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RESEARCH ARTICLE

Phytoefficacy of *Eicchornia crassipes* (Mart.) Solms-Laub for aqua-remediation of hexavalent chromium in chromite mine effluent of South Kaliapani, Odisha, India

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Abstract

A huge quantity of toxic hexavalent chromium (Cr-VI or Cr^{6+}) was released into the environment through mine effluent at the South Kaliapani chromite mining area during different mining activities. The present in situ bioremediation approach was conducted to assess the remediation potential of a well-known aquatic weed water hyacinth (*Eichhornia crassipes* (Mart.) Solms-Laub) for attenuating Cr(VI) from mine wastewater. The study correlates the bio-concentration factors (BCF) of Cr with the reduction percentage. The percent reduction of Cr content in mine effluent was maximum (53.5%) at 100 days after treatment (DAT) followed by 40.7% at 75 DAT after passage through 2000 sq. ft area covering four water hyacinth-populated (1350 plants) ponds. Reduction in Cr content of OMC discharged mine effluent varies with plant age as well as with the distance of passage. A constant increase in root biomass was recorded with increased passage distance and days of treatment of contaminated mine effluent. The plants could not survive after 125 days of treatment but could show an increasing trend in shoot biomass up to 100 DAT. After 75 days of treatment, it was noted that Cr concentration in roots decreased from 200 to 148 ppm and from 76 to 21 ppm in shoots after passage through the 2000 sq. ft area at 100 DAT. Water hyacinth roots exhibit maximum Cr bioaccumulation at 75 DAT, whereas this was highest in shoots at 100 DAT.

Keywords Aqua-remediation · Bioaccumulation · Chromium · Mine effluent · Phytoremediation · Water hyacinth · South Kaliapani

Introduction

Heavy metals are widely used by various manufacturing industries for the production of different usable products. Therefore, in developed and developing countries, rapid industrialization associated with mining activities is generally considered an index of economic growth. India is a rich source of valuable mineral resources. Owing to its various commercial applications, minerals and heavy metals are being increasingly extracted and used in industries with the approval of the government. However, as a result of extensive mining and industrial activity, heavy metal contamination in the environment and its ill effects on human life have become a matter of worry. Polluted soil and water are the consequences of these activities.

Odisha state accounts for about 98% of the total deposit of chromite in the country (IBM 2004; Mohanty and Patra 2020); needless to say, extensive extraction of chromium through open-cast mining systems has become a major source of chromium contamination in soil and water in

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Orissa (Mohanty et al. 2012). Mining activity, particularly through the opencast system, has posed wide-scale contamination of heavy metals in the environment.

Chromium contamination in soil and water due to mining activities is emerging day by day and deteriorates the mining environment to a great extent. There is serious environmental pollution resulting in the production of mine waste effluent released to nearby water bodies, along with pollution due to dust, smoke, noise, and other undesirable effects. The process of environmental degradation starts with the extraction of minerals, which results in land degradation along with the addition of pollutants to air and water. In addition to the impacts mentioned above, mining operations also lead to various sociological disturbances with adverse impacts that particularly affect the health of plants, animals, and human beings (Mohanty et al. 2012). These mine wastes are deficient in nutrient content and exhibit extremely poor microbial regeneration capacity, survival of microbial populations related to recycling of these nutrients owing to water stress, imbalance pH, and heavy metal toxicity problems as major constraints for sustaining the growth of plants (Mohanty and Patra 2013; Jiang et al. 2018). A higher concentration of chromium is very toxic to the biological system. The toxicity effect of Cr mostly depends on its valency state. The oxidation state of Cr ranges from -2 to $+6$, but the Cr(VI) is highly toxic, water soluble, and mobile. The objectives of this study were mainly to investigate the remediation ability of water hyacinth (*Eichhornia crassipes* (Mart.) Solms-Laub. The study encompasses the phytoaccumulation ability of water hyacinth considering its bio-concentration factor (BCF), along with the percent removal efficiency. The in situ phytoremediation program emphasizes the rhizofiltration and Cr phytoextraction ability of water hyacinth and attenuates the toxicity load of Cr(VI) from mine-discharged effluent. This study was an effort to attenuate the toxic level of Cr in mine effluent through a designed in situ phytoremediation program. This is the first report on the in situ remediation approach for attenuating Cr levels in mine effluent using water hyacinth as a tool of aqua-remediation. The rhizofiltration and bioconcentration potential of water hyacinth weeds in reducing the toxic load of chromium in mine effluent at the South Kaliapani Chromite mine area, Orissa was remarkable and significant in comparison to chemical treatment. The study aimed to use these aquatic weeds for removal of Cr with a cost-effective approach. The study also aimed to assess the hyperaccumulation potential of water hyacinth through assessing various phytoremediation indices. This will further open a perspective toward mine effluent remediation using aquatic macrophytes as green tools. The non-survival of plants after 125 days reveals its bioindicator property.

