The potentials of *Eichhornia crassipes* for Pb, Cu, and Fe removal from polluted waters

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Abstract

Toxic metals are a major group of water pollutants that find their way into water bodies through municipal, industrial, and agricultural waste discharges. Phytoremediation of these metals has become popular because of the low-cost and environmental friendliness of the technique. Here, we evaluated the potential of *Eichhornia crassipes* (water hyacinth, WH) to remove lead (Pb), copper (Cu), and iron (Fe) from polluted waters. Five experimental prototypes (**A–E**) were developed for the phytoremediation. Prototypes **A**, **B**, **C**, and **D** contained 2 L of the underlay water spiked with 1, 2, 5, and 10 mL of Pb, Cu, and Fe stock solutions, respectively, whereas prototype **E** was the control (i.e., deionized water). About 200 g of live WH of the same rootstock was relocated into each prototype and exposed to the same environmental conditions. The concentrations of the metals were measured every three days for a 12-day remedial period. Also, the metal concentrations in the plant tissues (leaf, stem, and root) were monitored. We observed that in prototypes **A** and **B**, the WH achieved significant Cu, Pb, and Fe removal after 12 days. The removal efficiency (RE) of 45.81%, 19.29%, and 72.03% were achieved for Pb, Cu, and Fe, respectively in prototype **A**, whereas it was 25.63%, 10.69%, and 42.77% in prototype **B**. Generally, the order of removal followed the order Fe > Pb > Cu. Likewise, the metal contents found accumulated in the plant tissues followed the same order. The leaves of WH in prototypes **C** and **D** showed rapid wilting and final death by the 12th day. Consequently, phytoaccumulation was established because the metal concentrations were in the order: root > stem > leaves.

Keywords Water hyacinth · Heavy metals · Removal efficiency · Phytoremediation

1 Introduction

Trace metal pollution has been a prominent environmental issue since the onset of modern civilization due to incessant increase in municipal, industrial, and agricultural waste generated and indiscriminate disposal practices [18]. Although some of these metals are essential micronutrients, at high concentrations, they are toxic and

impact the environment negatively which endangers aquatic ecosystems, especially humans [20]. Lead (Pb), copper (Cu), and iron (Fe) are some of the common toxic metals. High intake of Cu may result in nausea, vomiting, stomach cramps, diarrhea, kidney damage, even death [2]. Pb can accumulate in the human body and cause diseases such as anemia, encephalopathy, hepatitis, and nephritic syndrome [7]. Excess Fe in vital organs increases the risk of

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liver disease, heart attack, diabetes mellitus, osteoarthritis, and impotency [10]. Therefore, several efforts have been made to mitigate toxic metal-polluted waters before they become health issues.

Some of the conventional mitigation methods for removing toxic metals in wastewater treatment plants include chemical precipitation, ion exchange, adsorption, electro-deposition, and membrane operations [8]. Aside from being cost-ineffective, another major drawback with these treatments is the generation of huge quantities of sludge [7]. Therefore, the need for a more efficient and environmentally benign mitigation method is imperative.

Recently, phytoremediation has been considered an alternative to remediate contaminated sites. The technology requires the use of live plant capable of filtering, adsorbing, and accumulating target contaminants via translocation [19]. Specifically, some water plants (macrophytes) have shown prowess toward the removal of toxic metals from polluted waters [7]. Because of the highly economical and environmentally friendly attributes of phytoremediation, the technology has sufficed as well-researched for metal pollution mitigation in our waters [11]. However, there is insufficient literature on metal accumulation preferences and capabilities of the few phytoremediating water plants. Moreover, the measurement of toxic metals accumulation by these macrophytes can provide time-integrated, qualitative, and quantitative information about the metals of interest in the aquatic system [12]. Some of the aquatic plants that have been used in the practice of phytoremediation include duckweeds (*Lemna trisulca* L.), fool's watercress (*Apium nodiflorum*), Eurasian watermilfoil (*Myriophyllum spicatum*), and water hyacinth (*Eichhornia crassipes*) [1, 5].

In this research, water hyacinth, WH (*Eichhornia Crassipes*) is of particular interest because of its high rate of invasion in Nigeria coastal waters. Over 30 out of the 36 states and Federal Capital Territory of Nigeria are infested by WH [15]. During raining season, WH grows voraciously such that in twelve days, the plant can double its population [14]. The macrophyte is known for causing problems in navigation, fishing, and irrigation on the coastal environment [4]. However, researchers are focusing attention on its economic and environmental benefits. Some previous studies have shown that WH is capable of removing toxic metals such as Pb, Cu, and Cr [6, 14, 21]. But, because metals have different thresholds based on their phytotoxicity, we, therefore, evaluated the simultaneous removal capacity of WH toward competitive heavy metals Pb, Cu, and Fe from synthetic water solutions under the same environmental conditions. These metals are of interest because they represent popular hazardous metals found in effluents from various industries in Nigeria. Besides, we investigated the metal accumulation potential and plant

survival rate following a period determined by the plant's health.

