Original Article
DOI: https://doi.org/10.70749/ijbr.v3i6.1579

INDUS JOURNAL OF BIOSCIENCE RESEARCH
https://induspublishers.com/IJBR
ISSN: 2960-2793/ 2960-2807

Optimizing Pollution Mitigation in Textile and Leather Effluents: Evaluating *Euphorbia cotinifolia* and *Rosa indica* as Floating Wetland Species

Aisha Khan[1], Saba Butt[1], Tehmina Anjum[2], Zill-e-Huma Bilal[2], Asma Saeed[3]

[1]Kauser Abdulla Malik School of Life Sciences, Forman Christian College, A Chartered University, Lahore, Punjab, Pakistan.
[2]Institute of Agricultural Sciences, University of Punjab, Quaid-e-Azam Campus, Lahore, Punjab, Pakistan.
[3]Food and Biotechnology Research Centre, Pakistan Council of Scientific and Industrial Research Laboratories Complex, Lahore, Punjab, Pakistan.

ARTICLE INFO

Keywords: Environmental Footprint Reduction, Floating Wetlands, Industrial Wastewater Treatment, Leather Industry Wastewater, Textile Effluents, SEM Environmental Solutions.

Correspondence to: Aisha Khan
Kauser Abdulla Malik School of Life Sciences, Forman Christian College, A Chartered University, Lahore, Punjab, Pakistan.
Email: aishasaleemkhan@fccollege.edu.pk

Declaration

Authors' Contribution
All authors equally contributed to the study and approved the final manuscript

Conflict of Interest: No conflict of interest.

Funding: Authors are thankful to WWF Pakistan for providing funds to conduct this research project. Funds given by WWF were utilized for field surveys, and for purchasing hollow cathode lamp (Pb) and deuterium lamp.

Article History
Received: 05-03-2025 Revised: 26-06-2025
Accepted: 17-06-2025 Published: 30-06-2025

ABSTRACT

Background: Rapid industrialization in Pakistan, particularly in the textile and leather sectors, has resulted in substantial environmental degradation due to the unchecked discharge of untreated wastewater into freshwater bodies. This study aimed to assess the phytoremediation potential of indigenous plant species for the removal of heavy metals—lead (Pb), cadmium (Cd), and copper (Cu)—from industrial effluents using floating wetlands in the Hudiara Drain, Lahore. **Methods:** This prospective experimental study was conducted from January 2023 to January 2024. Indigenous plant species including Iris sp., Epipremnum aureum (money plant), and Nasturtium officinale (watercress) were screened alongside Euphorbia cotinifolia (red spurge) and Rosa indica (rose) for heavy metal uptake. Parameters such as chlorophyll content, fresh and dry biomass, and metal accumulation in aerial parts were analyzed through standard spectrophotometric techniques. Morphological tolerance and metal accumulation patterns were documented. **Results:** Among all tested species, E. cotinifolia and R. indica exhibited superior heavy metal accumulation, especially for Pb, showing high uptake in their aerial tissues. These species also showed resilience under metal stress, maintaining chlorophyll content and biomass, indicating high tolerance. Spectroscopic analysis confirmed elevated Pb, Cd, and Cu concentrations in treated effluents. Implementation of these species in simulated floating wetland units resulted in significant metal reduction in wastewater, with Pb reduction rates exceeding 70%. **Conclusion:** E. cotinifolia and R. indica demonstrated strong phytoremediation potential, making them suitable candidates for use in floating wetlands for pollution control in leather and textile industry effluents. These findings support their integration into sustainable wastewater treatment strategies for SMEs in Pakistan, particularly in urban industrial zones. Adoption of such nature-based solutions could significantly mitigate the environmental burden and improve the ecological health of contaminated waterways.