Materials and methods

Site of investigation

South Kaliapani chromite mine area of Sukinda valley of the state of Odisha, which is located within latitudes 20° 53′ and 21° 05′ and longitudes 85° 40′ and 85° 53′, was taken as the study site. The four experimental water ponds (each of size $25 \times 20 \times 2$ cubic ft) were made for the cultivation of water hyacinth using untreated mine effluents of Orissa Mining Corporation (OMC). The ponds were supplied with Cr(VI)-contaminated mine effluent water discharged from Orissa Mining Corporation (OMC). The pipeline was connected from the effluent discharge point of OMC, Kaliapani. After passing through 2000 sq. ft. of distance through 4 consecutive ponds, the level of Cr content was measured in inductively coupled plasma–optical emission spectrometry (ICP-OES) at NEERI, Nagpur, India.

Plant material

The plant water hyacinth has been chosen considering its massive root growth in the aquatic system with better rhizofiltration ability. As revealed by previous research reports (Huynh et al. 2021; Ingole and Bhole 2003; Priya and Selvan 2017), water hyacinths are used for wastewater treatment and removal of toxic contaminants, heavy metals from mine effluent, textile mills, etc. Uniform water hyacinth weeds having 4 leaves were collected from the roadside ponds of Phulnakhra, Odisha. They were transplanted in four designed ponds at the study site. The density of water hyacinth plants per pond was 450. A sum total of 1800 plants were used in 4 ponds containing contaminated water.

Preparation of bioremediation tank: bioremediation tank of size 8’ × 6’ × 5’ was prepared and contained charcoal and decomposed coir pith placed in alternate fashion. Coir pith was decomposed at nursery site at P. G. Dept. of Botany, Utkal University by adding 5 l each of *Azospirillum brasilense* and *Bacillus polymyxa* (PSB) to 800 kg of decomposed coir pith.

The plot design was made as shown below in Fig. 1. The arrow marks showed the passage route of Cr contaminated mine effluent water from tap.

Sampling and analysis

Samplings of effluent water and water hyacinth plants were carried out from the experimental ponds to examine Cr concentration through ICP-OES. The water samples from four different ponds were analyzed for pH, electrical conductivity (EC), and Cr content (APHA 1995). The sampling of mine wastewater was conducted before and after its passage through different

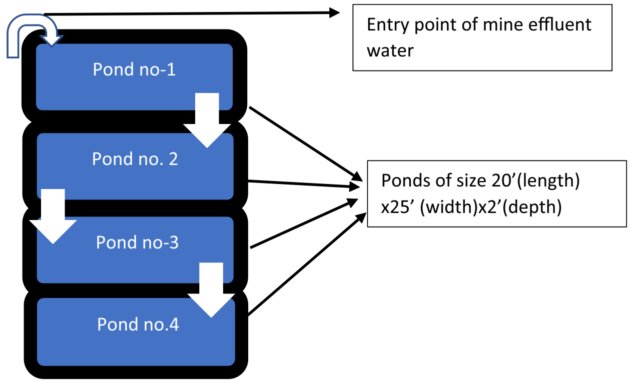


Fig. 1 Pond design and mine effluent passage route shown by thick white arrows

experimental water hyacinth ponds during regular intervals of plant growth, i.e., 75, 100, and 125 DAT (APHA 1995). Hexavalent Cr in water samples collected from ponds and mine effluents before passing through ponds were analyzed. using hexavalent chromium pocket colorimeter DR890 using the sachets of chromover-3 and ferrover supplied by HACH (1992), USA. The difference in Cr concentrations with reference to different plant tissues (root and shoot) during 75, 100 as well as 125 days after plant growth is significant at both $p \leq 0.05$ and $p \leq 0.01$, as evident from their F values.

Statistical analysis: water and plant samples were collected from four ponds in triplicates each, and the data presented in the figures and tables are AM ± SEM.

Result and discussion

The Cr^{6+} in the mine wastewater (0.646 ppm) was beyond the toxic limit, i.e., > 0.008 mg l^{-1}. (WHO 1997; Krishnamurthy and Wilkens 1994; Pawlisz 1997).

Physicochemical assessment of mine waste water

High alkaline pH value (8.4) of mine wastewater with elevated levels of Cr^{6+} was observed.

pH and EC of mine effluent

Mine effluents from four different water hyacinth cultivated ponds were analyzed for the changes in pH and EC values (Table 1). Mine effluent is alkaline with pH 8.3 at 75 DAT, and it gradually decreases neutral value (7.0) after passage through the four water hyacinth ponds. But at 100 days of treatment, the pH value of mine effluents does not show much variation after their passage through water hyacinth ponds (Table 1).

