ASSESSING EICHHORNIA CRASSIPES PHYTOREMEDIATION PROSPECTS FOR STEEL FABRICATION INDUSTRY EFFLUENT

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ABSTRACT

The present work aims to evaluate the phytoremediation potential of aquatic macrophyte viz. *Eichhornia crassipes* and explores its prospects for the treatment of steel fabrication industry effluent. The experiment was designed for 30 days treatment period at interval of 10 days for three concentration of effluents *i.e.* 20, 40 & 60% in pot culture experiments. The efficiency of the *E. crassipes* as phytoremediator plant; was measured initial and post treatment of effluent in terms of physico-chemical parameters such as pH, COD, TSS, TS, TDS, BOD and heavy metals (Fe, Cu & Zn). Assessment of physico-chemical parameters of effluent showed significant decrease with time in all physico-chemical parameters and heavy metal concentration. The effect of effluent treatment on plant was observed in terms of plant dry weight, leaf number and total chlorophyll content. The 40% concentration of effluent shown best results in terms of plant growth and reduction in effluent physico- chemical parameters. Phytoremediation ability of *E. crassipes* for iron (Fe), copper (Cu) and zinc (Zn) was also assessed in terms of reduction of heavy metal concentration in effluent along with time. Removal of heavy metals from the effluent as a result of phytoremediation was observed maximum for Fe followed by Cu and Zn in all concentration treatments. The accumulation of heavy metals in the plant was evident in terms of bioconcentration factor values more than 5 in each case. The study thus suggested *E. Crassipes* might be used as effective phytoremediator plant species for removal of Fe, Cu & Zn in steel fabrication industry effluent owing to its detoxification ability and accumulation of heavy metal in environmentally friendly manner.

Key words: Phytoremediation, Steel fabrication, Heavy metal, *Eichhornia crassipes*

INTRODUCTION

Steel industry is one of the basic industries on which the economic growth of the developing country is contingent. Steel fabrication and casting processes are unique in terms of fulfilling the demand of growing industrialization, economic development, rapid technological progress and boon of the construction sector in India. India being the second largest producer of the steel and its products in the world have high demand of fabrication work in the various industrial sectors and demand is expected to increase approximately three times up to 2030-31 as compared to 2018-19 (Indian steel industry analysis , Retrieved on Dec 2018, ibef.org).

Like other industrial processes the steel fabrication, casting and electroplating have several adverse impacts on each segment of environment. The steel industry involves high energy demanding industrial processes during manufacturing of steel from the ore and its further casting, fabrication and finishing into end products for use of the society and thus directly uses the energy and resulted into climate change aggregation. The processes also resulted into various air pollutants (CO, CO_2, SOx, NOx, Particulate matter and fly ash), wastewater contaminates, hazardous solid waste or sludge and heavy metals dust from the furnace and water used for cooling & washing. The heavy metals in effluent of the industry such as Fe, Pb, Zn, Cu, Cr, Cd etc. due to their recalcitrant nature have the impact not only in local area but also at the global level. The spread of heavy metals in the air from the fly ash and particulate matter of the steel industry process and the bioaccumulation of the heavy metals of effluent in aquatic and terrestrial ecosystem components further posed serious health hazards for the human and other living organisms (Naidoo & Olaniran, 2014). Likewise, other industry effluent treatment of steel manufacturing and fabrication industry wastewater is required to treated to minimize its footprints on the environmental health in total and long term sustainability of the industry in terms of various environmental standards for discharge of effluent. The integrated iron& steel industry wastewater also contain phenol, cyanide and ammonia, high BOD and COD load which are harmful for receiving surface water body when discharged untreated (Nazz el al., 2017). The heavy metals associated in wastewater by further casting, fabrication and electroplating processes of steel make the problem more aggravated.