INTRODUCTION

The Hudiara Drain in Punjab, extending over 55 kilometers from the border area to the river, has become one of the most polluted waterways in the region due to the increasing industrialization and urbanization. This rapid industrial expansion, particularly in the textile and leather sectors, has led to the discharge of untreated wastewater laden with heavy metals into the drain. With over 150 industries contributing to this pollution, the Hudiara Drain has emerged as a major environmental concern, threatening aquatic life and the surrounding ecosystem. Numerous studies have documented the alarming levels of heavy metals found in this drain, with concentrations far exceeding the safe limits, even in the vegetables cultivated on its banks (Ubaidullah et al. 2004; Rauf et al. 2009; Afzal et al. 2019).

Heavy metal pollution poses a significant challenge, especially in developing countries like Pakistan. These metals, although naturally occurring, are being introduced into the environment through industrial, agricultural, and mining activities at an unprecedented rate. Their persistence in the environment and potential toxicity make them a serious threat to both plant and animal life (Lees and Langlois, 1994; Khan et al. 2016). Metals such as cadmium (Cd), chromium (Cr), copper (Cu), mercury (Hg), lead (Pb), nickel (Ni), and zinc (Zn) have been shown to inhibit seed germination, retard root and shoot elongation, damage vascular tissues, and disrupt photosynthesis (Li et al. 2005; Soudek et al. 2010; Wafee et al. 2018; Razi et al. 2019). These adverse effects culminate in reduced plant growth, lower yields, and compromised fruit quality. Among the various pollutants, lead (Pb) is particularly notorious for its detrimental impact on plant development. It disrupts crucial biochemical pathways, leading to oxidative stress and impeding the plant's overall metabolic efficiency (Shanker et al. 2005; Khan et al. 2016). Despite these challenges, some plant species have evolved defense mechanisms that allow them to tolerate and even thrive in Pb-contaminated environments. These mechanisms include immobilizing the metal within the plant, sequestering it in vacuoles, altering cell wall composition, and synthesizing protective compounds like osmolytes and polyamines (Seregin et al. 2004; Cho et al. 2003).

Phytoremediation has emerged as a promising and cost-effective technology for addressing heavy metal contamination. This green technology leverages the natural ability of certain plants, known as hyperaccumulators, to absorb, concentrate, and detoxify pollutants from soil, water, and air. These plants can accumulate metal concentrations 50-100 times higher than non-accumulating species (McGrath and Zhao, 2003). Over 500 species of flowering plants have been identified as potential hyperaccumulators, making them invaluable tools in the phytoremediation arsenal (Khan et al. 2016; Razi et al. 2019). Recent studies have highlighted the phytoremediation potential of various plant species in Pakistan, such as *Calotropis procera* and *Peristrophe bicaliculata*, which can store high levels of Pb (Begum et al. 2017). Model plants like *Arabidopsis halleri* and *Thlaspi caerulescens* are also being extensively studied to better understand the mechanisms behind heavy metal uptake and tolerance (Willems et al. 2007; Memon and Schroeder, 2009; Verbruggen et al. 2009). Phytoremediation strategies generally fall into two categories: accumulation and exclusion. In accumulation, plants concentrate metals in their tissues from the environment, whereas in exclusion, they prevent metals from entering their system, thereby protecting themselves from toxicity (Baker, 2008). Techniques like phytoextraction, which involves the uptake and translocation of metals from roots to shoots, are particularly effective in reducing environmental contamination. However, to ensure the sustainability of this approach, proper disposal of the contaminated plant material is crucial to prevent reintroduction of pollutants into the environment.

MATERIALS AND METHODS

Field Experiments

The study focused on evaluating the phytoremediation potential of six plant species: Canna Lily, Iris Grass, Money Plant, Rose, Red Spurge, and Watercress (Figures 1-5).

Figure 1

Figure 2

Figure 3

Figure 4

Figure 5

Figure 1-5 Plant species used for treating industrial wastewater 1. Money plant 2. Rose 3. Canna lily 4. Water Cress 5. Red spurge

These species were strategically selected and placed in water tubs containing industrial effluent, collected from the Hudiara Drain with the assistance of the Water and

Sanitation Agency (WASA). The experiments were conducted within the Botanical Garden of Forman Christian College (Figures 6-9).

