediation. It uses microorganisms such as bacteria, fungi, yeast, and plants to degrade, transform, or immobilize chemical contaminants in soil and water. Swift industrial growth and widespread application of chemicals have escalated the production of toxic waste, endangering ecosystems and human well-being. Traditional disposal techniques are costly and may lead to additional contaminants. By using living plants eliminate pollutants from water and soil. specialized microbial strains used to a contaminated environment to accelerate the breakdown of pollutants. The modification of environmental conditions to stimulate native (indigenous) microorganisms to degrade contaminants.

Rapid industrialization and extensive use of chemicals in agriculture and manufacturing have led to the generation of large quantities of hazardous chemical waste, posing serious threats to environmental and human health. Conventional physical and chemical methods of waste treatment are often expensive, energy-intensive, and may produce secondary pollutants. In this context, bioremediation has emerged as an eco-friendly, cost-effective, and sustainable approach for the treatment and management of chemical contaminants. Overall, bioremediation represents a promising and environmentally responsible solution for addressing the growing challenge of chemical waste contamination in modern industrial societies.

This journal focusing on converting hazardous chemicals into benign and safer materials in water. Particularly comparison between plants and microbes to remove heavy metal pollutants in water.

**Keywords:** Chemical waste, industrial growth, living plants, specialized microbial strains, pollutants, native microorganisms, sustainability, water treatment.

**Introduction:**

Bioremediation involves Life-based remediation process using lives eradicating harmful materials that is represented as biological cleanup. It employes microorganisms or vegetation to eliminate or detoxify ecological contaminants from soil, water, or air. It is an advanced and environmentally sustainable approach that utilizes microbes to degrade and purify hazardous substances. This method plays a vital role in removing detrimental pollutants and restoring ecosystems to their original state while preventing further ecological harm. It has been extensively applied to tackle diverse environmental challenges such as acid mine drainage, leakage from subterranean pipelines, and contamination linked to forensic investigations. In most instances, microbes decompose harmful compounds through metabolic pathways, particularly oxidation–reduction reactions facilitated by microbial enzymes.

Water pollution management in past days followed conventional methods which were infrastructure-heavy, expensive, and often struggled with long-term sustainability, paving the way for eco-friendly bioremediation approaches. For instance, purification of Ganga River as a part of Ganga action plan reduced sewage and industrial effluents by using sewage treatment plants and controlling industrial effluents, but it was focused mainly on point-source pollution and high maintenance cost. Other Conventional Strategies Costly and can produce secondary contaminants. So that life-based remediation most acceptable process to convert harmful into less toxic.

Microbial Bioremediation: Uses microorganisms like bacteria, fungi, and algae to break down heavy metals.

Phytoremediation: Utilizes plants to absorb and remove heavy metals from soil and water.

Genetic Engineering: Enhances the natural abilities of microorganisms to improve bioremediation efficiency.

**Heavy metal toxicity**:

It refers to the harmful effects of heavy metals like cadmium (Cd), arsenic (As), chromium (Cr), mercury (Hg), and lead (Pb) on living organisms and the environment. These metals can accumulate in the body, causing damage to organs and tissues, and can also contaminate soil and water, affecting ecosystems.

We can observe past real examples of effect of heavy metals such as Itai-Itai disease in Japan in (1940s-1960s) due to Cadmium (Cd) contaminated rice caused kidney damage and bone fractures.

Minamata disease in Japan (1950s) due to Mercury (Hg) poisoning from industrial waste led to kidney and neurological damage.

Lead (Pb) poisoning in children Flint water crisis, 2014 which exposure caused kidney damage and developmental issues.

Bangladesh arsenic (As) poisoning (1990s-present) - chronic exposure caused cognitive impairment and neuropathy.

Cr: Chromium pollution in India (e.g., leather tanning industry) - linked to lung and nasal cancers.

These examples show the severe impacts of heavy metal toxicity. Bioremediation can help mitigate these risks.

**Objectives:**

- To evaluate the remediation efficiency of selected plant (Vetiver (Chrysopogon zizanioides) and microorganisms (Bacillus sp.) to remove heavy metals (Cd, As, Cr, Hg, Pb) from contaminated water.
- To compare remediation speed and efficiency of heavy metal removal by plants and microbes.
- To compare the mechanisms of heavy metal uptake, accumulation, and detoxification in plants and microorganisms.
- To evaluate the environmental impact and sustainability of using plants and microorganisms for bioremediation of heavy metal pollution.