The toxic limit of Cr + 6 in irrigated water has been prescribed as 0.008 mg l − 1.

(Krishnamurthy and Wilkens 1994; Pawlisz 1997).

Attenuation of Cr (VI) in Cr-contaminated mine effluent

Mine wastewater showed decreased hexavalent chromium level with increasing water passage area of flowing mine wastewater though water hyacinth ponds (Fig. 2). Attenuation of Cr(VI) from flowing mine wastewater was calculated in terms of percent reduction in the experimental ponds (Fig. 2).

Maximum reduction of 54% in Cr(VI) content was observed after 2000 sq. ft passage through water hyacinth ponds at 100 DAT. An increasing trend in reduction percent

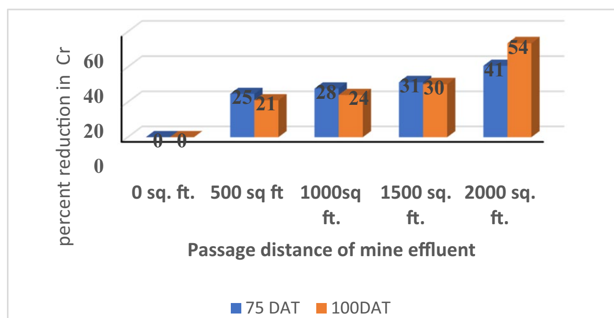


Fig. 2 Percent reduction in hexavalent chromium content of mine effluent after passage through water hyacinth ponds

Table 1 pH, EC, and hexavalent chromium content of mine effluent at 75 and 100 DAT

Samples	pH	E. C. (mS)	Hexavalent Cr (ppm)	pH	E. C. (mS)	Hexavalent Cr (ppm)
	75 DAT			100 DAT		
Mine effluent	8.3	0.29	0.646	7.9	0.34	0.646
Water hyacinth pond I (500 sq. ft)	7.9	0.30	0.486	7.4	0.28	0.510
Water hyacinth pond II (500 sq. ft)	7.7	0.29	0.466	7.9	0.28	0.490
Water hyacinth pond III (500 sq. ft)	7.2	0.31	0.443	8.0	0.28	0.450
Water hyacinth pond IV (500 sq. ft)	7.0	0.30	0.383	7.8	0.28	0.300

was observed with increasing passage area through water hyacinth ponds, which may be attributed to the high plant biomass content of 75 days grown water hyacinth plantlets.

Root biomass was increased by five-fold with an increased period of exposure to Cr(VI) contaminated mine effluent up to 125 days, after which it deteriorates. The increase in biomass of root is positively correlated with passage area and period of exposure (Fig. 3a and b).

Through a bioconcentration profiling of plants, it was observed that Cr bioaccumulation was higher in roots than in shoots. A similar trend was observed by several other researchers (Pulford and Watson 2003; Zayed and Terry 2003; Ghosh and Singh 2005a, b; Dong et al. 2007; Zhang et al. 2007; Mohanty and Patra 2020, Mohanty et al. 2012, Jiang et al. 2018). Shoot translocation was very poor as compared to root absorption, which is the most common resistance trait (Zayed and Terry 2003; Dickinson and Lepp 1997). Typical chromium concentration in plants growing in "normal" soil is in the order of 0.02–0.2 mg Cr kg − 1 dry weight (DW). The usual concentration was less than 1 mg kg − 1, which rarely exceeds 5 mg kg − 1, as reported by Zayed and Terry (2003). The high Cr accumulation in root cells was supported by Shanker et al. (2004) who suggested immobilization of chromium from the vacuoles. In the present investigation, roots showed very high bioconcentration of Cr, i.e., 200 ppm at 75 DAT which gradually translocated to shoots with the growing age of plants and subsequently shoots showed the highest Cr accumulation in 100 DAT (Fig. 4A and B).

The decreasing trend of above-ground biomass content (g) of plants was observed after 125 days of treatment with mine effluent, which might be due to the non-survivability of water hyacinth after this period. Due to the death and decay of plants after 100 days, the Cr content gets leached out of the plants to the surrounding water for which the total Cr content in plants decreases beyond 100 days of exposure to mine effluent.

Conclusion

The aquatic plants like water hyacinth can be used as low-cost, effective, and potential green tools for the removal of toxic Cr from polluted aquatic bodies and mine discharge. This review showed that aquatic plants like *E. crassipes* have phytoremediation potential to attenuate Cr(VI) from mine wastewater.

