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Removal of Heavy Metals from Integrated Industrial Wastewater (IIWW) using Canna Lilly (*Canna indica L.*): A Hydroponic System for Phytoremediation Potential

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Abstract: Delhi is a key center for industry, trade, and production as the country's capital. Due to heavy metals pollution's longevity, scientists are becoming interested in phytoremediation; a low-cost, ecologically friendly plant-based remediation approach. This study aims to see how effective plant species canna lilly (C. indica) grown in a hydroponic system using different concentrations for removing heavy metals (Cr, Cu, Fe, Pb, and Zn) from integrated industrial wastewater (IIWW). The test plants were placed in five different troughs containing 100%, 80%, 60%, 40% of IIWW, and a control trough (tap water) and conducted study for 25 days. The results suggest that C. indica has the maximum heavy metal reduction efficiency at 80% from IIWW. Besides this, the Bioconcentration factor (BAF) and translocation factor results were also recorded at 80% of IIWW concentrations. The plant attributes in terms of root and shoot plant length and fresh weight and dry weight (root and shoots) of C. indica was significantly ($P<0.001$) recorded after the phytoremediation experiment. This study may be encouraging to employ CW-based treatment as a decentralized water treatment in periurban and rural areas, to relieve stress on natural water bodies.

Keywords: C. indica, hydroponic system, integrated industrial wastewater (IIWW), Phytoremediation

I. INTRODUCTION

In India's metropolitan areas, sewage generation amounts to 61,754 million liters per day (MLD), of which 22,963 MLD is treated, and 38791 MLD is not. Being the country's capital, Delhi is a major center for commerce, trade, and manufacturing in northern India [1]. The concentration of micropollutants like heavy metals Cr, Cu, Pb, Cd, and Zn in numerous canals emanating from the River Yamuna has exceeded the maximum allowed drinking standards [2]. According to the Census 2011, the population of Delhi is 167.53 lakhs, with 322,931 people living in the Shahdara region. According to CPCB research, the city creates 3,800 MLD of wastewater each day, with around100 MLD created in Shahdara. As a result, environmental dangers and concerns have arisen due to a lack of sanitation, water supply, and other factors [3].

Because heavy metals persist, researchers are becoming interested in phytoremediation, a low-cost, environmentally benign plant-based remediation solution [4].

C. indica is a popular choice for sewage treatment. It offers a high economic return and is ideally suited for decorative usage in wastewater treatment. It's a perennial plant that grows along the wet borders of open sewage drains and bodies of water [5].

The hydroponic culture process implies the life connections of diverse bacteria, gravel, sun, and the roots of plants, gravel, sun, and water. Hydroponic cultivation is a new approach for effluent treatment in bioremediation [6]. However, this study aims to investigate the maximum removal efficiency of heavy metals in the remediation of industrial wastewater by selected C. indica. The performance of C. indica for industrial treatment is investigated in this study. The study's findings may encourage using this plant species for lake or river rejuvenation because of its high efficiency in removing pollutants.

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II. MATERIALS AND METHODS

A. Wastewater Sampling

The study area is in East Delhi, on the banks of the Yamuna River. Purani Dilli, as it is known, is one of Delhi's oldest inhabited regions. It is located at 28° 41' 24" N and 77° 17' 24" E. An onsite glass-in-mercury thermometer and an electric pH meter (Hanna instrument, Model HI 991301) were used to determine temperature and pH [7]. Shahdara Phytorid Treatment Plant (PTP) Site was selected based on industrial metal-rich inlet wastewater and physicochemical parameters on growth of suitability of plant species and survival of plant species. Vegetative portions' fresh and dry weights were measured electronically to determine aboveground and below-ground biomass. The metal contamination source is the paint industry, acid industry, etc. Preservation of samples was done per the standard methods for examining water and wastewater [8].

B. Plant Sampling

The plant species were selected from CSIR-NEERI, Industrial Area Phase I, Naraina Industrial Area Phase 1, Naraina, Delhi, India, where my experimental setup took place. It is situated at 28° 38'76" N and 77°8'96" E. These test plants were brought to the laboratory, rinsed, and placed hydroponically in 8L as a control in a trough (plastic trough). Industrial wastewater treatment systems based on C. indica are viable solutions to these problems. They can provide tertiary treatment performance on par with or better than traditional wastewater treatment systems generally suggested for large-scale applications.

C. Analysis of Parameters

ICP-AES was used to quantify the heavy metals lead (Pb), copper (Cu), iron (Fe), chromium (Cr), cadmium (Cd), zinc (Zn), and nickel (Ni) during the phytoremediation experiment.

D. Hydroponic System for Phytoremediation Setup

An offsite culture experiment was conducted in the general laboratory of CSIR-NEERI, Delhi Zonal centre, to determine the phytoremediation efficacy of C. indica in the improvement of integrated industrial wastewater (IIWW). The selected plant species were grown in the hydroponic system using different control concentrations (Tap water), 40%, 60%, 80%, and 100% of IIWW. Ten plastic tubs of round shaped 10L capacity were placed in an open area at day/night temperatures with exposure to sunlight to facilitate the plant to perform the photosynthetic activity. The plastic trough of C. indica was filled with gravels (2-5 mm) as a support medium for the plants to grow. All gravels were thoroughly washed with tap water before use. Plants were allowed to establish and acclimate to their new environment for a certain period. The phytoremediation experiment was performed for 25 days to achieve the maximum reduction of pollutants from the wastewater.