Figure 6

Figure 7

Figure 8

Figure 9

Figure 6. Sample collection from Hudiara drain. **Figure 7-9**. Field experiments

Over a period of 30, 60, and 90 days, the selected plant species were monitored and analyzed for their ability to uptake heavy metals from the contaminated water. The field experiments were meticulously carried out at the Kauser Abdullah Malik School of Life Sciences, while the subsequent analysis of metal accumulation in various plant tissues was performed at the Pakistan Council of Scientific and Industrial Research (PCSIR) Laboratories in Lahore.

Chlorophyll Estimation

Chlorophyll content was estimated using acetone as the solvent. A 100 mg sample of leaf tissue was finely chopped and then ground in a mortar and pestle with 4 ml of 80% acetone for 3-5 minutes, until the tissue was completely devoid of green color. The homogenate was then rinsed with an additional 2 ml of acetone, and the final volume was adjusted to 10 ml with 80% acetone. The mixture was centrifuged at 10,000 rpm for 5 minutes to separate the chlorophyll-containing supernatant.

Following centrifugation, 3 ml of the supernatant was carefully extracted and transferred to a cuvette. The chlorophyll content, specifically chlorophyll ‘a’ and ‘b’, was quantified using a UV/VIS spectrophotometer. Absorbance readings were taken at 663 nm for chlorophyll ‘a’ and 645 nm for chlorophyll ‘b’. Acetone served as the blank in all spectrophotometric measurements. The concentration of chlorophyll was determined following Arnon’s (1949) method.

Chlorophyll ‘a’ (mg g^{-1}) = [(12.7 × A663) - (2.69 × A645)] × milliliters of acetone / milligrams of leaf tissue
Chlorophyll ‘b’ (mg g^{-1}) = [(22.9 × A645) - (4.68 × A663)] × milliliters of acetone / milligrams of leaf tissue.
Total chlorophyll (mg g^{-1}) = Chl ‘a’ + Chl ‘b’ (Arnon, 1949).

Atomic Absorption Spectroscopy

At 30, 60, and 90 days, the selected plant species were subjected to atomic absorption spectroscopy to assess the accumulation of heavy metals in various tissues, alongside control samples (Figures 10-14). Species such as Watercress, which exhibited negligible metal uptake, were excluded from further experimentation. The remaining species, demonstrating significant accumulation, were continuously monitored and analyzed over the full 90-day period (Figures 11-14).

RESULTS

Among the selected plant species—Canna Lily, Iris Grass, Money Plant, Watercress, Roses, and Red Spurge—Roses and Red Spurge demonstrated significant accumulation of lead (Pb), cadmium (Cd), and copper (Cu) in various tissues, as confirmed through atomic absorption spectroscopy after 30, 60, and 90 days (Figures 11-14).