Terrestrial and aquatic plants have natural ability to remove and bioaccumulate various pollutants and heavy metals from contaminated soil and water into biomass and this phenomenon of these hyperaccumulator has been termed as Phytoremediation (Chandra and Yadava, 2010; Rahman and Hasegawa, 2011). The process of phytoremediation has been utilized for industrial wastewater treatment and heavy metal sequestration from the water under optimized conditions at very economic cost and time (Patel & Kanungo,2010). Most studies on bioaccumulation of pollutants were done by bioaccumulation of pollutants applying different aquatic weeds alone and-or in combination with microorganisms from industrial waste water. Some of these experiments applied through ex situ and in situ experiments for pulp paper, distillery, textile, brass industry effluents for treatment of BOD,COD, Colour, Dissolved solids and heavy metals and factors have been optimized for maximum benefit of the phytoremediation process (Matagi et al., 1998). The Water hyacinth (*E crassipes*) is being attributed to the fast growing, metal tolerant, free floating aquatic macrophyte. It also has a sophisticated metabolic and sequestration detoxification mechanism easily adopt to aquatic conditions and play important role in reducing pollution load and heavy metal in effluent (Kaur et al., 2010). There are bio-chemical oxidation methods available for the steel fabrication and electroplating industry effluent treatment which only reduce the phenol, cyanide and ammonia. Still few studies have been done to exploit the phytoremediation efficiency of the Water hyacinth as biological method of treatment, especially to the extraction of heavy metals from the wastewater before discharge for further irrigation purposes

(Biswas, 2013). Hence, in the present study *Eichhornia crassipes* was evaluated for phytoremediation of steel fabrication industry effluent and removal of heavy metals Cu, Fe and Zn.

MATERIAL AND METHODS

Collection of effluent

The effluent for the present study was collected from the site near to steel fabrication and electro-platting industry at industrial area of Bari brahmana in district Jammu, India in sterilized plastic containers of rayon grade and stored at 4^0C until further experiments. The effluent is analyzed for the physico-chemical parameters by standard methods and instrumentation (APHA, 2017). The effluent after the sampling point joins the river and further utilized for irrigation purpose of the crop in downstream villages.

Collection of hyperaccumulator plant

The Water hyacinth (*Eichhornia crassipes*) plants were randomly collected from a nearby village pond in the upstream direction of the collection of effluent samples. The pond contains natural rain water and used by villagers only as the washing and drinking water for the cattle and is supposed to be free from any industrial effluent contamination. The collected plants were brought to laboratory and washed with deionized water to avoid the surface contamination if any. Initial growth parameters of the collected plant were measured and further kept in deionized water tubs for eight hours in order to be adjustment in the environment.

Biosorption studies and treatments

The experiment was conducted in the experimental tanks as constructed wetland for the 20%, 40% and 60% of the effluent along with the control solution. Three replications were maintained for each dilution treatment to access the reduction in various parameters of the steel fabrication industry effluent and to monitor the growth parameters of the plants. Six plants of approximately equal size by naked eye were immersed in each set of experimental tanks. The plants were grown in tanks for 30 days and sampled at 10, 20 and 30 days of experiment along with control. The effect of the plant on effluent physico-chemical characteristics were analyzed. The analysis was done for plant dry biomass, growth parameters (leaf number and total chlorophyll content) of the plant and heavy metal (Fe, Cu & Zn) concentration in plant biomass as a result of phytoremediation of the effluent. To full fill the demand of the dissolved oxygen for growth of plant, the effluent in plastic tanks were mechanically aerated by pump for 10 min in each treatment at the interval of two days throughout the experiment. The heavy metal Fe, Cu and Zn were analyzed in effluent and plant samples by standard wet digestion method and using AAS, Model Phillips PU-9200X. The control group of plants and effluent were also measured in similar time interval for various parameters.

Statistical analysis

Data generated were analyzed by two way repeated measure ANOVA to check the precision of analytical results using SAS software (version 9.3).

