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Research Article

A study of aquatic macrophyte for remediation of chromium and cadmium in wastewater effluents in Yenagoa Metropolis, Niger Delta

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Abstract
Although aquatic macrophytes have been used individually for wastewater remediation, there is a dearth of studies comparing their efficiency level to determine the most effective for remediation of specific heavy metals. This study aimed to determine the most effective aquatic macrophyte amongst *Eichhornia crassipes, Pistia stratiotes, Nymphaea nouchalli, Lemna minor* and *Ceratophyllum demersum* for the remediation of Cr and Cd from wastewater effluents in Yenagoa Metropolis, Niger Delta. Wastewater samples from emulsion paint industries were collected from six locations (L1-L6) and analyzed for Cr and Cd concentration using Inductively Coupled Plasma Atomic Emission Spectroscopy. The wastewater samples were treated with these aquatic macrophytes and the concentration of Cr and Cd in the samples were assessed every two weeks for six weeks. Results showed that the mean Cr concentration (0.27mg/L) and Cd levels (0.080mg/L) in the wastewater samples were higher than the recommended WHO limits of 0.05 and 0.003mg/L respectively. The treated wastewater showed that Cr and Cd concentrations in the wastewater were reduced to minimum values by *P. statiotes* (0.003±0.001mg/L) and *E. crassipes* (0.000±0.000mg/L) respectively. The removal potentials of the macrophytes were in the order of *P. stratiotes* > *E. crassipes* > *N. nouchalli* > *L. minor* > *C. demersum* for Cr, and *E. crassipes* > *P. stratiotes* > *N. nouchalli* > *C. demersum* > *L. minor* for Cd. It was concluded that the most effective aquatic macrophyte for remediation of Cr was *P. stratiotes* (with 97% efficiency) and Cd was *E. crassipes* (87.5% efficiency). Therefore the macrophytes were considered good phytoremediators.

Keywords: Aquatic macrophytes, Bio-concentrator, Heavy metals, Niger Delta, Phytoremediation, Wastewater

INTRODUCTION

Water bodies are severely contaminated due to the discharge of untreated domestic and industrial wastewater effluents from various human activities into them (Ogoyi *et al*. 2011; Ayotunde and Bariweni 2018, Jan 2020, Bekeowei and Bariweni 2021). Water contaminants, which may be microbial, physico-chemical and or heavy metals are known to have caused a great deal of impact on public health and the environment (Kannji and Achi 2011; Burmamu *et al*. 2014; Ogamba *et al*. 2015a; Ebuete and Bariweni 2019; Briffa & Blundell, 2020).

The reasons for the tremendous increase of wastewater in the environment is rapid population growth, urbanization and industrialization (Lalevic *et al.* 2012; Ahmed *et al.* 2021). Many industries such as paint, automobile spray paint, dye, pharmaceuticals, etc. use materials that are rich in heavy metals because of their technological relevance. Wastewater released from such industries into the aquatic ecosystem may therefore contain heavy metals which could cause toxic effects on man through the food chain.

The main sources by which metals get into aquatic ecosystems in urban centers is through surface run-off and discharges from factories (Werimo *et al*. 2009; Ayotunde and Bariweni 2018). Considering the toxic effects of heavy metals in industrial effluents, wastewater treatment is required before they are discharged into the aquatic ecosystem (Roy *et al*. 2010).

The use of conventional techniques in wastewater treatment is considered costly in many developing nations. This has necessitated the use of macrophytes-based wastewater treatment system because it is cost-effective and environmentally friendly (Savyed and Sayadi, 2011). Several aquatic macrophytes have been shown to have great potential for heavy metal remediation in polluted aquatic ecosystems. The macrophytes include *Eichhornia crassipes* (Water Hyacinth) (Sukumaran 2013; Ogamba *et al*. 2015b); *Pistia stratiotes* **(**Water Lettuce**)** (Rai 2019)**,** *Nymphaea nouchalli* **(**Water Lily) (Shuaibu and Nasiru 2011; Tel-or and Forni 2011; Parisa, Jinous *et al*. 2015); *Lemna minor* (Duckweed) (Papadopoulos *et al*. 2011; Mohedano *et al*. 2012) and *Ceratophyllum demersum* (Hornwort) (Abdallah, 2012). Although these aquatic macrophytes have been used individually for wastewater remediation, there is a dearth of studies comparing their efficiency level to determine the most effective for any particular heavy metal. Therefore, this study investigated the remediation potentials of a few selected dominant indigenous aquatic macrophytes in removing Cr and Cd from polluted wastewater in the study area to identify the most effective.

