Phycoremediation Of Cd And Pb Contaminated Industrial Effluents Using *Cladophora Glomerata* And *Vaucheria Debaryana*

Sara Khan
Abasyn University
Amin Ullah
Abasyn University
Tehreem Ayaz (tehreemayaz17301@yahoo.com)
Hunan Agricultural University https://orcid.org/0000-0002-8462-6128
Neelma Hassan
Abasyn University
Amir Zeb Khan
Pak-Austria Fachhochschule Institute of Applied Sciences and Technology
Ming Lei
Hunan Agricultural University
Mudassir Habib
East-China Institute of Technology: East China University of Science and Technology
Faiz Ul Amin
Abasyn University
Aamir Aziz
Sarhad University: Sarhad University of Science & Information Technology

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Abstract

The rapid growth of urbanization and industrialization are regarded as the main source of environmental pollution, particularly aquatic pollution. This study was conducted to evaluate the pollution load of industrial effluents (IE) and to utilize algal species *Cladophora glomerata* (CG) and *Vaucheria debaryana* (VD) as cost effective and environmentally friendly bioremediators for the heavy metal (HM) contaminated IE. Samples of IE were collected from the main sewage line of Hayatabad Industrial Estate (HIE) and analyzed for physicochemical parameters using standard methods and HM concentration by Atomic Absorption spectrophotometry. The load of electrical conductivity (EC), dissolved oxygen (DO), biological oxygen demand (BOD), chemical oxygen demand (COD), total dissolved solids (TDS), total suspended solids (TSS), cadmium (Cd) and lead (Pb) were found 5.03 mS/cm, 186 mg/L, 168 mg/L, 336 mg/L, 46.30 mg/L, 53.72 mg/L, 0.507 mg/L and 1.211 mg/L, respectively. The IE was then treated with algal species collected from Peshawar and were transplanted in four pots for 14 days where pots labeled as CTVD and CTCG were serving as control having tap water and VD and CG containers as treatment pots provided with IE. Results found a considerable decrease in EC (49.10–81.46%), DO (3.76-8.60%), BOD (7.81–39.28%), COD (7.81–39.28%), TSS (38.09-62.21%) and TDS (38.09–62.21%), Cd (41.02-48.75%) and Pb (48.72-57.03%). The One-Way ANOVA and T-test analysis revealed that HM concentrations were significantly ($p \leq 0.05$) reduced by the phycoremediation. The analysis found that *C. glomerata* removed 48.75% of Cd and 57.027% Pb from IE. The study concluded that phycoremediation using *C. glomerata* and *V. debaryana* is one of the environmentally friendly techniques. The procedure is cost-effective and can be utilized for the remediation of IE due to the algal efficiency in terms of HMs removal.

1. Introduction

Nowadays, one of the utmost dilemmas is environmental pollution, particularly aquatic pollution due to rapid industrialization and urbanization. Water, despite being the most plentiful natural resource of the world, only about 1% of the water is accessible for the use of human beings (Anjum et al., 2019; Madhura et al., 2019). The industrial effluents (IE) from different industries such as steel, textile, electro-plating etc., enters aquatic environments through domestic and industrial sewage, shipping, runoff, leaching, and harbor activities, thus affecting aquatic ecosystems (Sononeet al., 2020). The IE contains inorganic contaminants that include different types of HM such as mercury (Hg), cadmium (Cd), cobalt (Co) copper (Cu), zinc (Zn), lead (Pb), nickel (Ni), chromium (Cr) and Arsenic (As) (Naskar *et al.*, 2018). HMs are non-degradable and can become dangerous due to their toxicity, and tendency to accumulate in living bodies in higher levels (Fatima et al., 2020). The effluents of such industries are widely used for irrigation purposes which causes severe effects on plant growth and quality. Particularly, by the process of biosorption and bioaccumulation, levels of HMs ions may increase across the food chain and ecosystem (Mehmood et al., 2019), become a health hazard and exert chronic and acute effects on animals, plants and humans (Umer et al., 2018). Thus, it is needed to effectively treat the IE before its final release in the environment (Ayaz et al., 2020) to avoid unevenness in supply of nutrients, which may cause excessive vegetation growth, reduced quality, uneven fruit maturity (Libutti et al., 2018).