The bioconcentration factor was calculated according to the following equation

$$B.C.F = \frac{\text{Conc. of element in plant}}{\text{Conc. of element in water}}$$

RESULT AND DISCUSSION

The steel fabrication industry effluent was brackish gray, alkaline (pH 8.5) and with no foul smell. Most of the physico-chemical parameters (Table 1) exhibited substantially higher values than their permissible limits as recommended for effluent discharge in surface water bodies (BIS, 1981). The BOD (628 mg l^{-1}) and COD (2318 mg l^{-1}) values were higher than the standards and indicated the high pollution load of the effluent. Similarly, the heavy metal concentrations of Fe (12.7 ppm), Cu (4.04 ppm) & Zn (6.81 ppm) were also found on substantially higher sides as per ISI standards. Similar observation for the physico-chemical parameters of the steel industry effluent were reported by (Krishnaveni et al, 2013 and Nazz et al., 2017).

Effect of *E. crassipes* on physico-chemical characteristics of the effluent

The physico- chemical characteristics of the different concentration treatments were found to be substantially reduced along time by *E. crassipes*. There was random variation in the pH of all treatments, but it ended towards neutral after 30 days (7.2,7.3 & 7.2 in 20%, 40% & 60% respectively) in comparison to 8.5 for the original undiluted effluent. Other parameters as COD, TSS, TS, TDS, BOD and Heavy metals Fe, Cu, Zn were found to be decreased in all concentration treatments along with time of phytoremediation treatment. The maximum reduction in percentage in all the physico-chemical characteristics was observed in 40% treatment at 30 days. The physico- chemical parameters (mg L^{-1}) and Heavy metals (ppm) were recorded to be reduced as a result of phytoremediation by plant to COD 504.45, 665.91, 1102.11; TSS 61.86, 99.55, 185.03; TS 158.51, 215.13, 398.94; TDS 156.70, 238.41, 303.56; BOD 7.0.78, 130.89, 209.14; Fe 0.57, 0.18, 0.95; Cu 0.11, 0.12, 0.28 and Zn 0.06 , 0.09, 0.29 in 20, 40 and 40% effluent treatments respectively after 30 days of the experiment. The trends of percent reduction in COD, TSS, TS, TDS and BOD are shown in Figure 1 for all treatments at 10, 20 & 20 days has shown an increasing trend with time, and maximum reduction was observed in 40% concentration of the effluent. The values shown significant difference among the group ($P>0.05$). Pal et al 2014 observed similar effect on the physicochemical characteristics of the effluent due to phytoremediation by plants for brass and electroplating industry. These results also corroborate for studies of Sukumaran, 2013 for rare earth separating industry, Mishra et al., 2013 for pulp & paper industry, Patel & Kanungo, 2010 for domestic waste water and Roy et al, 2010 for textile industry effluents. The 40% effluent concentration was found to be best for the treatment of steel fabrication and electroplating industry effluent because it contain optimum level of the nutrients and tolerant level of heavy metals which in turn promote the growth of the phytoremediator producing more biomass and reduction of effluent parameters.

Effect of effluent on the growth of plant

The growth of the phytoremediator plant *E. crassipes* was observed for control and all three effluent concentration treatments in terms of plant dry weight (g per plant), leaf number (per plant) and total chlorophyll content (mg / g fresh weight) in 10, 20 and 30 days is shown in Table 2. Increased duration of phytoremediation period resulted into gradual increase in plant growth however, optimum growth of the plant was observed in 20 days in all plant parameters and maximum growth was observed in 40% effluent followed by 20% and 60% effluent concentration. The total plant weight was increased upto 31% in 40%concentration of effluent in 30days and minimum 13% in 10 days in 20% effluent concentration. Leaf number per plant was increased 246% in 40% concentration effluent in 30 days while minimum increase of 63% observed in 60% effluent concentration in 10 days. For total chlorophyll, the increase was maximum 21 % in 20 days in 40 % effluent concentration afterwards prolonged increase was observed in all treatments. The growth in all plant parameters observed initially was due to the availability of the nutrients to the plants for growth resulted in maximum growth in mid of experiment i.e. 20 days. The accumulation of metals into the plant biomass with time might result in physiological toxicity; hence after optimum growth of the plant there was slow increase in all plant growth parameters. Heavy metal-induced stress may be the main factor resulting in slow growth of the plants after 20 days of the phytoremediation period. The relative growth of the plant differed significantly ($p>0.05$) among all the concentration treatments and time of phytoremediation. Iizawa (1977) suggested that the inhibition of chlorophyll might possibly be due to effluent induced inhibition of photosystem in plants resulting into slow growth of the phytoremediator plant in long term experiments. Other factors may be the dissolved oxygen stress, effect of effluent on the root microenvironment of the plant and effect of changing pH on the plant growth. Rezania el al. (2016) also reported 18 day time period to be optimum for the growth of *E crassipes* in phytoremediation treatment of waste water. Victor et al. (2016), Miretzky et al. (2004), Santos & Lenzi (2000) and Das et al. (2016) observed similar growth trends of *E crassipes* in phytoremediation of different effluents.