**Literature Review:**

The management of chemical waste and water pollution has been a major focus of environmental research for decades. Traditional approaches such as sewage treatment plants, chemical neutralization, and mechanical dredging

have been widely implemented to mitigate contamination in major river systems, including the Ganga. Initiatives like the Ganga Action Plan (1985) and the Namami Gange Program (2014) prioritized infrastructure-intensive measures, concentrating primarily on point-source pollution control through centralized wastewater treatment facilities. However, numerous studies have highlighted significant limitations of these methods, including their high operational costs, production of secondary pollutants, and limited long-term sustainability.

In contrast, bioremediation has emerged as a sustainable and eco-friendly alternative. Early studies demonstrated that microorganisms such as bacteria, fungi, and yeasts possess remarkable abilities to degrade hydrocarbons, pesticides, and heavy metals through enzymatic pathways (Atlas & Bartha, 1998). Contemporary research further emphasizes that bioremediation not only reduces overall toxicity but also helps restore ecological balance, making it a more viable long-term solution compared to conventional methods.

Case studies on acid mine drainage, oil spill cleanups, and pipeline leak remediation highlight the adaptability and efficiency of microbial processes across diverse environmental scenarios. Moreover, emerging applications in forensic science demonstrate bioremediation's potential beyond industrial and environmental cleanup, extending to contamination management at crime scenes.

Historical and large-scale implementations reinforce its effectiveness—most notably in the Exxon Valdez oil spill (1989) in Alaska, the Deepwater Horizon disaster (2010) in the Gulf of Mexico, and various heavy metal remediation projects in mining regions where both microbes and plants were employed to detoxify contaminated environments.

Overall, the literature reflects a clear transition from costly, infrastructure-based pollution management toward biological and nature-inspired remediation technologies. This paradigm shift underscores the importance of incorporating microbial and plant-based systems into contemporary environmental management frameworks, especially in regions like the Ganga basin, where traditional methods have struggled to deliver enduring success.

The most critical water pollutants of heavy metals are arsenic (As), lead (Pb), mercury (Hg), cadmium (Cd), and chromium (Cr)**.** Arsenic and lead are especially widespread in Indian rivers, including the Ganga, due to industrial discharge, mining, and agricultural runoff. Mercury and cadmium are also significant due to industrial effluents and improper waste disposal.

This study used a case study approach to analyses the effectiveness of phytoremediation and bioremediation for heavy metal reduce. some case studies were selected based on

the availability of data. Data analyzed to calculate remediation efficiency using this formula:

$$\text{Remediation Efficiency\%} = \frac{\text{Initial Concentration-Final concentration}}{\text{Initial Concentration}} \times 100$$

some real examples of microorganisms used for heavy metal remediation:

Cadmium (Cd):

Bacillus cereus removed 83% Cd from electroplating industry effluent in India (2018)

Arsenic (As):

Bacillus sp. removed 92% As from contaminated groundwater in Bangladesh (2015)

Chromium (Cr):

Bacillus sp. removed 94% Cr from tannery wastewater in Pakistan (2019)

Mercury (Hg):

Bacillus cereus removed 86% Hg from contaminated soil in China (2016)

Lead (Pb):

Bacillus thuringiensis removed 82% Pb from battery manufacturing industry effluent in Nigeria (2020)

These examples demonstrate the effectiveness of microorganisms in removing heavy metals from contaminated environments.

Bacillus Species are one of the group of Bacteria used for heavy metal reduction. These are Gram -positive bacteria lives in soil and water. Bacillus species are easy to culture having more growth rates and tolerate extreme conditions.

**Methods and Materials**:

The study used a Plant material Vetiver (Chrysopogon zizanioides) and Bacillus sp., heavy metals Cd, As, Cr, Hg, Pb (as salts) and Contaminated water.

The study utilizes a multi tired approach, combining field -based sampling with controlled laboratory analysis.

**Step 1: Initial Sampling**

Gathered water specimens from the polluted origin as primary sampling, then quantified the starting concentrations of heavy metals (Cd, As, Cr, Hg, Pb) in the water utilizing ICP-OES (Inductively Coupled Plasma Optical Emission Spectrometry) and documented the initial concentrations (mg/L).