The traditional physical methods (aeration, skimming, sedimentation, and screening) and chemical methods (electrochemical process, precipitation, flocculation, and coagulation) are in use to treat polluted waters; but, to meet the standards of water quality these methods are often considered as less efficient (Saikia et al., 2019). Moreover, these techniques have some disadvantages such as the process cost, high energy, time for operation, incomplete pollutants removal, release of toxic materials from sludge, need of stable lagoons installation and oxygen diffusional resistances (Mahmoud et al., 2020). Bioremediation is an environmentally friendly process that utilizes the innate ability of organisms like fungi, bacteria and algae to detoxify inorganic and organic contaminants from IE (Bharagavaet al., 2018). In the bioremediation technique, pollutants are transformed into some inorganic substances such as methane, water and carbon dioxide, and thus results in detoxification (Saxena et al., 2020). Bioremediation mainly relies on the inherent metabolic ability of microorganisms to degrade and alter the contaminants, which is greatly affected by bioavailability of contaminants. It can be carried out either ex situ (remediation elsewhere) or in situ (remediation at the site). Algae are most enviable because they are photosynthetic, capable of carbon fixation, thereby justifying the hazardous effects of greenhouse gas and quickly produce biomass using nutrient-rich wastewater (WW). In phycoremediation, the HMs either bind with the cell surface or with the intracellular ligands of the living algae. These HMs bounded ligands accumulate further by active biological transport (Aracenaet al., 2019). Carboxylate, amines and hydroxyls are the different functional groups which form complexes with HMs that affect the removal mechanism of these HMs from contaminated water (Piotrowska-Niczyporuk et al., 2015). Some organo-metallic complexes are also separated in the vacuoles that are formed due to action of HMs and peptides of algae to reduce the amount of these metals in the cytoplasm and overcome their toxic effect (Srivastava, 2016). Therefore, *Cladophora glomerata* and *Vaucheria debaryana* can be utilized for the removal of various HMs.

Agriculture constitutes a vital sector of the economy of developing countries like Pakistan. Majority of the population, directly or indirectly, is dependent on this sector. Water quality in Pakistan is affected badly due to numerous practices, like discharge of IE and agricultural run-off comprising fertilizers and pesticides. The economic hub of the Khyber Pakhtunkhwa is Hayatabad Industrial Estate (HIE) but lacks any adequate treatment facility for WW. Untreated IE and Municipal run together and released into Bara River. For agricultural practices, the main source of irrigation is the Bara River in Peshawar. Thus, it is needed to remediate the IE to elude the contamination food chain. In underdeveloped countries, the idea of algal utilization for the treatment of polluted IE is not in use generally. For IE treatment, algae may prove a better choice than traditional physical methods (aeration, skimming, sedimentation, and screening) and chemical methods (electrochemical process, precipitation, flocculation, and coagulation). Therefore, it is assumed that algae may contribute in purifying and reclaiming the IE released from HIE, Pakistan. The present research study aims to evaluate the pollution load of industrial effluents (IE) of Hayatabad Industrial Estate (HIE), assess the removal efficiency of the selected algae for the selected

HMs (Cd and Pb) and to identify the most efficient algae for the of HM removal (Cd and Pb) present in IE. For the proposed study, pot experiment was performed for individual algal species.

2. Material And Methods

2.1. Algae collection and transplantation

In this study, fresh-water algae *Cladophora glomerata* and *Vaucheria debaryana* were collected from the Sardaryab River, Charsadda and Naguman River, Peshawar, respectively. The species selection was based on their high tolerance towards HM toxicity and rapid growth, availability as wild species, and suitable climate for their growth. After collection, the algae were washed properly with tap water and then distilled water (Khan et al., 2017). Then the algal species were examined using a microscope and identified using procedure implemented by Shamshad et al. (2016). Algae were then transplanted and acclimatized into experimental pots in triplicates for 14 days at room temperature (20^{o}C) in natural daylight (light/dark duration was 10:14 hours). After 14 days the algae were collected, thoroughly washed and used for laboratory analysis.

2.2. Collection and analysis of IE

The IE was obtained from the main sewage line of Hayatabad Industrial Estate (HIE) using the procedure of Ayaz et al. (2020). The main drain of HIE were collecting effluents from various industries, such as match industry, rubber, steel, plastic, paint and pharmaceutical industry (Khan et al., 2017). The suspended solid materials were removed (Shamshad et al., 2015). The IE samples were then analyzed for different physiochemical parameters like pH, temperature, electrical conductivity (EC), total dissolved solids (TDS), total suspended solids (TSS), biological oxygen demand (BOD), chemical oxygen demand (COD) and HMs (Cd and Pb) to calculate the pollution load of the IE (Khan et al., 2017). The IE utilized for pot experiment and the samples were collected and analyzed for the selected parameters after experimentation. HMs were analyzed using atomic absorption spectrophotometry (AAS) in Central Resource Laboratory (CRL), University of Peshawar.

2.3. Experimental design

Pot experiment was performed to find out the efficiency of HMs removal by individual algal species. To perform the experiment four plastic containers were used that were first thoroughly rinsed using double deionized distilled water (DDW) and 10% diluted nitric acid. Then the containers were labeled as CTVD, CTCG, VD and CG for the transplantation of algal species. CTVD and CTCG containers were serving as control treatments containers for *V.debaryana* and *C. glomerata*, respectively. Whereas the other two plastic containers VD and CG were serving as the treatment containers and provided with *V. debaryana* and *C. glomerata*, respectively (Fig. 1). The water in the treatment containers was IE and, in the control treatment was clean tap water. The study was conducted in triplicates. The containers were kept at room temperature (20^{O}C) for the duration of 14 days. After experimentation, water and algal samples were collected from each container and analyzed for selected parameters.