Heavy metal accumulation by *E crassipes* plant and its phytoremediation efficiency

During the phytoremediation experiment the residual heavy metal concentration of Fe, Cu and Zn in effluent in all three concentration treatments viz 20,40, 60% were observed along with the metal up taken by *E crassipes* plant biomass (cumulative for whole plant). The values of heavy metal accumulated by plant is shown in figure 2 for different treatments. Metal up taken by plant was maximum in 40% effluent concentration followed by 60% and 20% effluent concentration. The 40% concentration of effluent provided optimum nutrient and heavy metal concentration to plant, which in turn reflected in terms of growth performance of the plant in the effluent. At all concentration of effluent the uptake of Fe (58.89 µg per g dry wt) was observed maximum followed by Zn (49.72) and Cu (48.56) and the uptake of plant was found to be increasing with time (Ndimele et al., 2014). At low concentration of effluent, the metal is accumulated by *E crassipes* as micronutrient and found to support the plant growth (Yasar et al., 2013). The metal induced toxicity was reported as the main factor for aquatic macrophytes limiting its growth after accumulation of the metals. In most of the research observations *E. crassipes* showed normal growth at low metal concentration, and the metal phytoremediation efficiency found to be decreased with time at high concentrations of the effluent (Prasad et al., 2001, Kumari et al., 2015, Okunowo & Ogunkanmi, 2010).

The bioconcentration factors for heavy metals are shown in table 3 represent the ability of the plant to accumulate the metal from effluent. The values were found significantly different ($P>0.05$) among various treatments and among the different heavy metals. For Fe & Zn highest BCF value were 25 & 29 at 20% concentration respectively. However, for Cu highest BCF was 35 at 40% concentration of effluent. The Fe & Zn at low concentration act as plant nutrient supporting the growth of the plant and metabolism, leading to higher uptake of metal by plant with increasing phytoremediation period (Prasad, 2004). The value of BCF were higher than 5 for each metal, thus represent the ability of *E crassipes* to grow in steel fabrication industry effluent and to be considered as a potential phytoremediator for heavy metals. Barazani et al. (2004), Lu et al. (2011) and Akinbile &Yusoff (2012) reported similar results for aquatic macrophytes. Moreover, observed that uptake of heavy metal and its accumulation in plant depends on growth rate of the plant, density and complexity of effluent and presence of other inhibitory substances in the growing medium.

