



**INSIGHTS INTO ACTINOBACTERIA FOR ITS POTENTIAL APPLICATION FOR  
METAL REMOVAL CONSIDERING SUSTAINABLE DEVELOPMENT**

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**ABSTRACT**

The momentous rise in heavy metal pollution of soil since the advent of the industrial revolution increased human activities on energy reservoirs and unsafe agricultural practices are of serious concern. This, in particular, the single pollution or the combined pollution caused by copper, cadmium, lead, mercury, chromium, etc. has an impact on the environmental quality, human health, and crop production. The toxic metal accumulation in agricultural soils could lead to their entry into the food chain and thereby cause a major threat to food security. The heavy metal aggregation could lead to drastic repercussions such as DNA damage, inhibition of respiration and photosynthesis, and rapid reactive oxygen species generation. Conventional and physical strategies are exorbitant and not effective in places with low metal toxicity. Bioremediation of these metals in leading to a reduced or nontoxic state is an attractive approach for removing pollution. This approach is considered a low-cost and highly effective technique, with fewer side effects as compared to chemical and physical methods. The process involves the application of inherent biological mechanisms of microorganisms and plants to eradicate hazardous contaminants. The current review discusses the different microbes and their mechanism involved in the bioremediation process. The microorganism has specific mechanisms evolved to prevail over the heavy metal toxicity, such as biotransformation, biosorption, and homeostasis.

**KEYWORDS:** Bioremediation, Biosorption, Bioaccumulation, Heavy metals, Toxicity.

Heavy metal disposal onto the topsoil is reported to lead to high-risk contamination and result in the leaching of metals into the groundwater. This occurs predominantly due to human activities that result in a higher pollution level.<sup>[1]</sup> The concentration of these metals Cd+2, Cr+6, Cu+2, Ni+2, and Zn+2 in excess are reported to disrupt the biological ecosystem.<sup>[2&3]</sup> The deposited Cadmium (Cd+2) is reported as a toxic substance to the plants<sup>[4]</sup>, whereas the remaining three elements, Ni, Cu, and Zn are essential its growth. Since the cleanup process for heavy metals is costly and non eco feasible, scientific reports recommend the exploitation of microbes as a cost-effective alternative.<sup>[5]</sup> For example, *Streptomyces* sp HM1 has been used in the removal of the toxic effect of soil caused by Cd+2. Like microbes, few plants also showed tolerance to heavy metal toxicity, for example, *Zea mays* germinate in the presence of Cd+2 contaminated soil. This was reported in work carried out by isolation of the bioactive strain from a wastewater treatment unit located in Jeddah, Saudi Arabia. The strain was reported to have the ability to grow in a Cd+2 environment as revealed by its growth in the medium containing Cd (0-40 ppm). The culture supernatant was

utilized for the growth determination of *Zea mays* and *L.* grains. The trial study was carried out for 10 weeks using *Zea mays* and supernatant of *Streptomyces* sp HM1. After a particular period, the chlorophyll content, total sugars, proline content, and essential element concentration were determined. The plants inoculated with the strain and later with Cd+2 showed better results for root and shoot growth. Likewise, the treated plants reported improved uptake of K+, Mg++, N +and P++. Therein, it can be concluded that *Zea mays* have good potential to grow in Cd+2 contaminated soil and a Cd+2 tolerant *Streptomyces* sp HM1 will help its growth rate through increased production of Indole acetic acid (IAA). The report also indicates preventing its usage as an animal feed, since it leads to the accumulation of toxic substances.<sup>[6]</sup>

Biosorption and bioaccumulation are the two methods reported for microbial bioremediation. These methods were reported for *Streptomyces* spp. with different heavy metal removal processes.

**Table 1: Difference between biosorption and bioaccumulation.**

Biosorption	Bioaccumulation
Fast process	Time consuming process
Energy independent	Energy dependent
Ions attach to the surface	Ions attached inside
Dead and live biomass will involve in the process	Only live cell will involve
Not effected by the environmental changes	Effected by the environmental changes
Reversible process	Partially reversible process

Biosorption has been widely reported in the *Streptomyces* spp. that are isolated from metal contaminated regions. They gained resistance towards metals through their continuous exposure and thus, it could be attributed to facilitating the bioremediation process. The present review discusses the findings related to heavy metal removal using *Streptomyces* spp.