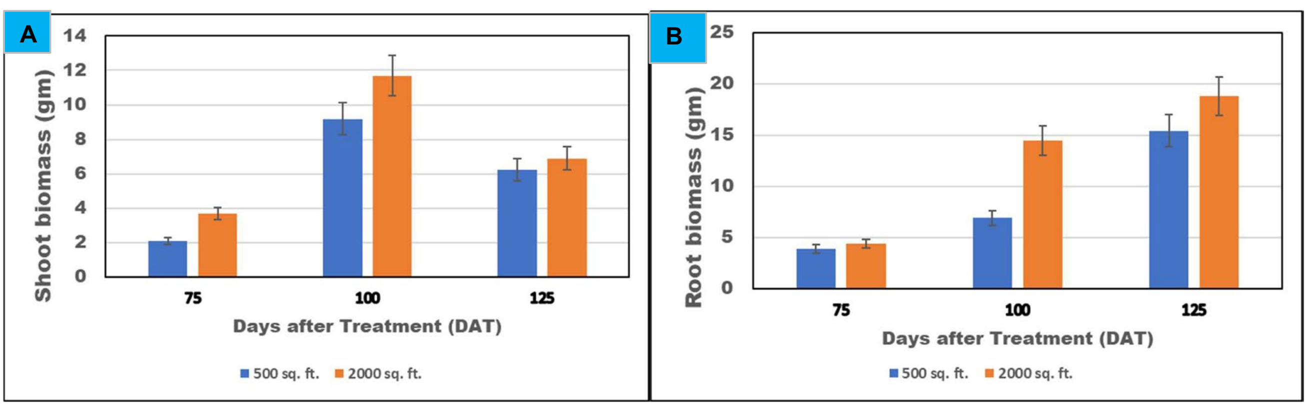
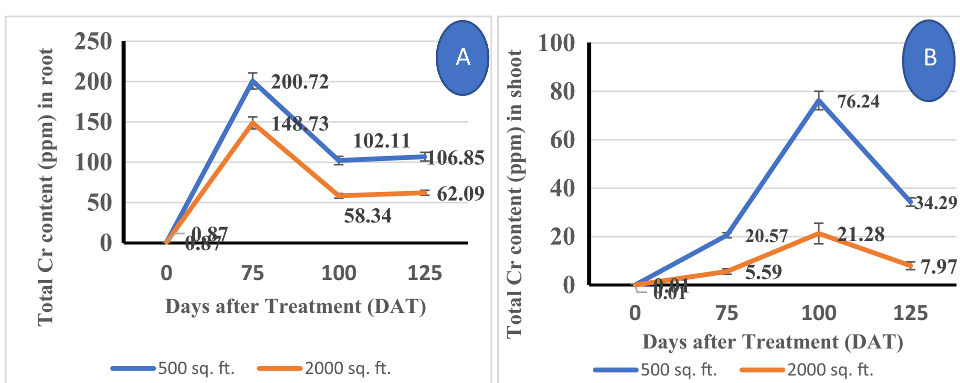


Fig. 3 **A**, **B** Change in biomass content (g) of water hyacinth with reference to passage area after 75, 100, and 125 days of treatment with mine effluent (**A** shoot; **B** root). Data are presented as mean ± SEM (standard error of mean)

Fig. 4 **A**, **B** Cr bioavailability in plant tissue after 75, 100, and 125 DAT (**A** root; **B** shoot)



Therefore, it is very much essential to utilize the remarkably potential macrophytes for the accumulation of environmental pollutants from wastewater, which become a frontier area of research in environmental science and technology. Further research on genetic engineering to enhance the accumulation and tolerance capacity of macrophytes is a perspective approach in phytoremediation technology. Aqua-remediation of wastewater through macrophytes can be effectively used to treat a huge volume of metal-contaminated wastewater. Treatment of contaminants by macrophytes is a low-cost and feasible advantageous approach for the sustainable development of aquatic ecosystems. Future research on screening the aquatic macrophytes for remediation of waste water may be undertaken.

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Author contribution Dr. M. Mohanty wrote, analyzed, and worked on the topic. Dr. M.M. Pattnaik worked on this topic. Dr. A.K. Mishra conceived the work and gave the idea. Dr. H.K. Patra conceived the work and gave the idea. All the authors contributed to the study conception and design [Dr. Monalisa Mohanty, Dr. MM Pattnaik, Professor A.K. Mishra, and Professor H.K Patra]. Material preparation, data collection, and analysis were performed by Dr. Monalisa Mohanty and Dr. MM Pattnaik. The first draft of the manuscript was written by Dr. Monalisa Mohanty, and all the authors commented on previous versions of the manuscript. All the authors read and approved the final version of the manuscript.

Declarations

Competing interests The authors declare no competing interests.

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