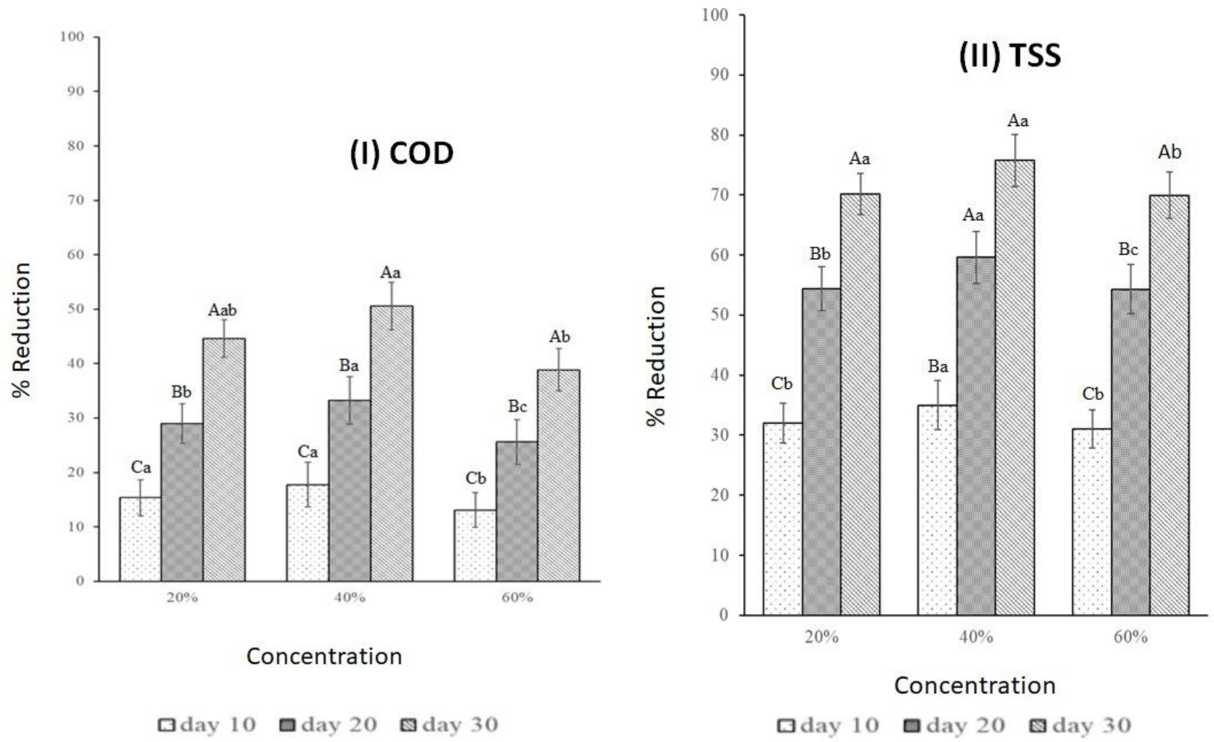
CONCLUSION

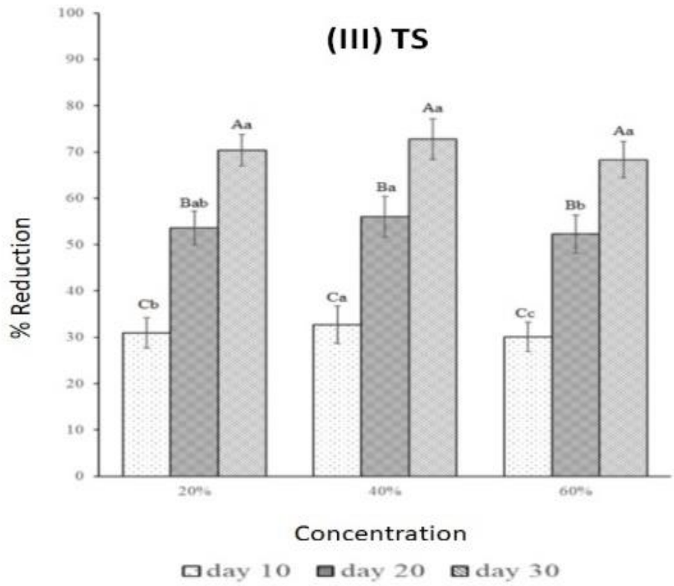
The steel fabrication industry effluent in the present study possessed pollutants above the prescribes limit. The present study showed the great potential of *E crassipes* towards efficient removal of the pollutants from steel fabrication industry effluent along with heavy metal accumulation. The plant showed its ability to grow at higher concentration of heavy metals without compromising the removal of pollutants from the effluent. The 40% effluent concentration was treated efficiently by the plant and the growth was also good for this treatment concentration. The plant showed higher values of BCF indicating its efficiency as tolerant phytoremediator of heavy metals Fe, Cu & Zn for complex effluents of steel fabrication and similar industry. *E crassipes* thus can be used as a good bio absorbent of pollutants and heavy metals for steel industry effluent. However, cyanide and phenolics in the effluent may limit the rate of the growth and nutrient absorption by plant along with the site-specific characters as light and temperature, dissolve oxygen in water, acclimatization time taken by plant in effluent etc. The presence of more than two heavy metals may also have inhibitory effect on the available binding site for metals in the root surface. Further research and optimization of the factors may be done for application of the *E crassipes* for phytoremediation of steel fabrication industry effluent on commercial large scale.