MATERIALS AND METHODS

Study area

Yenagoa Metropolis, the study area, is the headquarters of Yenagoa Local Government Area and capital of Bayelsa State, Nigeria. It lies between latitudes $4^o 55'$ and $5^o 02$'N and longitudes $6^o 15'$ and $6^o 25'$E. It is the most economically viable town in the state and occupies an area of about 706km^2 (Bariweni *et al*. 2002). The current administrative status of Yenagoa has attracted people from different walks of life, thus the City's rapid increase in population and economic activities and, consequently increase in waste and wastewater generation.

Wastewater samples

Wastewater samples from emulsion paint manufacturing industries were collected thrice monthly from September - December 2021, during morning and evening shifts from purposively selected paint industries in the Yenagoa Metropolis One litre plastic bottles properly washed with nitric acid, rinsed with distilled water following the technique adopted by Lokhande *et al*. (2011), and pre-rinsed with the wastewater to be sampled was employed for the collection of wastewater samples and all the sampled locations were georeferenced. The wastewater samples were stored in the ice box and subsequently transported to the laboratory for analysis.

Collection of aquatic macrophytes

The aquatic macrophytes were collected from different aquatic ecosystems such as streams and borrow pits in Yenagoa metropolis. The macrophytes were collected based on the principle of species richness estimate using quadrant sampling method. The collected plants – *Nymphaea nouchalli* (water lily), *Lemna minor* (duckweed), *Pistia stratiotes* (water lettuce)*, Ceratophyllum demersum* (hornwort) and *Eichhornia crassipes* (water hyacinth) were rinsed with distilled water to remove all the dirt. The macrophytes were allowed to stabilize and acclimatize for two weeks in a greenhouse before experimentation.

Experimental procedure

The experiment was conducted in a greenhouse at an ambient temperature of between 25 – 30^{0}C with circular plastic bowls containing 15 litres of wastewater samples from the sampled locations. Each macrophyte of similar weight (70g) was introduced into their respective bowls with fifteen (15) litres of composite wastewater samples. The experimental period lasted for six (6) weeks, and circular plastic bowls with fifteen (15) litres of the raw composite wastewater sample without plant specimen served as control (Bekeowei and Ohwo, 2021). The cultured plants were harvested after 14, 28, 42 days, respectively. The water loss from the bowls through evaporation and evapo-transpiration in both the experimental and the control system during the experiment was compensated by adding distilled water into them, as adopted by Priyanka *et al*. (2017). At the end of the six (6) weeks retention period, the concentrations of Cr and Cd in the water samples were determined.

Analysis of heavy metals in wastewater samples

The Cd and Cr concentrations in the wastewater samples were analyzed using Atomic Absorption Spectrophotometer (AAS) model AA6300 as described in the manufacturer's instruction manual following the methodology cited in APHA (2017) and Ademoroti (1996).

Evaluation of heavy metals concentration in macrophytes tissues

The Cd and Cr concentrations in the macrophyte samples before and after the experiment were determined using Inductively Coupled Plasma Atomic Emission Spectroscopy (ICP-AES) (APHA, 2017). All the cultured macrophyte samples were separately prepared by drying, grinding, dry ashing and wet ashing. Macrophytes were air-dried under the ambient temperature of 26^0 – 30^{0}C for 14 days (336 hours). Ceramic pestle and mortar were used to grind each of the macrophyte together with their roots, stem and leaves. The grinded powder materials were preserved in plastic bags, which were transferred to a muffle furnace 400-450^{o}C for 2 hours for dry ashing. The ash from this process was kept in a well-sealed cellophane bag as was adopted by Aurangzed *et al*. (2014). Wet ashing was also carried out in like manner as adopted by Aurangzed *et al*.

(2014). The liquid solution from these processes was filtered and preserved in graduated bottles and subsequently taken to the laboratory for analyses following the methods of APHA (2017).

Statistical analysis

Data was analyzed using both descriptive and inferential statistics (Analysis of variance - ANOVA). The statistical analysis was conducted using statistical package for the social sciences (SPSS) IBM Version 23 Software.

RESULTS AND DISCUSSION

Table: 1 shows the mean Cr and Cd removal potential by aquatic macrophytes after 14, 28 and 42 days of wastewater treatment. Baseline results from the study revealed that the Cr (0.270mg/L) and Cd (0.080mg/L) levels in the wastewater samples were higher than the recommended WHO (2008) levels of 0.05 and 0.003mg/L levels, respectively.