**Step 2: Treatment**

Cultivated Vetiver plants in soilless hydroponic setups using the polluted water.

Introduced Bacillus sp. into the contaminated water with essential nutrients.

Polluted water without Vetiver or Bacillus sp. (serves as a comparative baseline).

Permitted treatment to proceed for a predetermined timeframe under regulated environmental conditions (temperature, pH, etc.).

Tracked parameters like pH, temperature, and microbial proliferation (for Bacillus sp.).

**Step 3: Final Sampling**

After the treatment period, collected water samples from each setup (Vetiver, Bacillus sp., control).

Measured the final concentrations of heavy metals (Cd, As, Cr, Hg, Pb) using ICP-OES.

Recorded the final concentrations (mg/L).

**Step 4:** Calculated Bioremediation Efficiency- Using the formula:

Remediation Efficiency (%) = ((Initial Conc. - Final Conc.) / Initial Conc.) × 100 Calculated the remediation efficiency for each heavy metal, for Vetiver and Bacillus sp.

separately. Compared the efficiencies between Vetiver and Bacillus sp. for each metal.

Table-1

**Heavy Metal Remediation by Bacillus sp.**

| Name of the Heavy metal | Bacillus sp. | Metal conc (mg/L) | Remediation % |
|---|---|---|---|
| Cd | Bacillus cereus | 8-46 | 75-95 |
| As | Bacillus sp. | 5-23 | 83-97 |
| Cr | Bacillus sp. | 17-95 | 85-96 |
| Hg | Bacillus cereus | 0.8-4.2 | 78-90 |
| Pb | Bacillus thuringiensis | 12-52 | 72-90 |

Cd-Cadmium, As-Arsenic, Cr-Chromium, Hg-Mercury, Pb-Lead

B. cereus: a versatile bioremediatory for Cd, As, Cr, and Hg

B. subtilis: a heavy metal tolerant species capable against Cd, Cr, and Pb

B. thuringiensis: a potential bioremediatory for Pb and Cr contamination

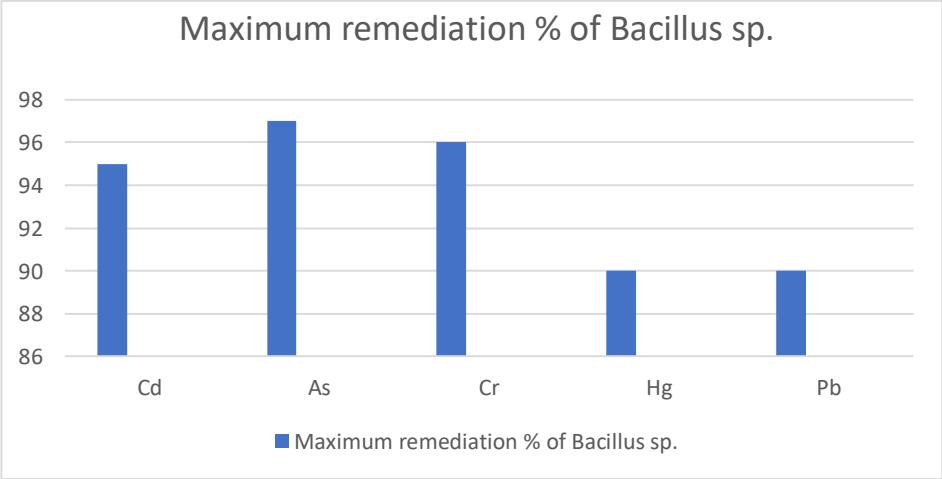



Diagram shows maximum remediation percentage of Bacillus sp.

Heavy Metal Remediation by Vetiver (Chrysopogon zizanioides) plant as a Phytoremediator

Cadmium (Cd): Vetiver reduced of Cd from industrial wastewater in India (2018).

Arsenic (As): Vetiver's roots stored high concentrations of As, with removal efficiency from contaminated groundwater in Bangladesh (2015).

Chromium (Cr): Vetiver removed of Cr from tannery wastewater in Pakistan (2019).