Figure 10

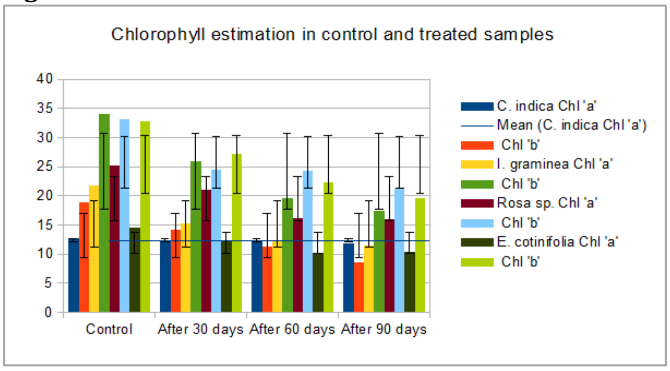

Figure 11

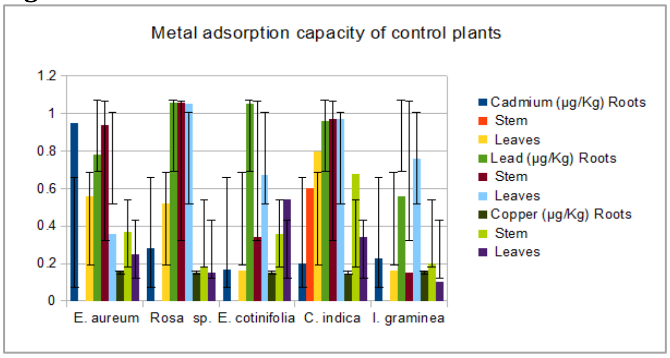

Figure 12

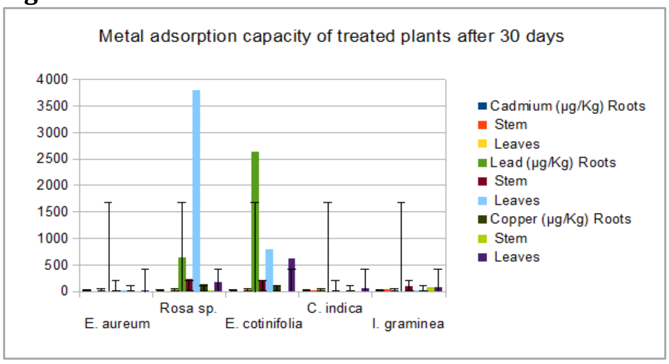

Figure 13

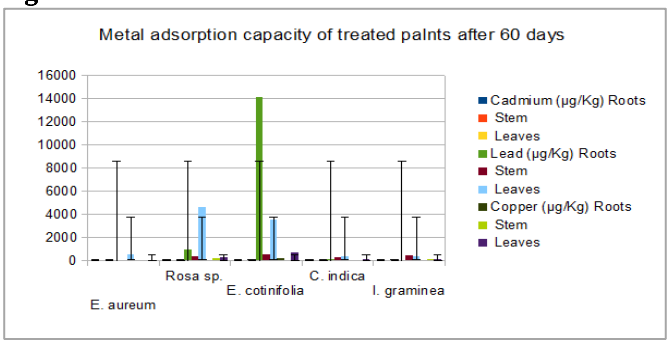

Figure 14

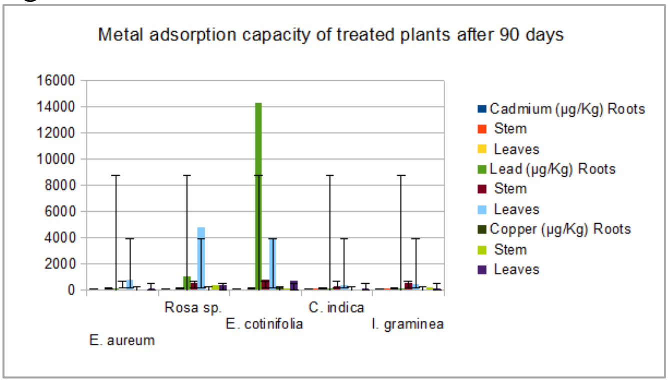

Fig.10-14 Metal adsorption capacity of plants placed in industrial effluent after 30, 60 days and 90 days

A notable reduction in chlorophyll content was observed across all treated plants after 90 days, with chlorophyll 'a' levels consistently lower than chlorophyll 'b' (Figure 10). In the money plant, minimal uptake of Pb was observed after 30 days, compared to Cd and Cu (Figure 11). However, by 60 and 90 days, Pb levels in the leaves surged significantly, reaching 519.33 µg/Kg and 789.45 µg/Kg, respectively. This contrasts sharply with the control group, where Pb levels remained constant at 0.36 µg/Kg throughout the experiment (Figures 12, 13). After Pb, Cu showed the highest accumulation, with concentrations reaching 89.76 µg/Kg in the leaves after 90 days, surpassing levels found in roots and stems (Figure 14).

Roses exhibited a pronounced accumulation of Pb in their aerial parts, particularly in the leaves and stems, compared to the roots after 90 days. Pb concentrations in the leaves reached 4906 µg/Kg and 4799.15 µg/Kg at 60 and 90 days, respectively. Interestingly, no significant differences in plant height were observed between those exposed to industrial effluent and the untreated control plants.