2 Materials and methods

2.1 Sampling

During the 2019 rainy season, WH and their underlay water were collected from five locations on the Ayetoro waterways of Ilaje Local Government Area (LGA), Ondo State, Nigeria. The sampling locations were denoted as A1 (6.17458 N, 4.70531 E), A2 (6.11675 N, 4.77428 E), A3 (6.10972 N, 4.78290 E), A4 (6.14229 N, 4.79364 E), and A5 (6.35030 N, 4.80533 E) representing Abereke coastal settlement, abandoned dredging platform, waterway T-junction, Jetty I (at Ode-Ugbo) and Jetty II (at Igbokoda), respectively (Fig. 1). Upon sampling, the plants and their respective underlay water samples were immediately transferred into polyethylene bowls. Figure 1 also depicts, via pie charts, the relative concentrations of the target metals.

2.2 Reagents

The analytical grade reagents used in this study included copper (II) sulfate pentahydrate ($\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$, 99%), iron (II) sulfate heptahydrate ($\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$, 99–101%), lead (II) acetate ($\text{Pb}(\text{C}_2\text{H}_3\text{O}_2)_2$, 95%), nitric acid (HNO_3 , 70%), hydrochloric acid (HCl, 36%), and lab-prepared aqua regia solution. Further, stock solutions (1000 mg l^{-1}) of Pb, Cu, and Fe were prepared from their respective salts.

2.3 Trace metal analysis

The background concentrations of the target metals (mg/g) in the underlay water and WH body parts were first determined before the phytoremediation experiments were carried out.

2.3.1 Water pre-treatment and analysis

Two mL 15.8 M nitric acid was added to 50 mL of the water sample in a pre-cleaned conical flask. It was placed on a hot plate (set to 90°C) in the fume cupboard. The sample was heated to half its initial volume before allowing it to cool to room temperature. Using $6 \mu\text{m}$ mesh size Whatman filter paper, the digestate was filtered. The filtrate was diluted with distilled water to 100 mL mark. The concentrations of Pb, Cu, and Fe therein were determined using an atomic absorption spectrophotometer (AAS, Buck Scientific VGP 210, USA).

Fig. 1 Map of the study area showing the spatial distribution of average values of metals' concentrations across the sampled locations

Table 1 Description of experimental prototypes based on the toxic metal spiking of the underlay water

Prototype	Description	Volume (mL) of stock solution added		
		Pb	Cu	Fe
A	WH and underlay water	1	1	1
B	WH and underlay water	2	2	2
C	WH and underlay water	5	5	5
D	WH and underlay water	10	10	10
E	WH and deionized water	Nil	Nil	Nil

Table 2 Mean status quo concentrations of Pb, Cu, and Fe in the water samples from the various locations and those of relevant standard limits

Water sample	Pb (mg/L)	Cu (mg/L)	Fe (mg/L)
Average	0.16 ± 0.09	0.01 ± 0.01	2.72 ± 0.88
Min	0.06	ND	2.06
Max	0.30	0.02	4.08
WHO standard	0.01	2	0.3
USEPA	0.50	0.50	0.50

ND not detected, WHO, World Health Organization; USEPA, United States Environment Protection Agency

2.3.2 Plant pretreatment and analysis

The WH rootstock was thoroughly washed with distilled water before separation into leaves, shoots, and root tissues. The samples were air-dried for seven (7) days and later oven-dried at 70 °C to constant weight. 0.5 g of the dried tissues were grounded with a porcelain mortar and

pestle before sieving to collect < 2 nm size. 2.5 mL of 2 M HNO₃ was added as an ashing aid to the samples before placing in the furnace, set at 500 °C for 2 h. After cooling to room temperature, the ashes were mineralized in aqua regia solution, filtered, and diluted to 50 mL with distilled water. The concentrations of Pb, Cu, and Fe were determined as in Sect. 2.3.1.