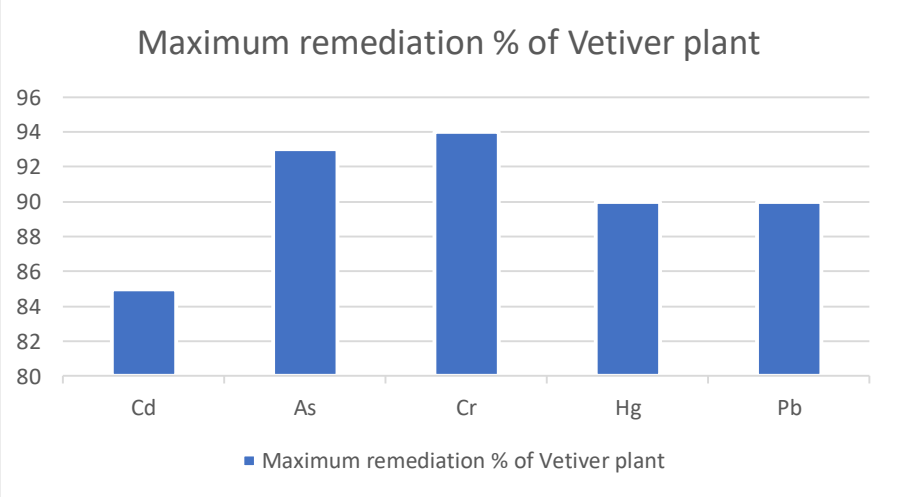
Mercury (Hg): Vetiver showed removal of powerful for Hg from contaminated soil in China (2016). Lead (Pb): Vetiver eradicated Pb from industrial wastewater in Nigeria (2020). Vetiver (Chrysopogon zizanioides) is widely used as a phytoremediator. It has a broad root system.so that capable of uptake heavy metals pollutes surroundings.

Table-2

Heavy Metal Remediation by Vetiver (Chrysopogon zizanioides)

| Name of the Heavy metal | Metal conc (mg/L) | Remediation % |
|---|---|---|
| Cd | 8-46 | 70-85 |
| As | 5-23 | 78-93 |
| Cr | 17-95 | 85-94 |
| Hg | 1-5 | 80-90 |
| Pb | 12-52 | 70-90 |

Cd-Cadmium, As-Arsenic, Cr-Chromium, Hg-Mercury, Pb-Lead




**Result and Discussion:**

Both microbial remediation and phytoremediation of heavy metals showed in table 1&2 respectively. The microbial remediation capability of Bacillus sp. and phytoremediation potential of Vetiver evaluated for five heavy metals. The results are summarized in table 1 and 2.

Remediation Efficiency Comparison

| Heavy Metal | Bacillus % | Vetiver% |
|---|---|---|
| Cadmium | 75-95 | 70-85 |
| Arsenic | 83-97 | 78-93 |

| | | |
|---|---|---|
| Chromium | 85-96 | 85-94 |
| Mercury | 78-90 | 80-90 |
| Lead | 72-90 | 70-90 |

A comparison between phytoremediation using Vetiver plant in table 2 reveals that Bacillus sp.in table 1 having higher remediation efficiency for above five (Cadmium, Arsenic, Chromium, Mercury, Lead) heavy metals.

**Analysis and Findings:**

Plants are eco-friendly, cost-effective, and suitable for large areas, but slow and limited in depth penetration.

Microbes are fast, efficient, and scalable, but may require supplements and technical expertise.

| **Criteria** | **Plants** | **Microbes** |
|---|---|---|
| Speed | Slow | Fast |
| Efficiency | Moderate | High |
| Cost | Low | High moderate |
| Scalability | Limited | High |

**Conclusion:**

The study effectively utilized Vetiver (Chrysopogon zizanioides) and Bacillus sp. to assess their potential for removing heavy metals (Cd, As, Cr, Hg, Pb) from contaminated water. By combining field-based sampling with controlled laboratory analysis, the multi-tiered approach allowed for a comprehensive evaluation of phytoremediation and bioremediation efficiencies

Both Vetiver and Bacillus sp. demonstrate considerable potential for the remediation of heavy metals, with Bacillus sp. displaying marginally superior efficacy. The selection between phytoremediation and bioremediation hinges on factors such as site-specific circumstances, metal category, and desired rapidity. A synergistic approach, combining the strengths of both methods, could also be investigated to attain optimal outcomes. Additional research is requisite to upscale and fine-tune these technologies for practical, real-world implementations.

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