E. Removal Efficiency (RE)

Removal efficiency was calculated from the following equation given by (Ugya et al., 2019) [9].

$$\text{Removal efficiency }(\%) = \frac{\text{A}-\text{B}}{\text{A}} \times 100$$

Where; A= Initial concentration; B= Final concentration

F. Bioconcentration Factor (BCF)

The bioconcentration factor was used to assess C. indica's ability to concentrate required metal from the media (BCF). It's an index that compares a plant's ability to accumulate a certain metal to its concentration in the nutrient solution [10] [De Jesus and Yllano, 2005]. After remediation, C. indica was removed and separated into shoots and roots. These pieces were washed with tap water, ionised water, and then oven dried at 70°C before being pulverised. The ground plant components were acid digested with HNO_3 and $HClO_4$ after that. ICP-AES was used to test for heavy metal concentrations in the root and shoot (leave and stem) of the C. indica after digestion. The bioconcentration factor (BCF) was determined as follows: [11, 12] **(**Cule et al., 2016; Yoon et al., 2006)**.**

$$\text{Bioconcentration factor (BAF)} = \frac{\text{b}}{\text{a}}$$

Where; b= metal concentration in plant (mg/kg); a= metal concentration in industrial wastewater (mg/L)

The BCF of below-ground biomass is a more accurate indicator of a plant's phytoremediation potential than the BCF of the plant body or the BCF of aboveground biomass [13]

G. Translocation Factor (TF)

The TF is a measure that indicates a plant's ability to transport heavy metals from the roots to aboveground biomass. By dividing the metal content in aboveground tissues by the metal content in root tissues, the TF was derived. The following formula was used to compute the TF [14].

$$\text{Translocation factor (TF)} = \frac{\text{metal concentrations in shoot (mg/kg)}}{\text{metal concentrations in root (mg/kg)}}$$

H. Plant Attributes

I. Estimation of Plant Biomass (Fresh and Dry Weight):

After soaking off the water from the plants with blotting paper, a fresh weight was taken. The plants were then oven

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dried for 72 hours at 65 °C and dry biomass was determined on an electronic balance to measure aboveground and below-ground biomass. [15].

II. Analysis of Plant Length (Roots and Shoots):

The root and shoot lengths were measured with inch tape on 25th day. Plants take up contaminants from wastewater and improve their root length and shoot length as a result. [16].

III. RESULTS

In the phytoremediation study, we have taken five selected heavy metals such as Cr, Cu, Fe, Pb, and Zn to treat integrated industrial wastewater using C. indica. Data were analyzed using an excel sheet for one-way variance analysis to select the macrophytes with the highest reduction efficiency, bio translocation factor, bioaccumulation factor, and ANOVA.

A. Concentration of Heavy Metals (mg/L) of Integrated Industrial Wastewater before and after Phytoremediation

In the present work, the Cr of IIWW was reduced from their initial values in various concentrations viz., 0% (tap water/control) (0.005mg/L), 40% (0.024 mg/L), 60% (0.035 mg/L), 80% (0.044mg/L), and 100% (0.055 mg/L) to 0% (0.003mg/L), 40% (0.011mg/L), 60% (0.007 mg/L), 80% (0.008 mg/L), and 100% (0.022 mg/L) after 25 days of the phytoremediation experiments using C. indica. The removal of Fe content from IIWW was significantly ($P<0.05$; $P<0.01$; $P<0.001$) recorded during the phytoremediation experiment. Removal efficiency was increased in different concentrations 0% (44.67%), 40% (56.92 %), 60% (80.09%), 80% (81.42%), and then decreased at 100% (59.13%) of IIWW; it's due to high concentration. (Table I and Figure I).

Table I. Concentration of heavy metals (HMs) of selected industrial wastewater (IWW) before and after phytoremediation using C. indica.

Parameter	Concentration	Before Phytoremediation	After Phytoremediation
Cr (mg/l)	40%	0.024± 0.008	0.011± 0.005*
	60%	0.035± 0.012	0.007±0.009**
	80%	0.044± 0.024	0.008±0.012***
	100%	0.055± 0.01	0.022±0.006**
	Control (TW)	0.005± 0.002	0.003±.001*
Cu (mg/l)	40%	0.054± 0.006	0.012±0.007**
	60%	0.056± 0.004	0.021±0.003**
	80%	0.146± 0.014	0.026±0.016***
	100%	0.064± 0.006	0.009±0.002**
	Control (TW)	0.052± 0.012	0.022±0.006*
Fe (mg/l)	40%	0.901± 0.004	0.227±0.323**
	60%	1.362± 0.003	0.155 ±0.108***
	80%	1.765±0.002	0.091±0.008***
	100%	2.197±0.012	0.133±0.006***
	Control (TW)	0.064±0.010	0.025±0.014*
Pb (mg/l)	40%	0.0075±0.003	0.002±0.002***
	60%	0.01±0.003	0.003±0.002***
	80%	0.0132±0.002	0.001±0.001***
	100%	0.016±0.005	0.002±0.002**
	Control (TW)	0.001±0.001	0.0009±0.0001*
Zn (mg/l)	40%	0.098±0.006	0.016±0.003**
	60%	0.145±0.009	0.02±0.002***
	80%	0.193±0.004	0.016±0.002***
	100%	0.241±0.006	0.023±0.009***
	Control (TW)	2.280±0.361	0.720±0.178***

*, **, ***:- Significant at $P<0.05$ or $P<0.01$ or $P<0.001$ level of ANOVA, respectively.

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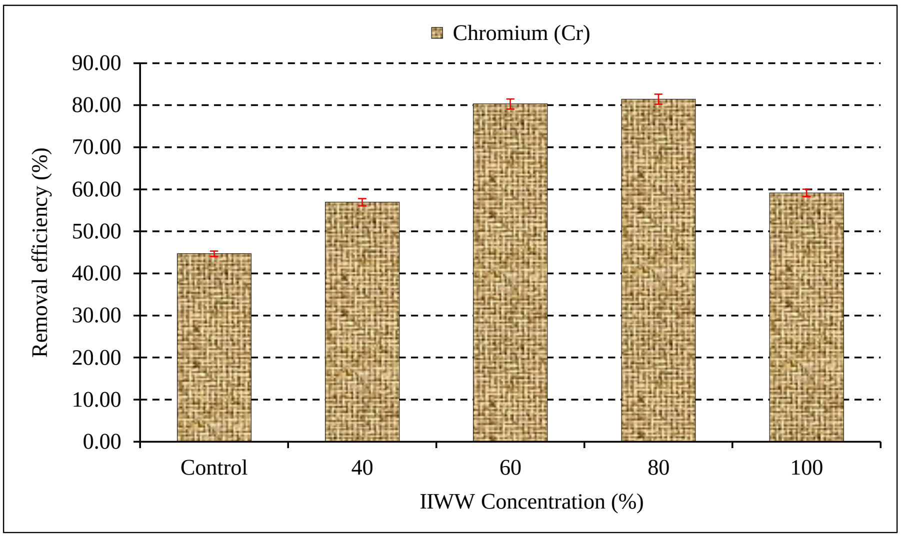

Figure I. Removal efficiency (%) of Cr after phytoremediation from integrated industrial wastewater (IIWW) at different concentration using C. indica.

