Containing contamination: trees, fungi and bacteria to the rescue

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Managing heavy metal pollution from industrial, urban and mining waste has become a major concern in the modern era. Take, for example, the state of Odisha. It accounts for 98% of total chromite mining reserves in India. The Sukinda chromite mine area, in particular, is reported to contain 60% of hexavalent chromium in drinking water[1]. And the maximum permissible limit for Cr(VI) is 0.05 mg/l for potable water.

Cr(VI) is carcinogenic and mutagenic even through oral inhalation. Hexavalent chromium is a toxic heavy metal pollutant, generated from many industrial processes. 40% of the total industrial chromium is used in the leather tanning industry. The discharge of used industrial effluents containing chromium creates soil or water pollution and extensive degradation of productive land.

Here we report some recent research on tackling the problem of Cr(VI) and other heavy metals using various bioengineering strategies, including trees, aquatic plants, fungi and bacteria.

Some tree species of Indian origin – *Pithecellobium dulce*, *Tamarindus indicus*, *Pongamia glabra* and *Azadirachta indica* – are known to remediate Cr from environments. However, there is no systematic assessment of these trees for their phytoremediation potential of tannery effluents.

Last month, a group of scientists from the Indian Institute of Technology, Chennai, the University of Madras, and the Konkuk University, Korea, examined the utility of tree species to reduce heavy metal toxicity in the leather industry[2].

The research team initially screened 26 perennial tree species of Indian origin. They selected 10 timber-yielding species to test their chromium accumulation potential.

The researchers also collected chromium-contaminated effluent sludge samples from a tannery industry. These were analysed for chemical constituents.

They planted three-month-old saplings in pots and used tannery effluent sludge diluted with four times tap water. This was done for five months.

The scientists extracted chromium from the soil and determined chromium content. And the powdered form of leaves, stem and roots helped determine the chromium content in the different parts of the plants.

They found that plants accumulate chromium in the root, stem and leaf regions. *Acacia auriculiformis* has a higher capacity to accumulate chromium in both roots and stem. *Dalbergia sissoo* and *Thespesia populnea* accumulated more chromium in the roots. In the case of *Azadirachta indica* and *Albizzia lebbeck*, it was the stem region.

These results demonstrate that these tree species could act as phytoremediators for chromium-contaminated soils. Using these tree species for chromium removal could avoid the problem of seasonal clearing and replanting. It provides long term benefits. While reducing the chances of chromium entry into the food chain, these trees could also be useful in reducing erosion, offer protection from wind, and provide timber…

Recently, scientists from the Sri Krishnadevaraya University, Anantapur, India, in collaboration with the Gyeongsang National University, Jinju; the University of South Australia, Mawson Lakes and the University of Newcastle, Callaghan, reported detoxification and removal of toxic metals from aqueous systems with *Melaleuca diosmifolia*[3].

M. diosmifolia, commonly called green honey myrtle, is known to provide low-cost coagulating adsorbents for removing both cationic and anionic dyes. But its value as an adsorbent of Cr has not been tested.

The research team examined the applicability of *M. diosmifolia* for the removal of Cr(VI) in water samples. They collected dried twigs from a fully grown *M. diosmifolia* plant. Then they conducted biosorption studies using the powdered twigs and evaluated the effect of various parameters such as pH, temperature, adsorbent dosage effect, contact time and initial Cr(VI) concentration. The researchers also checked the regeneration capacity under batch process.

The batch studies revealed that 5 g/l of biosorbent effectively removes 97–99.9% of Cr(VI) in 250 mg/l from lake and seawater samples. It could withstand a wide-ranging condition of pH 2–10 and temperature 24–48°C.

M. diosmifolia is thus useful to immobilize toxic metal ions in wastewater. In fact, the usually discarded dried twigs of this plant are better adsorbents than those commercially available for industrial wastewater treatment. This offers the possibility of a 'waste to resource' conversion for removing Cr(VI) from industrial effluents.

In another study, the Environment Research Group from Jamshedpur reported the use of an aquatic weed for removing Cr(VI) from contaminated water: water hyacinth – *Eichhornia crassipes*[4]. Water hyacinth is a noxious aquatic plant with a high growth rate. Its ability to remove heavy metals from wastewater has been recognized. However, these aquatic plants were not experimentally tested for large-scale treatment of wastewater from mines.

The researchers collected water samples from the Sukinda chromite mines area of Odisha. They estimated physicochemical parameters such as pH, total dissolved solids as well as dissolved biological and chemical oxygen demands. And they monitored the presence of elements such as Fe, Ca, Mg, Cr(VI) and SO_4 before and after treatment with water hyacinth.

The experiments were initially carried out on 5 l water and then large-scale experiments were done on 100 l of water. A fresh biomass of 250 g was used for 5 l and 5 kg for 100 l of water. The maximum limit of Cr(VI) uptake by water hyacinth at different concentrations was determined.