2.4. HM Extraction

After 14 days of treatment, the samples of *V. debaryana* from container CTVD and VD and *C. glomerata* from container CTCG and CG were collected. The collected samples of algal species were washed thoroughly with distilled water for the removal of impurities like sand, dust particles and clay. The samples were dried in shade and then in the oven at 80^{o}C for 1 hour and the dry weights were determined. The samples were then grinded, and the powdered form of samples was stored in polythene bags. The samples' related information was recorded. For the extraction of HMs, the powdered samples were digested in the digestion chamber as a procedure adapted by Shamshad et al. (2015). The solution samples were then analyzed for HMs quantification by AAS (Khan et al., 2017).

2.5. Water sampling and analysis

Water samples were obtained from each container at the start and end points of the experiment from all four containers (CTVD, CTCG, VD and CG) for laboratory analysis. All water samples were analyzed for Cd and Pb concentrations by AAS. The water samples were analyzed for the physicochemical parameters such as pH, and EC were measured using pH Meter (Model: pH-208) and EC meter (InoLab). By Gravimetric method, TDS and TSS were measured. BOD_5 and COD were observed titrimetrically through standard methods adapted by American Public Health Association (APHA, 1992).

2.6. Bioremoval efficiency (%)

Bioremoval efficiency (%) was determined through the following equation as adopted by Shamshad et al. (2015).

$$R = \frac{Ci - Cf}{Ci} \times 100 \text{ ——————— } (1)$$

Where, R represents the removal percentage, Ci is the initial HM concentration in water samples and Cf is the final HM concentration in water samples.

2.7. Bioaccumulation capacity (q)

Bioaccumulation capacity (q) was measured by formula (Flouty and Estephane, 2012).

$$q = \frac{Ci - Cf}{M} \times V \text{ ——————— } (2)$$

Where, Ci = initial HM concentration (mg/L), Cf = final concentration (mg/L), M = amount of the active biomass (g) and V = volume of the water (L) used.

2.8. Bioconcentration factor (BCF) (%)

Algal efficiency for HMs accumulation from water samples was calculated through BCF formula adapted by Basílico et al. (2018) and Wilson and Pyatt (2007).

$$BCF(\%) = \frac{CAlgae}{Cwater} \times 100 \text{ ———— } (3)$$

Where, C algae refers to HM concentration in algal tissue and C water represents the metal concentration in water samples.

2.9. Statistical analysis

Statistical analysis was performed using different software such as Microsoft Excel, Sigma plot, and statistical package for social science (SPSS 16.0) for the calculation, interpretation and graphical representation of the data. The t-test and ANOVA were used for significance (p) between two and more than two variables of the parameters.

3. Results And Discussion

3.1. Characteristics and pollution load of IE

The pH value (6.53 units) observed for IE was within the maximum permissible limit (MPL) set by Pakistan Environmental Protection Agency (Pak-EPA, 2008). The details of pollution load of IE and Pak-EPA MPLs are given in Table 1. The EC, BOD, COD, TSS and TDS values observed for IE were 5.03mS/cm, 168 mg/L,336 mg/L, 53.72 mg/L and 46.30 mg/L. The TSS and TDS values were analyzed below the Pak-EPA limit (150 mg/L and 3500 mg/L, respectively). Whereas the BOD and COD values were exceeding the limits (80 mg/L and 150 mg/L, respectively) set by Pak-EPA.

The IE was analyzed for different metals such as Cr, Ni, As, Hg, Cd, Zn and Pb. All the metals were beyond detectable limits except Cd and Pb. The initial concentrations of Cd (0.507mg/L) and Pb (1.211mg/L) in IE exceeded the MPL (0.1 mg/L and 0.5 mg/L, respectively) of Pak-EPA (Table 1). The results of this study were similar to the findings of Fito et al. (2019) (7.6 pH), Ayaz et al. (2020) (EC: 0.24–5.04 mS/cm, TDS: 0.7-2.0 mg/L, BOD: 176 mg/L and COD: 352 mg/L) and Hossain et al. (2019) (EC; 2.64 mS/cm). These results were not consistent with the results of Nirgude et al. (2013) and Aniyikaiye et al. (2019). The differences can be ascribed to type and characteristics of IE used for the study. The difference in characteristics was due to the fact that the industrial effluent was collected from different industries and not from the main drain by Nirgudeet al. (2013) and Aniyikaiye et al. (2019) (paint industry).