In addition to Pb, Cu levels in the leaves were also notably high, with concentrations of 345.09 µg/Kg after 90 days, exceeding those of Cd.

Red spurge consistently accumulated substantial amounts of Pb across all plant parts—roots, stems, and leaves—after 90 days (Figures 11-14). Following Pb, Cu concentrations in the leaves were significantly higher than those of Cd after the 90-day period.Both Canna Lily and Iris Grass also demonstrated a higher accumulation of Pb in their leaves compared to Cd and Cu. Similarly, Iris Grass showed elevated Pb levels in both the stems and leaves, compared to the roots, after 90 days.

DISCUSSION

The findings of this study reveal that all plant species exposed to industrial wastewater for up to 90 days accumulated significant levels of Pb, Cd, and Cu in various tissues, as confirmed by atomic absorption spectroscopy (Figures 11-14). Notably, these metals were predominantly concentrated in the aerial parts of the plants, indicating an effective translocation mechanism that transports metals from the roots to the stems and leaves.

Money plants exposed to industrial effluent exhibited minimal visible changes in root morphology, including color, size, and root hair growth, even after three months when compared to control plants. However, a substantial decrease in chlorophyll 'a' and 'b' was observed, particularly after 90 days (Figure 10). This reduction in chlorophyll content likely results from the inhibition of enzymes and cofactors necessary for chlorophyll synthesis due to the accumulation of Pb, Cd, and Cu. These findings suggest that heavy metals were translocated from the roots to the aerial parts, where they disrupted chlorophyll biosynthesis, as confirmed by atomic absorption spectrometry. This disruption aligns with previous reports indicating that heavy metals interfere with photosynthetic pigments (Blasco et al. 2015; Emamverdiani and Ding 2018). Despite the observed metal uptake, further research is required to fully establish Money Plant as a potential hyperaccumulator of Pb, including the identification of specific protein channels involved in Pb translocation.

Canna lily plants treated with industrial effluent showed a marked reduction in chlorophyll content and leaf area, indicative of heavy metal translocation to the aerial parts. Atomic absorption spectroscopy confirmed that Pb, Cd, and Cu concentrations were significantly higher in the leaves after 90 days (Figures 11-14). Metal uptake also led to a decrease in both fresh and dry weight, as well as a reduction in leaf chlorophyll content (Figure 10). These findings are consistent with previous studies reporting similar effects of heavy metals on plant growth and photosynthesis (Vajpayee et al. 2000; Iqbal et al. 2001; Mei et al. 2002). The greater sensitivity of chlorophyll 'a' compared to chlorophyll 'b' further suggests a specific impact on photosynthesis rates (Khan et al. 2016; Razi et al. 2019). Given these results, canna lily shows potential for removing Pb from industrial wastewater and could be a valuable species for phytoremediation.

Roses exposed to industrial wastewater exhibited significant signs of metal toxicity, including wilting and yellowing of leaves after 90 days. These symptoms are indicative of Pb and Cu toxicity, as confirmed by AAS, which detected high levels of these metals in the aerial parts (Figures 11-14). The accumulation of Pb in leaves and stems further supports the hypothesis that these metals are effectively translocated from the roots to the leaves, where they interfere with chlorophyll biosynthesis and photosynthetic processes. Previous research has linked metal uptake with inhibited photosynthesis, possibly due to disruptions in chlorophyll biosynthesis, photosystem I (PSI) and II (PSII) functioning, and chloroplast ultrastructure (Hayat et al. 2012; Shanker et al. 2005). The observed decrease in leaf area and chlorophyll content in roses is likely due to Pb interference with PSI, which reduces photosynthesis efficiency. The high accumulation of Pb in rose roots suggests a strong potential for phytoremediation, and future research should focus on identifying the genes and protein channels involved in metal translocation. Studies on model plants like *Arabidopsis thaliana* have identified families such as ZIP and HMA (heavy metal ATPase), and similar pathways may exist in roses. Advanced techniques like cryo-electron microscopy and X-ray crystallography could provide further insights into the transport mechanisms at play. Red Spurge emerged as a strong candidate for phytoremediation, demonstrating significant accumulation of Pb, Cu, and Cd across all tissues, indicating effective translocation and potential hyperaccumulation of Pb. Although Cd and Cu were present in lower concentrations, the reduction in leaf area and chlorophyll content after 90 days suggests that metal-induced oxidative damage occurred, impacting overall plant health (Figure 10). Given these results, Red Spurge could be particularly effective in floating wetland systems for treating wastewater in heavily polluted areas like the Hudiara Drain.