#### Removal of chromium

Chromium is a naturally occurring metal, existing in two different forms hexavalent Cr(VI) and trivalent Cr(III). Among this, the trivalent Cr(III) has physiological significance since it is involved in sugar and fat metabolism. In contrary, the hexavalent Cr(VI) is reported to be more toxic. A study conducted<sup>[7]</sup> reports a strain named as *Streptomyces* MC1, able to grow in minimal medium (MM) and minimal glycerol medium (MMY). The strain shows capability to reduce Cr(VI) to Cr(III) in the presence of glycerol up to 96%. Post 70 days incubation in the MM and MMY, the uptake was reported as 1.48 mg/g and 1.56 mg/g respectively. Likewise, another study conducted by different researchers in 2009 and 2010 concluded that the same strain reported about 45% reduction, post three weeks incubation in MM medium with glucose presence. Actinobacteria strain isolated from contaminated regions also revealed chromium reduction activity. Its presence in two copper filter plant (CFP) and sugar cane plant (SCP) showed efficient Cr(VI) removal. The results concluded that more than 40% of removal from SCP and 10–45% from CFP. Chromium reducing activity in four different Actinobacteria strains were reported<sup>[8]</sup>, and these strains were named as MC1, M3, C55, R22. These strains were reported with Cr(VI) reduction at sterile and nonsterile place as 94% and 86% respectively.

#### Removal of Nickel

The nickel-containing superoxide dismutase enzyme was observed in *Streptomyces*, growing in nickel contaminated region. The resistance characteristic development can be attributed to its continuous metal exposure. *Streptomyces roseorubens* SY was identified.<sup>[9]</sup> This strain was reported for its ability to absorb Ni(II) on its surface. Another report established the dried biomass of the isolate *Streptomyces coelicolor* A3<sup>[2]</sup>, which could reduce the concentration of nickel through the biosorption method at pH 8.0, the temperature of 25 °C.<sup>[10]</sup> the strain *Streptomyces thermovulgaris*, as the most tolerant strain towards nickel.<sup>[11]</sup> Two different strains namely *Nocardia* sp. MORSY1948 and *Nocardia* sp. MORSY2014 were

reported for nickel removal. *S. viridochromogenes* were also reported with the highest biosorption for Ni(II).<sup>[12]</sup>

#### Removal of Zinc

Biomass of *Streptomyces ciscaucasicus* strain CCNNWHX 72 for dead and living cells reported with zinc biosorption property<sup>[13]</sup> and the conditions were optimized as pH 5.0, agitation of 90 rpm, and 2 g/L of biosorbent dose. The biosorption in live cells was reported as 72.5% to 29.7%, and for dead biomass, the decrease was from 86.2% to 31.2%. The reason behind the reduction is due to the limited metal-binding sites on the biosorbent. *Streptomyces zinciresistens*, reported with absorption of zinc on cell wall as well as intracellular accumulation. In another study, around 27 actinobacteria were isolated with zinc removal ability.<sup>[14]</sup> Zn-tolerant *Streptomyces* K1 was isolated from highly alkaline aluminum brown mud for extracellular uptake it was reported as 43% and for intracellular 36%.<sup>[15]</sup>

#### Removal of copper

*S. coelicolor* A3 was reported for copper biosorption at pH 5 and a temperature of 25°C.<sup>[16]</sup> The maximal absorption was reported at 50.9% for an initial metal concentration of 32.2 mg/L within 5 min. Another researcher reported the strain *S. coelicolor* for copper removal after 6 days at 71.2% from the initial concentration of 39 mg/L. In another finding, around 27 selected strains of Actinobacteria were reported for copper removal with bioaccumulation.<sup>[14]</sup>

#### Removal of lead

The Pb(II) removal from the solution through biosorption by *S. fradiae* and *S. reimosus* were also reported.<sup>[17]</sup> Marine isolate *Streptomyces* VITSVK9 sp. showed biosorption of lead at 150 mg/g at neutral pH. Lead removal from the wastewater treatment plant by *Streptomyces* sp. WW1 and further lead removal by *S. viridochromogenes* were also determined.<sup>[18]</sup> Freeze-dried mycelium reported lead removal at 385 mg/g, while freeze-dried strain showed 163 mg/g removal.

*Actinomyces turicensis* AL36Cd isolated from contaminated soil revealed heavy metal resistance with maximum activity towards the removal of Cd(II).<sup>[19]</sup> Frankia species are also reported to have several heavy metal removal that includes Cd(II), Co(II), Cu(II), Cr(VI), Ni(II), and Zn(II).<sup>[20]</sup> They showed a high tolerance level to survive in contaminated soil. *Amycolatopsis tucumamensis* DSM 45259T, isolated drainage of the copper plant demonstrated high

growth adaptation to survive amid the presence of copper. Their metal tolerance mechanism is different from other organisms, which includes an up-regulation of genes to produce antioxidant proteins like superoxide dismutase, alkyl hydroperoxide reductase, mycothiol reductase, and cupric reductase which support the degradation of copper.<sup>[21]</sup>