3.2. Effect of selected algal species on physicochemical parameters

Table 1 summarizes the effects of algae on different physicochemical characteristics of water samples. The results showed that *C. glomerata* had significantly ($p < 0.05$) decreased EC (54.70–81.5%), TSS (42.86–62.21%), TDS (45.45–57.45%), BOD (10.94–39.28%) and COD (10.94–39.28%) during 14 days of experimentation. In the study, the effects of *V. debaryana* were found lower than *C. glomerata*. The effects of *V. debaryana* on EC (49.10–69.39%), TSS (38.09–54.39%), TDS (36.36–56.54%), BOD (7.81–38.09) and COD (7.81–38.09) was lower than *C. glomerata*. The results were consistent with the findings of

Khan et al. (2017), the study was conducted for the treatment of WW of HIE by four algal species (*Cladophora glomerata, Vaucheria debaryana, Oedogonium westi*, and *Zygnema insigne*) and considerable reduction in EC (85.9%), BOD (52.4%), COD (30.7%), and TDS (79%) were observed. However, these results were much lower than the results of Sharma et al. (2020), a bioremediation study on *Chlorella minutissima* and significant decreases in BOD (93%), COD (80.5%) and TDS (94.4%) values of wastewater were observed. Similarly, the finding of the present study was not consistent with the results of Okpozu et al. (2019), a study conducted on phycoremediation of cassava wastewater by *Desmodesmus armatus* and observed reduction in TDS by 83%, BOD by 87% and COD by 92%. The differences in efficiencies could be related with the wastewater characteristics, nutrients and species of algae. In the study the algae were cultivated in hydrolyzed cassava wastewater and Bold's basal medium.

Table 1
Physicochemical parameters and efficiency of algal species

Physiochemical Parameters		CTCG		CG		CTVD		VD		PAK-NEQS (ppm)
		Mean	Eff. (%)	Mean	Eff. (%)	Mean	Eff. (%)	Mean	Eff. (%)	
pH	I	7.1	-10.28	6.53	-5.82	7.1	-7.32	6.53	-2.90	6–10
	F	7.83		6.91		7.62		6.72		
EC (mS/cm)	I	2.32	81.46	5.03	54.07	2.32	69.39	5.03	49.10	–
	F	0.43		2.31		0.71		2.56		
BOD (mg/L)	I	64	10.94	168	39.28	64	7.81	168	38.09	80
	F	57		102		59		104		
COD (mg/L)	I	128	10.94	336	39.28	128	7.81	336	38.09	150
	F	114		204		118		208		
TSS (mg/L)	I	2.10	42.86	53.72	62.21	2.10	38.09	53.72	54.39	150
	F	1.20		20.30		1.30		24.50		
TDS (mg/L)	I	1.10	45.45	46.30	57.45	1.10	36.36	46.30	56.54	3500
	F	0.60		19.70		0.70		20.12		
Heavy Metals										
Cd (mg/L)	I	0.080	48.75	0.507	46.15	0.080	43.75	0.507	41.02	0.1
	F	0.041		0.273		0.045		0.299		
Pb (mg/L)	I	0.370	57.03	1.211	56.98	0.370	52.43	1.211	48.72	0.5
	F	0.159		0.521		0.176		0.621		

CTCG: Container of control for *Cladophora glomerata*; CG:Container of treatment for *Cladophora glomerata*; CTVD: Container of control for *Vaucheriadebaryana*; VD: Container of treatment for*Vaucheriadebaryana*; I: initial; F: final; % eff.: % efficiency

3.3. Effect of selected algal species on HM concentration

3.3.1. Cadmium

The mean Cd concentration values were observed in the water samples ranging 0.080–0.507 mg/L and 0.041–0.299 mg/L at initial and final stages of experimentation, respectively (Table 1). In initial water samples CG and VD, and in final water samples VD were observed for the highest Cd concentration. In the final stage the reduction in Cd concentration of water samples was noted by selected algal species (Fig. 2(A)). Cd removal efficiency was recorded in the range of 41.02–48.75%. Whereas CTCG, CG, CTVD and VD removed 48.75, 46.15, 43.75 and 41.02%, respectively. These findings were much lower and not in line with the results of Khan et al. (2017) observed for *C. glomerata* (80.3%) and *V. debaryana* (92.1%). The differences may be due to the higher initial concentrations of Cd (1.483 mg/L) and Pb (2.671 mg/L) observed by Khan et al. (2017). The results were also lower than the results (76%) of Faez and Al-Mamoori (2021) using immobilized *Chlorella vulgaris* specie. Similarly, Shen et al. (2018) conducted a study on a complex of water-hyacinth derived pellets immobilized with *Chlorella* sp. and observed maximum Cd(II) removal efficiency of 92.45%. The differences in the finding can be attributed to the difference in species of the algae used in the study. The T-test analysis revealed that CTCG, CG, CTVD and VD significantly ($P < 0.05$) decreased the Cd concentration in the final water samples than initial water samples.

Whereas *C. glomerata* and *V. debaryana* were more effective in control (CTCG and CTVD) as compared to treatment (CG and VD) as indicated in Table 1, suggesting that *C. glomerata* and *V. debaryana* are less effective at higher concentrations of Cd. 3.3.2. Lead (Pb)

