

Comparative Analysis of Bioremediation and Phytoremediation in Mitigation of Heavy Metals.

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Abstract

The study explored the use of bacterial and phytoremediation methods to address cobalt and nickel contamination. Bacterial species such as *Escherichia coli* and *Staphylococcus aureus* were cultivated in media contaminated with varying concentrations of cobalt and nickel, and their growth curves were analysed through colorimetry. The results showed that both species were effective in reducing the concentrations of cobalt and nickel, with *E. coli* exhibiting slightly better efficiency. A relationship between the growth phases of the bacteria and their metal uptake rates was noted, underscoring the potential of these microorganisms in bioremediation efforts. However, the ability of *E. coli* and *S. aureus* to remediate cobalt was found to be limited, indicating that their effectiveness may not be significant in environments with high levels of cobalt contamination.

The potential for phytoremediation was evaluated using *Eichhornia crassipes* (water hyacinth) and *Pistia stratiotes* (water lettuce). *E. crassipes*, which was grown in nickel-contaminated water for 20 days, showed a significant reduction in nickel concentrations, as measured by Atomic Absorption Spectroscopy (AAS). Likewise, *P. stratiotes* exhibited impressive capabilities in cobalt remediation, achieving a notable decrease in cobalt levels. The high efficiency of *P. stratiotes* was linked to its rapid growth, substantial biomass, and extensive root system, which provided a large surface area for metal absorption. These results are consistent with previous research that emphasized the effectiveness of aquatic plants like *P. stratiotes* in absorbing heavy metals, highlighting their potential for cobalt phytoremediation.

The comparative analysis indicated that bacterial remediation is a quick and effective method for metal reduction, while phytoremediation offers a sustainable and environmentally friendly alternative, along with the benefit of biomass production. This study supports an integrated approach that combines microbial and phytoremediation techniques to tackle heavy metal pollution effectively. Additionally, the findings may enhance understanding of the stress physiology in plants subjected to heavy metal exposure.

Keywords: Bioremediation, phytoremediation, Cobalt, Nickel, heavy metal pollution

INTRODUCTION

Environmental contamination by heavy metals from anthropogenic and industrial activities has caused considerable irreparable damage to aquatic ecosystems [1]. Sources include the mining and smelting of ores, effluent from storage batteries and automobile exhaust, and the manufacturing and inadequate use of fertilizers, pesticides, and many others. The metals and metalloids that contaminate waters and are most found in the environment include lead, chromium, mercury, uranium, selenium, zinc, arsenic, cadmium, silver, gold, and nickel [2]. These metals are the subject of concern due to their high toxicity [3].

Bioremediation is a method that uses living organisms, such as microorganisms, to destroy pollutants or

transform them into less harmful forms. It has gained attention as a promising method for environmental fixing. The success of bioremediation depends on the metabolic activities of microorganisms, such as bacteria, fungi, and algae ^[4]. Phytoremediation, on the other hand, involves using plants to clean up polluted soil and water resources ^[5].

Sources of Heavy Metal Pollution

Heavy metal contamination, primarily industrial and human, is primarily attributed to agricultural use. Natural processes like volcanic activity, metal corrosion, and metal evaporation from soil, water, and sediment also contribute to this pollution ^[6]

Examples of Heavy Metals

Heavy metals are natural elements with high atomic mass and density, found throughout the planet's crust. ^[7] They can interfere with vital cellular processes and enzyme functions, causing toxicity and bioaccumulation ^[8]. Some heavy metals, like cobalt, copper, and zinc, are vital for humans and widespread in nature ^[9]. These metals regulate physiological functions and penetrate the body via food, air, and water, affecting various biological activities. Their toxicity can be life-threatening ^[10].

Impact on Ecosystems and Human Health

Heavy metal pollution has profound impacts on ecosystems and human health. In ecosystems, heavy metals alter soil chemistry, impairing plant growth and affecting soil microorganisms essential for nutrient cycling ^[11]. Types of toxicity included is neurotoxicity (nerve cells), nephrotoxicity(nephrons), carcinogenicity, hepatotoxicity(liver), immunological toxicity, cardiovascular toxicity, skin toxicity, reproductive and developmental toxicity and genotoxicity ^[12].

Introduction of *E. crassipes* and *P. stratiotes* as a Potential Phytoremediator

Eichhornia, commonly known as water hyacinth, is an aquatic plant that has shown considerable promise as a phytoremediator for heavy metal-contaminated environments ^[13]. *P. stratiotes* have highly absorbing roots offer a wide surface area for the growing population of microbes which may further enhance its ability to absorb pollutants ^[14].

Objectives:

The study compares *E. coli* and *S. aureus* growth kinetics under heavy metal concentrations, evaluates their bioremediation potential for mitigating heavy metals, and assesses the phytoremediation efficacy of *P. stratiotes* and *E. crassipes* for heavy metal removal. It also compares bioremediation efficiency for nickel and cobalt removal.