All the aquatic macrophytes utilized for wastewater treatment were good bio-remediators of Cr. They effectively reduced the Cr level from 0.270mg/L to a safe level (<0.05mg/L), with *E. crassipes* being the most effective within the first 14 days. However, *P. stratiotes* was the most effective among the aquatic macrophyte as it achieved 97% removal efficiency after 42 days of treatment.

The macrophyte mean percentage bio removal efficiencies of Cr was in the order of *P. stratiotes* > *E. crassipes* > *N. nouchalli* > *L. minor* > *C. demersum*. However, the Cr reduction values of L. minor observed in this study were above the findings published by Alkhafaji *et al.* (2017) but less than the percentage value of 223% achieved by Sasmaz *et al*. (2016). The Cr removal efficiency of *P. stratiotes* observed in this study agreed with the percentage reduction range of 30 – 100% achieved by Santosh *et al*. (2012), who used wastewater generated under laboratory conditions, but above the findings of Aurangzed *et al*. (2014) who utilized wastewater from outlet of a steel foundry located in Hayatabad industrial estate, Peshawar. The observed mean Cr bio removal level by *E. crassipes* was also above the percentage reduction rates of 62.96% reported by Aurangzed *et al*. (2014) but less than the 99.9% removal efficiency report by Savitha and Rajan (2018) in their study of wastewater effluents from M/S BSA Electroplating and Color coating industry in Madurai. The Cr bioremediation potential of *C. demersum* also compares favourably at 93% to the result of Abdallah (2012), who reported a success rate of 84% efficiency in his experimental study.

Results from this study (Table 1) indicated that the aquatic macrophytes utilized for this study were not very efficient for the bio-remediation of Cd as it is with Cr. Only *E. crassipes* and *C. demersum* effectively reduced Cd concentration from 0.080mg/L to <0.003mg/L after a 42 days retention period, with *E. crassipes,* which achieved a mean % removal efficiency of 87.5%, being the most efficient. The study also indicated an outstanding reduction of Cd concentration by *C. demersum* with percentage reduction values of 37.5%, 50% and 98.8% at 14, 28 and 42 days of treatment respectively and a mean percentage removal value of 62.1%. This indicates that *C. demersum* is a good bioremediator of Cd-contaminated wastewater.

The mean percentage bioremediation efficiency of Cd by the native aquatic plants under review takes the following order *E. crassipes* > *P. stratiotes* > *N. nouchalli* > *C. demersum* >*L. minor.* The mean percentage Cd removal efficiency by *E. crassipes,* as ob-

Table 1. Mean Cr and Cd removal potential of aquatic macrophytes after 14, 28 and 42days of treatment

Sample macrophytes	Heavy Metal	Baseline conc. (mg/L)	Mean conc. After 14 days (mg/L)	Mean conc. After 28 days (mg/L)	Mean conc. After 42 days (mg/L)	Mean % removal efficiency	WHO (2008) llimits (mg/L)
L. minor	Cr	0.270	0.025±0.001	0.020±0.010	0.006±0.001	93.7%	0.05
	Cd	0.080	0.060±0.010	0.050±0.010	0.030±0.001	41.7%	0.003
N. nouchalli	Cr	0.270	0.018±0.001	0.015±0.001	0.010±0.001	94%	0.05
	Cd	0.080	0.040±0.001	0.040±0.010	0.010±0.001	62.5%	0.003
Pistia stratiotes	Cr	0.270	0.018±0.001	0.012±0.001	0.003±0.001	97%	0.05
	Cd	0.080	0.030±0.010	0.030±0.010	0.005±0.001	72.9%	0.003
E. crassipes	Cr	0.270	0.015±0.010	0.012±0.010	0.005±0.001	95%	0.05
	Cd	0.080	0.020±0.010	0.010±0.001	0.000±0.000	87.5%	0.003
C. demersum	Cr	0.270	0.027±0.001	0.021 ±0.001	0.008±0.001	93%	0.05
	Cd	0.080	0.050±0.001	0.040±0.001	0.001±0.000	62.1%	0.003

Table 2. Bioaccumulation of chromium and cadmium in plants' tissues (mg/L)