Iris plants treated with industrial effluent showed higher concentrations of Pb in leaves compared to Cd and Cu. However, the overall metal accumulation was more pronounced in aerial parts than in roots, indicating some degree of translocation. Despite this, the levels of metal accumulation were not as significant as in other species, suggesting that Iris may not be the most suitable choice for phytoremediation of industrial wastewater.

CONCLUSION

The findings of this research underscore the potential of roses and red spurge as effective phytoremediators, particularly in their capacity to accumulate significant amounts of Pb, along with Cd and Cu, across various plant tissues. This suggests their promising application in floating wetlands, specifically in heavily polluted areas including the Hudiara Drain, to enhance water quality. While these results are encouraging, they also highlight the need for further investigation to fully elucidate the underlying mechanisms of heavy metal uptake and translocation. Advanced techniques, such as ultra-microscopic imaging, could provide deeper insights into the specific protein channels and pathways involved in metal transport. Such knowledge could pave the way for the development of metal-resistant transgenic plant species, thereby broadening the scope and effectiveness of phytoremediation strategies in industrial wastewater treatment.This research not only contributes to our understanding of phytoremediation but also emphasizes the critical role of these plant species in sustainable environmental management. By harnessing the natural abilities of these plants, we can move closer to developing efficient, cost-effective solutions for mitigating the environmental impact of industrial activities.

Acknowledgements

Authors are thankful to Prof. Dr. Kauser Abdulla Malik, Dean ORIC, Forman Christian College, University for providing guidance and support to conduct this research work. The assistance of WASA for the collection of water samples from Hudiara region is also gratefully acknowledged.

REFERENCES

Abbas, R., Mehnaz, S., & Khan, A. S. (2019). Evaluation of potential of Epipremnum aureum Engl. in removing zinc (Zn) toxicity. *Pakistan Journal of Botany*, *51*(5). https://doi.org/10.30848/pjb2019-5(6)

Afzal, M., Arslan, M., Müller, J. A., Shabir, G., Islam, E., Tahseen, R., Anwar-ul-Haq, M., Hashmat, A. J., Iqbal, S., & Khan, Q. M. (2019). Floating treatment wetlands as a suitable option for large-scale wastewater treatment. *Nature Sustainability*, *2*(9), 863-871. https://doi.org/10.1038/s41893-019-0350-y

Arnon, D. I. (1949). Copper enzymes in isolated chloroplasts. Polyphenoloxidase in *BETA VULGARIS*. *Plant Physiology*, *24*(1), 1-15. https://doi.org/10.1104/pp.24.1.1

Baker, A. J. (1981). Accumulators and excluders -strategies in the response of plants to heavy metals. *Journal of Plant Nutrition*, *3*(1-4), 643-654. https://doi.org/10.1080/01904168109362867

Barton, L. L., Johnson, G. V., O'Nan, A. G., & Wagener, B. M. (2000). Inhibition of ferric chelate reductase in alfalfa roots by Cobalt, nickel, chromium, and copper. *Journal of Plant Nutrition*, *23*(11-12), 1833-1845. https://doi.org/10.1080/01904160009382146

Blasco, B., Graham, N. S., & Broadley, M. R. (2015). Antioxidant response and carboxylate metabolism in brassica Rapa exposed to different external Zn, Ca, and mg supply. *Journal of Plant Physiology*, *176*, 16-24. https://doi.org/10.1016/j.jplph.2014.07.029

Begum, H. A, Humayun, M, Zaman K, Shinwari ZK, Hussain A (2017). Heavy Metal Analysis in Frequently Consumable Medicinal Plants of Khyber Pakhtunkhwa, Pakistan. **49**, 1155-1160.