In the pot experiment the mean Pb concentration in the initial and final stages of water samples were examined in the range of 0.37–1.21 mg/L and 0.16–0.62 mg/L, respectively (Table 1). The highest Pb concentration was observed in the initial water samples of CG and VD and final stage of VD. The reduction in Pb concentrations in 14 days by algae in final stages of water samples were noted (Fig. 2(B)). The removal efficiency for Pb was calculated in the range of 48.72 to57.03%, whereas CTCG, CG, CTVD and VD removed 57.03, 56.98, 52.43 and 48.72% of Pb, respectively. However, the present results were not consistent with the results (75–98%) of Ajayan et al. (2015), a study conducted on phycoremediation of tannery wastewater using *Scenedesmus* species. These results are much lower than the results (81%) of Faez and Al-Mamoori (2021) using immobilized *Chlorella vulgaris* specie. The T-test analyses indicated that concentration of Pb in final water samples were significantly ($P < 0.05$) decreased than initial water samples, indicating that the algal species were effective in Pb removal from IE. Moreover, the study found both species (*C. glomerata* and *V. debaryana*) were more effective in control (CTCG and CTVD) as compared to treatment (CG and VD), suggesting that *C. glomerata* is more effective at lower concentrations of Pb. The results of our study were in pact with the study of Shamshad et al. (2015) that algal species are more effective at lower concentrations of Pb.

3.4. HM uptake by algae

The Cd concentration determined in CTCG, CG, CTVD and VD biomass were 0.06, 0.499, 0.035 and 0.476 mg/kg, respectively. The highest Cd uptake was recorded in CG and lowest in CTVD (Fig. 3 (A)). The Pb uptake determined in CTCG, CG, CTVD and VD were 0.32, 1.12, 0.31 and 0.49 mg/Kg respectively. The highest Pb uptake was recorded in CG and lowest in CTVD (Fig. (3B)).

3.5. Bioaccumulation capacity of selected algal species

The results of bioaccumulation capacity (q) of CTCG, CG, CTVD and VD for Cd were found 0.0936, 0.5616, 0.084 and 0.4992 mg/kg. Where, CG was observed for the highest and CTVD for the lowest bioaccumulation capacity (Fig. 4(A)). However, the Cd bioaccumulation rates by *C. glomerata* and *V. debaryana* were consistent with the results (0.745 and 0.363 mg/kg, respectively) of Khan et al. (2015). The results of the study conducted by Shamshad et al. (2015) on bioremediation using algae revealed higher Cd uptake. Similarly, the bioaccumulation capacity (q) of CTCG, CG, CTVD and VD for Pb were 0.506, 1.656, 0.465 and 1.416 mg/kg. CG was observed for the highest and CTVD for lowest bioaccumulation capacity. However, the bioaccumulation rates by *C. glomerata* and *V. debaryana* values for Pb were not in agreement to the findings (1.286 and 0.765 mg/kg, respectively) of Khan et al. (2017). The difference in the bioaccumulation capacity may be due the difference in initial concentration of Cd (1.483 mg/L) and Pb (2.671 mg/L) in the water sample (IE) or due to difference in culture period (12 days).

3.6. Bioconcentration factor (BCF) (%) of HMs

Table 2 summarizes the HM concentration bioaccumulated in selected algal species from water samples used, while HM removal efficiencies are shown in Fig. 4(B). The results showed that *C. glomerata* has significantly highest bioconcentration factor for the selected HMs such as Cd and Pb (Table 2). The data showed that *C. glomerata* has a bioconcentration factor for Cd (98.42%) followed by Pb (92.57%) at higher Cd concentration (IE). Thus, the bioaccumulation trend for selected HMs was observed in order of Cd > Pb in IE after 14 days of experimentation. Furthermore, *C. glomerata* showed highest bioconcentration factor for Pb (86.49%) as compared to Cd (75%) in tap water where the metal concentration was lower comparatively. The results indicated that the uptake potential of *V. debaryana* was lesser as compared to *C. glomerata.V. debaryana* had the highest removal capacity for Pb (40.38–83.75%) followed by Cd (43.75–93.88%) (Fig. 4(B)). The bioaccumulation of this algal specie for HMs was in order of Pb > Cd.

Table 2
Bioconcentration factor (%) of HMs in Algae (Algae/water)

HMs	CTCG	CG	CTVD	VD
Cd	75	98.42	43.75	93.88
Pb	86.49	92.57	83.78	40.38

The concentration of Pb in final water samples was reduced significantly ($P \leq 0.05$) than the initial water samples, signifying that algal species were effective in the removal of Pb from water samples. The highest Pb uptake was recorded in CG and lowest in CTCG. The CTCG was recorded for highest and VD for lowest bioconcentration factor. The highest bioremoval efficiency was observed for CTCG and lowest for VD. These values are comparable with the findings of Khan *et al.* (2017), a study conducted on the remediation of IWW by different algal species.