*Corynebacterium kutscheri* FL108Hg, isolated from the water and sediments of sewerage from industries in Nigeria, is reported to have a high tolerance towards different metals such as Cd(II), Co(II), Cr(VI), Hg(II), and Ni(II).<sup>[19]</sup> *Tsukamurella paurometabola* A155, isolated from zinc mines in Thailand can grow in the regions contaminated with either Cd(II) or Zn(II).<sup>[22]</sup> *Arthrobacter rhombi*-RE shows a high tolerance level against a wide range of heavy metals that include Hg(II), Cd(II), Ba(II), and Zn(II). The enzyme responsible for this reduction has been extracted, immobilized, and applied to achieve high metal tolerance activity through different further studies.<sup>[23]</sup> *Streptomyces* sp. MC1 isolated from sugar cane plant in a polluted area reported a high reduction of Cr(VI), in liquid medium.<sup>[7]</sup>

*Arthrobacter crystallopoietes* ES 32 isolated from dichromate contaminated soil reduced Cr(VI) to Cr(III),

through the production of periplasmic chromate reductase.<sup>[24]</sup> Cr(VI) reduction activity with reductases in the cell-free extract of *Arthrobacter rhombi*-RE have been demonstrated.<sup>[23&25]</sup> reported *Arthrobacter aurescens* MM10 with the bioremediation of chromium by producing chromate reductase and identified *Arthrobacter* sp. FB24 with the bioremediation of the same metal. *Arthrobacter ramosus* isolate showed Cr(VI) and Hg(II) reduction with the presence of chromate reductase and mercuric reductase, respectively in culture supernatants.<sup>[26]</sup>

*A. ferrooxidans* N39-30-03 isolated from copper sulfide heap has been demonstrated with bioremediation capacity.<sup>[27]</sup> *Actinomyces turicensis* AL36Cd isolated from heavy metal contaminated soil showed high tolerance against Cd(II).<sup>[19]</sup> A group of researchers has identified *Frankia* species isolated from the environmentally polluted area that showed tolerance against Cd(II), Co(II), Cu(II), Cr(VI), Ni(II), and Zn(II).<sup>[19]</sup> *Tsukamurella paurometabola* A155 isolated from zinc mine in Thailand can grow in the presence of Cd(II) or Zn(II).<sup>[21]</sup> *Arthrobacter crystallopoietes* ES 32 isolated from dichromate contaminated soil showed Cr(VI) reduction to Cr(III) through chromate reductase.<sup>[24]</sup>

**Table 2: Actinobacteria strains belonging to heavy metal bioremediation and their mechanism behind the process.**

Strain	Source of isolation	Metal undergone for bioremediation	Mechanism	References
<i>S. viridochromogenes</i>	NR	Cu(II)	Biosorption	[12]
<i>S. zinciresistens</i>	Zincocopper amine, Shaanxi, China	Cu(II)	Biosorption/Bioaccumulation	[28]
<i>S. albogriseolus</i> NGP	Contaminated soil Tamilnadu, India	Cu(II)	Biosorption	[29]
<i>S. coelicolor</i> A3(2)	Culture collection	Ni(II)	Biosorption	[16]
<i>S. aureofaciens</i> NR-3	Riparian sediments contaminated with high levels of Ni(II)	Ni(II)	Ni-influx and Ni-efflux transporters	[30]
<i>S. viridochromogenes</i>	NR	Pb(II)	Biosorption	[12]
<i>Streptomyces plumbiresistens</i> CCNWHX13-160	Lead-polluted soil, Gansu, China	Pb(II)	NR	[31]
<i>S. zinciresistens</i>	Zincocopper mine, Shaanxi, China	Zn(II)	Biosorption	[28]
<i>S. acrimycini</i> NGP	Marine sediments, Tamilnadu, India	Zn(II)	Biosorption	[29]
<i>S. flavovirens</i> ON3	Soil exposed to heavy traffic emissions, Brno, Czech Republic	Zn(II)	Biosorption	[32]
<i>S. lunalinharesii</i>	Culture collection	Zn(II)	Biosorption	[33]

## CONCLUSION

Environmental pollution is a critical concern that is regarded as one of the biggest challenges of the present century. Identifying and implementing efficient solutions to conserve the environment for the upcoming generation

is a time demanding task. Heavy metal pollution and contamination leads to severe issues such as decreased soil quality and fertility, loss of microbial biodiversity as well as destruction of the vegetal cover. The microorganisms inhabiting such sites can both mobilize

metals from mine wastes, and sequester metals from contaminated waters. They have incorporated a series of resistance mechanisms to overcome the metal toxicity, and can even obliquely change metal speciation. These mechanisms influence the environmental fate of metals, like transferring them between the terrestrial and aquatic environments, and thereby leading to cause adverse impacts on planetary health. The present review summarizes the latest research findings of microbes isolated from contamination sites with capacity to remediate heavy metals. The microbes used various processes such as precipitation, biosorption, enzymatic transformation of metals, complexation and phytoremediation techniques to effectively remediate the heavy metals. The reports point out towards a better understanding of the microbe-metal interaction that could hold the potential in limiting the metal toxicity in the contaminated regions.

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