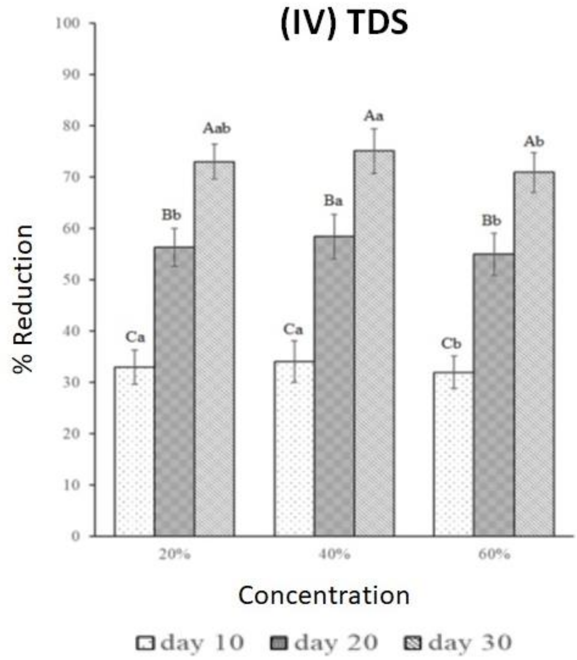
Table1: physico-chemical characterization of steel fabrication and electroplating industry effluent [values except for pH are in mg l^{-1}]

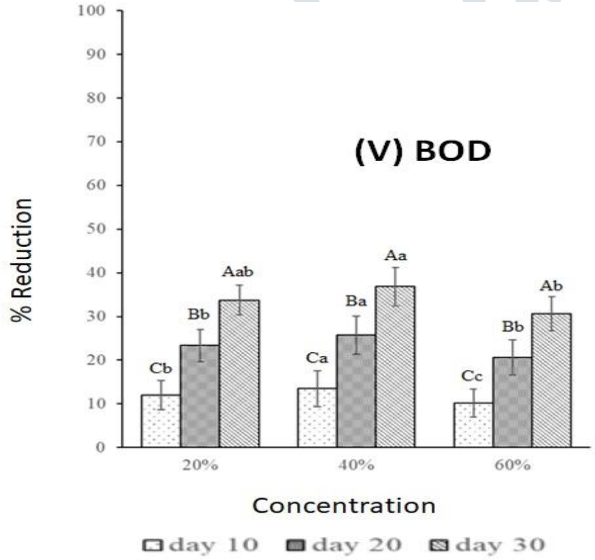
S No	Parameter	Effluent	Discharge Standard
1	PH	8.5	5.5-9.0
2	COD	2318.20	250
3	TSS	1041.00	100
4	TS	3240.03	-

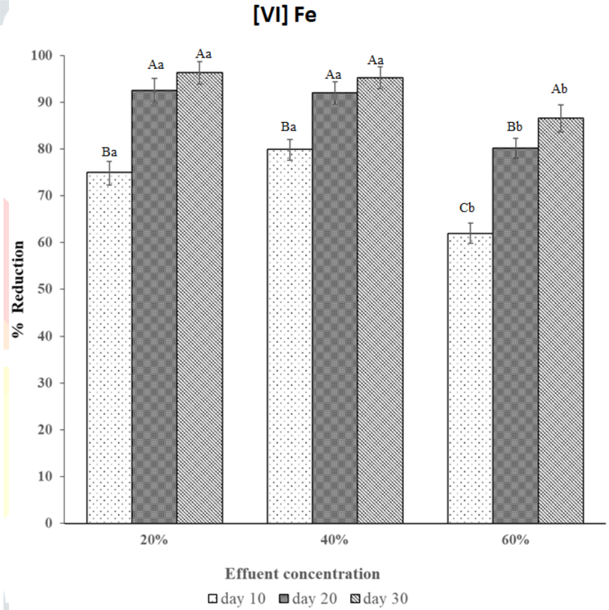
5	TDS	2209.01	500
6	BOD	182.25	30
7	Fe	4.60	3.0
8	Cu	4.04	3.0
9	Zn	6.80	5.0
10	Phenolics	7.7	1.0
11	Cyanide	0.4	0.2
12	Oil & Greece	6.0	10
13	Ammonical Nitrogen	63.2	50