Materials:

1. Microorganisms- *E. coli* and *S. aureus* authenticated by Department of Biotechnology, BKBC Kalyan.
2. Aquatic plant- *Pistia stratiotes* and *Eichhornia crassipes* authenticated by Blatter Herbarium, St. Xavier's College, Mumbai.
3. Heavy metals- Cobalt and Nickel separately.
4. Analysis of heavy metals by Colorimetry and Atomic Absorption Spectrophotometry method.

Methodology for Bioremediation using Bacteria

Experiment Collection and Preparation

- E. coli samples collected from pre-existing bulk culture at B.K. Birla College, Kalyan.
- S. aureus samples collected from pre-existing bulk culture at the same institution.
- Preparation of test water samples with Nickel and Cobalt Concentrations
- Fundamental procedure in analytical chemistry for calibration and testing.
- Accurate diluting of Nickel and Cobalt stock solution to achieve desired concentrations.
- Concentrations prepared include 2 ppm, 4 ppm, 6 ppm, 8 ppm, and 10 ppm.

The experiment investigates the bioremediation properties of bacteria in water samples contaminated with nickel and cobalt, using prepared solutions and bacteria in nutrient broth.

Methodology for Phytoremediation using E. crassipes and P. stratiotes

Collection of Plants

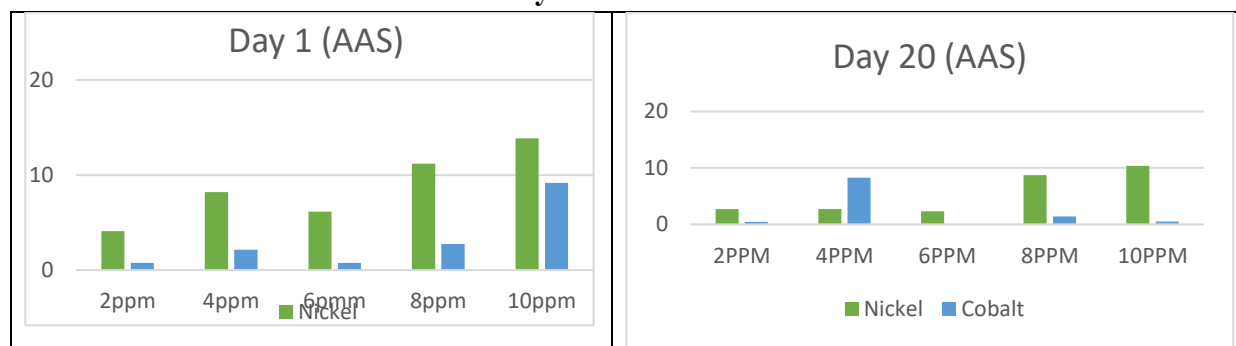
Aquatic plants were meticulously collected from the Besol River in Nalambi Gaon, Ambernath, Maharashtra (postal code: 421501), for an in-vitro study on their potential for phytoremediation of nickel and cobalt in water. The study aims to quantify and analyse their heavy metal absorption efficiency, providing insights for sustainable water purification.

Introduction of Aquatic plants in heavy metals-Contaminated Water Samples

Plants were introduced into nickel and cobalt-contaminated water samples individually, acclimatized, and monitored for uniform exposure to contaminants.

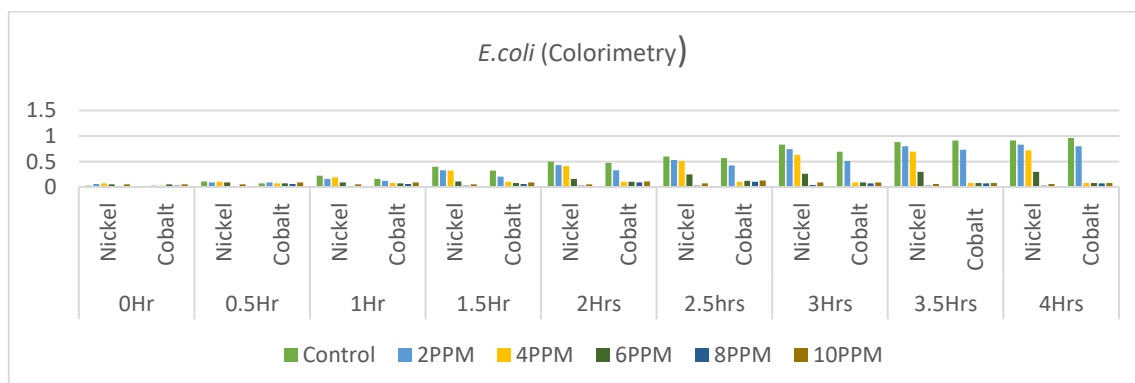
Results

By AAS Method:

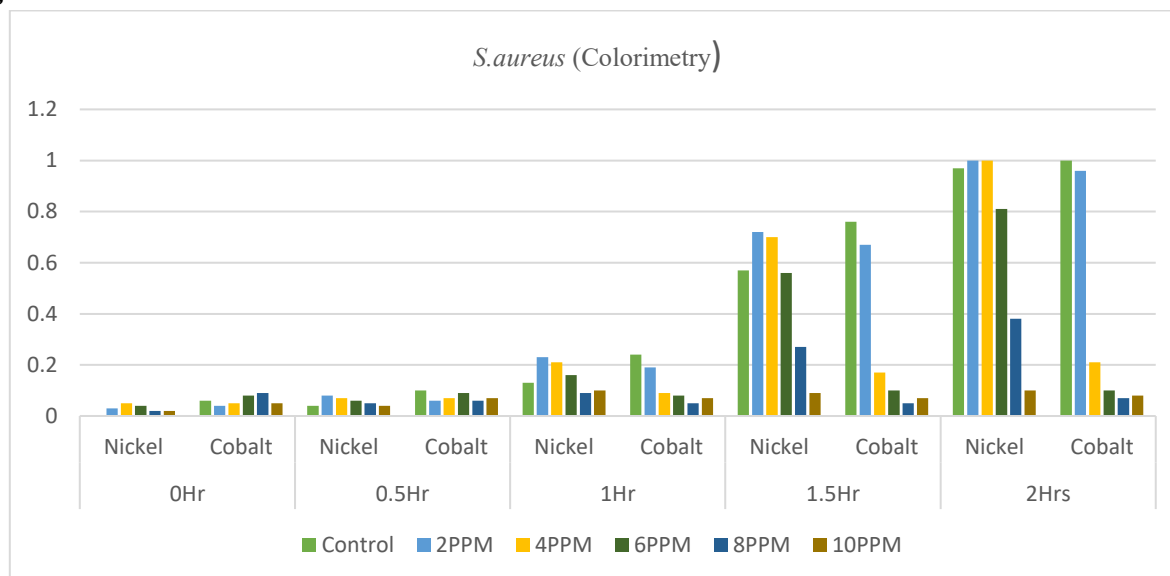


By colorimetry method:

Using E. coli



Using *S. aureus*



Discussion

From results, it is evident that *E. crassipes* and *P. stratiotes* exhibited a markedly higher efficiency in mitigation of heavy metals when compared with bioremediation by bacterial species *E. coli* and *S. aureus*. The data show that *E. crassipes* and *P. stratiotes* consistently absorbed higher concentrations of nickel and cobalt from the contaminated experimental water, demonstrating its robust capacity for heavy metals uptake. This finding aligns with existing literature that highlights the significant phytoremediation potential of aquatic plants, particularly those with extensive root systems capable of accumulating substantial amounts of heavy metals.

In contrast, the bacterial species *E. coli* and *S. aureus* displayed only slight bioremediation capabilities. While there was some evidence of nickel and cobalt absorption by these bacteria, the extent was considerably lower than that observed with *E. crassipes* and *P. stratiotes*. This discrepancy may be attributed to several factors, including the inherent metabolic and physiological differences between plants and bacteria. Bacteria primarily rely on biosorption and intracellular sequestration mechanisms, which might be less effective than the extensive root surface area and complex uptake processes of plant like *E. crassipes* and *P. stratiotes*.

Furthermore, the experimental conditions might have favoured the growth and heavy metals absorption of *E. crassipes* and *P. stratiotes*, given its aquatic nature and the specific environmental setup used in this study. The bacteria, on the other hand, might have faced limitations in terms of growth medium, competition, and other environmental factors that potentially restricted their bioremediation efficacy.

Conclusion

The current study investigated the efficacy of two bacterial species, *E. coli* and *S. aureus*, alongside the aquatic plants *P. stratiotes* and *E. crassipes*, in mitigating Cobalt and Nickel contamination.

This study was aimed at comparing Cobalt and Nickel absorption capacities and overall effectiveness of these biological agents. The findings indicate significant differences in the cobalt and nickel uptake abilities of *E. coli*, *S. aureus*, and *P. stratiotes* and *E. crassipes*, providing insights into their potential applications for bioremediation.

In interpreting the results on the mitigation of cobalt using *E. coli*, *S. aureus*, and *P. stratiotes* and *E. crassipes* it became evident that the efficiency of bioremediation varied significantly among the biological agents. The bacterial species, *E. coli* and *S. aureus*, demonstrated a limited capacity for cobalt and nickel bioremediation. While they did show some ability to absorb and reduce heavy metals concentrations in the contaminated environment, the extent of their effectiveness was limited.

This suggested that bacteria can play an important role in bioremediation, but impact may not be substantial enough for practical applications in environments with high levels of heavy metals contamination. Further studies in this direction using combination of bacterial cultures may be helpful in understanding effective bioremediation process.

In contrast, *P. stratiotes* and *E. crassipes* exhibited a remarkable ability to mitigate cobalt and nickel through phytoremediation. The results showed a significant reduction in Ni and Co, indicating that this aquatic plant is highly efficient in absorbing and withdraw heavy metal from its surroundings. The high efficiency of *P. stratiotes* and *E. crassipes* can be attributed to its rapid growth rate, large biomass, and extensive root system, which provide ample surface area for metal uptake.

To effectively mitigate heavy metal contamination, it will be interesting to combine bioremediation and phytoremediation in future research.

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