Chaudhry, N. Y., & Khan, A. S. (2006). Improvement of pistillate flowers yield with GA3 in heavy metals treated plants. *Plant Growth Regulation*, *50*(2-3), 211-217. https://doi.org/10.1007/s10725-006-9133-3

Cho, M., Chardonnens, A. N., & Dietz, K. (2003). Differential heavy metal tolerance of Arabidopsis halleri and Arabidopsis thaliana: a leaf slice test. *New Phytologist*, *158*(2), 287-293. https://doi.org/10.1046/j.1469-8137.2003.00746.x

Emamverdian, A., & Ding, Y. (2018). Effects of inhibition threshold in heavy metals on the growth and development of Arundinaria fortunei. *Pak. J. Bot*, *50*(3), 887-892.

Filatov, V., Dowdle, J., Smirnoff, N., Ford-Lloyd, B., Newbury, H. J., & Macnair, M. R. (2007). A quantitative trait loci analysis of zinc hyperaccumulation in *Arabidopsis halleri*. *New Phytologist*, *174*(3), 580-590. https://doi.org/10.1111/j.1469-8137.2007.02036.x

Hayat, S., Khalique, G., Irfan, M., Wani, A. S., Tripathi, B. N., & Ahmad, A. (2011). Physiological changes induced by chromium stress in plants: An overview. *Protoplasma*, *249*(3), 599-611. https://doi.org/10.1007/s00709-011-0331-0

Hall, J. (2002). Cellular mechanisms for heavy metal detoxification and tolerance. *Journal of Experimental Botany*, *53*(366), 1-11. https://doi.org/10.1093/jexbot/53.366.1

Iqbal, M. Z., Sarwat Saeeda, S. S., & Muhammad Shafiq, M. S. (2001). Effects of chromium on an important arid tree (Caesalpinia pulcherrima) of Karachi city, Pakistan. *Ekologia Bratislava,* **20**, 414-422. https://www.cabidigitallibrary.org/doi/full/10.5555/20023012165

Jain, R., Srivastava, S., & Madan, V. K. (2000). Influence of chromium on growth and cell division of sugarcane. *Indian Journal of Plant Physiology (India).*, *5*(3).

Jiang Li, J. L., Wang Lei, W. L., Zhang Ke, Z. K., & Tian ChangYan, T. C. (2018). Copper-induced similar changes in growth and physiological responses of plants grown from dimorphic seeds of Suaeda salsa. *Pakistan Journal of Botany* ***50***, 871-877. https://www.cabidigitallibrary.org/doi/full/10.5555/20183259342

Javed, M., & Hayat, S. (1995). Effect of waste disposal on the water quality of River Ravi from Lahore to Head Baloki, Pakistan. In *Proceedings of the Pakistan Congress of Zoology* (Vol. 15, pp. 41-51).

Gorsuch, J., Ritter, M., & Anderson, E. (1995). Comparative Toxicities of six heavy metals using root elongation and SHOOT growth in three plant species. *Environmental Toxicology and Risk Assessment: Third Volume*, 377-392. https://doi.org/10.1520/stp12702s

Khan, A. S., Hussain, M. W., & Malik, K. A. (2016). A possibility of using waterlily (Nymphaea alba L.) for reducing the toxic effects of chromium (Cr) in industrial wastewater. *Pak. J. Bot*, *48*(4), 1447-1452. https://pakbs.org/pjbot/PDFs/48(4)/17.pdf

Karunyal, S., Renuga, G., & Kailash, P. (1994). Effects of tannery effluent on seed germination, leaf area, biomass and mineral content of some plants. *Bioresource Technology*, *47*(3), 215-218. https://doi.org/10.1016/0960-8524(94)90183-x

Lees, REM, Langlois PH (1994) Lead in the Environment. *Canadian Journal of Public Health* **85**, 150-151.