Similarly, the Cu of IIWW was reduced from their initial values in various concentrations viz., 0% (0.052mg/L) 40% (0.054 mg/L), 60% (0.056 mg/L), 80% (0.146mg/L), and 100% (0.064 mg/L) to 0% (0.022mg/L), 40% (0.012mg/L), 60% (0.021 mg/L), 80% (0.026 mg/L), and 100% (0.009 mg/L) after 25 days of the phytoremediation experiments using C. indica. The removal of Cu content from IIWW was significantly (($P<0.05$; $P<0.01$; $P<0.001$) recorded during the phytoremediation experiment. The Cu content of IIWW was significantly reduced at the selected concentration. Removal efficiency was increased in different concentrations 0% (56.8%), 40% (70.80 %), 60% (74.5%), 80% (94.5%), and at 100% (86.6%) during the experiment. (Table I and Figure II).

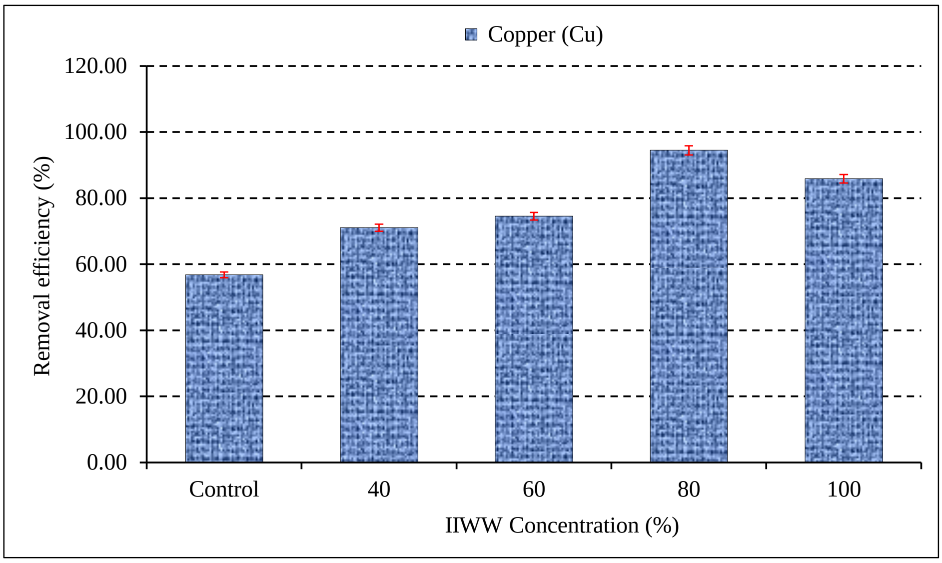

Figure II. Removal efficiency (%) of Cu after phytoremediation from integrated industrial wastewater (IIWW) at different concentration using C. indica.

The performance of Fe was reduced from their initial values in various concentrations viz., 0% (0.064mg/L) 40% (0.901mg /l), 60% (1.362 mg/L), 80% (1.765mg/L), and 100% (2.197 mg/L) to 0% (0.025mg/L), 40% (0.227mg/L), 60% (0.155 mg/L), 80% (0.091 mg/L), and 100% (0.133 mg/L) after 25 days of the phytoremediation experiments using C. indica. The removal of Fe content from IIWW was significantly ($P<0.05$; $P<0.01$; $P<0.001$) recorded during the phytoremediation experiment. The removal efficiency was increased in different concentrations 0% (61.26 %), 40% (69.2 %), 60% (88.6%), 80% (94.9%), and at 100% (93.93%) after the experiment. (Table I and Figure III).

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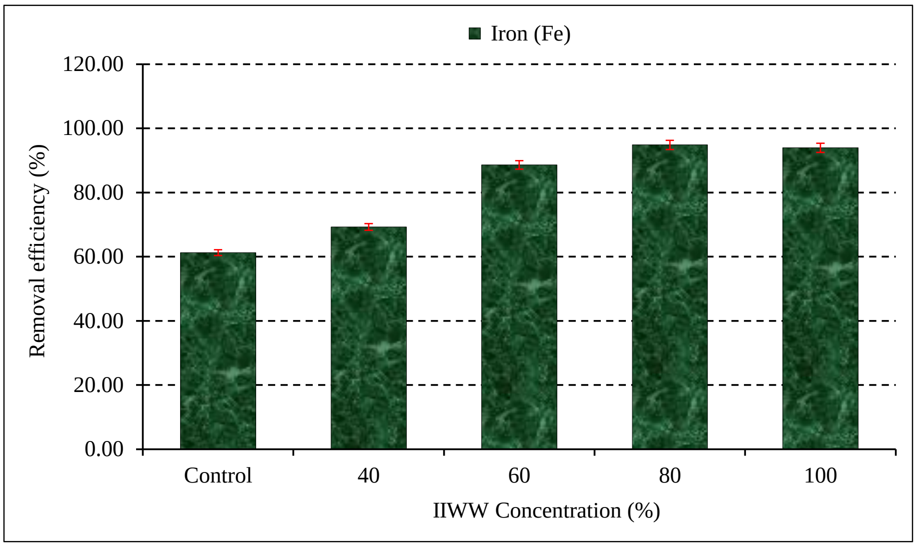

Figure III. Removal efficiency (%) of Fe after phytoremediation from integrated industrial wastewater (IIWW) at different concentration using C. indica.