4. Conclusion

The study found that the pollution load of industrial effluents (IE) of Hayatabad Industrial Estate (HIE) such as pH, total suspended solids (TSS) and total dissolved solids (TDS) were within maximum permissible limit (MPL) set by Pakistan Environmental Protection Agency (Pak-EPA, 2008), while biological oxygen demand (BOD), chemical oxygen demand (COD) and concentration of heavy metals (HMs) (Cd and Pb) were beyond MPLs. The study concluded that the algal species played a significant role in the remediation and effectively decreased the pollution load of IE. The *C. glomerata* has the best HM (Cd and Pb) removal efficiency as compared to *V. debaryana*. Overall, the pollution of IE was significantly decreased ($P \leq 0.05$) by the remediation of both algal species. The HMs removal trend was in Pb > Cd order. Furthermore, the study found that the removal efficiency of *C. glomerata* and *V. debaryana* was higher at lower HM concentrations. The results showed that *C. glomerata* and *V. debaryana* were best hyper accumulative species for Pb removal as compared to Cd. Results of the pot experiment confirmed that the algal species *C. glomerata* and *V. debaryana* are effective in HM uptake. These algal species survived in the stress conditions triggered by the HM concentrations. So, this quality can be positive evidence for algal species to be utilized for bioremediation of polluted water. Therefore, it is concluded that phycoremediation is a cost effective, environment friendly technique and can be utilized for the remediation of IE contaminated with Cd and Pb.

Abbreviations

IE	Industrial Effluents
CG	*Cladophora glomerata*
VD	*Vaucheria debaryana*
HM	Heavy Metal
HIE	Hayatabad Industrial Estate
EC	Electrical conductivity
TSS	Total suspended solids
TDS	Total dissolved solids
DO	Dissolved oxygen
COD	Chemical oxygen demand
BOD	Biological oxygen demand
WW	Wastewater
Pb	Lead
EDTA	Ethylene diamine tetra acetic acid
AAS	Atomic absorption spectrophotometry
CRL	Central Resource Laboratory
APHA	American Public Health Association
MPL	Maximum permissible limit
Pak-EPA	Pakistan Environmental Protection Agency
BCF	Bioconcentration Factor
CTCG	Control for *Cladophora glomerata*
CTVD	Control for *Vaucheria debaryana*
ANOVA	Analysis of Variance
DDW	Double deionized water

Statements And Declarations

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Ethics approval and consent to participate

Not applicable

Consent for publication

Not applicable

Availability of data and materials

All data generated or analyzed during this study are included in this published article.

Authors’ contributions

Sara Khan: Writing original draft, Software, Data Collection and analysis. **Amin Ullah:** Supervision, Conceptualization, Visualization. **Tehreem Ayaz:** Methodology, Software, Data Curation, Reviewing, Editing and Formatting. **Neelma Hassan:** Reviewing and Editing. **Amir Zeb Khan:** Reviewing and Editing. **Ming Lei:** Reviewing and Editing. **Mudassir Habib:** Software, Review and Editing. **Faiz Ul Amin:** Reviewing and Editing. **Amir Aziz:** Reviewing and Editing.