The researchers found that water hyacinth could remove 99.5% of Cr(VI) from the water of the Sukinda chromite mines within 15 days. The removal efficiency was the same for 5 l and 100 l. The weed also reduced total dissolved solids and pH. It was found effective in reducing hardness in wastewater.

This result highlights the potential of water hyacinth and associated microorganisms as an effective method to reduce the levels of chromium in waste water to permissible levels before discharge into water bodies. This will reduce the chances of chromium contamination in groundwater.

Perhaps other weeds like duckweed, small water ferns and water lettuce also need to be studied as phytoremediators to combat the problem of *in situ* chromium contamination in mining areas.

It is not only trees and weeds that can help us. In the last decade, some bacterial strains have been found to detoxify Cr(VI) to insoluble and less toxic Cr(III). But empirical studies to identify the bacterial isolates present in contaminated wastewater from coal mine areas and their capacity quantification for deionizing metals were missing.

Last month, scientists from the National Institute of Technology, West Bengal, and the North-Eastern Hill University, Shillong, reported the effective use of microbial treatment for chromium reduction from the wastewater of coal mine areas[5]. The research team identified chromium-resistant bacterial species from both single and bimetallic contaminated wastewater.

They isolated twenty different bacterial strains using soil and water samples collected from coal mine areas. Their tests revealed that one bacterium could resist multiple metal ions and sustained higher Cr^{6+} concentrations. Using biochemical, morphological and 16S rRNA characterization, they confirmed the identity of this bacterium: *Rhodococcus erythropolis*.

They found that *R. erythropolis* tolerated a wide range of Cr^{6+} concentrations of up to 150 mg/l before reaching minimum inhibition. The bacteria removed 89.54% of Cr^{6+} from an initial metal concentration of 50 mg/l. It could withstand an acidic range of pH 5–7 and temperature of 20–35°C. Moreover, it reduced heavy metals such as Fe, As, Cu, Ag, Zn, Mn, Mg and Pb from aqueous solutions. In fact, Cr^{6+} removal was more prominent in bimetallic solutions.

To understand the mechanism behind the reduction in the metal ion concentration, the researchers proposed biosorption and bioaccumulation in the cell as a mechanism for Cr^{6+} reduction to Cr^{3+}. This was corroborated by the observation that the oxidation of chromium is both within and outside the cell.

These results underline the potential of this bacterial isolate for large scale Cr^{6+} reduction from contaminated aqueous solutions.

Cases of bioremediation are not restricted to plants or weeds and bacteria. Microorganisms can also deal with heavy metal pollutants such as cadmium in solid wastes. A World Bank report predicts a municipal solid waste generation of about 0.7 kg/capita/day and 376,639 tonnes/day by 2025 (ref. 6). Leachates from municipal solid waste are an important issue worldwide.

Microbes like fungi are used in metal-polluted sites owing to their tolerance to heavy metals. And also due to higher metal uptake capacity, continuous enrichment capabilities, adaptive nature, minimal sludge production and high reusability bulky biomass. But empirical studies to test the strength of fungal strains on Cd^{2+} metal reduction are lacking.

Recently, researchers from the Rani Durgavati University, Jabalpur, and the V.A.B. College, Chhatarpur, identified an indigenous fungus capable of removing cadmium from municipal solid waste[7].

The research team collected 30 fungal isolates from different dumping sites of municipal solid waste. The researchers evaluated diverse environmental conditions such as pH, temperature, inoculum concentration and incubation period to test the removal efficiency of cadmium metal in the medium on the growth of the fungal strains.

They found that a consortium of three isolates – *Trichoderma harzianum*, *Aspergillus niger* and *Aspergillus flavus* – shows higher Cd^{2+} tolerance than a single fungal strain. And these survived in a culture media with more than 1.5 mg/l Cd^{2+} concentration.

Extensive assessment of the use of these fungal strains for biosorption of heavy metals from municipal solid-waste needs to be undertaken before large scale implementation.

1. Indian Bureau of Mines, Annual Report of IBM, Govt of India, 2004.
2. Manikandan, M., Kannan, V., Mahalingam, K., Vimala, A. and Chun, S., *Prep. Biochem. Biotech*., 2015, **46**(1), 100–108.
3. Kuppusamy, S., Thavamani, P., Megharaj, M., Venkateswarlu, K., Lee, Y. B. and Naidu, R., *Process Safety Environ. Protect.*, 2016, **100**, 173–182.
4. Saha, P., Shinde, O. and Sarkar, S., *Int. J. Phytoremediat.*, 2017, **19**(1), 87–96.
5. Banerjee, S., Joshi, S. R., Mandal, T. and Halder, G., *Chemosphere*, 2017, **167**, 269–281.
6. Hoornweg, D and Tata, P. B., *The World Bank*, 2012, **5**, 81.
7. Awasthi, A. K., Pandey, A. K. and Khan, J., *J. Clean Technol.*, 2017, **140**(3), 1618–1625.

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