The Pb of IIWW was reduced from their initial values in various concentrations viz., 0% (0.001 mg/L) 40% (0.0075 mg /l), 60% (0.01 mg/L), 80% (0.0132 mg/L), and 100% (0.016 mg/L) to 0% (0.001 mg/L), 40% (0.002mg/L), 60% (0.003 mg/L), 80% (0.001 mg/L), and 100% (0.002 mg/L) after 25 days of the phytoremediation experiments using C. indica. The Pb content of IIWW was significantly ($P<0.05$ at 100%; $P<0.01$ at control; and $P<0.001$ at 40%, 60% and 80%) recorded during the study. The reduction efficiency was increased in different concentrations 0% (53 %), 40% (69.64 %), 60% (74.85%), 80% (91.6%), and 100% (88.5%). (Table I and Figure IV).

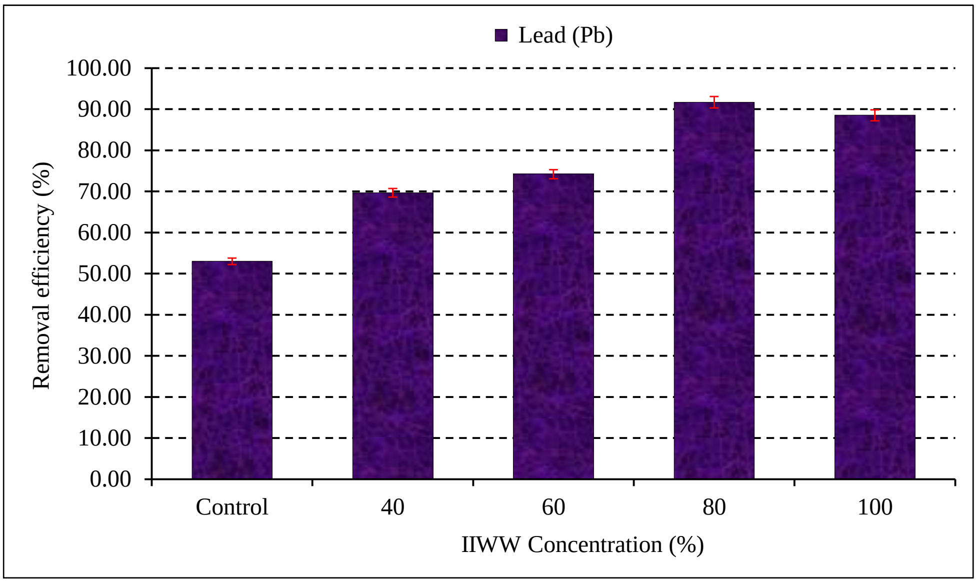

Figure IV. Removal efficiency (%) of Pb after phytoremediation from integrated industrial wastewater (IIWW) at different concentration using C. indica.

The Zn of IIWW was reduced from their preliminary values in various concentrations viz., 0% (2.28 mg/L) 40% (0.098 mg /l), 60% (0.145 mg/L), 80% (0.193 mg/L), and 100% (0.241 mg/L) to 0% (0.720 mg/L), 40% (0.016mg/L), 60% (0.02 mg/L), 80% (0.016 mg/L), and 100% (0.023 mg/L) after 25 days of the phytoremediation experiments using C. indica. The Zn content of IIWW was significantly ($P<0.05$; $P<0.001$) recorded during the study. The reduction efficiency was increased in different concentrations such as 0% (68.42 %), 40% (84.07 %), 60% (85.97%), 80% (91.59%), and then decreased at 100% (90.45%) of IIWW. (Table I and Figure V).

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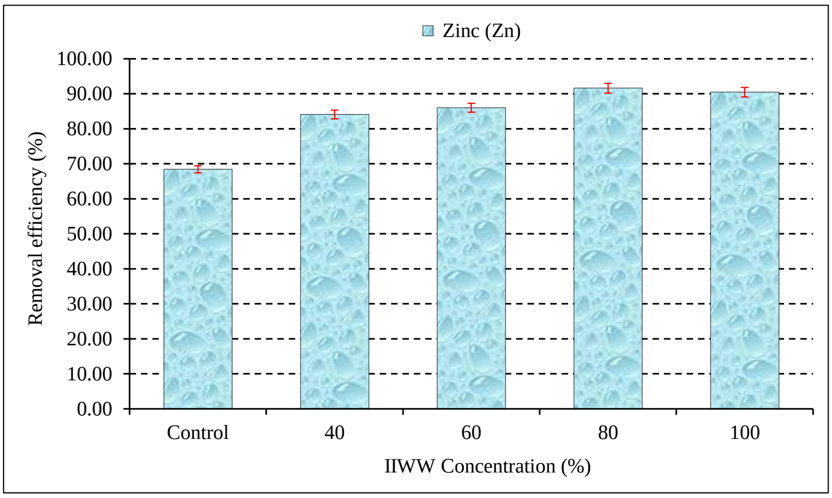

Figure V. Removal efficiency (%) of Zn after phytoremediation from integrated industrial wastewater (IIWW) at different concentration using C. indica.

B. Concentration of Heavy Metals (mg/kg) in Shoots and Roots of Plant before and after Phytoremediation

During the phytoremediation experiments, in the treatment of IIWW using C. indica, it was found that the amounts of heavy metals from IIWW to different plant parts were significantly accumulated differently. The results (table II) showed that in the different treatments of IIWW, the highest contents of selected heavy metals in shoots increased from 0.006 mg/kg to viz., Cr 0% (0.009 mg/kg) 40 % (0.012 mg/kg), 60% (0.021 mg/kg), 80% (0.026 mg/kg), and 100 % (0.023mg/kg) were recorded after phytoremediation of IIWW. In the experiment, the accumulation of Cr content was significantly ($P<0.05$; $P<0.01$; $P<0.001$) found during the study. (Table II).