(III) TS
% Reduction
Concentration
20%
40%
60%
day 10 day 20 day 30
Cb Bab Aa Ca Ba Aa Cc Bb Aa


(IV) TDS
% Reduction
Concentration
20%
40%
60%
day 10 day 20 day 30
Ca Bb Aab Ca Ba Aa Cb Bb Ab


(V) BOD
% Reduction
Concentration
20%
40%
60%
day 10 day 20 day 30
Cb Bb Aab Ca Ba Aa Cc Bb Ab


[VI] Fe
% Reduction
Effluent concentration
20%
40%
60%
day 10 day 20 day 30
Ba Aa Aa Ba Aa Aa Cb Bb Ab

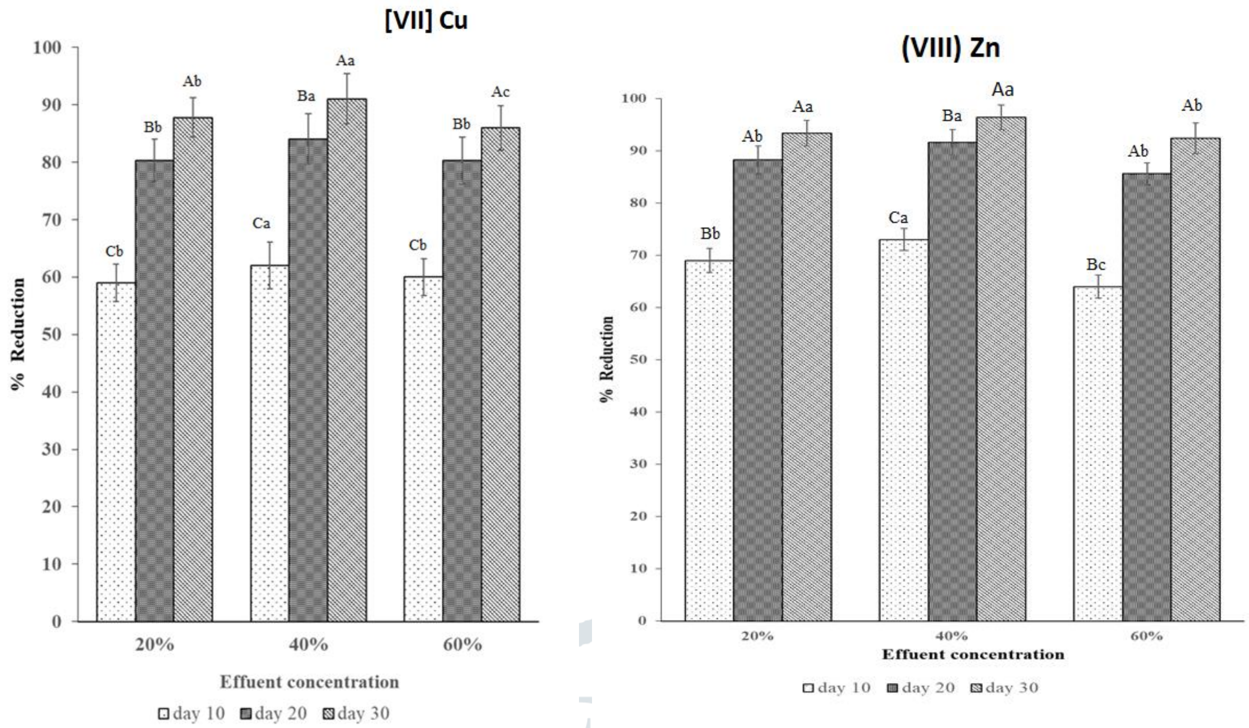


Figure 1: Per cent (%) reduction in physico-chemical parameters and heavy metals in steel fabrication industry effluent after phytoremediation with *E. Crassipes* (I) COD (II) TSS (III) TS (IV) TDS (V) BOD (VI) Fe (VII) Cu (VIII) Zn