Fig. 2 Changes in the concentrations of spiked underlay waters with days in prototypes **A**, **B**, **C**, **D**, and **E**

2.4 Phytoremediation experiment

The underlay water collected at Jetty I (A4) was spiked with prepared stock solutions of Pb, Cu, and Fe to higher concentration in different prototypes. A single sampling location was selected from the sampling locations for this experiment to avoid metal concentration differences in the plant and underlay water samples. Prototypes **A**, **B**, **C**, and **D** were spiked with 1, 2, 5, and 10 mL of the stock solutions of Pb, Cu, and Fe, respectively. The control prototype **E** was not spiked. The total volume of each prototype was made up to 2000 mL. The WH that weighs an average of 200 g was introduced into all prototypes (**A–E**). The setups were placed in open surroundings with natural temperature and adequate sunlight, albeit, protected from rainfall. The concentrations of the metals in the underlay water was monitored (quantitated every three days) for 12 days remedial period at which the final death of the WH became obvious in some prototypes. Afterward, the plants were withdrawn from their waters and separated into leaves, stems, and roots. The final metal analysis was then carried out on their digestates. Table 1 provides the properties of each prototype setup.

QC/QA: During the laboratory experiments, all analytical measurements and analyses were carried out in triplicates. All outliers were expunged and measurements were repeated until a reliable mean of three consecutive measurements was obtained. The mean values are presented in the Results section.

3 Results and discussion

3.1 Background study

Table 2 shows the average, minimum, and maximum concentrations of the target metals in the water samples, compared with permissible environmental standard values of the World Health Organization (WHO) [24, 25] and the United Nations Environment Protection Agency (USEPA).

In this research, references and comparisons are made against WHO standards because the phyto-removal of the metals was performed to render the water potable. However, the USEPA standards [23] for drinking water pollutants found in estuary and harbor basin water are provided in Table 2 as an additional reference.

On the average, Fe was more phyto-accumulated than Pb and Cu, whereas Cu was more accumulated in the leaves, suggesting that translocation of Cu was likely favored as previously observed [16].

3.2 Metal removal in the prototypes

The quality of the underlay water was checked every three days for the 12-day remedial period. Figure 2a–e shows how the metal ions concentration varied with days in Prototypes **A**, **B**, **C**, **D**, and **E**, respectively. Also, the removal efficiency (RE) for all the metals was calculated using Eq. 1.

Removal Efficiency (%)

$$= \frac{\text{Initial concentration} - \text{Final concentration}}{\text{Initial concentration}} \times 100\% \quad (1)$$

Figure 2a–e show that only prototypes **A** and **B** removed the three metals after 12 days.

A considerable RE was observed in prototypes **A** and **B** whereas, in **C** and **D**, the concentrations stayed relatively the same. In prototype **A**, Pb, Cu, and Fe reduced from 3.52 to 1.85 mg/L (RE of 45.81%), 3.58 to 2.89 mg/L (RE of 19.29%), and 10.58 to 2.96 mg/L (RE of 72.03%), respectively (see Fig. 2a). Likewise, prototype **B** showed Pb, Cu, and Fe concentrations dropped from 4.32 to 3.21 mg/L (RE of 25.63%), 6.48 to 5.79 mg/L (RE of 10.69%), and 11.50 to 6.58 mg/L (RE of 42.77%), respectively (see Fig. 2b). We observed that WH exhibits the highest affinity toward Fe (sequence of $\text{Fe} > \text{Pb} > \text{Cu}$). Also, the RE for the metals (especially for Fe) was higher at lower contaminant concentrations. The threshold toxicity of Cu that WH could withstand was between 1 and 2 mg/L. Any concentration beyond this value could cause chlorosis, suppressing the development of new roots [22]. Prototypes **C** and **D** had their initial concentration of Cu at 20.9 and 30 mg/L, respectively. At such high concentrations, removal efficiency was minimized as the plant no longer encourage transpiration of the metals and water into its tissue. The variation in these prototypes may be attributed to the

Table 3 Mean concentrations of Pb, Cu, and Fe found in WH tissues sampled from the various locations

Water Hyacinth		Pb	Cu	Fe
Root (mg/g)	Mean	0.03 ± 0.02	0.05 ± 0.03	1.30 ± 0.19
	Min	0.01	0.03	0.04
	Max	0.05	0.09	2.17
Stem (mg/g)	Mean	0.08 ± 0.06	0.08 ± 0.07	0.86 ± 0.82
	Min	0.04	0.00	0.07
	Max	0.19	0.13	2.20
Leaf (mg/g)	Mean	0.05 ± 0.40	0.21 ± 0.08	1.53 ± 1.22
	Min	0.02	0.16	0.08
	Max	0.10	0.33	2.97

Fig. 3 Comparison of target metals' accumulation along the water hyacinth body in the prototypes **A** to **D**

evaporation and precipitation of metals in these prototypes. Hence, metal accumulation in the WH tissues was further investigated. However, the prototypes **A**, **B**, and **E** did not show any phytotoxic damage.