In the phytoremediation experiment, the concentration of Cu increased from 0.291 mg/kg to viz., 0% (0.306 mg/kg), 40 % (0.309 mg/kg), 60% (0.312 mg/kg), 80% (0.363 mg/kg), and 100 % (0.316 mg/kg) were recorded after phytoremediation of IIWW. The accumulation of Cu was significantly ($P<0.01$; $P<0.001$) found during the study. Similarly, the Fe increased from 0.296 mg/kg to viz., 0% (0.315 mg/kg), 40% (0.604mg/kg), 60% (0.895 mg/kg), 80% (1.130 mg/kg), and 100% (1.324 mg/kg) was recorded after phytoremediation IIWW. The Fe content of IIWW was significantly ($P<0.01$; $P<0.001$) found during the study. Whereas the amount of Pb increased from 0.099 mg/kg to viz., 0% (0.101 mg/kg), 40% (0.102 mg/kg), 60% (0.103 mg/kg), 80% (0.106 mg/kg), and 100% (0.107 mg/kg) was recorded after phytoremediation of IIWW. The Pb content of IIWW was significantly ($P<0.05$; $P< 0.01$; $P<0.001$) found during the study. Besides this, the concentration of Zn increased from 0.299 mg/kg to viz., 0% (1.078 mg/kg), 40% (0.342 mg/kg), 60% (0.360 mg/kg), 80% (0.383mg/kg), and 100% (0.407 mg/kg) was recorded after phytoremediation of IIWW. The Zn content of IIWW was significantly ($P<0.01$; $P<0.001$) recorded during the study. (Table II)

Table II. Concentrations of heavy metals (HMs) in shoot of C. indica before and after phytoremediation of selected industrial wastewater (IWW).

Parameter	Concentration	Before phytoremediation	After phytoremediation
Cr (mg/kg)	40%	0.006±0.005	0.012±0.01*
	60%		0.021±0.012**
	80%		0.026±0.016***
	100%		0.023±0.007**
	Control (TW)		0.009±0.004*
Cu (mg/kg)	40%	0.291±0.027	0.309±0.036**
	60%		0.312±0.016**
	80%		0.363±0.023***
	100%		0.316±0.025**
	Control (TW)		0.306±0.031**
Fe (mg/kg)	40%	0.296±0.035	0.604±0.016**
	60%		0.895±0.025**
	80%		1.130±0.020***
	100%		1.324±0.021***

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	Control (TW)		0.315±0.019**
Pb (mg/kg)	40%	0.099±0.032	0.102±0.023*
	60%		0.103±0.013*
	80%		0.106±0.021**
	100%		0.107±0.009***
	Control (TW)		0.101±0.011**
Zn (mg/kg)	40%	0.299±0.077	0.342±0.007**
	60%		0.360±0.017**
	80%		0.383±0.014***
	100%		0.407±0.020***
	Control (TW)		1.078±0.189***

*, **, ***:- Significant at P<0.05 or P<0.01 or P<0.001 level of ANOVA, respectively.

However, in roots of plant (Table III), the results found in the different treatments of IIWW viz., 0% (TW), 40%, 60%, 80%, and 100%, the highest contents of selected heavy metals increased from 0.088 mg/kg to viz., Cr 0% (0.09 mg/kg) 40 % (0.097 mg/kg), 60% (0.101 mg/kg), 80% (0.146 mg/kg), and 100 % (0.103 mg/kg) was recorded after phytoremediation of IIWW. The Cr content of IIWW was significantly (P<0.05; P<0.01; P<0.001) found during the study. The Cu increased from 0.078 mg/kg to viz., 0% (0.09 mg/kg), 40 % (0.096 mg/kg), 60% (0.1 mg/kg), 80% (0.146 mg/kg), and 100 % (0.104 mg/kg) was recorded after phytoremediation of IIWW. The Cu content of IIWW was significantly (P<0.05; P< 0.01; P<0.001) found during the study. The Fe increased from 0.853 mg/kg to viz., 0% (0.871 mg/kg), 40% (1.161 mg/kg), 60% (1.456 mg/kg), 80% (1.688 mg/kg), and 100% (0.951 mg/kg) was recorded after phytoremediation of IIWW. The Fe content of IIWW was significantly (P<0.05; P< 0.01; P<0.001) found during the study. The concentration of Pb increased from 0.741 mg/kg to viz., 0% (0.741 mg/kg), 40% (0.743 mg/kg), 60% (0.745 mg/kg), 80% (0.746 mg/kg), and 100% (0.748 mg/kg) was recorded after phytoremediation of IIWW. The Pb content of IIWW was significantly (P<0.05; P<0.001 at 100%) found during the study. Zn increased from 0.842 mg/kg to viz., 0% (1.616 mg/kg), 40% (0.882 mg/kg), 60% (0.904 mg/kg), 80% (0.928 mg/kg), and 100% (1.046 mg/kg) was recorded after phytoremediation IIWW. The Zn content was significantly (P<0.05; P<0.001) reported during the study.

Table III. Concentrations of heavy metals (HMs) in root of C. indica before and after phytoremediation of selected industrial wastewater (IWW).

Parameter	Concentration	Before phytoremediation	After phytoremediation
Cr (mg/kg)	40%	0.088±0.033	0.097±0.033*
	60%		0.101±0.027**
	80%		0.146±0.039***
	100%		0.103±0.038**
	Control (TW)		0.090±0.012*
Cu (mg/kg)	40%	0.078±0.009	0.096±0.014*
	60%		0.100±0.022**
	80%		0.146±0.031***
	100%		0.104±0.023**
	Control (TW)		0.090±0.010*
Fe (mg/kg)	40%	0.853±0.015	1.161±0.027**
	60%		1.456±0.040***
	80%		1.688±0.022***
	100%		0.951±0.041*
	Control (TW)		0.871±0.022*
Pb (mg/kg)	40%	0.741±0.031	0.743±0.019*
	60%		0.745±0.037*
	80%		0.746±0.049*
	100%		0.748±0.016**
	Control (TW)		0.741±0.011*
Zn (mg/kg)	40%	0.842±0.046	0.882±0.015*
	60%		0.904±0.105*
	80%		0.928±0.188*

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	100%		1.046±0.919***
	Control (TW)		1.616±0.589***

*, **, ***:- Significant at P<0.05 or P<0.01 or P<0.001 level of ANOVA, respectively