Li, W., Khan, M. A., Yamaguchi, S., & Kamiya, Y. (2005). Effects of heavy metals on seed germination and early seedling growth of arabidopsis thaliana. *Plant Growth Regulation*, *46*(1), 45-50. https://doi.org/10.1007/s10725-005-6324-2

McGrath, S. P., & Zhao, F. (2003). Phytoextraction of metals and metalloids from contaminated soils. *Current Opinion in Biotechnology*, *14*(3), 277-282. https://doi.org/10.1016/s0958-1669(03)00060-0

Mei, B., Puryear, J. D., & Newton, R. J. (2002). Assessment of Cr tolerance and accumulation in selected plant species. *Plant and Soil*, *247*(2), 223-231. https://doi.org/10.1023/a:1021509115343

Memon, A. R., & Schröder, P. (2008). Implications of metal accumulation mechanisms to phytoremediation. *Environmental Science and Pollution Research*, *16*(2), 162-175. https://doi.org/10.1007/s11356-008-0079-z

Abdul Rauf, A. R., Muhammad Javed, M. J., Muhammad Ubaidullah, M. U., & Sajid Abdullah, S. A. (2009). Assessment of heavy metals in sediments of the river Ravi, Pakistan. *International Journal of Agriculture and Biology* **11,** 97-200. https://www.cabidigitallibrary.org/doi/full/10.5555/20093065673

Seregin, I. V., Shpigun, L. K., & Ivanov, V. B. (2004). Distribution and toxic effects of cadmium and lead on maize roots. *Russian Journal of Plant Physiology*, *51*(4), 525-533. https://doi.org/10.1023/b:rupp.0000035747.42399.84

SHANKER, A., CERVANTES, C., LOZATAVERA, H., & AVUDAINAYAGAM, S. (2005). Chromium toxicity in plants. *Environment International*, *31*(5), 739-753. https://doi.org/10.1016/j.envint.2005.02.003

Soudek, P., Katrušáková, A., Sedláček, L., Petrová, Š., Kočí, V., Maršík, P., Griga, M., & Vaněk, T. (2010). Effect of heavy metals on inhibition of root elongation in 23 cultivars of flax (Linum usitatissimum L.). *Archives of Environmental Contamination and Toxicology*, *59*(2), 194-203. https://doi.org/10.1007/s00244-010-9480-y

Ubaidullah, M., Javed, M., & Abdullah, S. (2004). Metals toxicity of sediments in the river Ravi and related effluents discharging tributaries. *Indus Journal of Biological Science*, *1*(1), 43-49.

Vajpayee, P., Tripathi, R., Rai, U., Ali, M., & Singh, S. (2000). Chromium (VI) accumulation reduces chlorophyll biosynthesis, nitrate reductase activity and protein content in nymphaea alba L. *Chemosphere*, *41*(7), 1075-1082. https://doi.org/10.1016/s0045-6535(99)00426-9

Verbruggen, N., Hermans, C., & Schat, H. (2009). Molecular mechanisms of metal hyperaccumulation in plants. *New Phytologist*, *181*(4), 759-776. https://doi.org/10.1111/j.1469-8137.2008.02748.x

Charisma Wafee, C. W., Khan, A. S., & Siddiqi, M. R. (2018). Phytoremediation potential of Catharanthus roseus L. and effects of lead (Pb) toxicity on its morpho-anatomical features. *Pakistan Journal of Botany* **50**, 1323-1326. https://www.cabidigitallibrary.org/doi/full/10.5555/20183275529

Willems, G., Dräger, D. B., Courbot, M., Godé, C., Verbruggen, N., & Saumitou-Laprade, P. (2007). The genetic basis of zinc tolerance in the metallophyte Arabidopsis halleri ssp. halleri (Brassicaceae): An analysis of quantitative trait loci. *Genetics*, *176*(1), 659-674. https://doi.org/10.1534/genetics.106.064485