Table 2: effect of varied concentration of steel fabrication industry effluent on growth parameters of *E. Crassipes* used for phytoremediation

Physical Parameter	Control			Effluent								
Concentration of effluent (%)	Control			20%			40%			60%		
Days	10	20	30	10	20	30	10	20	30	10	20	30
Weight (g dry weight per plant}	1.89	2.11	2.52	2.13	2.20	2.33	2.26	2.38	2.48	2.05	2.16	2.25
Leaf number (average per plant)	6.8	7.3	8.1	11.51	15.36	19.98	12.35	17.37	23.54	11.12	14.17	16.52
Total Chlorophyll (mg per g fresh weight)	2.2	2.6	2.8	2.34	2.39	2.38	2.43	2.66	2.27	2.27	2.32	2.37

Table 3: bio- concentration factors of heavy metals viz. Fe, Cu and Zn for *E. crassipes* in different effluent concentration

Concentration of effluent (%) / Days	Metal (ppm)	Bio- concentration factor 20	40	60
20	Fe	18.60	23.06	25.04
	Cu	23.40	29.38	32.72
	Zn	19.91	27.08	29.60
40	Fe	10.34	13.01	15.10
	Cu	18.63	30.71	35.45
	Zn	11.51	17.43	19.35
60	Fe	5.50	6.44	7.33
	Cu	13.30	18.14	19.76
	Zn	8.17	10.16	10.82

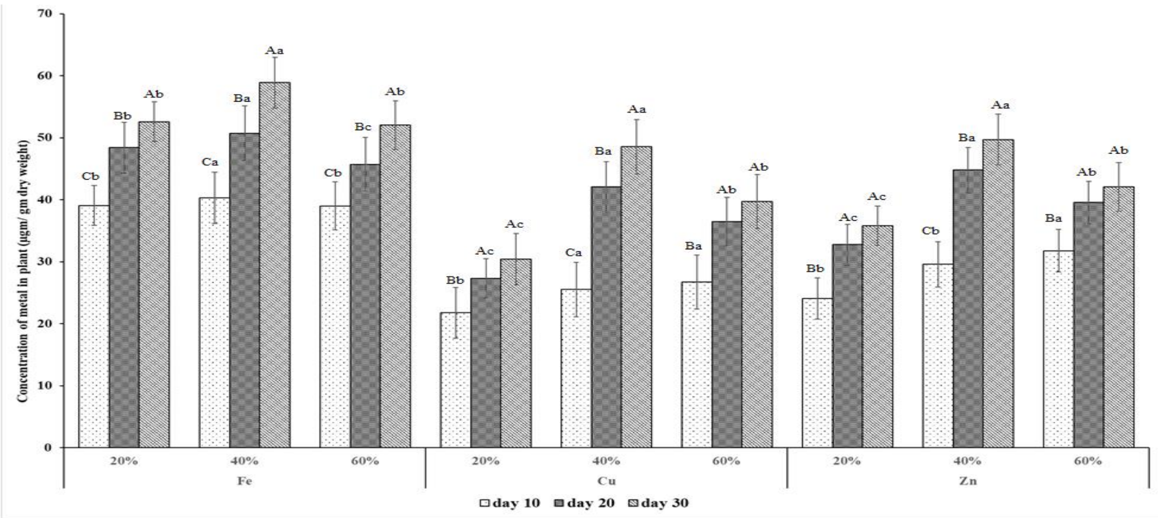


Figure 2: Accumulation of heavy metals viz. Fe, Cu & Zn from the steel fabrication industry effluent after phytoremediation in *E. crassipes*

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