C. Bioconcentration factor of Heavy Metals before and after Phytoremediation

The bio concentration factors of different heavy metals (Table IV) before phytoremediation and after phytoremediation in shoot part of plant viz. Cr at 40 % (0.25 to 1.091), 60 % (0.171 to 3.0), 80% (0.136 to 3.714), 100 % (0.109 to 1.045) and 0% (1.2 to 2.0) while in root part Cr at 40 % (3.667 to 8.818), 60 % (2.514 to 14.429), 80% (2.0 to 13.375), 100 % (1.6 to 4.68) and 0% (17.6 to 29.67). Similarly, the bio concentration factors encountered before phytoremediation and increased to after phytoremediation in shoot part viz., Cu at 40 % (5.389 to 19.31), 60 % (5.196 to 22.286), 80% (1.99 to 39.5), 100 % (4.547 to 40.33) and 0% (6.191 to 3.87) while in the root part such as Cu at 40 % (1.44 to 6.06), 60 % (1.393 to 7.214), 80% (0.534 to 13.375), 100 % (1.219 to 11.44) and 0% (1.66 to 3.87). However, the Fe in shoot part at 40 % (0.329 to 1.116), 60 % (0.217 to 2.013), 80% (0.168 to 3.473), 100 % (0.135 to 2.771) and 0% (4.625 to 12.08) while in root part Fe at 40 % (0.945 to 0.350), 60 % (0.625 to 0.652), 80% (0.482 to 1.176), 100% (0.387 to 0.786) and 0% (13.297 to 3.56)

The bio concentration of Pb, before phytoremediation and after phytoremediation in shoot part viz. Pb at 40 % (13.2 to 51.0), 60 % (9.9 to 34.33), 80% (7.5 to 106.0), 100 % (6.19 to 53.5) and 0% (99.0 to 101.0) while in root part Pb at 40 % (98.8 to 371.5), 60 % (74.1 to 248.33), 80% (56.14 to 746), 100% (53.5 to 374.0) and 0% (741.0 to 742.0). However, the bio concentration factors of Zn, before phytoremediation and after phytoremediation in shoot part viz. Zn at 40 % (3.051 to 21.38), 60 % (2.06 to 18.0), 80% (1.55 to 23.94), 100 % (1.24 to 17.69) and 0% (0.131 to 0.473) while in root part Zn at 40 % (8.58 to 55.13), 60 % (5.8 to 45.2), 80% (4.36 to 58.0), 100% (3.49 to 45.48) and 0% (1.17 to 2.24) were recorded during the phytoremediation experiment. (Table IV).

Table IV. Bio-concentration factor of heavy metals in shoot and root of C. indica before after phytoremediation of selected industrial wastewater (IWW).

Parameter	Concentration	Before phytoremediation		After phytoremediation	
		Shoot part	Root part	Shoot part	Root part
Cr	40%	0.25	3.67	1.09	8.81
	60%	0.17	2.51	3.00	14.42
	80%	0.14	2.00	3.71	13.38
	100%	0.11	1.60	1.05	4.68
	Control (TW)	1.200	17.600	2.000	29.667
Cu	40%	5.39	1.44	19.31	6.06
	60%	5.20	1.39	22.29	7.21
	80%	1.99	0.53	39.50	13.38
	100%	4.55	1.22	40.33	11.44
	Control (TW)	6.19	1.66	13.30	3.87
Fe	40%	0.33	0.95	1.12	0.35
	60%	0.22	0.63	2.01	0.65
	80%	0.17	0.48	3.47	1.18
	100%	0.14	0.39	2.77	0.79
	Control (TW)	4.63	13.30	12.08	3.56
Pb	40%	13.20	98.80	51.00	371.50
	60%	9.90	74.10	34.33	248.33
	80%	7.50	56.14	106.00	746.00
	100%	6.19	46.31	53.50	374.00
	Control (TW)	99.00	741.00	101.00	742.00
Zn	40%	3.05	8.58	21.38	55.13
	60%	2.06	5.80	18.00	45.20
	80%	1.55	4.36	23.94	58.00
	100%	1.24	3.49	17.70	45.48
	Control (TW)	0.13	1.17	0.47	2.24

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D. Translocation Factor of Heavy Metals before and after Phytoremediation

The results (Table V) revealed that the translocation factor of heavy metals increased from 0.068 before phytoremediation to Cr (0.067, 0.123, 0.208, 0.278, and 0.223) after phytoremediation at various concentrations of heavy metals, i.e., 0 %, 40 %, 60 %, 80 %, and 100 %. Similarly, the value of Cu before cleanup was 3.73, but it climbed to (3.44, 3.19, 3.09, 2.95, 3.52, and 3.44). The TF of Fe before phytoremediation was 0.347, whereas after phytoremediation it was (3.393, 3.186, 3.089, 2.953, and 3.524). Pb concentration TF was 0.134 before phytoremediation, with 0 % (0.136), 40% (0.137), 60% (0.138), 80% (0.142), and 100% (0.143) after phytoremediation, while Zn concentration TF was 0.356 before phytoremediation, with 0 % (0.211), 40% (0.388), 60% (0.398), 80% (0.413), and 100% (0.389) after phytoremediation.

Table V. Translocation factor (shoot-root) of heavy metals in C. indica before after phytoremediation of selected industrial wastewater (IWW).

Parameter	Concentration	Before phytoremediation	After phytoremediation
Cr	40%	0.07	0.12
	60%		0.21
	80%		0.28
	100%		0.22
	Control (TW)		0.07
Cu	40%	3.73	3.19
	60%		3.09
	80%		2.95
	100%		3.52
	Control (TW)		3.44
Fe	40%	0.35	3.19
	60%		3.09
	80%		2.95
	100%		3.52
	Control (TW)		3.39
Pb	40%	0.13	0.14
	60%		0.14
	80%		0.14
	100%		0.14
	Control (TW)		0.14
Zn	40%	0.36	0.38
	60%		0.39
	80%		0.41
	100%		0.40
	Control (TW)		0.21