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Figures

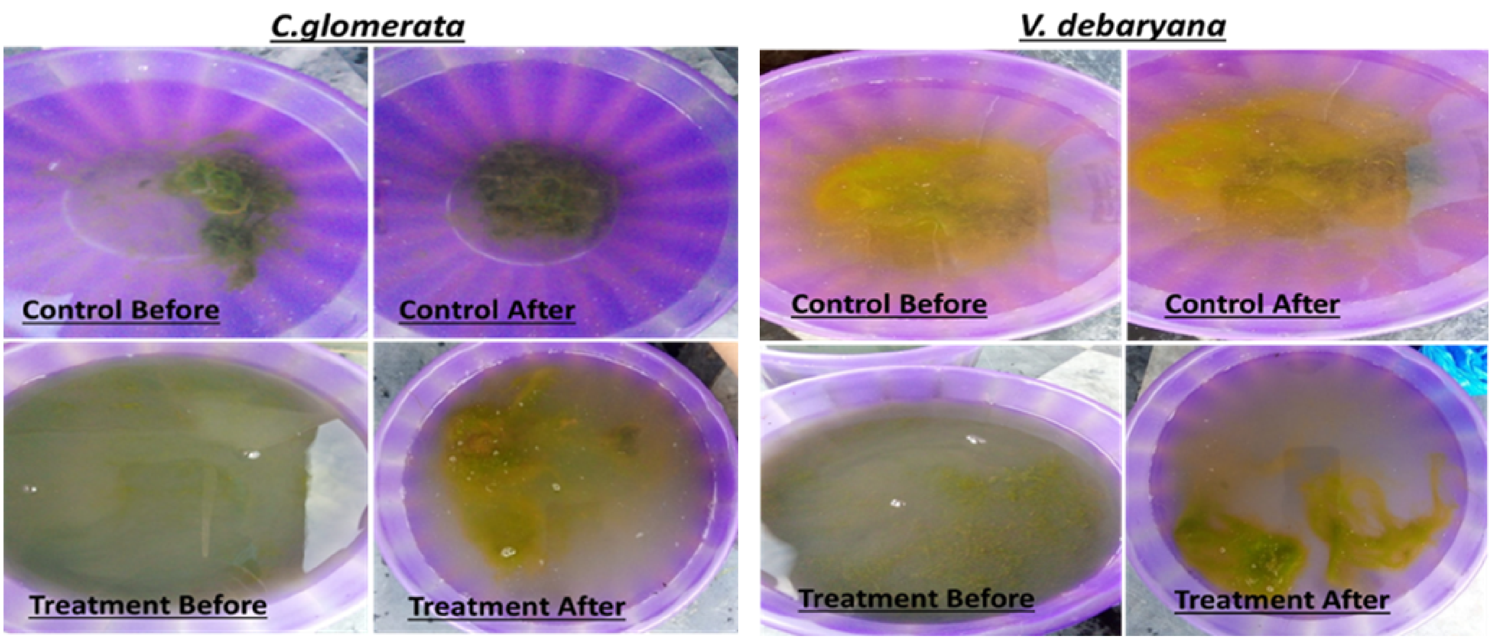

Figure 1

Experimental design showing different treatments

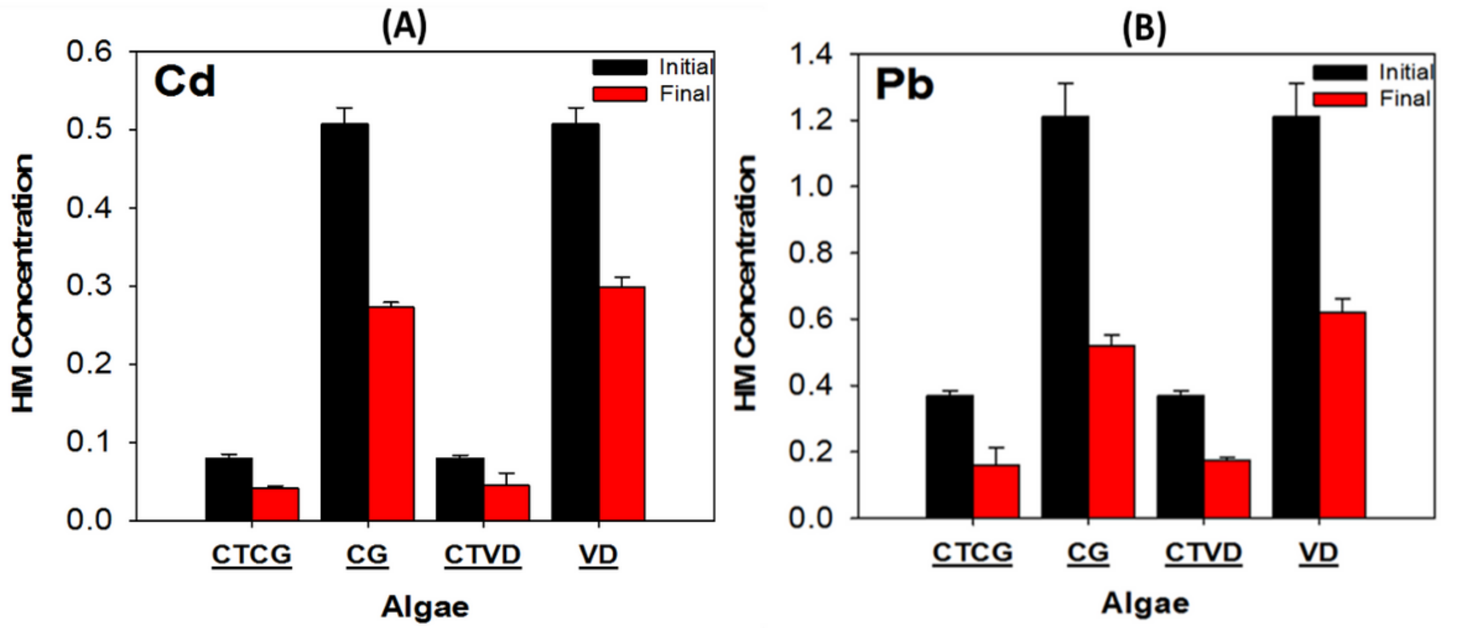

Figure 2

HM concentration in water samples (A) Cd, (B) Pb