Figure 2e shows the concentration of water in the control setup (deionized water). We observed a steady increase in Fe concentration in the water while Pb and Cu remained relatively constant. This observation explains that WH has low retention capability for Fe than Pb and Cu. Therefore, in practice, we suggest the immediate removal of dead WH from wastewater as they may likely leach out already-adsorbed metals back into the solution, causing an in situ recontamination.

3.3 Metal concentrations in the WH tissue

Although the metal concentrations in prototypes **C** and **D** remained relatively constant for the 12-day duration, the plant tissues showed elevated levels of the metals compared to those found in the live, pristine (status quo) samples (Table 3). By comparison, prototypes **C** and **D** propertyed their highest concentrations of 2.31, 5.38, 164, and 11.5, 19.75, 197 mg/g for Cu, Pb, and Fe, respectively against 0.76, 0.66 and 28.4 mg/g observed before

phytoremediation. Thus, the metals were continually accumulated despite the wilting of the plant leaves. This observation also insinuates that WH can be used as a biomarker or a bioindicator for the metals.

Further, via translocation, the metals were transferred from the root to the upper shoot. Figure 3 shows that the accumulation of the metals was highest in the roots followed by the stem then leaves. As indicated in Table 4, metal accumulation by WH was in the order of root > stem > leaves. Cu tends to accumulate in the root tissue with inferior mode of translocation into the shoot suspected (Fig. 4) [13]. Figure 5 depicts the metal concentration in WH plant tissue with increased doping concentrations. In Fig. 5b, the metal concentration increased in the

Table 4 The average metal concentrations observed in the plant tissues of the spiked prototypes on the 12th day

Plant tissue	Pb (mg/g)	Cu (mg/g)	Fe (mg/g)
Leaf	0.56 ± 0.69	0.74 ± 0.76	7.58 ± 1.21
Stem	3.46 ± 3.90	3.65 ± 3.92	10.48 ± 1.96
Root	10.78 ± 6.61	5.88 ± 4.40	183.18 ± 40.31

Fig. 4 Comparison of WH plant tissues (leaf, stem, and root) accumulation of metals in prototype **A** to **D** after 12 days

Fig. 5 Average concentrations of target metals (Pb, Cu, and Fe) accumulated in the WH **a** roots, **b** stem, and **c** leaves (with increasing metal doping concentration) on the 12th day

stem with increasing metal concentration in the underlay water. A similar trend was observed in the roots as the maximum concentrations of Pb, Cu, and Fe were observed in water samples bearing the maximum ion levels (Fig. 5a).

3.4 Morphological changes

Except for hyperaccumulators, most plants suffer phytotoxic damage after prolonged uptake of toxic metals, concentrated within their tissues [9, 17]. The morphological changes observed during the phytoremediation experiment were used to guesstimate the plant's tolerance for the metals. According to Yau et al. [26], plant leaves can

wilt under excess copper. Likewise, excess Pb could deter the growth of plants by inhibiting the synthesis of chlorophyll [3]. Photographs of the morphological changes observed in our work during the 12-day experiment are provided as supplementary information (SI).

Prototypes **C** and **D** suffered phytotoxic damage as the leaves wilted off within 3–6 days before final death by the 12th day. However, prototypes **A**, **B**, and **E** exhibited negligible changes, particularly, prototype **B** showed the growth of a flower after 6 days. The number of leaves in these prototypes remained the same throughout the remedial period (SI). From our observations of prototype **A**, **B**, and **E**, the morphological changes suggest that WH is

tolerant to polluted water containing metals within the following ranges: 0–4.32, 0–6.48, and 0–12.4 mg/L for Pb, Cu, and Fe, respectively. At concentrations above 15.5, 20.9, 24.4 mg/L of Pb, Cu, and Fe, respectively, WH might suffer observable phytotoxic damage.

4 Conclusion

The intrinsic removal efficiency (RE) of water hyacinth (*Eichhornia crassipes*) toward Pb, Cu, and Fe, especially at lower concentrations, was established. The respective removal efficiency for Cu, Pb, and Fe were 19.29%, 45.81%, and 72.03% in prototype **A**, and 10.69%, 25.63% and 42.77% in prototype **B**. Also, at an elevated concentration of metal ions containing more than about 15 mg/l of the metals, the plant suffered phytotoxic damage, with the highest concentrations found accumulated in the stems and roots. The accumulation of the metals was in the order of Fe > Pb > Cu, while the accumulating prowess of the plant tissues was in the order of root > stem > leaves. Hence, the accumulation of the target Pb, Cu, and Fe by water hyacinth was established because the levels of these metals in the plant tissues became higher than the background concentration in all the prototypes, which suggest the plant can be used as a bioindicator for pollution.

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Compliance with ethical standards

Conflict of interests On behalf of all authors, the corresponding author states that there is no conflict of interest.

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