E. Plant Attributes before and after Phytoremediation

I. Plant Biomass (Fresh and Dry Weight)

In the phytoremediation experiments, the C. indica plants grown in different concentrations of IIWW showed a varied increase in their fresh weight. The fresh shoot biomass of the C. indica plants in the different concentrations of IIWW (Table VII) such as 0% (65.07 g), 40% (77.03 g), 60% (84.4 g), 80% (81.07 g), and 100% (89.7g) was recorded respectively. At the same time, the dry shoot weight in the different concentrations of IIWW such as 0% (13.98 g), 40% (15.7 g), 60% (21.8 g), 80% (16.9 g), and 100% (18.6 g) was found respectively. However, the fresh root biomass of the C. indica plants in the different concentrations of IIWW such as 0% (19.32 g), 40% (18.7 g), 60% (29.37 g), 80% (27.1 g), and 100% (26.83 g) was recorded respectively. In contrast, the dry root weight in the different concentrations of IIWW such as 0% (3.47 g), 40% (3.86 g), 60% (4.2 g), 80% (4.87), and 100% (3.97 g) were found respectively. (Table VI)

Table VI. Plant biomass in terms of fresh weight and dry weight (root) after phytoremediation of selected industrial wastewater (IWW) using C. indica.

Plant	Concentration	Fresh weight	Dry weight
C. indica	40%	18.7±0.58	3.86± 0.97
	60%	27.37±0.66	4.20±0.51
	80%	39.10±1.13	5.87±0.55
	100%	26.83±2.22	3.97. ±0.76
	Control (TW)	19.32±1.72	3.47±1.67

Table VII. Plant biomass in terms of fresh weight and dry weight (shoot) after phytoremediation of selected industrial wastewater (IWW) using C. indica.

Plant	Concentration	Fresh weight	Dry weight
C. indica	40%	77.03±3.004	15.70 ±2.5
	60%	84.40±2.35	21.78±1.16
	80%	81.07±3.52	16.90±3.46
	100%	89.70±2.94	18.60±2.88
	Control (TW)	65.07±2.59	13.98±3.02

II. Plant Length (Roots and Shoots)

The root and shoot length of C. indica plants grown in various concentrations of IIWW increased in different ways in this experiment. The root length of C. indica in different IIWW concentrations was measured before and after phytoremediation: 0% (17.6 cm increased to 22.4 cm), 40% (19.32 cm increased to 24.9 cm), 60% (18.9 cm to 24.6 cm), 80% (17.1 cm to 30.2 cm), and 100% (18.7 cm increased to 23.8 cm) (Table 8). Similarly, the shoot length of C. indica (table 9) was raised by 0% (45.6 cm to 55.4 cm), 40% (31.32 cm to 41.2 cm), 60% (34.9 cm to 50.8 cm), 80% (47.1 cm to 63.2 cm), and 100% (42.7 cm to 61.8 cm) at varied IIWW concentrations before and after phytoremediation. During the investigation, the root and shoot plant lengths of C. indica were significantly ($P<0.05$; $P<0.01$; $P<0.001$) reported. (Table VII and IX)

Table VII. Root length (cm) of C. indica before and after phytoremediation of selected industrial wastewater (IWW).

Plant	Concentration	Before phytoremediation	After phytoremediation
C. indica	40%	19.32±0.57	24.90±1.25*
	60%	18.9±0.79	24.60±0.82**
	80%	17.10±0.87	30.20±1.56***
	100%	18.7±1.12	23.80±0.92*
	Control (TW)	17.6±0.57	22.40±0.47*

*, **, ***:- Significant at P<0.05 or P<0.01 or P<0.001 level of ANOVA, respectively.

Table IX. Shoot length (cm) of C. indica before and after phytoremediation of selected industrial wastewater (IWW).

Plant	Concentration	Before phytoremediation	After phytoremediation
C. indica	40%	31.32±2.57	41.20±1.25*
	60%	34.90±0.79	50.80±0.82***
	80%	47.10 ±0.87	63.20±1.56***
	100%	42.70±1.12	61.80±0.92**
	Control (TW)	45.60±0.57	55.40±0.47**

*, **, ***:- Significant at P<0.05 or P<0.01 or P<0.001 level of ANOVA, respectively.

IV. DISCUSSION

A. Heavy Metals Removal Efficiency after Phytoremediation

In the study, the Cr was efficiently and significantly ($P<0.001$) reduced from the different concentrations of the IIWW C. indica plants. The results determined that among all treatments of the IIWW, the maximum reduction of Cr (81.42%) with 80% concentration of IIWW after 25 days of the experiment (Figure I). The chromium absorption by ipes was investigated at four distinct levels in Cr metal solution: 1, 5, 10, and 20 mg/L. In 11 days, 84 % of the Cr was eliminated [17]. The Cu was proficiently and significantly ($P<0.001$) decreased from varied concentrations of IIWW using C. indica plants in this investigation. The results showed that the highest reduction of Cu (94.5%) was achieved

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with an 80 % concentration of IIWW (Figure II). Similar research was performed by Kumar et al., 2019 for the Cu removal from the aqueous solution. [18]

Fe is a biologically important element in all living things [19]. Tijerina-Sáenz et al.,2015 [20] found that iron deficiency has many health consequences [18]. The results showed that after 25 days of experimentation, the highest reduction of Fe (94.9%) was achieved with an 80 % concentration of IIWW (Figure III). Fe was efficiently and significantly ($P<0.001$) decreased from varied concentrations of IIWW C. indica plants in this result. Daud et al. (2018) also reported similar results for the Fe phytoremediation from landfill leachate by Lemna minor L. at different periods [21].

Lead is a poisonous chemical that can harm people's health. A significant amount of lead can cause convulsions and unconsciousness, leading to death as mentioned in WHO, 2017 [22]. The results showed that after 25 days of experimentation, the highest reduction of Pb (91.6%) was achieved with an 80 % concentration of IIWW (Figure IV). Pb was efficiently and significantly ($P<0.001$) decreased from varied concentrations of IIWW C. indica plants in this result. L.minor, a common aquatic plant, can eliminate up to 90% of soluble Pb from water. The potential of aquatic plants like duckweed (Lemna sp.) plays a vital role in metal extraction and buildup from wastewater [23]. Zinc is extensively utilized in various sectors, including galvanization paint, and so on, and the effluent from these industries contains enormous amounts of zinc. The maximum removal of Zn (91.5%) of IIWW was observed using C. indica plants at an 80% concentration of IIWW (Figure V), and this result was significantly ($P<0.001$) found from various concentrations of IIWW. C. indica plants. In the batch sorption trials, the aquatic plant Duckweed was employed to remove Zn from wastewater. Bokhari et al., 2016 confirmed the concentration of heavy metals within the L.minor, and was the consequent drop in effluents [24].