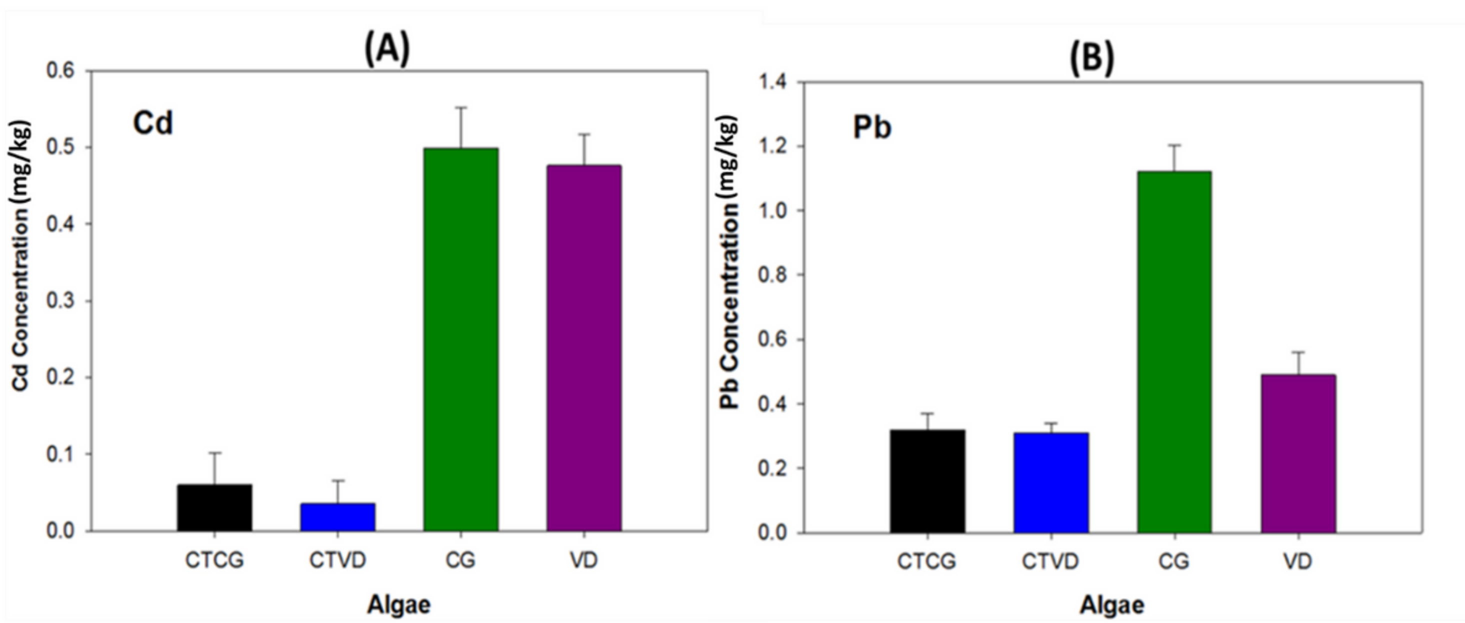

Figure 3

HM concentration in Algal species (A) Cd, (B) Pb

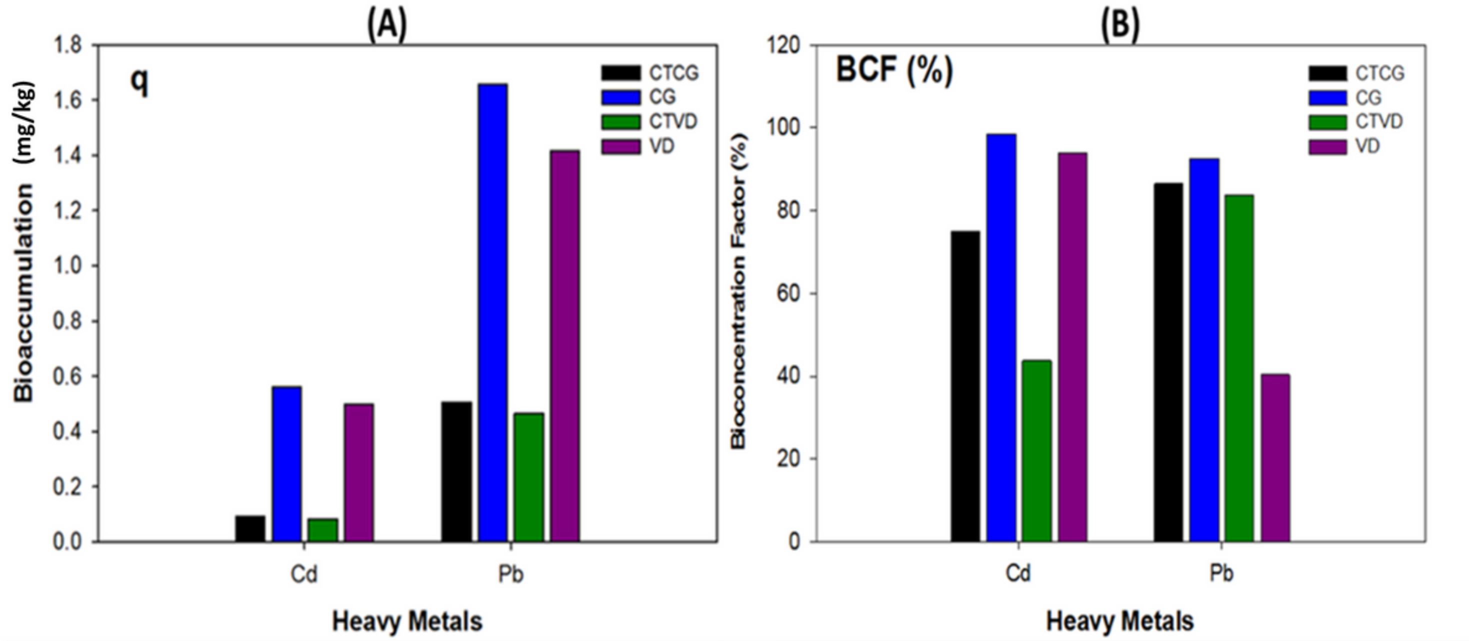

Figure 4

Bioaccumulation (q) (A) and Bioconcentration factor (BCF) (B) of HMs in algal species