Sample macro-phytes	Elements	Baseline conc. (mg/L)	14 days of treatment (mg/L)	28 days of treatment (mg/L)	42 days of treatment (mg/L)	Bioconcentration factor %
L. minor	Cr	0.270	0.134	0.151	0.151	55.9%
	Cd	0.080	0.015	0.020	0.032	40%
N. ouchalli	Cr	0.270	0.185	0.185	0.190	70.4%
	Cd	0.080	0.010	0.023	0.026	32.5%
P. stratiotes	Cr	0.270	0.120	0.125	0.135	50%
	Cd	0.080	0.039	0.041	0.041	51.3%
E. crassipes	Cr	0,270	0.192	0.201	0.207	76.7%
	Cd	0.080	0.032	0.038	0.043	53.8%
C. demer-sum	Cr	0270	0.134	0.142	0.167	62.2%
	Cd	0.080	0.006	0.007	0.007	8.8%

served in this study, was above the percentage values of 66.4% and 36.8% achieved by Gupta and Balomajumder (2015) and Wickramasinghe and Jayawardana (2018), respectively, but below the findings published by Aurangzed *et al*. (2014). The level of Cd removal by *P. stratiotes* observed was slightly below the percentage reduction value of 47.4% achieved by Wickramasinghe and Jayawardana (2018), but above the reduction values of 0.0299mg/L – 0.014mg/L (1.59%) reported by Aurangzed *et al*. (2014). Also, the mean percentage Cd reduction values by *L. minor* recorded were far below the values of 80% achieved by Bokhari *et al*. (2016) in their phytoremediation assessment of two raw effluents and above the 30% value recorded by Echiegu et al (2021) using Lemna minor to remove Cd from paint wastewater. The Cd reduction level by *C. demersum* in this study was lower than the percentage reduction values of 97.77% and 82.01% published by Tel-or and Forni (2011) and Parnian *et al*. (2016). Meanwhile, a marked reduction of Cd concentration in the *N. nouchalli* treated wastewater sample in this study is comparable to the report of Tel-or and Forni (2011) in their assessment of the phytoremediation potentials of aquatic macrophytes.

The results of the Inductively Coupled Plasma Atomic Emission Spectroscopy analysis concerning bioaccumulation of Cr in macrophytes tissues (Table 2) revealed that *E. crassipes* accumulated 0.192mg/L, 0.201 and 0.207mg/L at 14, 28 and 42 days of treatment. The finding indicated that *E. crassipes* recorded the highest values of Cr accumulation compared to others and attained its peak at 42 days retention period.

It was observed that *N. nouchalli* recorded the second highest Cr accumulation rate with values in the order of 0.185mg/L, 0.185mg/L and 0.190mg/L at 14, 28 and 42 days respectively. *N. nouchalli*'s peak period for Cr accumulation was observed at 42 days retention period. It was also observed that Cr accumulation peak period for *P. Stratiotes* and *C. demersum* was also at 42 days of treatment. The Cr bioaccumulation efficiencies by the cultured macrophytes in this study takes the following order *E. crassipes* > *N. nouchalli* > *C. demersum* > L. minor > *P. stratiotes.*

The results of the ICP-AES analysis for the bioaccumulation level of Cd in the macrophytes specimens at the end of 14, 28 and 42 days of treatment as shown in Table 2 indicated that *E. crassipes* accumulated the highest amount of Cd into its tissue with values in the order of 0.032mg/L, 0.038mg/L, 0.043mg/L after 14, 28 and 42 days of wastewater treatment. The results further revealed that *E. crassipes* attained its peak accumulation of Cd at 42 days of treatment. Almost the same trend was observed in the tissues of *P. stratiotes* and *N. nouchalli* in which peak accumulation of cadmium was also recorded at 42 days. The bioaccumulation potentials of the tested macrophytes was in the order *E. crassipes* > *P. stratiotes* > *L. minor* > *N. nouchalli* > *C. demersum*.

This indicated that *E. crassipes* recorded the highest value of cadmium (Cd) accumulation in its biomass. As the percentage values of the calculated BCF of these macrophytes were greater than one, they were considered good hyperaccumulators (Table 2) (Brooks 2008).

Conclusion

The present study concluded that all the macrophytes namely- *E. crassipes, P. stratiotes, L. minor, N. nouchalli* and *C. demersum* considered for the remediation of Cr and Cd were good bio-remediators. Among them *E. crassipes* was the best bio-remediator of these metals. From the result of the bioconcentration factor analysis, all these macrophytes were hyperaccumulators.

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Conflict of interest

The authors declare that they have no conflict of interest.

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