B. Heavy Metals Concentration in Roots and Shoots of the Plant after Phytoremediation

The heavy metal capture and uptake process are largely affected by the early metal quantity within the medium. We found that significant ($P<0.001$) contents of different heavy metals as Cr, Cu, Fe, Pb, and Zn were absorbed by C. indica. After 25 days of the study in the plant's shoot (Table II), the Cr and Cu content of IIWW was considerably higher ($P<0.001$) at 80%. During the investigation, the Fe and Pb content of IIWW was significantly higher ($P<0.001$) at 80% and 100%. During the study, the Pb concentration of IIWW was considerably ($P<0.001$) at 100%. The Zn content of IIWW in the plant shoot was greatly increased ($P<0.001$) at 0%, 80% and 100%.

However, the results from Table III, demonstrated that the varied treatments of IIWW had diverse effects on plant roots. During the analysis, the highest Cr and Cu concentration of IIWW was considerably ($P<0.001$) at 80. During the investigation, the Fe content of IIWW was considerably higher ($P<0.001$ at 60% and 80%). During the study, the Pb concentration of IIWW was considerably ($P<0.5$) at 60%. During the investigation, the Zn content of IIWW was dramatically increased ($P<0.001$) at 0% and 100%. The other study aims to see how effective native species remove heavy metals from the soil. C. indica has the highest stem concentration, followed by Abutilon indicum and Catharanthus roseus. [25]

C. Bio Concentration Factor after Phytoremediation

The Bioconcentration factors are the most important factor which reflects the phytoremediation potential of plants used in wastewater decontamination. On the 25th sample day, the maximum bioconcentration factors of various heavy metals were discovered in my study following phytoremediation in the shoot and root parts (Table IV), viz. Cr was found at 80 % (3.714 and 13.375), Cu was found at 80 % (39.5 and 13.375), Fe was found at 80 % (3.473 and 1.176), Pb was found at 80 % (106.0 and 746), and Zn was found at 80 % (23.94 and 58.0). According to Cule,[11], the study's outcomes strongly imply that C. indica is a very suitable choice for biofiltration of Pb-contaminated water. Amare et al., 2018b [26] claim that the bioconcentration factor for Cd^{2+} and Ni^{3+} obtained in their study showed that E. crassipes has the highest bioconcentration factor, indicating that the plant can effectively absorb Cd^{2+} and Ni^{3+} from wastewater and transport the heavy metal to the shoot (stem and leaves) for utilization.

D. Translocation Factor after Phytoremediation

According to the experimental results, the maximum values of the heavy metal TF obtained in the study after the 25th sampling day (Table V) are as follows: Cr value is 0.068 before phytoremediation, which climbed to Cr at 80 % (0.278) after phytoremediation. Cu and Zn have similar pre-remediation values of 3.73 and 0.356, respectively, which increased to 3.52 at 80 %. Before phytoremediation, the Fe and Pb TF values were 0.347 and 0.134, respectively, while after phytoremediation, they were 3.933 and 0.143, respectively. The researchers focused on Cd movement from Canna roots to aboveground sections, according to Dong et al., 2019 [16]. As the concentration of Cd2+ grew from 5 to 15 mg/L, the translocation factor (TF) of Cd decreased by 27.1–33.3 %. Yadav et al,. 2012 investigated the potential of Cr, Zn, Cu, Co, and Ni removal in C. indica, T. angustifolia, and C. alternifolius plants planted in Constructed Wetlands [27]. It was discovered that different plant species had variable amounts of heavy metal translocation and bioconcentration, and that below-ground biomass (roots) contributed more to metal removal than above-ground biomass (leaves and stem).

D. Effect on Plant Biomass (Fresh and Dry Weight) after Phytoremediation

The highest fresh shoot biomass of the C. indica plants in the different IIWW concentrations was discovered at 80 % (81.07 g), whereas the highest dry shoot weight in the different IIWW concentrations was found at 80 % (16.9 g) during the phytoremediation experiment. However, the C. indica plants had the largest fresh and dry root biomass at 80 %, with 27.1 g and 4.87 g, respectively (Table VI and VII). Sudiarto et al., 2019 found that plants (Eichhornia crassipes and Pistia stratiotes) grew at a faster relative growth rate for 21 days [28]. When compared to Pistia stratiotes, E. crassipes showed a greater DW/FW ratio. This is due to the fact that PS had more water than EC.

E. Effect on Plant Length (Roots and Shoots) after Phytoremediation

In the present study, the maximum root and shoot plant length of the C. indica was found at 80% (17.1 cm to 30.2 cm) and (47.1 cm to 63.2 cm). The root plant length content of C. indica was significantly ($P<0.001$ at 80 %) recorded during the study, while the shoot plant length content of C. indica was significantly ($P<0.001$ at 60 % and 80 %) recorded during the study (Table 8 and 9). According to the findings of the Pinninti et al., 2021 study, a tropical environment encourages the growth of the canna plant, making the Canna Indica a suitable plant species for a designed wetland treatment system [29]. According to the study of Ferreira et al., 2002 showed that algal bloom and macrophytes radicle growth were more susceptible in toxicological studies than plant growth [30].

CONCLUSION

In the present study, the C. indica was a good metal accumulator, mostly at concentrations of 80% of IIWW and a moderate accumulator of heavy metals at other concentrations, demonstrating the ability to remove contaminants from industrial wastewater. The findings of this research are remarkable, and they are critical for the environmentally friendly and long-term treatment of very toxic substances. The present study responded effectively in terms of heavy metals removal, bioaccumulation, translocation factors, and plant features such as root, shoot length, fresh and dry plant weight.

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